THE HYDROGEOLOGY AND HYDROGEOCHEMISTRY OF THE STAR FIRE SITE, EASTERN KENTUCKY[1]

David R. Wunsch and James S. Dinger[2]

Abstract: The Kentucky Geological Survey is directing an applied research program to determine the potential water supply for future property development at the Star Fire site. It is anticipated that an aquifer constructed in mine spoil could provide base flow to streams that could feed water-supply reservoirs. Dye tracing, water-level measurements, and chemical analyses of water samples indicate that ground water moves slowly in the spoil's interior, where it must flow into surrounding hollow fills before discharging out of the spoil. Two water tables have been established: one in the spoil's interior, and the second in the hollow fills below the main spoil body. Based on an average saturated thickness of 6.4 m, the saturated spoil stores an estimated 5.2 x 10^6 m^3 (1.37 billion gal.) of water. Hydraulic conductivity (K) values derived from slug tests range from 7.0 x E-5 to > 9.0 x E-4 cm/sec. All of the waters are a calcium-magnesium-sulfate type, differing mainly in the total concentration of these constituents. Saturation indices calculated using the geochemical model PHREEQE indicate that most of the ground water at the site is near equilibrium with gypsum. Nearly all of the samples had pH measurements in a favorable range between 6.0 and 7.0, indicating that the spoil at the site does not produce highly acidic water.

Additional Key Words: ground-water movement, conceptual model, hydraulic conductivity, mineral equilibria.

Introduction

Areas of Appalachia dependent on mining economies are finding out that economic diversification is hampered by the lack of water supplies and flat usable land. Although significant areas of relatively flat land are continuously being created by surface-mining operations throughout Appalachia, the question remains as to the availability of water resources to sustain alternative land uses such as industrial development or agriculture. This study by the Kentucky Geological Survey evaluates the potential development of water resources in a thick and extensive spoil at the reclaimed site owned and operated by Star Fire Coal Co., a subsidiary of Cyprus Minerals, Inc. The results of this study should (1) contribute to the basic understanding of the hydrogeology and hydrogeochemistry of the Star Fire site and (2) create baseline data and transferable technology that may be applicable to other reclaimed mine areas in the Appalachian Coal Field.

Geologic and Hydrologic Setting

The Star Fire Mine encompasses portions of Breathitt, Perry, and Knott Counties in eastern Kentucky (fig. 1). The coals being mined include the Hazard Nos. 7, 8, 9, and 10 seams, all of which are included in the Breathitt Formation of Pennsylvanian age. These seams consist of high-volatile bituminous coal ranging in thickness from 1.0 to 2.1 m. Several of the seams contain rider coals that are also mined. The overburden consists of interbedded sandstones, shales, siltstones, and underclays. In the process of mining, spoil up to 91 m thick is being created.

Analyses of sandstone samples taken from cores revealed the following average mineral percentages: quartz, 47%; feldspar, mainly K-spar, 29%; rock fragments, 11.9%; mica, 5.4%; and heavy minerals (pyrite, siderite), 0.5%. The majority of the cement was determined to be ferroan-calcite (Weinheimer 1983). Abundant authigenic kaolinite was found to fill pore spaces and form reaction rims around feldspar grains. The occurrence of dolomite in Breathitt rocks was rare. Shales and claystones in the Breathitt Formation contain illite, kaolinite, and chlorite (Papp 1976). The overburden should not produce acid mine drainage problems. All pre-mining overburden analyses show a potential acidity (PA) of less than 5. If PA < 5, the stratum is generally considered a non-acid producer, regardless of the neutralization potential (Sobek et al., 1978).

Ground-Water Considerations

Aquifer Framework

Several previous papers have described, in detail, components of the spoil and their interpreted implications toward controlling the movement and storage of ground

---

[1] Paper presented at the International Land Reclamation and Mine Drainage Conference and the Third International Conference on the Abatement of Acidic Drainage, Pittsburgh, PA, April 24-29, 1994.

[2] David R. Wunsch, Hydrogeologist, and James S. Dinger, Section Head, Water Resources Section, Kentucky Geological Survey, University of Kentucky, Lexington, KY, USA.

Proceedings America Society of Mining and Reclamation, 1994 pp 188-197
DOI: 10.21000/JASMR94020188

https://doi.org/10.21000/JASMR94020188

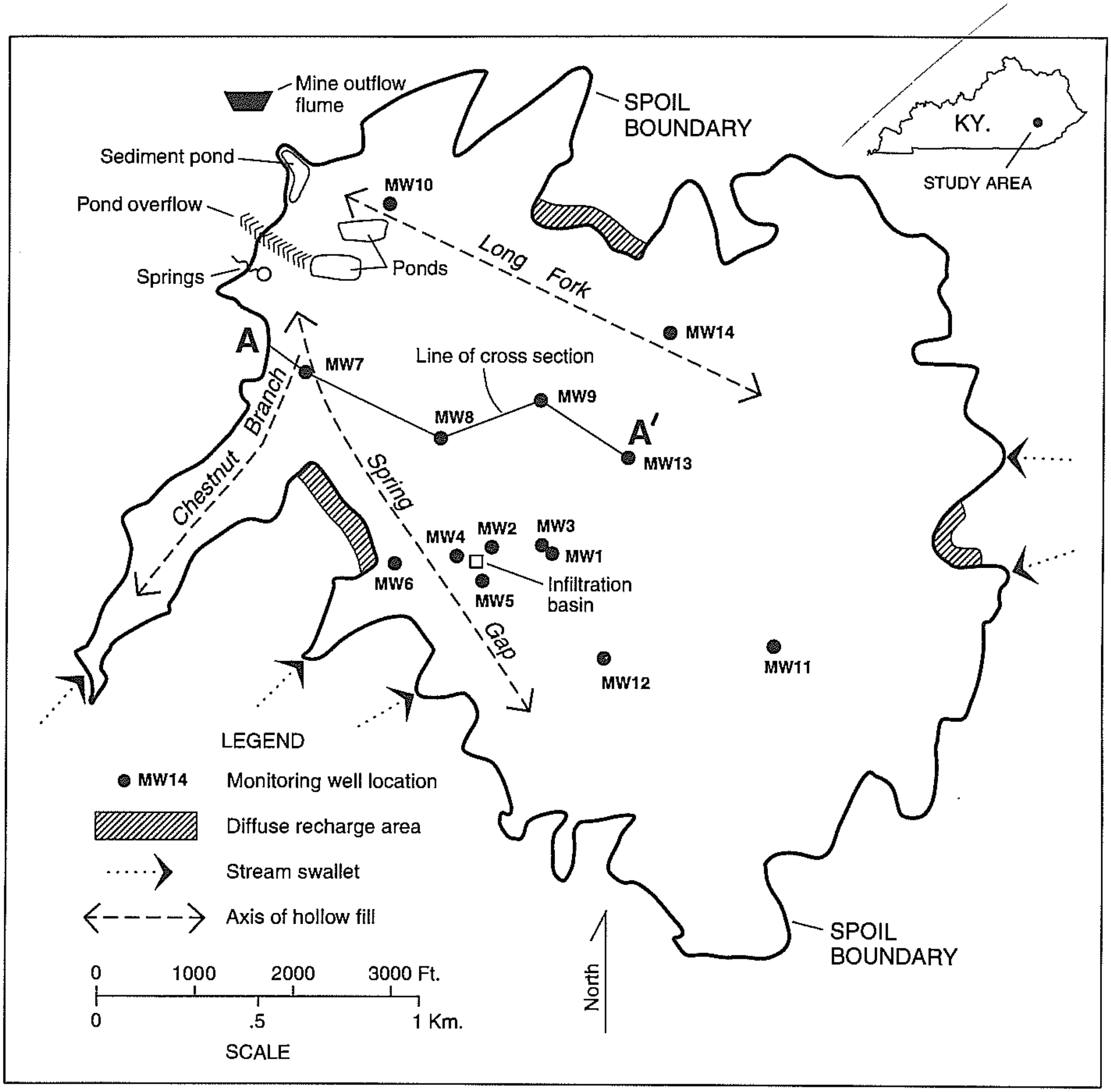

Figure 1. Location map, showing sigificant features at the site.

water at the site (Wunsch et al. 1992; Dinger et al. 1990). Therefore, these points are discussed only briefly here.

The spoil at the site, which approaches 91 m in thickness, consists of a heterogeneous mixture of broken clastic sedimentary rocks. A continuous coarse boulder zone exists on top of the pavement rock that lies below the No. 7 coal seam, which is the lowest seam in the section presently being mined. This boulder zone, and similar boulder zones that are found in hollow fills, should permit the storage and rapid movement of ground water. Because of their thick and continuous nature, these zones are anticipated to be the most capable of providing significant ground-water quantities.

A surface-water infiltration basin with a continuously penetrating rock chimney was constructed to create a direct connection to the rubble zone resting on top of the No. 7 coal underburden. The rock chimney was constructed to bypass all intermediate compacted zones within the spoil that might tend to perch percolating ground water.

Water Monitoring Methods

Monitoring Wells

Fourteen monitoring wells ranging in depth from 16.7 to 72.8 m were installed in the spoil. Several monitoring wells are equipped with data loggers at alternate times to record changes in the water table for extended periods of time.

Slug Tests

Based on methods first described by Hvorslev (1951), falling-head slug tests were performed in monitoring wells to determine the hydraulic characteristics of the spoil. The hydraulic conductivity values were then calculated by using the computer program TIMELAG (Thompson 1987). Nine tests were performed by injecting water (ground water derived from the spoil) as quickly as possible into the monitoring wells (injected at 3.2 liter/second) until the water level reached the top of the plastic casing. In most cases, the well casing could be filled with water in less than a minute. An equilibrium water level was maintained for several seconds while any trapped air bubbles were allowed to escape from the water column.

The instantaneous drop in head when the water flow was cut off was recorded by a submerged pressure transducer and digital data logger. These tests violate the assumption that instantaneous change in water level occurs at the initiation of the test. Even under ideal conditions this method is not precise, but it is generally considered as an appropriate means of estimating the order of magnitude of hydraulic conductivity (Thompson 1987).

In some cases, wells took more water than could be supplied by the pump. In these wells, the hydraulic conductivity calculated represents a minimum value based on a water injection rate of 3.2 liters/second. The static head level used in calculations was the maximum head level (top of casing) for each well, which provided for a minimum hydraulic conductivity value that would sustain the flow rate.

Water-Quality Sampling and Analysis

Water samples from the largest spring, monitoring wells, 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. Field variables determined in most samples were temperature, specific electrical conductance, Eh, and pH. These parameters were collected utilizing a flow-through cell with water supplied by a 5 cm submersible pump. Laboratory analyses of water samples included dissolved concentrations of 30 major and trace metals and major anions.

Dye Tracing

Ground-water dye traces using Rhodamine WT were conducted to define flow paths and travel times through the the spoil. Dye traces were performed to determine the flow path of water entering the spoil at various points. Dye trace data from previous studies (Kemp 1990; Wunsch et al. in press) were also used to aid in the determination of ground-water flow paths.

Ground-Water Movement

Ground-water movement within the spoil will be controlled by the gradients that form as a function of the interaction of recharge and discharge zones, by the topography of the relatively impermeable pavement that underlies the lowest coal seam being mined (Hazard No. 7), and the drainage patterns that existed before mining began. The major streams that drained the pre-mined area (Fig. 2) (Chestnut Branch, Spring Gap, and Long Fork) eroded valleys whose bottoms are at elevations well below the elevation of the No. 7 coal. These drainage valleys became hollow fills as contour-cut mining occurred along the valley walls.

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

Results and Discussion

Recharge

Field reconnaissance of the study area revealed numerous places where streams and storm runoff recharge the spoil aquifer. Several streams were observed to flow directly into swallets (i.e., disappearing stream channel) at the toe of spoil slopes. The largest of these streams is Chestnut Gap Branch, a first-order stream with a watershed area of 0.85 km^2.

A number of recharge zones were observed on the spoil during storm runoff events. These occur where the spoil adjoins highwalls or natural bedrock slopes, or where spoil handling resulted in boulder zones being locally exposed at the surface. Storm runoff flows into these areas and then rapidly disappears into the spoil. Likewise, the deep infiltration basin has been functional in this regard, although its present watershed is limited. Numerous small cracks and fissures in the spoil surface were observed to capture lesser amounts of storm runoff. These discrete recharge points or "snakeholes" usually occur where rubble or boulders are exposed or intersect the surface.

Infiltration through the spoil surface is not thought to account for a significant amount of recharge owing to the compacted nature of the graded spoil. A percolation test performed at the site revealed very low infiltration rate (0.47 cm/h) for water entering the spoil through the graded, compacted surface.

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 (fig. 1). The springs crop out at an elevation of approximately 1,040 ft. (317 m). This discharge area is located at the toe of a 39.6-m-thick lift of end-dumped sandstone spoil that overrides a 13.7-m-thick lift of end-dumped shale that is believed to have a lower permeability than the sandstone spoil (Kemp 1990).

Discharge was not observed from the toe of the Long Fork hollow fill. Based on observations made by mine personnel, ground water is flowing through this hollow fill, but discharges directly into the sediment pond located at the bottom of this fill below the surface of the pond.

Ground water also discharges from the spoil into the active dragline pit when the pit is at the level of the No. 7 coal bed, requiring pumping on a daily basis. On occasion pumping rates have reached an estimated 1,360 m^3/d.

Two ponds have been created to store water for dust control. These ponds, shown on figure 1, are located at the northwest corner of the spoil, above the spoil springs. The bottom surface of the northern pond is on the underclay of the Hazard No. 7 coal. The bottom of the second pond has been excavated into the shale unit that is below the No. 7 coal and underclay. Both of these ponds are fed by water from the saturated spoil. Evidence for this observation is (1) the water levels in the ponds are very similar to those observed in the nearest monitoring wells that are located on the buried plateau, (2) although these ponds are pumped to fill 38 m^3 water trucks, the water is never depleted, (3) the ponds do not freeze in the winter, and (4) the electrical conductance (2,100 microsiemens) of the water flowing out of the overflow is similar to that of the spoil-fed springs that crop out below (Kemp 1990). Water overflows from the lower pond during wet periods and cascades down the spoil face by way of a riprap-lined drainage channel, and contributes to the total mine outflow.

A large-capacity flume was installed below the sediment pond to gage the total water outflow. Data collection from the flume has not been continuous owing to periods of freezing conditions and vandalism. However, for the 1992 water year, data were collected for 255 days. The monthly mean discharge data show a range of 0.13 to 0.29 m^3/s. Mean and median discharge are both approximately 0.16 m^3/s.

Ground-Water Occurrence

Figure 2 shows the outline of the spoil complex with a contoured surface of the present buried basal topography. The bottom surface of the interior is dominated by a gently undulating plateau capped by the underclay and shale that underlie the No. 7 coal. This "buried plateau" is bordered by the pre-existing stream drainage (shaded areas) formed by Long Fork to the northeast and Spring Gap-Chestnut Branch to the southwest. A considerable drop in elevation occurs from the plateau level to the bottom of the old stream drainages. Maximum relief (approximately 45.7 m) occurs in the northwest corner of the spoil where the the two buried drainage valleys converge.

A contour map of the water table within the spoil (fig. 3) was created from water elevation data from all 14 monitoring wells on the site, ponds, Chestnut Branch, and spring 1. Water-level elevation data for the wells were collected in June 1991. This map was produced without regard to the basal topography revealed on figure 2. A northwesterly sloping water table is shown with a relatively low gradient in the central plateau of the spoil bottom. Generally, the slope of the water table in this area follows the structure of the bedrock plateau. A structural low exists at approximately the center of the plateau (as shown by the nearly closed 1,110-ft. (335.3 m) contour line(*see* fig. 2). The gradient of the water table increases drastically near the northwest section of the plateau. The steep gradient is interpreted as representing the boundary between two sep-

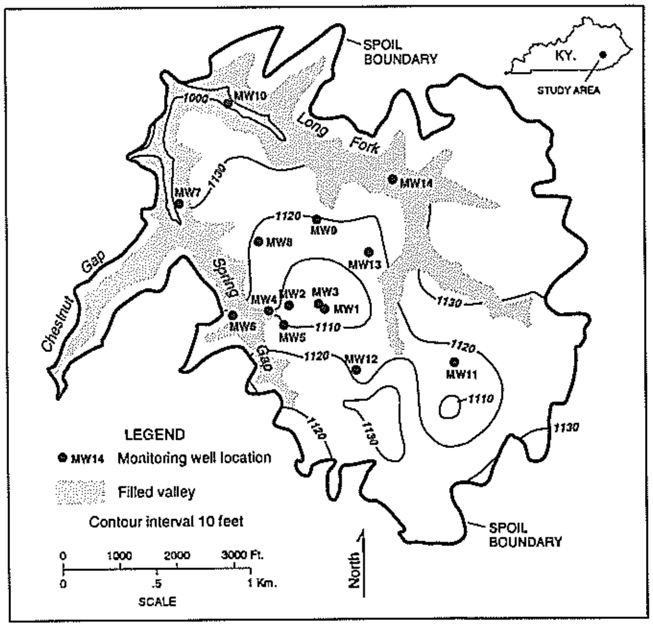

Figure 2. Map showing the contoured bedrock surface after removal of the No. 7 coal.

arate but interconnected saturated zones, separated by the increasing elevation difference toward the northwest between the buried plateau and the bottom of the pre-mining valleys. The structural contour map (fig. 2) shows that the interior basal plateau has roughly a "spoon" shape; thus, the slopes formed by the bedrock along the edges of the plateau may form the barriers that retard water movement in the plateau region.

The overall picture of the distribution of water within a section of the spoil is more clearly illustrated in figure 4, which is a cross section of the spoil through monitoring wells 7, 8, 9, and 13 along the line A-A' shown on figure 1. Two saturated zones are shown: one relatively shallow zone perched on the buried plateau formed by the removal of the No. 7 coal, and the other in the hollow fill of the Chestnut Branch drainage. The water levels in wells on the northern side of the spoil suggest that a similar configuration exists in the Long Fork hollow fill. The saturated zones should be connected at the southeast reaches of the spoil, where the elevation of the buried valleys approaches the elevation of the base of the No. 7 coal.

The apparent lack of direct connection suggests that the water system in the spoil's interior is somewhat stagnant, and that the majority of ground water must flow into either of the two buried valleys before finally discharging in the northwestern corner of the spoil. Additionally, some ground water from the spoil's interior discharges into the two ponds on the northwestern corner of the spoil and contributes to the total mine discharge through the pond's overflow.

Based on an average saturated thickness (6.9 m) determined from water levels taken from the 14 wells during April 1991, and an estimated porosity of 20%, there would be approximately 5.2 x E^6 m^3 (1.37 billion gal.) of water stored within this 4 km^2 acres of spoil. Diodato and Parizek (1994) found that the porosity of mine spoil ranged from 30.1 to 57% in shallow, unsaturated boreholes. However, because of the greater spoil thickness, compaction, and saturated conditions at the Star Fire site, the 20% porosity estimate used here seems reasonable.

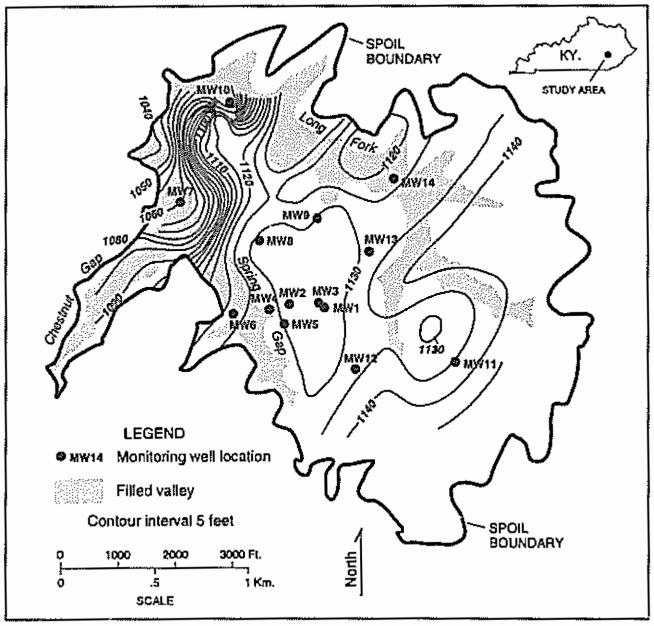

Figure 3. Contour map of the water table.

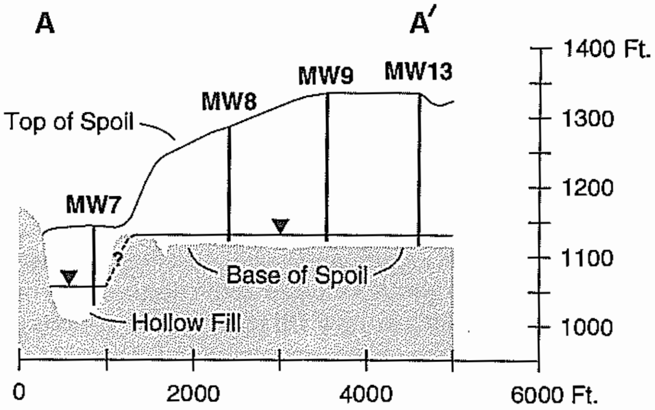

Figure 4. Cross section through line A–A' showing two water tables.

Slug Tests

Falling-head slug tests were performed in nine monitoring wells at the site during the fall of 1992 (table 1). The hydraulic conductivity (K) values ranged from 7.0 x E-5 to > 9.0 x E-4 cm/s. These values are comparable to those for silty sand (Freeze and Cherry 1979). These values are also consistent with hydraulic conductivity values determined by other researchers in mines that employ similar mining methods. For example, Oertel and Hood (1983) found K values in the range from 4.6 x E-5 to 2.1 x E-2 cm/s and Herring and Shanks (1980) found a range from 4.6 x E-5 to 4.8 x E-2 cm/s.

Table 1. Slug test data—hydraulic conductivity.

Well	cm/sec	ft./sec
MW 4	7.0 X E-5	2.0 X E-6
MW 5	> 8.2 X E-4	> 2.7 X E-5
MW 7	2.0 X E-5	8.0 X E-6
MW 8	> 7.3 X E-4	> 2.4 X E-5
MW 9	4.0 X E-5	1.0 X E-6
MW 10	> 9.0 X E-4	> 2.9 X E-5
MW 12	4.0 X E-4	1.0 X E-5
MW 13	> 5.8 X E-4	> 1.9 X E-5
MW 14	2.0 X E-4	8.0 X E-6

Because some wells (Nos. 5, 8, 10, and 13) were able to take water at a rate that exceeded injection capabilities, only a minimum hydraulic conductivity could be calculated. The actual K's for these wells may be significantly higher than the values given. In addition, high K's may be representative of spoil that exhibits turbulent or non-darcian flow, rendering dubious results.

Infiltration Basin

Water entering the basin probably flows in the direction of well 4 (southwest) toward the Spring Gap hollow fill (Wunsch et al. in press). Therefore, the Spring Gap hollow fill is probably capturing the water infiltrating the spoil through the infiltration basin, from where it most likely moves downslope to the Chestnut Branch hollow fill and discharges from the spoil at one of the springs located on the spoil's outslope. The structure contours shown on figure 2 support this hypothesis. The 1,110-ft. contour and surrounding intervals indicate a structural low in the base of the No. 7 coal beneath the infiltration basin, which slopes in the direction of the Spring Gap hollow fill.

Dye Tracing

A dye trace performed by Kemp (1990) involved injecting dye into monitoring well 1 (fig. 1). This dye was not recovered in the springs in the northwest corner of the spoil. Dye was still visible in well 1 after several months, indicating that ground-water movement is sluggish in the center of the interior spoil area. No discernible difference in hydraulic conductivity appears to exist between the wells tested in the hollow fills or the spoil interior. Therefore, the apparent sluggish nature of the ground-water movement in the spoil interior must be related to gradients induced by recharge-discharge relationships. The spoil interior, lacking any major direct recharge from the surface, remains stagnant, whereas the ground water in the hollow fills receives recharge from the streams that disappear into the base of the spoil, from adjacent bedrock aquifers, and from surface water that seeps in near the bedrock-spoil interface.

Additional dye tracing using Rhodamine WT was performed during the spring of 1991 to determine the flow path of recharge water that enters the spoil through the infiltration basin. Three dye-trace positives were detected to the west of the infiltration basin, which is consistent with the direction of flow as determined by hydraulic gradients and basal topography (Wunsch et al. in press). One positive trace was located in a pit excavated along the highwall-hollow fill contact near well 6. Additional positive traces were found where water flowed from the spoil's face below the elevation of the infiltration basin during wet periods. This indicates that not all of the water that flows into the infiltration basin penetrates to the base of the spoil; instead it may travel along highly conductive paths or be diverted by low-permeability horizontal barriers within the spoil.

Conceptual Model for Ground-Water Flow in the Spoil

Figure 5 shows a map of the spoil body with arrows indicating the assumed direction of ground-water flow. Water that slowly accumulates in the spoil interior flows toward the head of the buried valleys that now are hollow fills. This is evidenced by (1) dye trace data, (2) head data, and (3) bottom structure of the buried plateau.

Water contained in the hollow fills flows toward the northwest, where it discharges. Some of the water stored in the spoil's interior supplies the water to the ponds used for dust control that are situated above the springs. The pond water, in turn, discharges through the overflow down the face of the spoil, where it joins with the spring discharge before entering the lowermost sediment pond.

In summary, this model presents a scenario where the majority of water contained in the spoil moves through the hollow fills from the main spoil body and discharges at the northwest corner of the spoil. Recharge enters the spoil mainly along the edges of the hollow fills, and at discrete points on the reclaimed surface, which includes the infiltration basin.

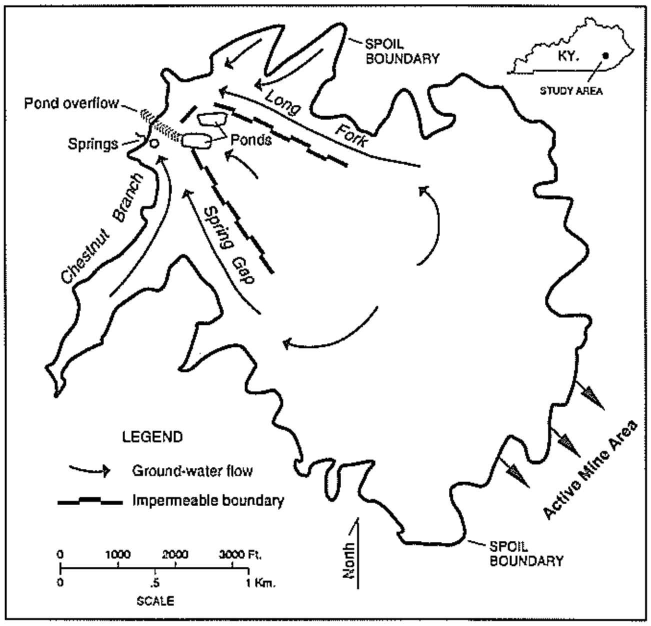

Figure 5. Conceptual model of ground-water flow at the Star Fire site.

Hydrogeochemistry

Interpretation of Spoil Water-Quality Data

Figure 6 shows water samples plotted as a function of the normalized percentage of the samples' major cations and anions. Sixty-eight water samples are represented on the diagram, which includes all samples taken from April 1991 through June 1992 and represent five sampling events. A complete list of data for samples collected from the Star Fire site can be found in Wunsch et al. (in press). All of the samples plot close to a single location on the diamond-shaped field of the diagram, indicating that calcium and magnesium are the major cations and sulfate is the dominant anion. The most likely origin for the Ca-Mg-SO_4 water type found at the site is the oxidation of iron sulfide minerals with the contemporaneous dissolution of calcium carbonate. The data shown here represent four sampling events spanning 14 months, indicating that the water-quality type has little temporal variation.

Figure 7 shows the distribution of pH values for all monitoring wells and spring 1. Monitoring wells show maximum, median, and minimum pH values greater than 6.0 with the exception of wells 6, 11, and 14. Overall, the majority of pH data collected at the site indicate that the mine spoil does not produce highly acidic water.

All samples from well 14 have pH's less than 4.5, which represents the lowest pH encountered on the site. Samples taken from MW 14 are somewhat separated from the group of other samples plotted on the Piper diagram (fig. 6). The samples from well 14 show that the distribution of cations (mainly calcium and magnesium) is consistent with the percentages found in other wells' samples, with the major difference being in the distribution of the anions. The range of HCO_3^- concentrations in well 14 is from 3.66 to 8.54 mg/L, while the range of HCO_3^- from all other wells is from 185 to 1,045 mg/L. The highest average Eh value (mean Eh = 196 mV, coefficient of variation = 6.97%) of all of the wells surveyed was observed at well 14. This is well into the range where the oxidation of sulfides is likely to take place (Champ et al. 1979). Most likely an area of "hot" spoil exists in the zone monitored by well 14. The abundance of sulfide minerals in this zone with a deficiency of calcium carbonate could result in the low HCO_3^- concentrations and low pH observed in well 14.

Sodium and potassium concentrations are generally low compared to the calcium and magnesium concentrations in all samples. The most common clay minerals found in overburden rocks in the vicinity of the site are kaolinite and illite (Papp 1976). These clay minerals typically have low to medium cation exchange capacity (CEC) (Bohn et al. 1985). Therefore, it is unlikely that cation exchange is an important factor in controlling the distribution of cations in the spoil ground water. The release of divalent cations from the dissolution of carbonate minerals appears to dominate the water chemistry reactions, such that any effect of cation exchange is insignificant.

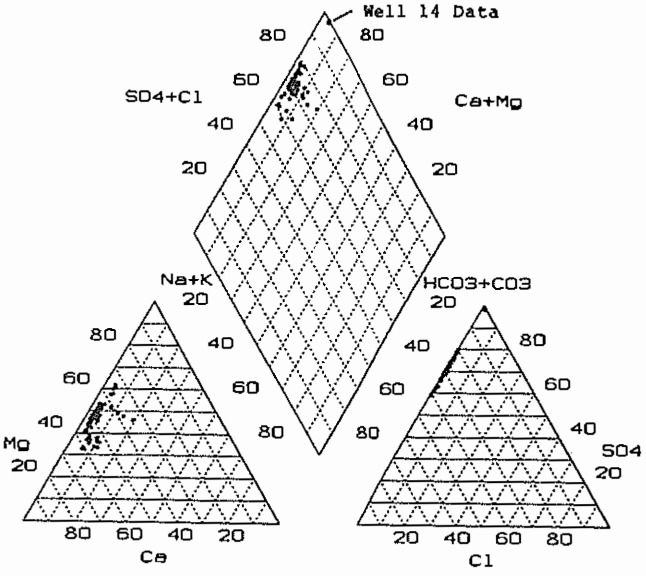

Figure 6. Piper diagram showing water types of ground-water samples from monitoring wells and the main spring.

Based on April 1991 data, the total dissolved solids (TDS) of water samples from wells in the spoil interior are higher than the TDS of wells located over hollow fills. Wells located in the interior section of the spoil (monitoring wells 2, 3, 5, 8, 9, 11, 12, and 13) have a mean TDS of 2,812 mg/L (std. dev. = 457), whereas hollow-fill samples (wells 4, 6, 7, 10, 14, and spring 1) have a mean of 1,128 mg/L (std. dev. = 766). The higher TDS values character-

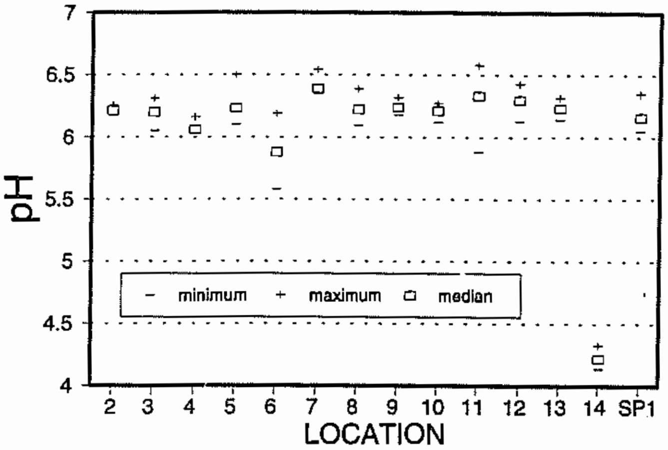

Figure 7. Distribution of pH values for water samples collected from monitoring wells and the spoil spring (SP1).

istic of wells located in the interior of the spoil are most likely the result of longer contact time between ground water and spoil due to slow ground-water movement. The extended contact time allows for greater water-rock interaction and leaching of soluble and reactive rock materials, therefore increasing the concentration of the dissolved constituents.

The TDS for samples taken from the springs and monitoring wells in the northwest area of the spoil (MW 7 and MW 10) are very similar to the TDS of the discharge water exiting the mine site through the flume. TDS values are 2,608 and 2,116 mg/L for wells 7 and 10, respectively, and 2,127 mg/L for the flume discharge water. These preliminary data suggest that the major source of the water discharging from the entire mine site is ground water derived from the mine spoil. If surface-water runoff at the site were making a significant contribution to the total mine outflow, it would be expected that the TDS would be considerably less than that observed. Water from the stream at Chesnut Branch and water entering the infiltration basin have TDS concentrations that are generally less than 500 mg/L (Dinger et al. 1990).

Saturation indices for minerals thought to impart a significant control on the water chemistry were calculated using the geochemical model PHREEQE (Parkhurst et al. 1980). Data used in the calculations are from water samples collected on June 16, 1992. The equilibrium data (table 2) indicate that all water samples are undersaturated with respect to both calcite and dolomite and suggest that these minerals, if present, should dissolve. Dolomite is not abundant in the rocks that comprise the overburden, and probably does not make a significant contribution to the magnesium content of the ground water at the site.

The carbonate cements in the sandstones indigenous to the overburden rocks were determined to be ferroan calcite, which may also contain magnesium and could provide calcium, iron, and magnesium to the ground water. Chlorite is abundant in the overburden, based on mineralogical assessments performed by Papp (1976), and is probably the main source of magnesium. Powell and Larson (1985) found chlorite to be a probable source of magnesium in ground water derived from rocks that are stratigraphically and lithologically similar to the rocks that comprise the overburden at the site. Table 2 shows that all of the water samples are undersaturated with respect to chlorite.

The water from nearly all wells is at or near equilibrium with gypsum ($CaSO_4 \cdot 2H_2O$), with the exception of monitoring wells 4, 6, and 14 (table 2). Each of these monitoring wells is located in an area of the spoil where surface water can easily influence the ground water. The effect of dilution by surface water and lower residence time is the most likely explanation for the degree of undersaturation with respect to gypsum in these three wells. The average total dissolved solids calculated for these wells was the lowest observed from all wells at the site, but the distribution-percentage of cations and anions remained consistent with that of all other ground-water samples.

Table 2. Saturation indices for selected minerals shown in log IAP/K using the model PHREEQE (Parkhurst et al. 1980). IAP=ion activity product, K=equilibrium constant, TDS=total dissolved solids (calculated).

Well	Calcite	Dolomite	Gypsum	Chlorite	TDS
MW 2	–0.3618	–0.8095	0.0116	–10.9561	2412
MW 3	–0.2230	–0.6151	0.0364	–10.8265	2796
MW 4	–1.2823	–2.4945	–0.8279	–15.3130	874
MW 5	–0.2750	–0.6708	–0.0378	–10.2089	2380
MW 6	–1.5691	–3.0704	–0.8140	–17.2109	726
MW 7	–0.2747	–0.3551	0.0095	–7.3621	2608
MW 8	–0.0049	–0.1510	0.0754	–7.8246	3409
MW 9	–0.2792	–0.5369	–0.0681	–9.2461	2812
MW 10	–0.4647	–0.8510	–0.1012	–10.3842	2117
MW 11	–0.5093	–0.9636	0.1195	–12.3585	3596
MW 12	–0.2738	–0.7338	0.1251	–11.3047	2574
MW 13	–0.4078	–0.8301	–0.0217	–9.9278	2521
MW 14	–4.5345	–9.0036	–0.4288	–34.2911	926
SP 1	–2.4520	–4.9492	–0.0336	–11.5458	1591

Wells 8, 11, and 12 show saturation with respect to gypsum. Each of these wells is located in the interior area of the spoil. Two of these wells (8 and 11) contain some of the highest TDS contents observed at the site (table 2). The degree of gypsum saturation in these wells correlates well with the increased mineralization of the ground water in the spoil's interior.

Summary

A ground-water resource evaluation has been initiated to monitor the development of the water table in the spoil, assess the effect of infiltration basins on ground-water development, perform tests to determine the hydraulic properties of the spoil, and delineate ground-water quality over time.

Water-table elevation data from the monitoring wells, springs, and ponds indicate that separate saturated zones exist in the spoil, one in the interior section of the spoil, and two additional at lower elevations in the two adjoining hollow fills (Spring Gap/Chestnut Branch and Long Fork). Most likely these saturated zones are in hydraulic connection in the upper reaches (southeast area) of the spoil body, but are separated by elevation due to the topography of the basal aquitard in the northwestern section of the spoil.

Based on an average saturated thickness of 6.9 m for the site, an estimated 5.2 x 10^6 m^3 (1.37 billion gal.) exists in the 4 km^2 acre spoil at the Star Fire site.

Slug tests performed in monitoring wells at the site show the range of hydraulic conductivity (K) values encountered in the spoil is from 7.0 x E-5 to > 9.0 x E-4 cm/s. The upper limit of K for spoil could not be determined because of equipment limitations and could be significantly higher than reported.

All waters at the site are a calcium-magnesium-sulfate type. The pH of most ground-water samples fell into a favorable range of 6 to 7. The TDS values for wells located in the spoil interior are significantly higher than those for wells located in the hollow fills. Higher mineralization of the water samples from the interior spoil area probably reflects the longer contact time of ground water with reactive spoil material. These data are consistent with the gentle gradient of the water table and dye-tracing data. Lower TDS values for the hollow-fill wells probably results from a greater contribution of less mineralized surface water into the ground-water flow system and a lower residence time.

Ground-water chemistry appears to be controlled by the dissolution of carbonate minerals and the oxidation of sulfide minerals, resulting in a Ca-Mg-sulfate water type for both ground and surface water at the site. Most of the ground water in the spoil is at or near equilibrium with the mineral gypsum. This may inhibit the use of ground water from the spoil for certain industrial or agricultural applications. Therefore, monitoring of water quality will continue to measure any changes in dissolved mineral equilibria with time.

Two saturated zones occur in the spoil. The interior of the spoil contains a relatively thin and stagnant saturated zone from the accumulation of water from discrete infiltration, the infiltration basin, and the active mining area where uncompacted or reclaimed spoil is present.

Water in the hollow fills is a combination of spoil seepage and ground water from the adjacent unmined bedrock highwall and surface water that accumulates and later percolates into the hollow fills along the spoil/bedrock contact.

Total mine outflow measured in the northwest area of the reclaimed spoil produces a base flow of approximately 0.16 m^3/s (3.9 mgd). Variations in water quality observed at the site are related to the flow system described by this conceptual model.

The initial water-quality and -quantity data measured at the Star Fire Mine demonstrate that ongoing mining techniques can provide the physical framework for an aquifer in the extensive mine spoil. Although the ground water stored in the spoil is not potable at this time, it is likely that it could serve for various agricultural and industrial uses. Development of a useful water supply from within the spoil will be a key factor in future land use and economic diversity of the site and other similar sites in eastern Kentucky.

Literature Cited

Bohn, H. L, B. L. McNeal, and G. A. O'Connor. 1985. Soil chemistry. 2nd ed. John Wiley and Sons, Inc., New York. 341 p.

Champ, D. R., J. Gulens, and R. E. Jackson. 1979. Oxidation-reduction sequences in ground water flow systems. Canadian Journal of Earth Science 16:12–23.
http://dx.doi.org/10.1139/e79-002

Dinger, J. S, D. R. Wunsch, and J. E. Kemp. 1990. Occurrence of ground water in mine spoil, a renewable resource: Star Fire tract, eastern Kentucky. Mining and Reclamation Conference and Exhibition. (Charleston, West Virginia, April 23-26, 1990).
http://dx.doi.org/10.21000/JASMR90010171

Diodato, D. M., and P. R. Parizek. 1994. Unsaturated hydrogeologic properties of reclaimed coal strip mines. Ground Water 32(1).

Freeze, A. R., and J. A. Cherry. 1979. Groundwater. Prentice-Hall, Inc., Englewood Cliffs, N. J. 604 p.

Herring, W. A., and T. J. Shanks. 1980. Hydraulic conductivity of cast overburden. EOS 61(48):1193.

Hvorslev, M. J. 1951. Time lag and soil permeability in groundwater observations. U.S. Army Corps of Engineers Waterways Experiment Station Bulletin 36.

Kemp, J. E. 1990. Hydrogeologic characterization of surface mine spoil, Star Fire Mine, eastern Kentucky. M.S. Thesis, University of Kentucky, 102 p.

Oertel, A. O., and W. C. Hood. 1983. Changes in ground water quality associated with cast overburden material in southwest Perry County, Illinois. p. 73–78. In Proceedings of the 1983 Symposium on Surface Mining, Hydrology, and Reclamation. (University of Kentucky, Lexington).

Papp, A. R. 1976. Extractable cations from claystones and shales of the Pennsylvanian Breathitt Formation in eastern Kentucky as related to depositional environments. M.S. Thesis, Eastern Kentucky University, Richmond, Kentucky, 153 p.

Parkhurst, D. L, D. C. Thorstenson, and N. L. Plummer. 1980. PHREEQE, a computer program for geochemical calculations. U.S. Geological Survey Water-Resources Investigations 80-96. 210 p.

Powell, J. D., and J. D. Larson. 1985. Relation between ground-water quality and mineralogy in the coal-producing Norton Formation of buchanan County, Virginia. U.S. Geol. Surv. Water-Supply Paper 2274.

Sobek, A. A., W. A. Schuller, A., J. R. Freeman, and R. M. Smith. 1978. Field and laboratory methods applicable to overburdens and minesoils. Environmental Protection Agency, EPA-600/2-78-054.

Thompson, D. B. 1987. A microcomputer program for interpreting time-lag permeability tests. Ground Water 25(2):212–218.

http://dx.doi.org/10.1111/j.1745-6584.1987.tb02878.x

Weinheimer, R. L. 1983. Vertical sequence and diagenesis in Breathitt sandstones in Eastern Kentucky: M.S. Thesis, University of Cincinnati, 147 p.

Wunsch, D. R, J. S. Dinger, and P. B. Taylor. 1992. Design, construction, and monitoring of the ground-water resources of a large spoil area: Star Fire tract, eastern Kentucky. Kentucky Geological Survey, ser. 11, Report of Investigations 6. 16 p.

Wunsch, D. R, J. S. Dinger, P. B. Taylor, D. I. Carey. in press. The hydrogeology and hydrogeochemistry of a large mine spoil area: Star Fire tract, eastern Kentucky. Kentucky Geological Survey Report of Investigations.