ENHANCED COVER METHODS FOR SURFACE COAL REFUSE RECLAMATION[1]

by

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Abstract. Controlling acid rock drainage (ARD) can be a major component of surface mining reclamation. An enhanced reclamation cover system is being constructed to control infiltration of rain water and generation of ARD from coal-refuse disposal areas at a closed mine in southern Illinois. Development of the mine reclamation plan required consideration of ARD generation in coal refuse disposal areas located adjacent to an alluvial aquifer used for public water supply. An integrated site characterization was performed at the mine to provide information to develop and support the enhanced reclamation plan. The enhanced cover system is similar to covers required for municipal solid waste landfills by the Resource Conversation and Recovery Act (RCRA), Subtitle D regulations. The system comprises a graded and compacted gob layer, overlain by a compacted clay liner, and a protective soil cover. The results of infiltration modeling and analyses showed that the standard reclamation cover is effective in reducing infiltration by about 18 percent compared to an unreclaimed coal-refuse surface. The modeling results showed that the enhanced cover system should reduce infiltration by about 84 percent. The geochemical modeling results showed that the reduction in infiltration would help minimize ARD generation and contribute to an earlier reclamation of the mine site.

Additional Key Words: ground-water impacts, ARD control, infiltration modeling.

Introduction

A corrective action plan (CAP) based on an integrated site characterization was performed for a closed coal mine in southern Illinois to support a modification to the reclamation plan for the mine (GeoSyntec, 1995a). The primary objectives of the CAP were source control of coal-refuse acid-rock drainage (ARD) and the mitigation of groundwater exhibiting elevated total dissolved solids, metals, and other chemical compounds. A primary component of the CAP involved substituting an enhanced, reduced thickness cover system for the standard cover normally required for the reclamation of surface coal-refuse areas. The site characterization study provided understanding of site conditions and included: a hydrogeologic investigation of the mine site and vicinity; geochemical analyses; ground-water flow modeling; a geotechnical investigation; and precipitation infiltration analyses. A summary of the site characterization has been provided, followed by a description of the enhanced reclamation cover system and a discussion of the effectiveness of the cover in achieving the CAP objectives.

Integrated Site Characterization

The underground mining operation produced coal from the Illinois No. 5 (Springfield) coal. Coal washing operations produced both coarse coal refuse (gob) and fine refuse (slurry). The coal washing by-products were contained in six surface coal refuse areas (now dewatered) totaling approximately 180 acres (73 ha.) (Figure 1) in aerial extent. Both slurry and gob were intermixed in three of the six coal refuse areas. One of the coal refuse areas included gob disposed in trenches excavated to or slightly below the water table. The mine area also includes a reclaimed tipple site and two lakes for coal-wash water storage and recycling.

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Hydrogeology

The mine site is situated at the margin of a large alluvial valley (Saline Valley) (1,000 sq mi (2,600 sq km)) and adjacent to a low bedrock ridge composed of Pennsylvania age sandstone and shale (Poole and Sanderson, 1981). The bedrock beneath the alluvial valley and, the lateral stratigraphic pinchout of the sand and gravel are the limiting boundaries of the alluvial aquifer. The water-bearing alluvial sediments, known as the Henry Formation, comprise sands and gravel deposited during Wisconsin-age glacial flooding. The thickness of the Henry Formation ranges from 0 ft at the valley margins to 150 ft (45 cm) near the axis of the valley. The aquifer ranges in thickness from 10 ft (3 cm) to 100 ft (37 cm) beneath the mine site. Figure 2 is a hydrogeologic cross-section through the mine and normal to the valley axis.

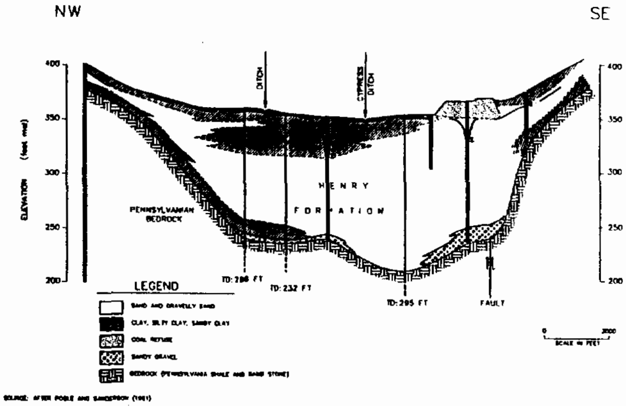


FIGURE 2. Hydrogeologic cross-section through Saline Valley illustrating the lithology of the Henry Aquifer. The site is located near the southeast end of the section.

Ground-water flow in the alluvial valley is generally northeast to southwesterly and from the margins toward the axis (Figure 3). The ground-water flow system has also been influenced by artificial sinks (i.e., wells and drains). Agricultural drains were dug in the 1920's in the valley to remove shallow ground water and surface water and to improve the land for agricultural use. Ground water is plentiful in the Henry Formation, and hundreds of shallow wells have been dug for individual farms and residences in the valley (Illinois State Water Survey, 1995). The mine also used ground water from three production wells for the coal washing process. Significant development of ground-water resources in the Henry Formation began in the 1980's with the installation of municipal water supply systems using large volume wells and installation of wells for crop irrigation. One municipal supply system consisting of five production wells has been developed about one-half mile west of the mine site. The proximity of the well field had a major effect on the development of the CAP.

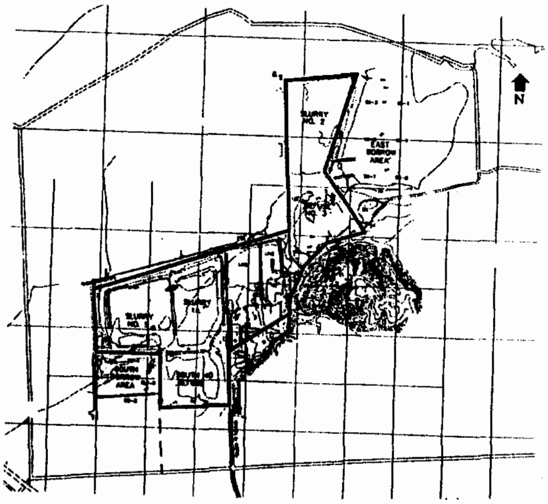


FIGURE 1. Site location map with the coal refuse coal refuse areas outlined. The site sits in the Saline Valley, with the Shawneetown Hills adjacent to the Southeast.

Geochemistry

An important factor in understanding site conditions and in developing the CAP was the geochemistry of the coal refuse. Samples of the gob and slurry were collected and analyzed by x-ray diffractometry for their mineralogical content (Table 1). Both were more than 50 percent clay (illite/smectite and kaolinite). Pyrite ranged from a high of 19 percent in the gob samples to a low of 8 percent in the slurry samples. Up to 3 percent gypsum was present in the gob, probably as a secondary mineral from the decomposition of pyrite. Effects of ARD from the coal-refuse coal refuse areas were observed in both surface and ground water. ARD surface run off from the gob disposal areas was collected in sumps at the mine site. The results of chemical analysis of samples from the sumps indicated concentrations up to 9,000 mg/l of total dissolved solids (TDS), 5,200 mg/l sulfate, and pH values as low as 2.7. Results of analysis of samples from the slurry pond supernatant indicated TDS values up to 6,800 mg/l, sulfate concentration up to 4,200 mg/l, and pH values up as low as 2.9. Infiltrating ARD and ARD produced by precipitation infiltration has apparently resulted in mineralized ground water at the site.

Geochemical modeling using the codes MINTEQ (Allison, et al. 1991) and PHREEQE

(Parkhurst et al. 1980) showed that minimizing the amount of precipitation infiltration and eliminating exposure of the gob to atmospheric conditions were keys to controlling ARD. The modeling results also showed that the gob trenches at or below the water table were not a significant source of ARD. Further details are provided in a paper by Simmons, et al, (1997) in preparation.

An existing network of 14 monitoring wells was augmented with 25 new monitoring wells during the site characterization. Ground-water samples were collected biweekly for 3 months, monthly for the next 9 months and then quarterly thereafter. The samples were analyzed for selected Illinois Environmental Protection Agency (IEPA) coal-reclamation site water-quality parameters to characterize the ground-water chemistry at the site. Based on this sampling, it was shown that the ground water beneath the coal-refuse disposal coal refuse areas was impacted by ARD, (Table 2). TDS and sulfate concentrations greater than background concentrations were detected in nearly all monitoring wells within the mine permit boundary. Sulfate typically comprised about 40 to 60 percent of the TDS concentration from the samples of impacted ground water. The impacted ground water had not affected the water quality in the public supply system adjacent to the mine due to hydraulic control provided by pumping the on-site wells used to supply coal-wash water. Continuing the protection of water quality in the alluvial valley and preventing impacts to the public supply system were essential to formulating the CAP.

Ground-Water Flow Modeling

Conceptual and numerical ground-water flow models were developed for the site to evaluate potential corrective measures for the CAP. Development of the conceptual model included identifying the general components of the hydrogeologic system at the site.

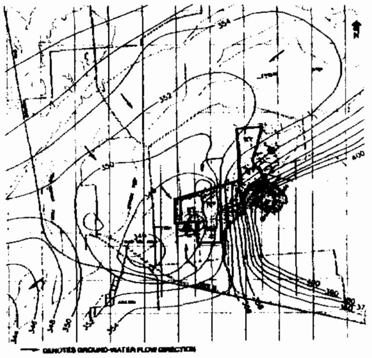


FIGURE 3. Potentiometric surface map for the Henry Aquifer in the area surrounding the site.

The hydrogeological components basically consist of an unconfined (shallow) alluvial ground-water zone overlying a deeper ground-water zone. Using this conceptual model, the hydrogeologic characterization of the mine site is numerically interpreted using MODFLOW, (McDonald and Harbaugh, 1988), a three-dimensional ground-water flow model.

After calibration, the model was used to simulate four scenarios involving different site development alternatives which may affect reclamation activities. The alternatives include continuation of on-site pumping (except Scenario II) and the following:

- Scenario I: installation of an enhanced reclamation cover system;
- Scenario II: installation of an enhanced reclamation cover system and termination of on-site pumping;
- Scenario III: installation of three new on-site pumping wells; and
- Scenario IV: installation of four new municipal supply pumping wells.

In order to visualize the impact of different alternatives to the ground-water system, the MODPATH (Pollack, 1989) model was used in conjunction with the MODFLOW analysis. A group of 12 particles were placed around each extraction well and a reversed-direction analysis was conducted to identify the effective capture zone of each extraction well. The particle pathlines and time intervals were plotted. The results of the simulations can be summarized as follows:

- installation of an enhanced cover system has little or no effect on ground-water flow;
- on-site ground-water pumping provides hydraulic control of migration of impacted ground-water;
- discontinuing on-site pumping while ARD is actively being produced would allow impacted ground water to migrate from the mine toward the municipal well field;
- further development of the municipal supply system would not affect reclamation activities, provided that on-site pumping is continued; and
- installation of additional on-site pumping wells should accelerate reclamation.

Precipitation Infiltration Modeling

Infiltration modeling was performed in conjunction with other site characterization activities to provide information required for the development of an effective CAP for the mine (GeoSyntec, 1995b). The requirement for and benefits of a reduced infiltration rate through the coal refuse areas was demonstrated in the geochemical modeling. In order to evaluate the effectiveness of a final cover system in reducing precipitation infiltration through the coal refuse areas, a base infiltration rate for these areas was established as described in the following paragraph. The base infiltration rate was then compared to both a conventional reclamation cover and an enhanced final cover system. The conventional reclamation cover is defined as a 4-ft (1.2-m) soil layer consisting of area soils placed without compaction control. The enhanced final cover system is defined as low-permeability and protective soil layers placed with compaction controls and is designed to use existing materials available at the site. The obvious goal of the enhanced final cover system is to reduce infiltration to the lowest practical level.

The methodology chosen for calculation of infiltration rates was the United States Environmental Protection Agency (USEPA) Hydrological Evaluation of Landfill Performance (HELP) model (Schroeder, et al, 1994). Due to the variable topography and distribution of material types at the mine site, prediction of actual precipitation infiltration rates through the coal refuse areas may not be possible. However, the HELP model represents an appropriate tool for relative comparisons of base infiltration rates with the predicted infiltration rates of different designs.

Relative Percent Composition	Sample[1]			
	GW-6 (gob)	GW-9 (gob)	GW-3 (slurry)	GW-11 (slurry)
Quartz	5	5		5
Albite	5	5	5	5
Calcite	3	1		
Gypsum	3	1		
Pyrite	9	19	11	8
Clay(2)	63	63	74	72

1 Sample collected from drill cores at depths of 10 to 12 feet.
2 Clay includes illute/smactite and kaolinite.

Table 1: Coal slurry and gob minerology

	Maximum	Background[2]
Alkalinity (as $CaCO_3$) (mg/l)	871.6	404.0
Chloride (mg/l)	1004.4	3.4
Conductivity Mmhos/cm2	8447	700
Hardness (as $CaCO^3$)	3805	407
Iron, dissolved (mg/l)	37.7	0.4
Manganese dissolved (mg/l)	2.97	0.06
pH[1]	6.62	7.13
TDS (mg/l)	7830	470
Sulfate (mg/l)	4082	<5

1 pH value is the minimum observed.
2 background values measurd in a well hydraulically upgradient of mine activities.

Table 2: Water quality indicators in mine site monitoring wells

The HELP model (Version 3) is described in the USEPA publications EPA/600/R-94/168a and 168b [Schroeder et al, 1994]. The former document contains guidance on the use of the HELP model computer program and indicates the following:

"The HELP program is a quasi-two-dimensional hydrological model for conducting water balance analysis of landfills, cover systems, and other solid waste containment facilities. The model accepts weather, soil and design data, and uses solution techniques that account for the effects of surface storage, snowmelt, runoff, infiltration, evapotranspiration, vegetative growth, soil moisture storage, lateral subsurface drainage, leachate recirculation, unsaturated vertical drainage, and leakage through soil, geomembrane or composite liners. Landfill systems including various combinations of vegetation, cover soils, waste cells, lateral drain layers, low permeability barrier soils, and synthetic geomembrane liners may be modeled. The model facilitates rapid estimation of the amounts of runoff, evapotranspiration, drainage, leachate collection and liner leakage that may be expected to result from the operation of a wide variety of landfill design."

The above-mentioned capabilities make the HELP model a suitable tool for the estimation of precipitation infiltration at the coal refuse areas of the mine. However, to undertake the analyses, several assumptions are required. Primary among the assumptions is that the complex topography and material subsurface conditions of the refuse areas can be represented by a simplified average condition which will adequately represent the entire area of the coal refuse coal refuse areas. This assumption is reasonable since the same assumptions are made about the conditions of the conventional reclamation cover and the enhanced final cover system used for comparisons. The general assumptions of the HELP model study were as follows:

- climatological conditions at the mine can be approximated from nearby stations for which weather conditions are available;
- surface slope of the refuse areas can be averaged;
- for the purpose of comparison, vegetation conditions in the refuse areas are constant;
- areas contributing to runoff within the refuse areas can be averaged;
- evaporation within the refuse areas is confined to a constant thickness;
- for the purpose of calculating a base infiltration rate, clayey soils underlying the coal refuse areas perform as a low-permeability layer and have a constant thickness;
- coal refuse material can be modeled as a vertical percolation layer and has a constant depth; and
- the properties of soil and coal refuse materials are relatively constant throughout the depths at which they are defined as a low-permeability layer or a vertical percolation layer.

Coal Refuse Area Infiltration

The specific assumptions used in estimating the base precipitation infiltration rate to be expected through existing coal refuse impoundment areas at the mine were as follows:

- evapotranspiration, precipitation, temperature, and solar radiation data can be synthetically generated using information and coefficients for Evansville, Indiana, located about 40 miles (64 km) northeast of the mine;
- surface slope of the coal refuse areas was chosen at 0 percent to simulate the conditions expected during their use as coal refuse areas;
- vegetative conditions in the coal refuse areas are approximated by bare ground for runoff considerations and a leaf index of 0.5 as defined by EPA/600/R-94/168a (User's Guide) (Schroeder, et al 1994); for evapotranspiration considerations;
- areas contributing to runoff in the refuse areas were selected as either 0 or 50 percent to account for average inundation during periods of use, and resulting infiltration rates were averaged in the estimation of a final infiltration rate;
- depth of the evaporative zone was limited to 12 in. (0.3 m);
- based on previous geotechnical testing of on-site borrow, clayey soils underlying the coal refuse areas were modeled as a low-permeability layer having a thickness of 1 ft (0.3 m) and with material characteristics based on default values for material No. 24, a sandy clay, in Table 4 of the User's Guide; and
- coal refuse material in the impoundment areas was modeled as a vertical percolation layer having a thickness of 10 ft (3 m) and with material characteristics based on default values for material No. 15, a fat clay, in the User's Guide.

Under these assumptions, the HELP model was used to make predictions of infiltration, evapotranspiration, and runoff as illustrated in Figure 4. The HELP model calculated the annual average precipitation for the site to be 41.05 in. (10.4 cm). With 0 percent runoff, infiltration was calculated to be 26 percent of average annual precipitation, and with 50 percent runoff, calculated infiltration is 19 percent. Assuming that runoff from the coal refuse areas is between 0 and 50 percent, the average precipitation infiltration in the coal refuse areas is 22 percent or 9.2 in. (23.4 cm) annually for the existing conditions during their active life. This value is also considered the base rate for comparative purposes. It should be noted that although higher runoff percentages produce less infiltration, runoff is also a source of ARD for the existing condition and is not a viable reclamation alternative.

Coal Refuse Cover Analyses.

The HELP model was also used to predict precipitation infiltration for a conventional reclamation cover as shown in Figure 5 and for enhanced cover systems as shown in Figure 6. The specific assumptions common to all the cover analyses were:

- evapotranspiration, precipitation, temperature, and solar radiation data were the same as for the base rate calculation;
- surface slope of the reclamation covers over the coal refuse areas was chosen at 1, 2, and 5 percent to simulate the average conditions expected after grading of the gob and construction of the cover and to examine the effects of a varying surface slope;
- vegetative conditions in the coal refuse areas are approximated by fair ground cover for runoff considerations and a leaf index of 2.5 for evapotranspiration considerations;
- areas contributing to runoff in the coal refuse areas were selected as 100 percent as a representation of average conditions in the areas after gob grading and placement of the reclamation covers;
- clayey soils underlying the coal refuse areas were modeled the same as for the base rate calculation; and
- coal refuse material in the impoundment areas was modeled the same as for the base rate calculation.

Conventional Reclamation Cover Infiltration

The specific assumptions described above were used with the following parameters to estimate precipitation infiltration rates to be expected through a conventional reclamation cover over the coal refuse areas at the mine:

- depth of the evaporative zone was limited to 24 in (0.6 m); and

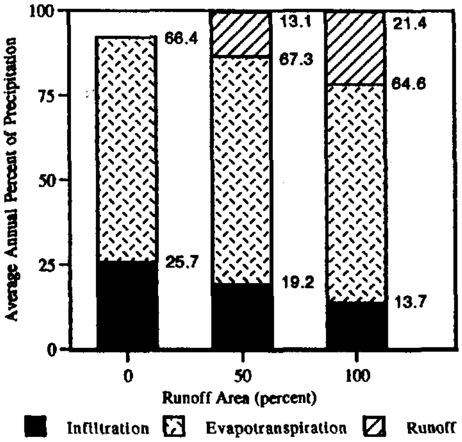


FIGURE 4. Runoff, evapotranspiration, and infiltration in existing coal refuse areas as a function of area capable of runoff.

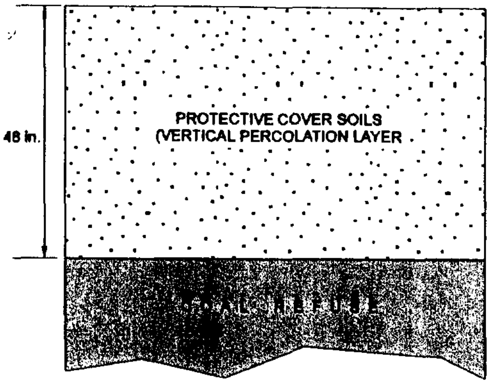


FIGURE 5. The conventional reclamation cover.

- based on previous geotechnical testing of on-site borrow, soils comprising the conventional reclamation cover were modeled as a vertical percolation layer having a thickness of 4 ft (1.2 m) and material characteristics based on default values for material No. 10, a sandy clay, of the User's Guide.

Again, the annual average precipitation for the site is 41.05 in (10.4 cm). With a 1 percent surface slope, the infiltration is 18.6 percent of average annual precipitation. With a 2 percent surface slope, calculated infiltration is 18.4 percent, while with a 5 percent surface slope, calculated infiltration is 18.2 percent. Therefore, the average precipitation infiltration in the coal refuse areas is approximately 18 percent or 7.5 in. (19.2 cm) annually. It should be noted that the effects of varying the surface slope between 1 and 5 percent has minimal impact on the average annual infiltration, evapotranspiration, or runoff rates as shown in Figure 7 (which also shows the effect of slope on an enhanced cover as discussed below).

Enhanced Reclamation Cover System Infiltration

The specific assumptions described above were also used with the following parameters to estimate precipitation infiltration rates to be expected through an enhanced final cover system over the coal refuse areas at the mine:

- for consistency of comparisons, the depth of the evaporative zone was limited to 12 in (0.3 m) for comparison of protective soil thicknesses and to 24 in. (0.6 m) for comparison to the conventional reclamation cover;

- a low-permeability layer in the enhanced final cover system was modeled as a barrier material having a thickness of 1, 2, or 3 ft (0.3, 0.6 or 0.9 m) to examine the effects of a varying low-permeability layer thickness with material characteristics based on the default values for material No. 16, a barrier soil, in the User's Guide; and
- soils above the low-permeability layer in the enhanced final cover system were modeled as a vertical percolation layer having a thickness of 1, 2, and 3 ft (0.3, 0.6, and 0.9 m) to examine the effects of a varying cover thickness over the low-permeability liner and having material characteristics based on default values for material No. 10, a sandy clay, in the User's Guide.

The annual average precipitation for the site is calculated to be 41.05 in. (10.4 cm). As shown in Figure 7, variations in the surface slope of the final cover system between 1, 2, and 5 percent respectively resulted in no significant variation in infiltration, evapotranspiration, or runoff. For each of these slopes, the average infiltration was approximately 2.5 percent of precipitation. It should be noted that this relatively low infiltration rate is dependent on 100 percent runoff. At the flatter slopes, provisions must be made to assure that 100 percent runoff is maintained and that zero slope areas or slope reversals do not result from differential settlements of the final cover system.

The HELP model was also used to make comparisons of enhanced cover systems using various low-permeability layer thicknesses. For these analyses, a 24 in. (0.6 m) protective soil layer was and 24 in. (0.6#m) evaporative zone were assumed. Figure 8

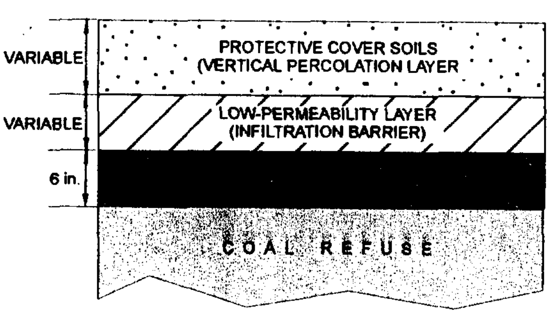


FIGURE 6. The enhanced reclamation cover system.

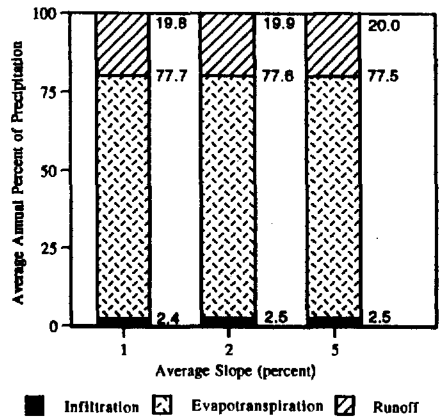


FIGURE 7. Runoff, evapotranspiration, and infiltration of conventional and enhanced covers as a function of average slope in coal refuse areas.

illustrates the model results. As can be seen in the figure, a low-permeability layer thickness between 1 to 3 ft (0.3 to 0.9 m) allows 3.6 to 2.5 percent infiltration, and runoff and evapotranspiration percentages that are also relatively constant.

Evaluations of infiltration for various thicknesses of the protective cover soil were also performed. For these analyses, a 12 in. (0.3m) low permeability layer thickness and 12 in. (0.3 m) evaporative zone were assumed. The protective cover soil for the enhanced cover system was varied in total thickness between 1 and 3 ft (0.3 and 0.9 m). The enhanced final cover system with 1 ft (0.3 m) of soil cover above the low-permeability layer results in 2.8 percent infiltration, whereas the system with 3 ft (0.9 m) of soil cover above the low-permeability layer results in 9.2 percent infiltration. Figure 9 illustrates the average annual totals for infiltration, evapotranspiration, and runoff as calculated by the HELP model.

The HELP model calculations indicate that the most effective enhanced final cover system among those evaluated is the system with the least amount of cover soil above the low-permeability layer. The increase in infiltration with a thicker protective soil cover above the low-permeability layer is due to the storage of water above the low-permeability layer. The water storage increases the hydraulic head, and thereby the pressure gradient, causing more infiltration through the low-permeability layer. For example, a 3-ft (0.9-m) thick protective soil cover layer results in an average annual hydraulic head of about 16 in. (0.4 m). By contrast, a 1-ft (0.3-m) thick cover soil layer results in average annual hydraulic head of about 4 in (0.1 m).

The reduction in head is due to: (i) a greater percentage of the cover soil layer being available for evapotranspiration losses; and (ii) the thinner soil layer becoming fully saturated sooner than the thicker layer, thus promoting runoff sooner.

Selection of Enhanced Final Cover System

The control of ARD generation from the coal refuse areas is of principal importance for the successful long-term reclamation of the mine site. While the on-site pumping wells provide hydraulic containment of the impacted ground water beneath the coal refuse areas, ongoing infiltration of precipitation into the coal refuse, ARD generation and subsequent leakage into the aquifer continue to affect ground-water quality beneath the site. The reclamation plan required under the applicable regulations requires covering the coal refuse areas with 4 ft (1.2 m) of cover material (soil) and planting with cover vegetation. Based on an evaluation of precipitation infiltration rates, the conventional reclamation cover does not adequately limit infiltration and ARD leaching to be protective of ground-water quality.

The results of the infiltration analyses indicate that the conventional reclamation cover is effective in reducing infiltration from 9.2 in (23.4 cm) to 7.5 in. (19.3 cm), or a reduction of 18 percent of the current infiltration through the coal refuse. HELP model analyses show that an enhanced final cover system constructed with a 12-in (0.3 m) low-permeability layer and a 24-in (0.6 m) protective soil layer which allows for a 24-in (0.6 m) evaporative zone, can reduce infiltration to 1.5-in. (3.8 cm), or a reduction of 84 percent of the current infiltration through the coal

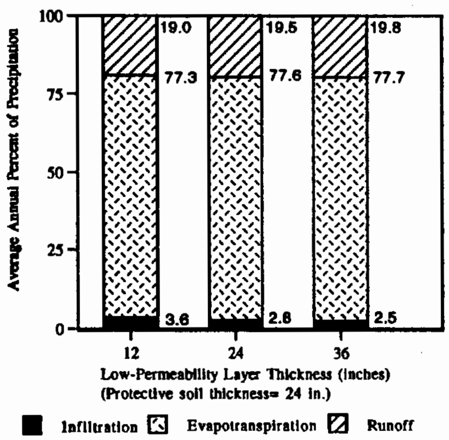


FIGURE 8 Runoff, evapotranspiration, and infiltration of enhanced cover system as a function of the low-permeability layer thicknesses.

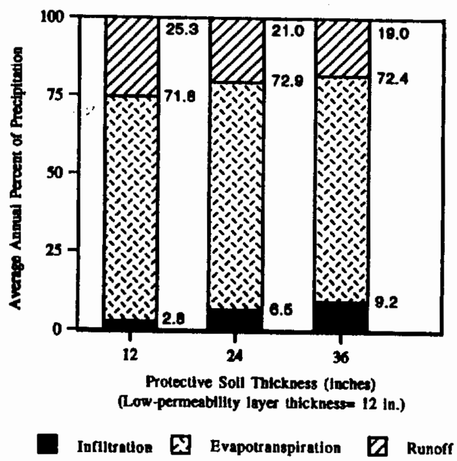


FIGURE 9. Runoff, evapotranspiration, and infiltration of enhanced cover system as a function of the protective soil thickness.

refuse. A comparison of the conventional and enhanced cover systems to the existing condition is illustrated in Figure 10. This significant reduction in the total infiltration through the coal refuse would be expected to contribute to an earlier remediation of detrimental effects on ground-water quality at the site.

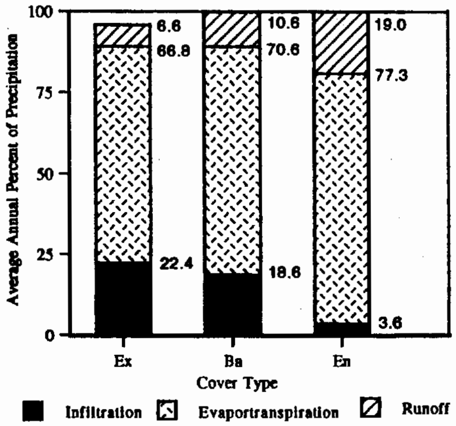
The design of the proposed enhanced final cover system is similar to that required for municipal solid waste landfills under U.S. Environmental Protection Agency Resource Conservation and Recovery Act (RCRA), Subtitled D regulations. The design consists of a multi-layered system which accomplishes the following: (i) reduces infiltration by encapsulating the refuse in a low permeability (e.g., hydraulic conductivity of 10^{-7} cm/s (or less))layer; (ii) promotes and manages runoff through engineered drainage areas that direct precipitation away from the coal refuse; and (iii) provides a vegetative growth layer for erosion control, frost protection, and aesthetic purposes. The enhanced final cover system also achieves the above by using locally available materials, making it similar in material costs to the conventional reclamation cover. The selected system also has the additional advantage of having a total new material thickness of 3 ft (1 m) versus the 4 ft (1.2 m) of the conventional reclamation cover.

Ground-Water Impact Mitigation

The numerical ground-water flow modeling results demonstrated that the on-site pumping wells provide adequate hydraulic containment of the impacted ground water beneath the site. The available ground-water monitoring data also support this conclusion by showing that the extent of impacted ground water (i.e., concentrations greater than background) are limited to the site area, in most cases, and that the public supply well field has not been impacted. The on-site pumping wells remove mineralized ground water, but due to their construction (e.g., short well screens situated near the bottom of the Henry Formation aquifer), they are not efficient in mitigating impacted ground water which is believed to be primarily in the upper portions of the aquifer. A conceptual design for mitigating the impacted ground water at the site, which is the second element of the CAP for the mine reclamation, includes installation of additional shallow pumping wells. Hydraulic control of the impacted ground water will also continue to be provided by the existing on-site pumping wells.

Status of Reclamation Activities

The reclamation plan, to date including the enhanced cover system for the mine, has been approved by the Illinois Office of Mines and Minerals. The gob surface has been graded and compacted on two of the largest coal refuse areas. Agricultural-grade lime was applied to the gob at a rate of 200 tons per acre and incorporated to a depth of about 6-in. (0.15 m) using a disc harrow. Grading has been completed on a third refuse area. Field moisture and density measurements were made to verify that the gob was compacted to a minimum density of 102 lb/ft^3 (16.1 kN/m^3) and a moisture content within an established permeability window and a minimum water content of 16.5 percent.



Ex= Existing: bare ground, 12" evap zone, 10' gob, 12" sandy clay, 0-50% runoff, 0% slope.
Ba= Conventional Cover: fair vegetation, 24" evap zone, 48" sandy clay, 10' gob, 100% runoff, 1% slope.
En= Enhanced Cover: fair vegeation, 24" evap zone, 24" sandy clay, 12" liner, 10' gob, 100% runoff, 1% slope.

FIGURE 10. Runoff, evapotranspiration, and infiltration comparisons between existing conditions, conventional cover, and enhanced cover system

The enhanced cover system has been completed on one of the coal refuse areas, including the compacted clay-liner component and the protective cover soil layers. The low-permeability layer has been constructed using compacted clayey soil from permitted borrow areas at the site. The clayey silt was classified under the Unified Soil Classification System (USCS) as either CL or CH and compacted in 6-in. (15 cm) layers. Based on laboratory testing, the clayey soil was compacted within a defined permeability window and to a minimum dry density of 102.5 lb/ft^3 (16.1 kN/m^3) and a minimum water content of 20 percent.

The enhanced final cover system was constructed on a compacted gob surface in one of the refuse cells. The engineered drainage structures consisted of swales and ditches which directed runoff away from the reclaimed areas, minimized erosion, and further limited infiltration. The top soil has been seeded and the reclamation of this impoundment is considered complete. A fourth containing slurry only is being excavated for carbon recovery. Depending on the completeness of the recovery activities, a reclamation cover may not be warranted for this cell. The borrow areas are also being reclaimed for post-mining land use. Due to shallow ground-water conditions, one borrow area will be maintained as a wetland.

Ground-water monitoring will continue in all available wells. On-site pumping will continue in the mine production wells and in the additional shallow wells, as they are added, to provide hydraulic control and mitigation of impacted ground water beneath the site.

Conclusion

The integrated site characterization activities demonstrated the need for ARD source control and mitigation of impacted ground water. The infiltration modeling showed that the enhanced reclamation cover system should reduce precipitation infiltration by about 84 percent of the average annual current infiltration into unreclaimed coal refuse, compared to about 18 percent for a standard reclamation cover. The results of the geochemical modeling indicates that reducing infiltration will significantly control ARD generation and help mitigate impacts to the ground water, thus expediting reclamation activities at this mine site. The application of cover systems similar to those in wide use for municipal solid-waste systems can be a valuable technology for surface mine reclamation, and in some cases contribute to an earlier reclamation.

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