Integration of Hydrogeologic and Geophysical Techniques for Identification of AMD Seepage and Remedial Design

Prepared by:

Ronald H. Mullennex, C.P.G., C.G.W.P.

Marshall Miller & Associates

Vance P. Wiram, C.P.G.

Amax Coal Corporation

Hans E. Naumann, P.E.

Marshall Miller & Associates

INTRODUCTION

Successful remediation of AMD at most mined sites requires thorough understanding of hydrogeologic conditions at a local, highly detailed scale. The combination of layered stratigraphy, dipping strata, fracture control on ground water flow in bedrock, and bedrock/overburden interrelationships, along with topographic flow controls and modifications to the natural hydrologic system created by mining, results in complex flow systems and complex interactions between various flow regimes. In order to maximize the cost-effectiveness of AMD remediation, it is essential that the mechanisms and pathways of impacted flow be understood, along with surface water-ground water interactions. A wide array of hydrogeological, geochemical, and geophysical applications exist to assist in defining the components of a complex hydrogeologic system, and well-planned, methodical usage of these applications in a phased manner will greatly enhance the cost-effectiveness and overall success of the remedial investigation.

This paper documents an example in which a phased, integrated investigative approach including geophysical, hydrogeological, and geochemical techniques was successfully utilized to unravel the hydrogeological complexities of a mined site experiencing AMD discharge. Results of the investigation and interpretation allowed development of a methodical approach to AMD site remediation that would not otherwise have been possible. It is the purpose of this paper to share the problem-solving experiences gained in the investigation, for the ultimate goal of expanding the knowledge base in AMD control.

STATEMENT OF PURPOSE

The primary objectives of this paper are essentially threefold:

- Briefly define the technical approaches taken to identify the primary sources of subsurface flows contributing to undesired seepage discharge;
- Highlight the findings of the various investigative techniques that were used to establish the necessary data base for understanding of the hydrologic regime;
- Demonstrate use of the information that was acquired, in order to explore problem-solving alternatives for temporary and long-term AMD abatement at the subject site.

BACKGROUND

The mine site and related coal reserve properties involved with this study are owned and/or controlled by Skyline Coal Company, a subsidiary of Cyprus AMAX Coal Company. Skyline Coal is a small surface operation (<500,000 tons/year) located in Sequatchie County, approximately 15 miles northwest of Dunlap, Tennessee.

The subject mine is the Pine Ridge East Mine. Surface operations commenced in the spring of 1989 along an abandoned, contour strip job of the same seam. The area surface mining method is employed at the site, with the combination of dragline and cast blasting techniques being the primary mode of overburden movement in advance of coal-extraction. Coal mining in this area of the Cumberland Plateau takes place on upland divides between major drainage systems dissecting the plateau surface. The major stream adjacent to the mine site is Big Brush Creek.

In the mid-1990 time period, Skyline coal began experiencing water problems at the Pine Ridge East Mine site. The water concerns were in the form of mine impacted seepage emanating downslope from the active mining area with ultimate drainage to select reaches or zones of Big Brush Creek. The defined sources of the actual seepage areas are complicated by the presence of AML contour stripping along the valley side slopes, and observed seepage occurrences on both sides and mid-stream of the creek. Active mining at Pine Ridge occurs only in the upland areas east of the stream. The mine impacted seepage can be characterized as acidic, manganese enriched, ferruginous water.

Geologic Setting

The coal bearing sequence under development consist of Pennsylvanian Age rocks of the Crab Orchard Group. The coal seam being mined is the Sewanee Coal Member of the Whitwell Shale Formation. The portion of the stratigraphic section of specific import to this discussion include, in descending order, the Newton Sandstone, the Whitwell Shale (with associated Sewanee Coal and Richland Coal), and the Sewanee Conglomerate. The subject mine operates in the Sewanee Coal, exposing the Whitwell Shale and overlying Newton Sandstone in the mine highwall. The mine pit floor is the seatrock of the Sewanee Coal, and the Richland Coal lies approximately 20 to 30 feet beneath the Sewanee Coal within the subject area. The top of the Sewanee Conglomerate underlies the Richland Coal by approximately 5 to 20 feet in the subject area.

Both the Newton Sandstone and the Sewanee Conglomerate are hard, competent sandstones, fine - to coarse-grained, often massive but cross-bedded, and are ferruginous in part. Because of their competent, brittle nature and the structural setting of the subject area, these sandstones typically exhibit a pronounced joint system, and the joints appear to be important in allowing ground water movement, particularly at shallow depths.

The local structural configuration exhibits several small-scale, gentle folds or undulations with dip magnitudes on the order of 2 percent, and an eastward-plunging anticlinal axis bisects the subject mine area. As will be further discussed, the anticlinal axis and resulting pit floor dip directions appear to be the controlling force on water flow directions within the backfill area, which in turn is a dominant factor in the occurrence of mining-related seepages reaching Big Brush Creek. Also of importance to the present flow regime and to potential remedial steps that may be taken is the presence of a small synclinal flexure located at the southwestern "comer" of the present backfill area. This feature appears to act as a collection point for water moving through the spoil backfill, from whence it is then discharged southwestward along the synclinal axis toward specific seeps and Big Brush Creek in general *(see Figure 1)*.

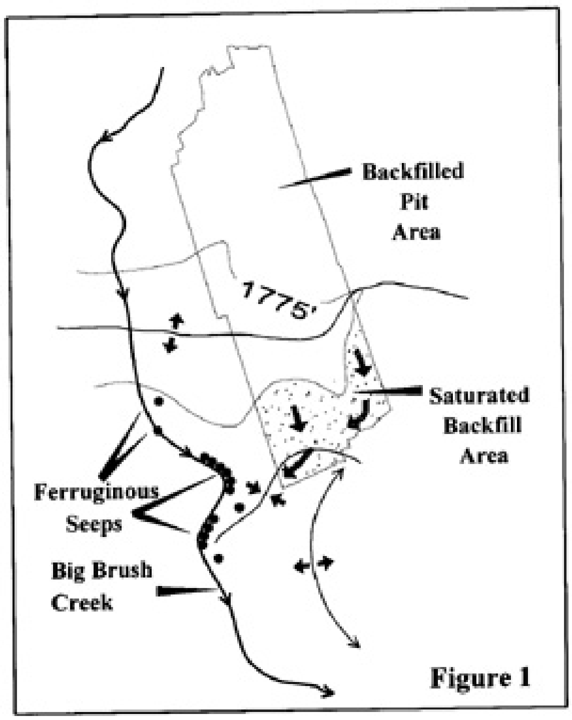

Figure 1

IMPLEMENTATION OF GEOPHYSICAL AND HYDROGEOLOGIC TECHNIQUES AND METHODOLOGIES

A hydrogeologic investigation, involving a number of components performed in phases, was undertaken in order to define subsurface water flow routes associated with seepages that occur adjacent to (or in some cases in the bed of) Big Brush Creek. Many of these seepages exhibit water quality deleterious to quality of the surface stream, through, in particular, objectionably high concentrations of iron and/or manganese, and low pH values. The investigation's objectives were to provide an understanding of subsurface water movement within the permit area, and thereby allow development of a remedial plan to mitigate water quality impacts on Big Brush Creek, to the extent that those impacts are a result of recent mining activities within the subject permit area and not those related to AML contour stripping that occurs on both sides of the stream valley in the vicinity of Skyline Coal's Pine Ridge East mine.

Initial investigation involved overview assessment of the geologic setting and topography, and review of available historical hydrological and water chemistry data (precipitation, surface water quality, and ground water quality from a limited number of monitoring stations). While ferruginous seeps were found to occur at many points between the mine and Big Brush Creek, early sampling of the seeps indicated discernible differences in water quality from one location to another.

Recognition of fracture control on bedrock flow paths and possible bedrock surface configuration controls on flow within mine spoil and colluvium led to implementation of surface geophysical profiling as the first data-gathering phase. A combination of seismic profiling, electrical resistivity profiling, and resistivity depth sounding (vertical profiling) was performed with the objective of identifying both fractured zones in the bedrock and the configuration of the buried bedrock surface. Detailed topographic mapping of the site was performed in conjunction with surface geophysical investigation, to enhance quantification of geophysical data and provide a base map for future work.

Subsequent to and based upon results of surface geophysical profiling, and exploratory drilling and monitoring well installation program was executed, with drilling locations selected on the basis of geophysical interpretations. The intent of the drilling was to: identify and characterize zones of increased fracture-controlled permeability; isolate and characterize, through construction of cluster wells, the vertical nature of hydraulic head components and chemical parameters of ground water encountered; and define and characterize the interaction of hydrogeological flow paths and mine spoil/bedrock relationships.

Drilling was conducted using air-rotary methods, with an experienced geologist present to document occurrences of water, yield rates, and general geologic information. The borings were geophysically logged utilizing a combined suite of tools selected to provide both geological and hydrological information. Geological information generated from the drilling programs was used to analyze the detailed geologic structure of the site, including the mine pit floor. After drilling, the borings were converted to constructed monitoring wells with screen placements selected on the basis of geophysical log responses and observations made during drilling. The final array of monitoring wells provided information pertaining to each discrete zone or horizon of hydrologic interest in defining flow routes from the mine backfill to the seepage discharge points.

After the wells were installed, a water level monitoring and water quality sampling program was undertaken to provide the data for development of potentiometric maps of various flow horizons, determination of horizontal and vertical gradients, and characterization of water chemistry from one area or horizon to another. Graphical plots of basic water chemistry (Stiff diagrams), in addition to review of specific dissolved constituents, were used to great advantage in assessing hydrological parameters.

Surface Geophysical Methods

The resistivity method is used to measure the electrical resistivity of the geological section in both the lateral and vertical sense. In general, most soil and rock types are considered electrically resistive and the flow of current is influenced by moisture filled pore (or fracture) spaces within the subsurface. Zones of low resistivity values are predominantly controlled by the porosity and permeability of the system, the degree of saturation of the subsurface, and the concentration of dissolved solids within the saturated subsurface. Both "profiling" and "sounding" resistivity techniques were applied. Profiling provided a means of delineating lateral resistivity contrast within the subsurface electrical properties. Resistivity sounding yielded characterization of vertical resistivity contrasts and provided an estimate of the "depth layering" within the subsurface. The purpose of the resistivity survey was to delineate zones of suspected increased permeability and attendant ground water flow paths, as potential sites for borehole drilling and subsequent monitoring well installation. The correlation of known seepage areas with resistivity anomalies was extrapolated to defining areas of suspected increased subsurface flow.

Refraction seismic methods were utilized to delineate the contact between the unconsolidated material and underlying bedrock. Seismic waves, introduced by an energy source, are transmitted through the subsurface and are eventually detected by geophones or receivers. The travel time between the seismic event and arrival at the geophones is recorded and manipulated by a seismograph. The seismic energy is transmitted through the subsurface at varying velocities, depending upon the density of the subsurface material. As the seismic waves pass from one subsurface material to another, the wave train is refracted at density contrasts between materials. By resolution of travel time-distance information of the seismic wave train, an inference concerning the depth of subsurface contacts can be made. The results of the refraction seismic survey were used to delineate potential zones of shallow ground water flow along the upper surface of the bedrock.

Borehole Geophysical Methods

After the drilling of the initial "pilot hole" at each location, geophysical logging was performed on each hole. Interpretation of the geophysical logs and correlation with geological logs (compiled while the drilling was advanced) resulted in the determination of zones to be completed as monitoring wells, or to be completed as offset "cluster" wells. A comprehensive suite of geophysical logs was utilized to provide both geological and hydrological data. Suites included natural gamma ray, high resolution density, focused resistivity, caliper, neutron density, spontaneous potential, fluid resistivity and temperature logs. Detailed descriptions of the principles and applications of each of these logs is not possible within this paper. Briefly, the combination of logs provided a comprehensive analysis of lithological variations and positions, position of fractures, and location of salient water-bearing horizons in each of the wells. This analysis defined the most appropriate horizons for screen installation in each well or well cluster.

Hydrogeologic Characterization

Following geophysical surveying, drilling, and monitoring well installation, a water level (and rainfall) monitoring program and water quality sampling program were pursued. The data was utilized to prepare potentiometric maps of various lateral flow horizons, structural contour maps of both undisturbed strata and the mine pit floor, and to confirm relationships in hydraulic interaction between various elements of the hydrologic regime and the seeps themselves. Water chemistry facies were identified and characterized by assessing the overall ionic make-up of samples taken from different horizons and areas, as well as specific dissolved constituents. The objective was to identify aquifer and flowpath interrelationships and spatial hydrologic changes across the site, to allow planning of optimal remedial design.

RESULTS AND DISCUSSION

Geophysical Profiling Results

Results of geophysical profiling revealed a distinct difference in resistivity values from north to south across the area. As shown on *Figure 2,* the northern part of the area exhibits an overall high resistivity in the subsurface, with occasional "spike" anomalies of lower resistivity. This condition reflects comparatively low levels of water content and/or low levels of dissolved solids in ground water in that area. The anomalous low-resistivity "spikes" are apparently indicative of increased water content along localized water-bearing fracture zones.

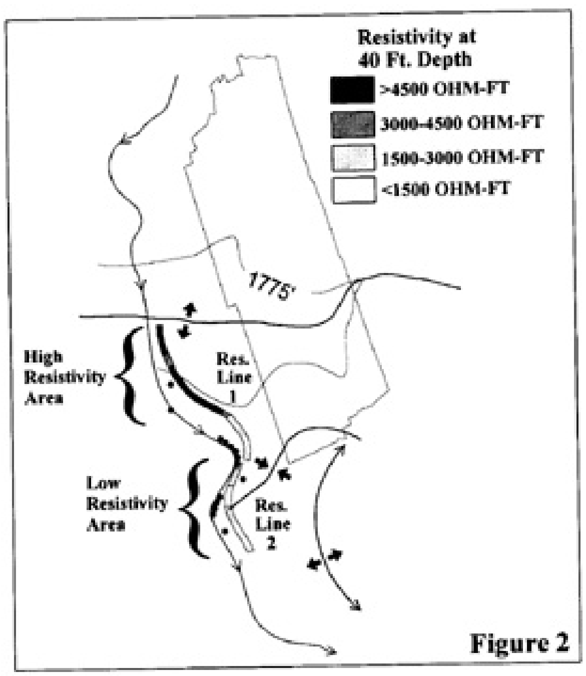

Figure 2

To the south, resistivity values decrease dramatically, even though the subsurface rock strata remains essentially the same (Sewanee Conglomerate). The lower resistivity indicates increased saturated and/or increased dissolved solids content. The change in resistivity from north to south is quite clear-cut and abrupt.

Monitoring Well Installation and Geophysical Logging

Exploratory drilling and monitoring well installation was conducted utilizing geophysical profiling results as a guide to well site selection. The majority of the borings and wells were placed between the mine spoil area and the seepage discharge area, and two wells were placed in the spoil backfill itself.

In drilling, substantial water inflows were consistently encountered in the Sewanee Conglomerate. Drilling depths into the Sewanee were to horizons approximately 50 feet below the top of the unit in the southern part of the investigation area, and to 100 feet or more below the top of the unit in the anticlinal area. In every instance of the drilling to significant depths below the top of the Sewanee Conglomerate, an "artesian" inflow was encountered whereby water inflow rose in the borehole to levels well above the inflow horizon. These locally "confined" flow horizons are apparent near-horizontal fracture zones, probably associated with bedding planes. Monitoring wells installed at such inflow horizons confirm the substantial degree of local confinement, with potentiometric surfaces situated several feet to tens of feet above the actual point of the inflow to the well.

Geophysical logging of the borings detected fractures, many of which coincide with points of water inflow observed in drilling. The logs proved invaluable in determination of specific horizons of water movement, and monitoring well screen placement was guided by results of logging, with great success.

Hydrogeological Characterization Findings

In spite of evidence of confined or artesian conditions encountered in drilling, water level hydrographs of bedrock wells in comparison to rainfall events show that the bedrock aquifer downslope of the spoil backfill exhibits a rapid respond to rainfall. The shallow bedrock aquifer behaves as an unconfined system overall, but with local confinement occurring as a result of fracture control on flow. (Conversely, wells located in the spoil material do not show significant response to individual rainfall events, indicating lower hydraulic conductivity in the spoil than in the fractures that comprise the bedrock flow paths). The shallow ground water system, then, is dominated by stress relief fractures and joints which allow rapid recharge by percolating water, but massive blocks of sound bedrock exist within which there is very little hydraulic conductivity.

Results of the investigation show two very different regimes to exist in the study area. One regime occurs in the anticlinal crest area, in which flow appears to be largely confined to discrete fractures and to involve relatively highly-resistive (low dissolved solids) waters. The other regime to the south corresponds to the synclinal depression in the pit floor and is characterized by water with much higher dissolved solids content and a more diffuse flow pattern.

The pit floor configuration appears to be a dominant control on flow directions and on the degree of infiltration of mineral-laden water into the subsurface. As shown on *Figure* 1, the structure of the pit floor and water level measurements in the backfill material indicate that elevations within the backfill below approximately 1775 feet are essentially saturated. Conversely, the anticlinal area remains unsaturated, with infiltrating flow being directed along the pit floor away from the anticlinal crest, toward the south. The saturated backfill outflow area is the southwest comer of the pit. This scenario correlates closely with and is supported by the resistivity survey results.

Figure 3 exhibits the potentiometric surface shown by wells screened in the middle to upper portion of the Sewanee Conglomerate. Flow direction is westward, away from the topographically high area to the east and toward Big Brush Creek, where there is apparently some discharge to the creek itself, and quite likely a substantial downstream-directed underflow of the creek by ground water within the Sewanee Conglomerate. Available data indicates that, in the "shallow depth of cover" area west of the backfill, percolating waters recharge the subsurface fractured aquifer system, including the Sewanee Conglomerate aquifer. Along with this recharge, of course, is the potential for migration of mining-impacted water from the backfill area into the upper part of the Sewanee Conglomerate aquifer. Away from the valley margin, where the Sewanee Conglomerate occurs under deeper cover, this is not the case, due to the closing of stress-relief fractures with depth and the change in topographic setting (stress-relief fractures are typically more developed and extend to deeper depths beneath valley floors as opposed to hillside or broad plateau crests).

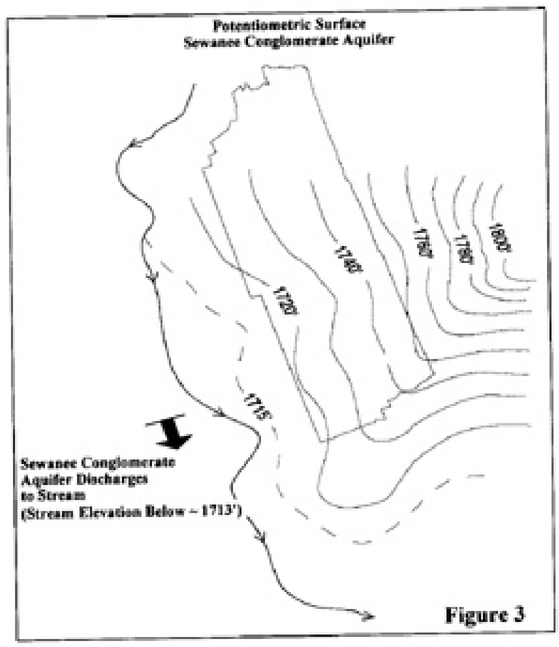

Figure 3

Water chemistry characteristics, in terms of predominance of ionc species and total dissolved solids contents from one location to another within the subject area, further support the hydrogeologic assessment presented here. Stiff diagrams were utilized to graphically illustrate the dominant ionic species present in water from each of the various sampling points. These diagrams also reflect the magnitude of total dissolved solids in each sample, since the milliequivalents per liter scale in the exhibits is constant from one graph to another.

Background wells located east of the mined area and wells in the anticlinal area show relatively low dissolved solids contents as compared to wells located in the southern area. Those screened in the spoil material itself show very high total dissolved solids contents, as would be expected.

In association with the increase in total dissolved solids in water that is influenced by mine spoil material is a similar increase in sulfate dominance among ions present in the water. Stiff diagrams of wells located in the southern part of the area show a pronounced calcium-sulfate ionic facies of ground water at essentially all sampled stratigraphic horizons, including the Sewanee Conglomerate. This ionic facies is commonly associated with water discharging from mine spoil material, and its ubiquitous occurrence throughout the southern part of this area suggests intercommunication of mining-impacted surface water with shallow ground water horizons. In contrast, wells screened at depth in areas east of the backfill show a calcium-bicarbonate facies. Wells located west of the backfill but in the anticlinal area show calcium as the dominant cation, but anionic dominance is rather evenly balanced between bicarbonate and sulfate. Again, wells in the anticlinal area display a low dissolved solids content in contrast to those located to the south.

Summary of Hydrogeological Characterization

The present-day hydrological configuration results from a combination of multiple natural hydrogeological factors and modifications to the natural system by both past (AML areas) mining and recent activities. Ground water recharge into and movement through the bedrock is governed by horizontal and vertical fractures of joint, bedding plane, and stress-relief origin. The spoil backfill material acts as a semi-perched storage reservoir from which mineralized water is released into the fractured bedrock aquifer, and the structural configuration of the pit pavement beneath the spoil dictates the areas in which such recharge occurs.

The source of ferruginous mineralization in backfill water is from natural leaching of the spoil material itself in the absence of an implemented toxic materials handling plan, However, other sources of ferruginous ground water also contribute to seepage discharges and are, in fact, the only sources in some portions of the subject area. In the anticlinal area, the backfill remains unsaturated and the buried pit floor is essentially dry. There is a general lack of impact to the ground water by drainage from the backfill or other mine spoil material in that part of the area; and although local instances of elevated iron or manganese seepages may occur there, they are natural occurrences. The low total dissolved solids and lack of sulfate ionic dominance indicates that ground water in the anticlinal area is not impacted to any significant degree by recharge from the backfill area.

Southward of the anticlinal. area, structurally-controlled recharge emanating from the backfill impacts the bedrock aquifer, and moves to seepage discharge points by way of fractures. Determination of the factors controlling recharge, flow, and discharge has allowed remedial efforts to focus directly upon problematic areas and guide the planning of remedial approaches of both a temporary and long-term nature.

APPLICATION OF HYDROGEOLOGICAL DATA IN DESIGN OF AMD CONTROL AND PREVENTION

Having defined the key site-specific hydrogeologic sources and factors contributing to the occurrence of AMD seepage, both temporary and long term remedial plans have and/or will be developed. The immediate objective of the temporary action plan focuses solely on eliminating seepage of deleterious waters to Big Brush Creek. The ultimate goal of the long term remedial plans is to achieve a permanent resolution to the mine site's current AMD drainage issues. The following briefly illustrates how the hydrogeologic information has been integrated into the development of the various abatement schemes.

Bedrock/Coal Cropline Seepage Sources

Isolated valley side-slope seepage has arisen following mine development along an abandoned contour surface operation bordering Big Brush Creek. The flowpath mechanisms of the seepage have been determined to be primarily stress relief fractures and joints associated with a shallow bedrock aquifer system downslope of the spoil backfill. Flow within the shallow aquifer is unconfined in character and exhibits a rapid response to rainfall events. When present, seepage occurrence is characteristically near or slightly below the coal cropline elevation along the side slopes of the valley. Sources of water responsible for the seepage occurrences are a combination of mining impacted surface waters (both AML and recent mining), shallow ground water horizons, and rainfall recharge.

Temporary control measures implemented to intercept and prevent discharge of this type of seepage to the creek consist of installation of a collection and pump back system. Where physical space will allow, pit excavations are made for seepage collection. In space-restricted areas, a portable tank unit in combination with necessary piping is installed to collect the seepage flows. Regardless of the type collection device used, the collection/pump back system is supplemented with necessary treatment to meet effluent discharge standards prior to release off-site. Water treatment consists of natural "air stripping" of metals in combination with chemical neutralization and sediment pond control. Calcium-based chemicals are used for neutralizing purposes (when necessary) and are dispensed to the flow regime via a portable Aqua-Fix feeder system.

Permanent resolution of the bedrock/coal cropline seepage will involve installation of a combination anoxic alkaline drain(s) and passive wetland systems. The accumulated hydrogeological data base generated from the exhaustive site specific studies provides the technical foundation for designing both the anoxic alkaline drain(s) and wetlands needed to passively but effectively handle this type of seepage discharge.

Stream Bank and/or In-Stream Seepage Sources

Of the two basic seepage occurrences encountered at the site, this type of seepage presents by far the greater challenge to achieving either a temporary or long term solution for controlling and preventing AMD. The situation is further complicated by bank and in-stream seepage possibly originating from AML contour stripping which borders both sides of the valley in the immediate area where the more recent mining has occurred. However, once again, the information gained from the in-depth hydrogeologic investigations along the perimeter and within the backfill of the more recent mining provides the technical guidance needed for developing remedial plans for the site.

The array of hydrogeological techniques used at the site clearly defined suspect "fracture zones" or flowpath routing connections between the mine impacted seepage discharges at the creek and the adjoining surface mine areas (both past and present). The registered occasional "spike" anomalies of lower resistivity (indicative of localized water bearing fracture zones) aligned closely with isolated stream bank seepage observed along the northern end of the study area. The extensive lower resistivity anomaly observed along the southwestern edge of the mine area correlated extremely well with the observed seepage zones identified in the adjacent reach of the stream. The additional investigative disclosure of intercommunication relationships between the defined backfill synclinal depression area and the subsurface/downslope "fracture zones" provided the linkage mechanism between the observed mine-impacted seepage at the creek with the spoil backfill. The mine-impacted water percolating downward from the syncline area of the pit floor into the underlying fractured aquifer system was identified as a primary source of the contaminated seepage reaching the creek.

A two-pronged approach to establishing temporary control of the deleterious seepage flows has been taken. Efforts have been made to cut off the subsurface recharge from the backfill synclinal depression feature. Secondly, a comprehensive seepage dewatering plan has been installed along the creek to intercept contaminated seepage flows to the stream.

A backfill dewatering system has been put into place in the immediate area of the synclinal depression for the purpose of eliminating the hydrostatic head driving the suspected mine-impacted subsurface recharge activities cited above. Two (2) dewatering wells, installed with a combined pumping capacity of 180+ gpm, have effectively maintained a dewatered backfill condition *(see Figure 4)*.

A comprehensive dewatering plan has been devised and implemented to effectively eliminate mine impacted seepage to the creek. Again, information gained in the in-depth hydrogeological investigations guided the well installations and setting of rated pumpage equipment designed to meet yield rates of the Sewanee Conglomerate aquifer driving the observed seepage. To date, a total of twenty five (25) shallow dewatering wells (<20') have been installed along the creek. Five (5) wells presently equipped with a two (2) pump system have been effective in eliminating seepage to the creek in northern part of the study area. Twenty (20) dewatering wells have been located in the major seepage zone defined along the creek in the southwestern section of the study site *(see Figure* 4). Initially, seven (7) pumps are planned for installation in the 20 dewatering well program. Production ratings of individual pumps range from 30 gpm to 150 gpm. Measured yield rates of the aquifer defined during well installation provide guidance to ultimate positioning of respective pumps. The combined yield capacity of the seven pumps equates to an estimated 600 gpm dewatering capability of the seepage flow. Such pumpage productivity should effectively lower the hydrostatic head of the aquifer and eliminate the seepage flow. A phased approach to evaluating the overall effectiveness of the dewatering scheme is planned, however. If the seven pump system proves inadequate to curtail seepage flows to the creek, additional pumps can be installed in the twenty well system.

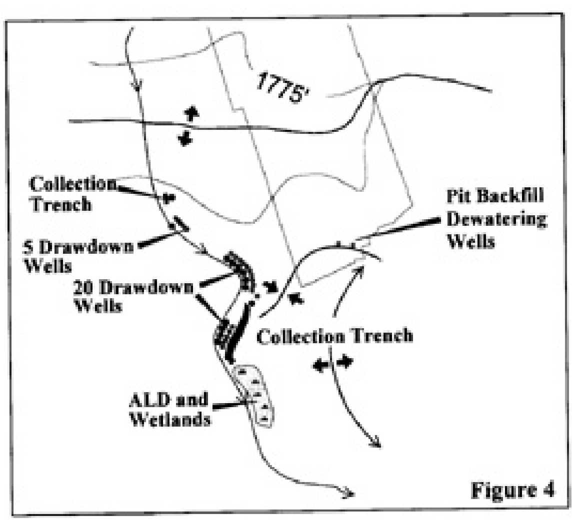

Figure 4

A similar approach to water treatment (as defined earlier for the collection/pump back system) designed for handling the bedrock/coal outcrop seepage will be followed. The water management of the dewatering initiative allows for open channel metal "air stripping" and neutralization via the Aqua-Fix dispensing equipment. Sediment pond collection and retention allows for adequate flocculent settling prior to off-site discharge.

The long term solution to AMD control and prevention following mine closure has yet to be finalized. The existing hydrogeologic data base, when combined with added information to be gained from observations and data gathering associated with the implemented spoil backfill and stream bank dewatering activities, will once again provide guidance in finalizing long term remedial plans. Primary focus for future planning is to: 1) significantly alter on a permanent basis the mine-impacted subsurface recharge from the backfill; and, 2) clean up the existing "plume" of contaminated ground water that is currently feeding seepage flows to the creek. It is envisioned that the first objective will be accomplished by establishing an alternative passive dewatering system for the backfill which can freely drain the synclinal depression area and direct backfill ground water flows away from the creek. Such a passive dewatering system would undoubtedly be complimented with a network of passive treatment technologies (i.e. anoxic alkaline drains, open channel "air stripping" and alkaline loading devices, and passive alkaline rock filter and wetland systems, etc.). The prolonged drawdown of the backfill water via on-going spoil dewatering in combination with the planned continued dewatering of seepage flows to the creek can be expected to eliminate the "plume" of mine impacted ground water feeding current seepage. With final installation of the proposed passive backfill dewatering and treatment systems, the post-mine water quality objectives of preventing AMD as it relates to the present mining activities will be achieved.

CONCLUSION

This paper illustrates the importance of developing a comprehensive understanding of the hydrologic regime of a given mine site in order to optimize the time and overall cost-effectiveness of AMD remediation. Geophysical techniques, in particular seismic profiling, electrical resistivity profiling and sounding, and down hole logging, are demonstrated to be effective tools for identifying mine impacted ground water flowpaths in the subsurface. Such exploratory tools should be given routine consideration as a cost effective means for narrowing the scope of more detailed hydrogeologic investigations involving expensive drilling and monitoring activities. When the results of the geophysical applications are integrated with the findings of other hydrogeologic and geochernical techniques, a much-needed technical foundation is established for unraveling the hydrogeologic complexities of the mine site, exploring problem solving alternatives, and ultimately developing a methodical, phased approach to achieving both temporary and long term AMD control and preventative goals.