REPRINT

Presentation at 2000 Annual Meeting
of
Society for Mining, Metallurgy, and Exploration
Salt Lake City, Utah

Session: Hydrology
February 28 - March 1, 2000

NUMERICAL EVALUATION OF EFFECTIVENESS OF DRAINWELLS IN DEWATERING OVERBURDEN AT SURFACE COAL MINES

Roger L. Howell
Lee C. Atkinson
Houmao Liu
Hydrologic Consultants, Inc. of Colorado
Lakewood, Colorado

ABSTRACT

Typical sedimentary sequences overlying coal seams consist of interbedded sandstones, siltstones, shales, and rider coal seams. In many surface coal mine settings, these sediments are saturated; and prior dewatering of them is necessary for effective and economic mining, including the stacking of saturated spoils. Such sedimentary sections usually have a very low vertical hydraulic conductivity that does not allow them to drain in a timely manner prior to their being stripped. One potential solution is installation of drainwells. Drainwells are small diameter wells that can collect water laterally from the various more permeable layers in the overburden and then gravity drain it to a lower layer – often the coal seam being mined – where it can be removed by pumping wells or sumps located in the bottom of the pit. A ground-water flow model utilizing the 3-dimensional finite element code *MINEDW* has been used to evaluate the effectiveness of using drainwells in a hydrogeologic setting that is typical of the Powder River Basin. A series of numerical simulations were completed using various combinations and spacings of drainwells and pumping wells to dewater the overburden and coal seams. The numerical simulations suggest that drainwells can be a very effective method of overburden dewatering.

INTRODUCTION

Ground water in coal seams and in overlying strata generally must be removed ahead of surface coal mine advancement in order to minimize handling difficulties and combustion hazards in the coal, and to maintain the stability of the working face and spoil slopes. This paper summarizes the procedures and results of a ground-water modeling investigation conducted by Hydrologic Consultants, Inc. of Colorado (HCI) to improve the dewatering system for a major surface coal mine in the Powder River Basin of north-central Wyoming.

The dewatering system currently employed at the mine includes from 30 to 50 nominal 5-inch diameter pumping wells screened in the principal coal unit. The dewatering wells are installed on approximate 200-ft centers in lines about 1,000 ft ahead of the mine highwall, which corresponds to a useable life of approximately one year. Each line of new dewatering wells is activated at about the same time that the previous line of wells is overtaken by mining, so that there is little or no overlap of service. Wells pump at approximately 2 to 15 gpm, but the actual rates are not recorded nor is the total volume of the system known.

The current dewatering system is relatively successful in dewatering the coal, but not the overburden. Extensive pumping from the coal in the vicinity of the mine has resulted in up to 100-ft declines of the ground-water levels in the coal across the study area. Far less drawdown has occurred in the overburden due to the relatively low permeability of clay and siltstones overlying the coal. Consequently, a perched ground-water system with an underlying unsaturated zone has developed in the overburden, extending as much as 10,000 ft beyond the active highwall of the mine. As a result, continued pumping from the coal has little effect on the ground water remaining in the overburden.

Ground water remaining in the overburden impedes excavation and causes highwall and backfill stability problems. This study was commissioned to optimize the number and sequencing of pumping wells in the coal, as well as to evaluate the possible use of pumpless, passive drainwells to remove additional water from the overburden. This concept is certainly not new (Clar et al., 1981); but, to our knowledge, it has not been broadly applied.

CONCEPTUAL HYDROGEOLOGIC MODEL

Geologic Setting

The geologic units in the study area include the Paleocene-age Fort Union Formation, the Wasatch Formation of Eocene age, and Quaternary alluvium. The Wyodak-Anderson coal occurs in the uppermost Fort Union Formation. The thickness of the coal seam ranges from 50 to 70 ft in the mine area; it dips to the west at 0.4^o to 0.5^o. Results from pumping tests show that the values of hydraulic conductivity of the coal seam range from 0.7 to 38 ft/day with a geometric mean of about 4 ft/day.

The overburden is about 150 to 250 ft thick in the mine area. Approximately 10 sandstone units have been mapped within the overburden near the mine. The individual sandstone units range in thickness from 5 to 50 ft and show lateral continuity of about 1,000 to 2,500 ft. Textures range from silty and very fine-grained sandstone, to very coarse-grained and pebbly sandstone. Claystones, siltstones, and shales comprise the bulk of the overburden, and are collectively called mudstones in this paper. The hydraulic properties of the overburden units were not known. Therefore, values of hydraulic conductivity and storativity were obtained from a pilot study of a passive drainwell, described below.

Ground-Water Conditions

Figure 1 shows the potentiometric surfaces in the coal and the overburden based on available piezometers. The water level in the principal coal unit is about 80 to 130 ft lower than the perched water table. There is a ground-water divide in the coal aquifer caused by dewatering of the mine to the east and ground-water withdrawal for coal-bed methane production in the west. The potentiometric surface in the overburden is not as well defined as that in the coal because of the limited number of shallow monitoring wells, especially in the west. As shown in Figure 1, the lateral component of flow in the overburden is from northwest to southeast, toward areas of current and former mining.

Recharge and Surface Water

Annual precipitation in the study area averages about 11 inches, most of which occurs in the spring (Martin et al., 1988). Recharge to the ground-water system is only about 0.71 inches (BLM, 1999), the remainder is lost to evaporation, sublimation, and evapotranspiration.

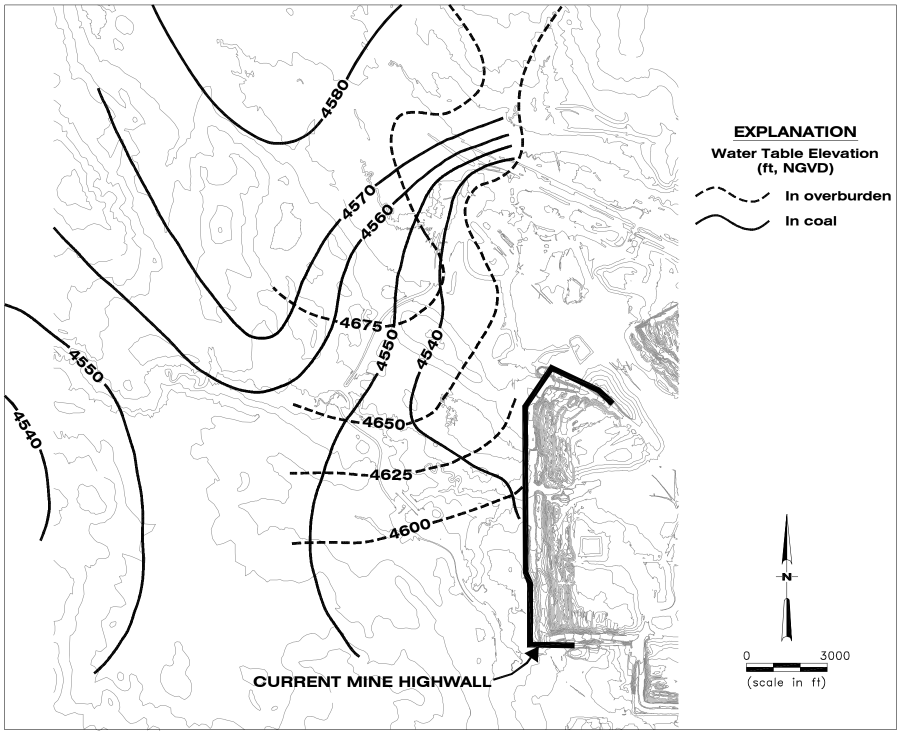

Figure 1. Water Tables in Overburden and Coal

Several ephemeral streams cross the study area; however, the limited available data suggest that for the purpose of this study, their effect on ground-water levels is insignificant in comparison with the effects caused by mining. Thus, no surface water interaction was included in the numerical modeling.

PILOT TESTING OF PASSIVE DRAINWELL

A pilot drainwell was installed and tested in order to assess the potential effectiveness of using passive drainwells to help dewater the overburden, and to obtain hydraulic parameters of the sandstones and the intervening mudstones. Initially, four piezometers were installed, each at a radial distance of 15 ft from the planned drainwell. Two piezometers were screened in overburden sandstones, and two in mudstones, as shown in Figure 2. Static water levels in the three upper overburden piezometers were at 9 to 10 ft below ground surface (bgs); the static water level in the deepest mudstone piezometer was 20 ft bgs. The drainwell was completed as a 5-inch diameter well screened both in the coal and in the upper overburden, with a gravel pack extending the length of the well. The water level in the coal was approximately 100 ft bgs. Water could be heard cascading into the casing upon completion of the well.

Water levels in all piezometers drew down after installation of the drainwell. The water levels were monitored for 68.5 hours; drawdown in the sandy units ranged from 16.3 ft in the lower sandstone to 4.7 ft in the upper sandstone. Drawdown in the finer-grained units ranged from 2.6 ft in the mudstone between the sandy units to approximately 1.0 ft in the lower mudstone.

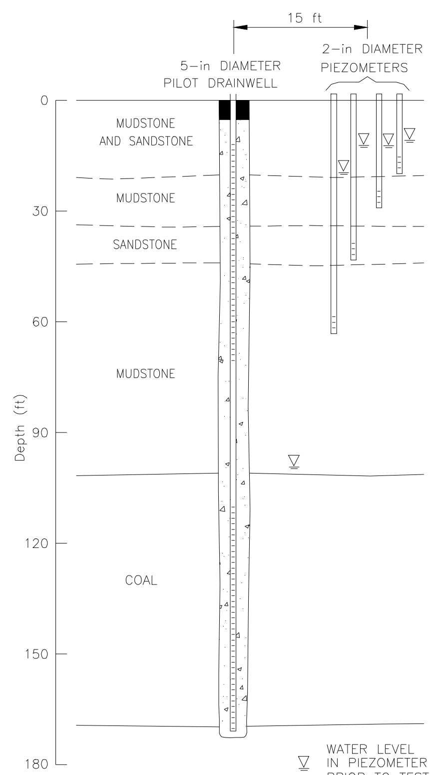

Figure 2. Pilot Test of Passive Drainwell

Because simulating the flow system created during the passive drainage monitoring period is well beyond the ability of any analytic solutions, we used a simple finite-difference numerical ground-water flow model to analyze the passive drainage data. The drainwell and local stratigraphy were simulated with the model, and the model was calibrated to the field data by 1) varying the values of the hydraulic properties of the various hydrostratigraphic units until reasonable matches of measured and calculated water levels were obtained, and 2) varying the leakance value of drain nodes until a reasonable flux into the drainwell was obtained. Table 1 shows values of horizontal and vertical hydraulic conductivity (K_h and K_v) and specific storage (S_s) derived primarily from the passive drainwell test. The drainwell nodes collectively produced an average of 3.4 gpm during the simulated 68.5 hours of drainage, a reasonable amount based on observations at the well head.

MODEL DOMAIN AND BOUNDARY CONDITIONS

Based on the results of the pilot drainwell study, a more-comprehensive numerical ground-water flow model was constructed to predict the optimum spacing and timing of pumping wells and drainwells in the hydraulically "disconnected" coal and overburden. The numerical model utilizes the code *MINEDW* which solves the equation for three-dimensional ground-water flow with an unconfined or phreatic surface using the finite element method (HCI, 1993). *MINEDW* was developed by HCI for mine dewatering problems and has been verified by Sandia National Laboratories (SNL, 1999).

A fully 3-dimensional ground-water flow model of the entire mine area was deemed impractical, due primarily to data insufficiencies (including records of pumping rates, surface-water flows, and detailed geology). However, the generally linear geometry of mine advancement and well layout allowed us to apply principles of superposition to a simplified strip model, while still incorporating the essential hydrogeologic features of the dewatering system. The strip model comprises a narrow block of generalized hydrostratigraphy with characteristics representative of the total area to which the model results are applied. The model employs boundary conditions that mathematically simulate a larger flow domain and a more extensive array of pumping or drainwells; analogous to invoking "image wells" in analytical solutions for pumping problems. Despite these idealizations, the strip model is still three-dimensional and incorporates measured values for the hydraulic properties of the various hydrostratigraphic units, known water levels, and an estimated value for recharge.

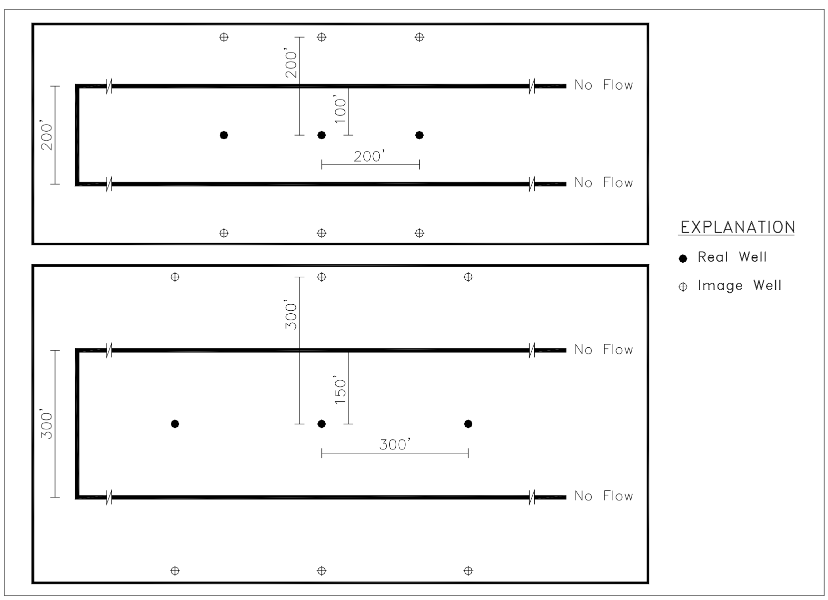

Figure 3. Effects of Boundary Locations on the Spacing of Image Wells

The strip model encompasses an area 10,000 ft long with a width that varies according to the desired spacing of pumping or drainwells. As shown in Figure 3, the lateral distance to image wells (which represent additional wells on a regular geometric pattern in an implicitly extended domain) is determined by the position of no-flow boundaries. The numerical solution for the single line of real wells in the flow field with these parallel no-flow boundaries will essentially be the same as for a laterally extended model with a regular rectangular pattern of wells.

The long dimension of the model domain is oriented perpendicular to the mine highwall. The model domain is discretized with 15,510 nodes and 25,200 elements (Figure 4). The westward dip of the sedimentary sequence has been represented by maintaining constant layer thickness while varying the elevation of the bottom of the model. Finer discretization was used near the mine highwall to simulate the drainage wells and dewatering wells. The model domain was vertically discretized into nine model layers. The thicknesses of the various model layers are summarized in Table 1 and shown on Figure 4. Table 1 also summarizes calibrated values of hydraulic parameters for each model layer.

No-flow boundaries were assigned to the lateral edges of the strip model as described above. Although ground-water flow in the overburden is not parallel to the no-flow boundaries, the error imparted by ignoring the boundary flux associated with a partial cross gradient will be small within a large array of pumping wells and drainwells. In addition, the boundary flux is small due to the low permeability nature of the overburden.

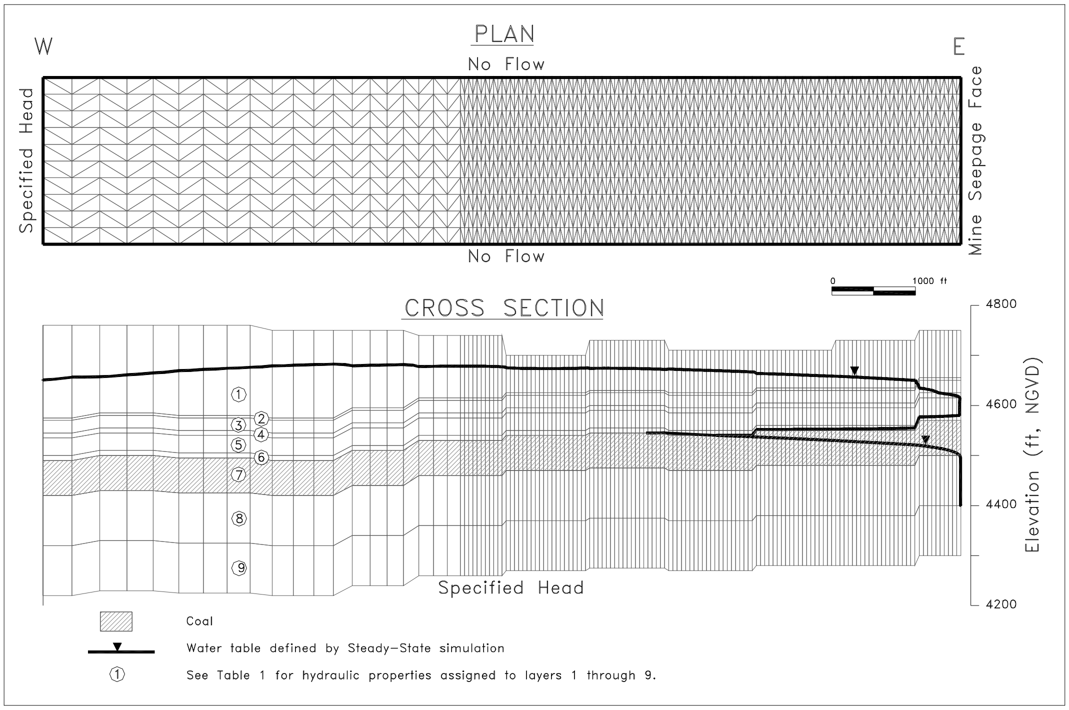

Figure 4. Model Grid in Plan and Cross Section

Table 1. Hydrostratigraphy and Calibrated Hydraulic Parameters

Model Layer	Hydrostratigraphic Unit	Thickness (ft)	K_x, K_y (ft/day)	K_z (ft/day)	Ss (ft^{-1})	Sy ( )
1	Upper Mudstone	15	0.02	0.001	7×10^{-6}	0.1
2	Upper Sandstone	5	7.5	0.4	1×10^{-5}	0.01
3	Middle Mudstone	15	0.02	0.001	1×10^{-4}	0.2
4	Lower Sandstone	10	3.5	0.04	7×10^{-6}	0.1
5	Lower Mudstone	35	0.001	0.0001	1×10^{-4}	0.2
6	Lower Mudstone	10	0.0001	0.00001	1×10^{-4}	0.2
7	Coal	70	4.6	0.46	1×10^{-5}	0.03
8	Basal Mudstone	100	0.001	0.0001	1×10^{-4}	0.2
9	Basal Mudstone	100	0.001	0.0001	1×10^{-4}	0.2

The bottom of the model domain was assigned a specified head boundary condition that simulates leakance through the underlying mudstone into the coal. A specified-head boundary condition was also assigned to the western end of the strip model (Figure 4). The value of the specified-head will change over time due to mining and methane production activities. However, because no information is available concerning future activities at this boundary, the specified head was maintained at current levels in model simulations. Assigning the current specified head is a conservative assumption which will over-predict the dewatering requirements.

A seepage-face boundary condition was assigned to the eastern boundary of the strip model to simulate the highwall of the pit. To incorporate the upward seepage through the floor of the pit at the highwall, the seepage face condition was extended into the underlying mudstone.

MODEL SIMULATIONS

The results from a steady-state simulation are illustrated in Figure 4. Because the actual pre-mining steady-state water levels were not known, the steady-state model simulation was run to approximately match the average conditions of the current ground-water level and gradient in the coal seam and to generate the perched ground water in overburden units observed in the field. Water levels from the steady-state model simulation were used as the initial heads for transient simulations.

For the transient simulations, the pumping rates of current dewatering wells were not known. Consequently, the pumping wells and drainage wells were simulated as drain nodes in the model.

Transient Model Runs for Active Pumping Scenarios

Transient predictive simulations were conducted to evaluate dewatering requirements under various pumping-well grid configurations. The modeled configurations (Table 2) included longitudinal well spacings (parallel to the mine highwall) of 200 ft and 400 ft, and lateral, or line, spacings ranging from 1,000 ft to 2,500 ft. The advancement of the highwall was incorporated into the model by turning on lines of drain nodes representing the pit seepage face at 250-ft intervals in three-month time steps, simulating a mining advancement rate of 1,000 ft per year.

The eight grid spacings were tested under two pumping schedules. Under the first schedule, sequential pumping was simulated by allowing the highwall (i.e., the seepage face boundary condition) to intersect one line of wells before the next line of wells was activated; this is essentially the current practice at the mine. Under the second pumping schedule, concurrent pumping from two lines of wells was simulated. In these pumping scenarios, the highwall was advanced only to within 1,000 ft of the first line of wells before the next line was turned on. Both lines of wells were then pumped concurrently until the first line was overtaken by the highwall.

Transient Model Runs For Passive Drainwell Scenarios

In predictive scenarios considering passive drainwells, three drainwell configurations were simulated. The spacings of these configurations are 250 ft x 250 ft, 250 ft x 500 ft, and 500 ft x 500 ft. Unlike the pumping well scenarios, the lateral progression of mining was not incorporated into the drainwell scenarios. Because in actual practice the drainwells would be constantly maintained in front of an advancing highwall and new drainwells would be installed as old ones were overtaken by the mining, in all of the drainwell simulations a highwall was maintained at a distance of 500 ft from the drainwell grids.

RESULTS AND DISCUSSION

Pumping Scenarios

Results from pumping well scenarios (Table 2) were evaluated based on the summed rates of seepage into the pit as reported from the various simulations. The rates were compared to a base case, which simulated the current practice of using sequential lines of pumping wells with spacings of 200 ft x 1000 ft. The most significant finding is that concurrent pumping of two parallel lines of wells, regardless of the spacing of the lines of wells or the spacing between the wells in the lines (at least within the scenarios evaluated), can more effectively dewater the coal than the current practice of pumping from a single line of relatively closely spaced wells.

Under the concurrent-pumping scenarios, increasing the distance between wells from 200 to 400 ft on any given line spacing results in an increase in calculated discharge through the highwall seepage face of about 30 to 35 percent. If a constant well spacing on any given line is maintained, increasing the line spacing from 1,500 to 2,000 ft results in about a 10 percent increase in calculated seepage; while increasing the line spacing from 2,000 to 2,500 ft results in about a 20 percent increase in calculated seepage. (Note in Table 2 that the modeled flux appears to increase in the scenarios using the narrowest line spacings: the 200 ft x 1,000 ft grid yields 56 percent of base seepage, while the 200 ft x 1,500 ft grid yields only 47 percent. This apparent increase is a relic of the coarseness of the model grid, and the method of evaluation. Relatively large changes in flux occurred where the advancing seepage face encountered changes in the elevation of the base of the coal layer (see cross-section, Figure 3). These flux anomalies were averaged out in the wider line spacings, but not in the 1,000-ft spacings.

Drainwell Scenarios

Modeled results from the pumping well scenarios suggest that pumping wells alone will not effectively reduce the water level in the overburden. The results of the model simulations of the three different overburden dewatering scenarios are summarized in Table 3 and shown in Figure 5. The effectiveness of the different scenarios was evaluated by comparing the total drawdown in the overburden layers, through time, at a point near the centers of the different drainage grids. The results show that for the assumed hydrostratigraphy with the given hydraulic properties, drainwells will produce as much as 7 gpm in early time (up to about one month) and then the drainage rates will quickly diminish as water levels in the sandstones decrease. The drawdown vs. time graphs for all three simulations clearly show that the water levels in the overburden will decrease at a nearly logarithmic rate with respect to time and that the majority of overburden dewatering will occur in the first three months after installation of the drainwells.

As indicated in Table 3, it is predicted that at a drainwell spacing of 250 ft x 250 ft, approximately 71 percent of the total potential drainage will occur by the third month. The total potential drainage is defined as the amount of drawdown that would occur after 36 months using a 250 x 250 ft drainwell spacing. A drawdown of 69 percent of the total potential drainage might be achievable by the third month with a drainwell spacing of 250 x 500 ft; and at a drainwell spacing of 500 by 500 ft, it is predicted that 62 percent of the total potential drainage will occur by the third month. The results show that although the densest drainwell grid will result in the most drawdown at any time, nearly as much short term overburden drainage can be achieved with half the number of wells (i.e., at a 250 x 500 ft spacing vs. a 250 by 250 ft spacing). By using only one quarter the number of drainwells (by using a 500 x 500 ft spacing), the short-term drainage effect would be lessened by only about 15 percent (see Figure 5, at time = 3 months).

Table 2. Results of Simulations of Pumping Wells in Coal

Installation Schedule	Line Spacing (ft)	Well Spacing (ft)	Seepage to Pit (% of Base Case*)	Number of Wells (10,000' x 10,000')
Sequential pumping: first line of wells is mined through before the next line of wells is activated	1,000	200	100	441
		400	260	216
	1,500	200	143	269
		400	185	132
	2,000	200	142	196
		400	#	96
Concurrent Pumping: Second line of wells is installed one year before first line of wells is mined through	1,000	200	56	441
		400	77	216
	1,500	200	47	269
		400	63	132
	2,000	200	52	196
		400	69	96
	2,500	200	63	147
		400	83	72

* Base case is defined as seepage to pit resulting from pumping of wells 200 ft apart on sequential lines spaced 1,000 ft apart.
# Not calculated

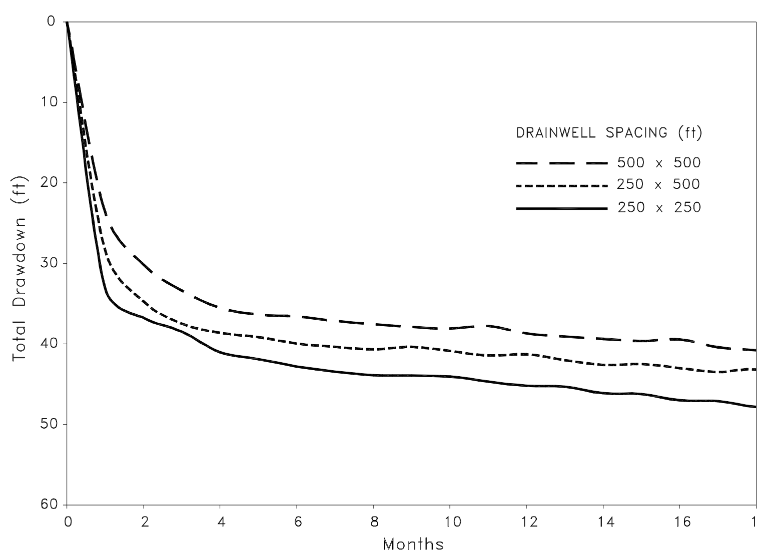

Figure 5. Drawdown Through Time in Drainwells

Table 3. Results of Passive Drainwell Simulations in Overburden Aquifer

Time Since Drainwell Installation (months)	Percent of Maximum Potential Drawdown* For Given Drain-Well Spacing		
	250 ft x 250 ft	250 ft x 500 ft	500 ft x 500 ft
3	71	69	62
6	79	74	68
9	81	75	70
12	83	76	71
15	85	78	73
18	88	80	75
36	100	82	82

* Maximum potential drawdown is defined, for the purpose of comparison only, to be the total drawdown achieved with the tightest grid spacing over a period of 36 months.

The model results suggest that optimum drainage of the overburden could be accomplished by installing relatively widely spaced drainwells at an earlier time. For instance, drainwells on a 500 x 500 ft grid could potentially lower the water table in the overburden by the same amount in 12 months as would drainwells on a 250 x 250 ft grid in three months.

CONCLUSIONS

The results from field studies and model simulations lead to the following conclusions:

1) Ground water in the overburden in the vicinity of the mine is no longer hydraulically connected with the ground water in the coal. Consequently, pumping from the coal and further lowering of the water levels in the coal do not increase the rate of drainage of the overburden.

2) The three-dimensional strip model is a highly flexible tool that can be calibrated to demonstrate favorable spacing and timing of large numbers of pumping and drainwells.

3) The model results suggest that the coal could potentially be dewatered using as few as 25 percent of the current total number of pumping wells. To be effective, however, the smaller number of wells will have to be installed on a schedule that allows two parallel lines of wells to pump concurrently.

4) In areas where a separation has developed between ground water in coal seams and ground water in overlying strata, dewatering of the overburden can be significantly improved by using small diameter passive drainwells, without pumps. The most effective spacing and timing of drainwell installation will depend on many factors, including the hydraulic properties and relative proportions of the low- and high-transmissivity units in the overburden, geometry of the high-transmissivity units, and mine-advancement rates.

REFERENCES

Clar, M.L., Ferradino, J.J., and Bosma, C., 1981, "Feasibility of Water Diversion and Overburden Dewatering, Volume I - Technical Report", U.S. Bureau of Mines, A Minerals Research Contracts Report, 253 pp.

Hydrologic Consultants, Inc., 1993, "*MINEDW* - A Finite-Element Program for Three-Dimensional Simulation of Mine Dewatering," unpublished report, 79 pp.

Martin, L.J., Naftz, D.L., Lowham, H.W., and Rankl, J.G., "Cumulative Potential Hydrologic Impacts of Surface Coal Mining in the Eastern Powder River Structural Basin, Northeastern Wyoming," U.S. Geological Survey Water-Resources Investigation Report 88-4046, 201 pp.

Sandia National Laboratories, 1998, "Review and Verification of the *MINEDW* Groundwater Flow Code," report prepared for Graystone, Inc., December.

U.S. Bureau of Land Management, 1999, "Wyodak Coal Bed Methane Project Draft Environmental Impact Statement," May.