Mitigation of Environmental Impacts Resulting from Mine Pool Build-up: A Case History

by

Ronald Mullennex, CPG, CGWP[a]

Sr. Vice President, Marshall Miller & Associates

Abstract

This presentation is intended to share experiences in development of a successful AMD mitigation action; and document the circumstances, investigation, and remediation of a case in which mine pool build-up had resulted in increased ground water recharge and water quality deterioration in the receiving watershed. Results of the investigation and subsequent remedial action indicate that minimization of water contact time in the mine environment and prevention of water level fluctuations is, in this case, effective in minimizing water quality deterioration.

[a] Marshall Miller & Associates
P.O. Box 848
Bluefield, VA 24605

Introduction

Current West Virginia mining regulations prohibit "up-dip" mining, or mining that will result in gravity discharge of water from the workings, in seams that are believed to have the potential to produce acidic or ferruginous drainage. While one obvious intent of the regulation is to prevent direct discharge of acidic and/or ferruginous water to the surface hydrologic system, the other facet is that an impoundment is created in the post-mining workings which may, in above-drainage seams, result in increased seepage down dip of the workings. The concept behind the required approach is that water accumulating in those workings will create a static pool in which anoxic chemical conditions prevail, thereby inhibiting the oxidation of iron sulfide minerals.

However, in actuality, physically static and chemically anoxic conditions commonly are not achieved in the pool in above-drainage seams, and the down-dip seepage created may result in adverse effects both from hydrologic balance and water quality standpoints. In some cases, adverse impacts are created where none would have existed had the mine pool not been formed. In such instances, a more environmentally-sound approach to mine hydrology is to minimize the contact time of water within the mine and adjacent strata, so that water passes through the system with little opportunity to become mineralized. It is also likely that, by avoiding inundation of the mine and fluctuations in water levels, much less exposed rock is contacted by water, thereby reducing the overall availability of sulfide minerals for dissolution and minimizing the flushing of oxidized minerals into solution. In other words, if inundation is avoided, water is passed through the system along preferred flow paths that do not contact as much surface area of rock as would occur in an inundated mine. The result, again, is less mineralization of the transient water.

This paper presents a case history of adverse impacts resulting from mine inundation, and discusses the hydrogeologic and aqueous chemical assessment that provided a basis for design of a successful mitigation approach in which both the hydrologic and water quality impacts have been alleviated. Parts of the remedial system are currently passive in function, and the remainder has potential to become passive in the future.

Location and Description of Site

The subject area of investigation is in central West Virginia (Clay County), and involves underground mining of the No. 5 Block seam, which is included in the list of potentially acid-producing seams in the State regulations. The seam dips west-northwest, outcropping along the east side of a perennial stream. The outcrop position in the area of hydrologic impact varies from essentially at the elevation of the stream to perhaps 30 feet above the stream. The mine is overlain by approximately 150 to 450 feet of overburden cover, and was fairly extensively pillared in the final stages of mining. Barriers were left on the down-dip side of the mine in compliance with regulatory requirements, and are of sufficient breadth to preclude the likelihood of barrier failure and instantaneous discharge of water accumulated in the mine pool.

After mine abandonment, numerous seepages were found along the outcrop area, discharging water with iron concentrations in excess of effluent criteria for stream protection. Most, but not all, of the discharges occurred from old "house coal" adits that pre-existed the modem mining, and which had always produced some seepage. However, upon abandonment of the modem mine, both the flow rates and the dissolved mineral loads (especially iron) of these seepages increased. There was also a rise in the water table of the adjacent stream valley, such that home garden and lawn areas became perpetually "wet". Some shallow water supply sources experienced a substantial increase in iron content, making treatment of normal domestic iron-removal systems difficult.

Assessment Methods

Investigation and assessment of the site involved delineation of the geologic framework and structural dip utilizing pre-existing core borehole records and mine maps; determination of the impounded mine pool level through installation and monitoring of two monitoring wells in the mined area; assessment of recharge characteristics by monitoring and comparison of rainfall and water levels within the mine; and sampling and analysis of the mine pool, various seepage discharges, and the receiving stream and its tributaries. Analytical suites were selected to provide information as to the overall chemistry of the various points, in addition to the pH, iron, manganese, acidity, and alkalinity analyses which are commonly performed in mine drainage monitoring. Analyses of ferrous versus ferric iron, and of dissolved versus total iron were also conducted. Dissolved oxygen content was measured in the field during sample collection.

After the initial investigation, interpretation, and remedial efforts, periodic monitoring, and sampling has continued, to determine the degree to which the remedial efforts have succeeded in mitigating the adverse impacts.

Results of Hydrogeologic Characterization

Natural Hydrogeologic Set

The naturally-occurring hydrogeologic regime of the subject area is characterized as a system of perched and/or semi-perched aquifers underlying the uplands, caused by the interbedding of different clastic sedimentary strata that are nearly flat-lying. Ground water movement in these strata is controlled dominantly by fractures rather than by primary pore spaces, and the more hydraulically conductive strata are those which exhibit or maintain a higher degree of open fractures. Such strata typically include coal (where cleat structure is important) and sandstones (which, because of their competency, tend to maintain open fractures at shallow horizons). Shales and underclays, in contrast, typically act as aquitards due to healing or infilling of fractures in these "softer" strata, and as such tend to form perching horizons which impede downward movement of ground water and shunt it laterally to the surface outcrop of the more conductive layers.

The stress relief that occurs beneath valley floors results in creation and opening of fractures at shallow depth, including the separation of bedding planes which become dominant pathways for ground water movement. While stress relief fracture systems may create an aquifer in any rock type, aquifer potential is typically best developed where the valley floor is underlain by sandstone strata which maintain open fractures better than do less competent strata.

Underground mining of a gently dipping coal scam creates a conduit for ground water movement beneath ridges, so that the ground water flow at this horizon becomes dip-controlled rather than topography-controlled. Ground water flow at the mine horizon no longer follows the original drainage divides, and interbasin flow may occur. The removal of pillars, as has occurred within portions of the subject mine, creates subsidence fractures in overlying strata that increase the vertical percolation of water from overlying horizons down to the mine opening. The mine then acts essentially as a catchment basin for percolating water, and shunts such water to the downdip portions of the mine.

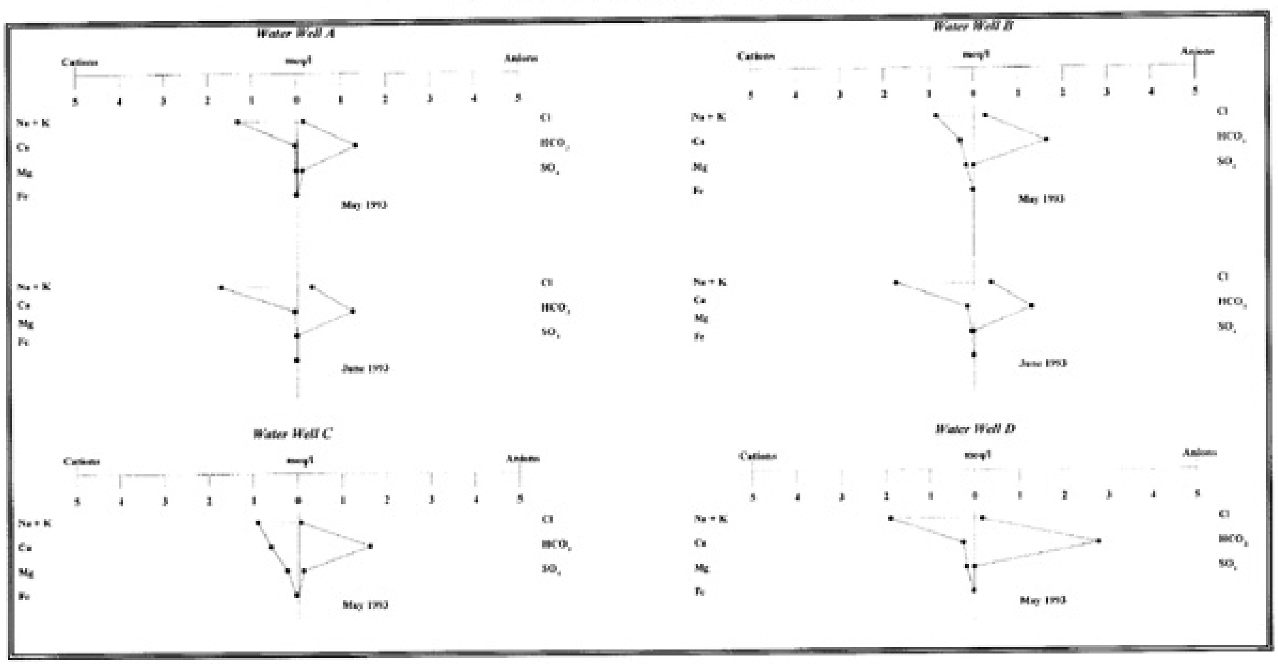
At the subject site, the mine performs just such function, and since the mined seam lies above drainage levels on the downdip (western) side of the mining, water is collected and preferentially conducted toward the downdip outcrop area where it is discharged via seepage. The dominant discharge points are via old "house coal" adits, representing workings of unknown but probably quite limited extent. The flow volumes from certain of these suggest that these old mines may penetrate fairly close to the modem workings. The pool elevation in the mine is well below the updip outcrop point, and the fact that the pool extends over only a relatively small extent of the mine speaks to the effectiveness of seepage discharge in preventing larger head build-ups within the mine.

Background Water Quality

Aqueous geochemistry at the site, under natural conditions, is a function of the hydrogeologic controls. Evidence established by the recent sampling program, and supported by the literature and the writer's experience, shows that the water chemistry of deeper subsurface aquifers is significantly different than that of shallow horizons and of surface water. Determination of major ionic facies in ground and surface water demonstrates these essential differences quite well.

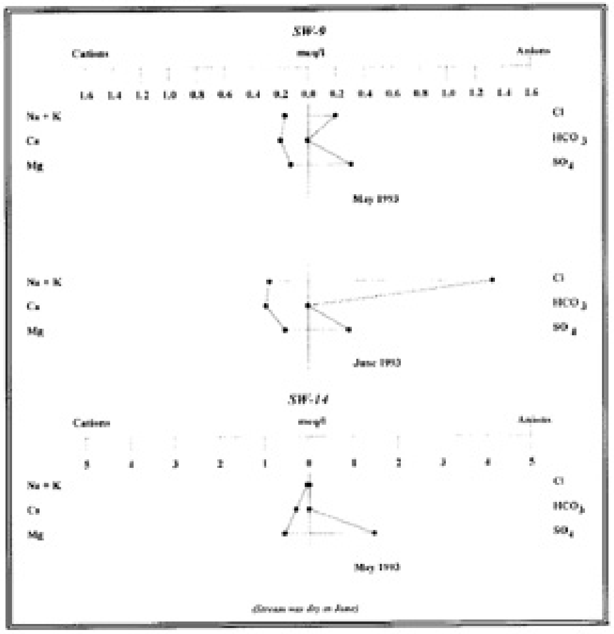
Natural ground water occurring at depth in the subject area is characterized as a sodium - bicarbonate dominant ionic facies. In samples collected from the site, such ground water is typified by the following Stiff diagrams:

Figure 1
Background Water Quality, Deep Ground Water



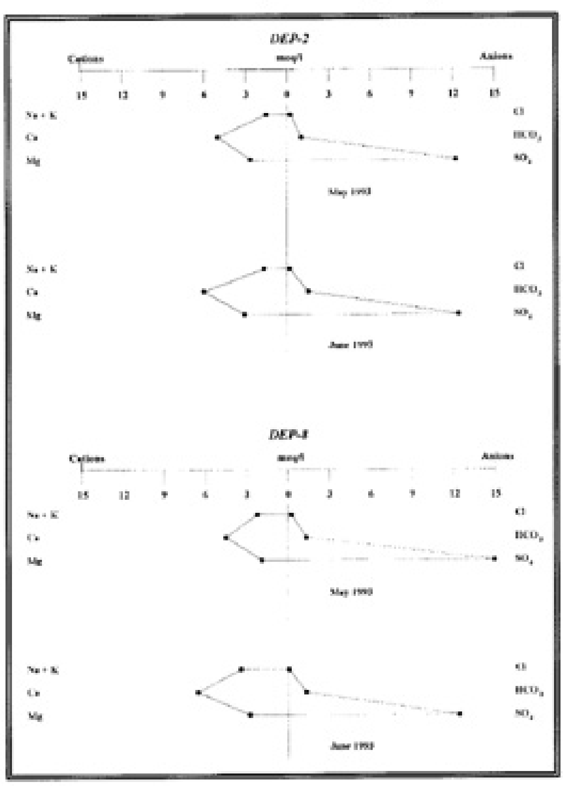
Surface water under background conditions and on the headwater stream reaches contains less total dissolved solids than ground water which has spent substantial time in contact with minerals in the rock, as would be expected. Available analyses from such settings include those from stations SW-9 and SW-14 along the stream *(see Figure 4)*. These analyses show very low bicarbonate content, but exhibit sulfate ionic dominance. Cationic dominance is fairly evenly distributed among sodium, calcium, and magnesium ions, as shown on *Figure 2*.

Figure 2
Background Stream Water Quality



Water discharge from old "house coal" mine adits and from seeps along the downdip outcrop exhibits a calcium-sulfate dominance. Sampling stations DEP-2 and DEP-8 are mine outflows with water representative of oxidation of sulfide minerals and calcium-bearing strata in the area.

Figure 3
Mine Discharge Water Quality



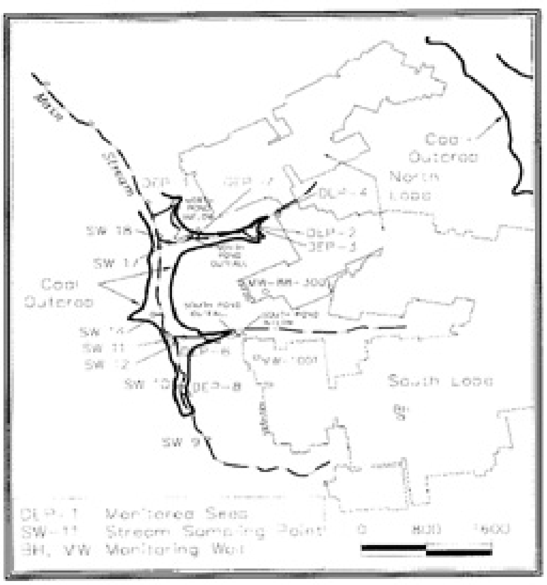
Surface stream ionic characteristics in the middle and lower stream reaches also exhibit a calcium-sulfate dominance, due to the influx of ground water from springs and seeps associated with the coal horizon.

In addition to ionic characterization, many other parameters were analyzed in the sampling program. Analysis of trace metals showed no concerns in this regard. Iron, manganese, and sulfate were elevated in many samples, and some of this (as regards iron and manganese) is reflective of naturally-occurring quality, whereas in other instances the high levels appear to reflect mining impact.

Mine Pool Characterization

As is shown on *Figure 4,* the mine consists of two major lobes, one lying south of a tributary hollow (south lobe) and one lying north of that hollow (north lobe). The northern lobe is further subdividable at a narrow "neck" of four entries utilized to advance beneath a shallow cover area in another tributary hollow.

Figure 4
Mine and Data Collection Locations

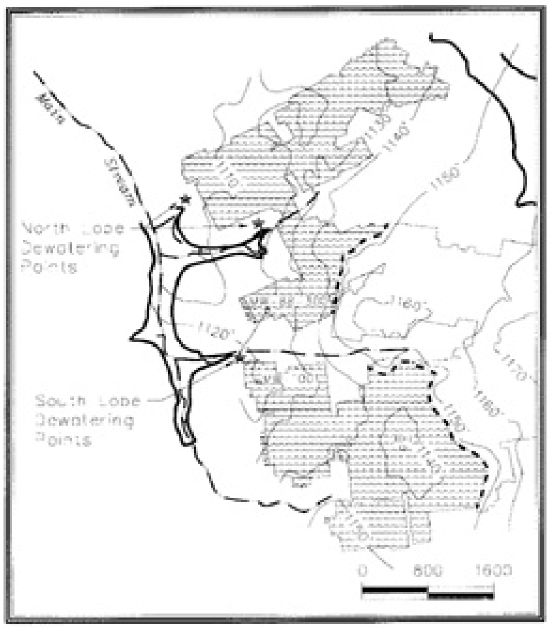


In early stages of the investigation, regulatory personnel expressed a concern that the entire mine may be essentially completely inundated, such that the lobes were hydrologically interconnected and that up to 50 feet of hydraulic head may be present to drive the seepages that had been observed along the downdip outcrop. In order to address this concern, two monitoring wells were installed, one in the south lobe and one in the north lobe. Monitoring of those wells confirmed that the pool level was situated elevationally below the point where the two lobes bifurcate: that is, the lobes were not completely hydraulically interconnected by virtue of the mine entries themselves. However, the two lobes displayed a similar, but not identical, water elevation, suggesting some degree of hydraulic interconnection through the 500 to 600 feet wide solid coal barrier that separates the two lobes beneath the hollow. The total head found to exist above the outcrop seepage points was approximately 30 feet (in April, 1993), with seasonal variations (declines) of about eight feet between April and October, 1993. Abrupt rises in response to heavy rainfall events were found to occur, with up to a three feet rise resulting from a 2.7-inch rainfall event in March, 1994 *(see Figure 8*).

Mine Pool Water Quality

During the initial investigation, the mine pool was sampled three times at three different locations (monitoring wells BH, MW-1001, and MW-88-300, *see Figure* 5). Results of these analyses reveal some interesting and significant circumstances concerning the nature of the pool. Evaluation of dominant ionic character shows that this character is different from one sampling location to another; and at one of the locations, it also changes with time, apparently in response to recharge from precipitation.

Figure 5
Geologic Structure and Mine Pool



Well BH, located in the southern mine lobe, is consistently a calcium-sulfate water, with relatively high sodium levels. This well is situated in a local depression in the mine floor, where water is collected and contained, but is also within the main pool of the southern lobe. Its characteristics are similar in all three pre-dewatering sampling events, and are representative of essentially stagnant mine pool conditions. MW-1001, also in the southern lobe, showed very similar ionic characteristics to BH in May, 1993; but in the June, 1993 sample, it exhibited much lower sulfate levels, a bicarbonate anionic dominance, and lower levels of total dissolved solids in general. The June sampling event occurred a few days following an extremely heavy rain (1.86 inches), followed by other small-magnitude rains. The dramatic change in water quality in MW-1001, including lower dissolved solids, sodium, sulfate, and calcium than previously and increased dissolved oxygen reflects an apparent impact of recharge by precipitation runoff waters. The impact is that of dilution of "typical" mine pool water (as represented at monitoring point BH) by surface runoff apparently entering through subsidence fractures.

Well MW-88-300, in the northern mine lobe, has exhibited characteristics indicative of significant surface-water infiltration in all sampling events. These characteristics include high dissolved oxygen contents (6 to 11 mg/1) and low dissolved solids.

In summation, the mine pool exhibits very high dissolved solids, with a pronounced calcium-sulfate ionic dominance, only where the water is basically stagnant, which appears to occur only locally within the pool. Throughout most of the pool, there is significant continual movement of water toward the seepage discharge points, being recharged by vertical percolation of relatively unmineralized water via fractures. The effect of such recharge on water quality in the mine pool is that of dilution of dissolved mineral concentrations and addition of oxygen.

Water Quality Changes between Pool and Seepage Discharge Points

In contrasting the characteristics of water found within the mine pool with that occurring at seeps downgradient of the pool, it is apparent that much of the mineral loading found in the seeps takes place in the barrier region between the mine workings and the outcrop. On the following *Table*, the contrasts between mineral loading of typical "mining-related" parameters in the mine pool versus the seeps are clearly discernible.

As can be seen on this table, dissolved parameters such as iron, manganese, and sulfates are significantly higher in concentration in those seeps driven by head from the mine pool than they are in the pool itself. Much of the mineral loading that is exhibited by the seeps apparently occurs in the barrier region that water passes through in moving from the pool to the discharge points. This circumstance has bearing upon remedial alternatives, in that water which does not spend residence time in the barrier strata or in the local stagnant "pockets" within the mine is of markedly improved quality as compared to the problematic seeps. The remedial implication is that, if the mine were to be drained and future recharging water allowed to pass through quickly by means of a constructed downdip outlet, that future water may require little, if any, treatment before being discharged to surface streams.

streams.

Table 1

Mineral Concentration Levels, Mine Pools versus Seeps

(all parameters in mg/l, except pH in Standard Units)

Station	Date	Dis. Oxygen	pH	Fe^{+2}	Fe^{+3}	Dis. Fe	Dis. Mn	SO_4
Mine Pool Stations								
DH	May	3.1	6.80	1.0	ND	0.290	0.32	560
	June	2.5	6.54	0.9	0.5	0.630	0.45	570
	September	2.5	7.01	2.8	2.5	5.900	0.41	820
SW-1001	May	2.8	6.79	2.1	1.6	8.900	0.42	550
	June	6.6	7.28	1.0	4.8	0.580	0.54	84
	September	1.5	7.36	0.6	ND	0.190	0.53	86
SW-88-300	May	11.0	6.87	1.0	ND	0.065	0.13	13
	June	6.2	6.17	ND	0.7	0.150	0.20	17
	September	4.5	7.11	ND	ND	0.022	0.09	35
Seeps Apparently Driven by Mine Pool								
DEP-1	May	7.2	7.12	7.0	ND	3.2	1.50	410
	June	7.1	6.76	3.0	3.5	1.4	1.50	490
	September	6.1	6.87	2.6	6.4	9.4	1.90	700
DEP-2	May	2.5	6.38	18.2	ND	15.0	1.90	590
	June	6.1	6.51	4.4	11.6	17.0	1.70	600
	September	--	--	--	--	--	--	--
DEP-5	May	1.1	6.51	16.8	ND	18.0	1.60	450
	June	1.1	6.23	10.8	9.2	18.0	1.60	510
	September	--	--	--	--	--	--	--
DEP-6	May	1.8	6.60	11.5	ND	8.4	0.69	450
	June	2.8	5.80	10.0	ND	8.6	0.75	600
	September	1.2	6.42	7.0	9.0	14	0.56	800
DEP-8	May	5.0	6.09	6.6	2.2	8.7	0.64	720
	June	3.9	5.88	2.3	12.0	8.8	0.70	600
	September	1.9	6.72	3.2	11.8	9.7	0.79	860
Seeps of Mixed Origin, or Non-pool Origin								
DEP-4	May	11.6	7.34	ND	0.46	0.15	0.024	200
	June	8.8	7.00	ND	1.60	0.45	0.160	330
	September	--	--	--	--	--	--	11
DEP-7	May	5.2	7.15	ND	3.50	0.12	0.069	420
	June	7.8	7.25	ND	1.00	0.59	0.240	440
	September	--	--	--	--	--	--	11

Results of sample analyses also confirm the expected relationship between dissolved oxygen and dissolved iron contents (and between dissolved oxygen and iron species). As shown on *Figures* 6 and 7, the presence of increased amounts of dissolved oxygen result in conversion of dissolved ferrous iron to ferric iron, with subsequent precipitation of the iron and drop in total dissolved iron levels. Again, this circumstance has important implications for remediation, in that the iron, in particular, appears to respond quickly and effectively to oxygenation such as could potentially be provided by a simple cascading channel and sedimentation pond.

Figure 6
Dissolved Iron vs. Dissolved Oxygen

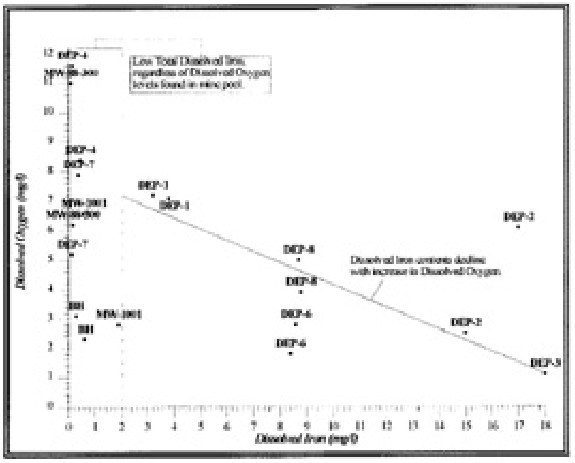
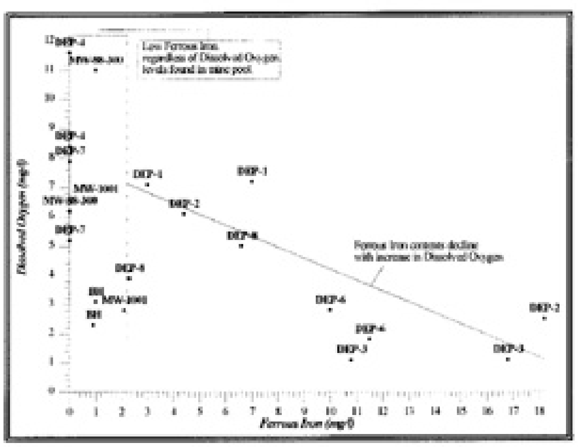


Figure 7
Ferrous Iron vs. Dissolved Oxygen



Assessment of Seep Mechanisms

The seeps occurring downgradient of the mine workings can be subdivided into two groups: 1) those which discharge directly from the No. 5 Block coal, driven by hydraulic head in the mine pool; and 2) those which issue from overlying strata, but which may be at least partially driven by mine pool head. Seeps in the former category discharge via old "house coal" adits, with the exception of seep DEP-3.

The seeps which issue directly from the coal are characterized by high levels of dissolved minerals commonly associated with coal, i.e. iron, manganese, and sulfates. As discussed previously, the levels of these constituents in these seeps are generally higher than those found in the mine pool itself, and are apparently derived from interaction of the water with minerals in the coal as the water passes through cleat and bedding plane fissures within the seam.

In contrast, seeps which issue from overlying rock strata, rather than the seam itself, exhibit better water quality than those issuing from the seam. While possibly still driven by hydraulic head in the mine pool, water associated with these seeps spends less time in contact with the coal seam and consequently undergoes less mineralization. These seeps also exhibit no ferrous iron content, indicating that a great deal of oxidation occurs within the fractured overburden strata.

Impact to Receiving Stream

Sampling and analyses were conducted from multiple stations in the receiving stream, upstream of the seepages, downstream of the seepages, and at several points between seepages and along tributaries which received seepage water. The parameters found to be of concern are those frequently associated with mining in the region, namely iron, manganese, and sulfates. Analyses of trace heavy metal constituents showed no such parameters to be of concern.

Results of the sampling at various stations showed sulfate increases downstream of the seeps, with no significant diminution of concentrations with distance from the seep beyond that afforded by dilution from other waters entering the stream. Manganese was found to be slightly increased from pre-mining background levels, but did not exceed approximately 0.55 mg/l in the main trunk stream.

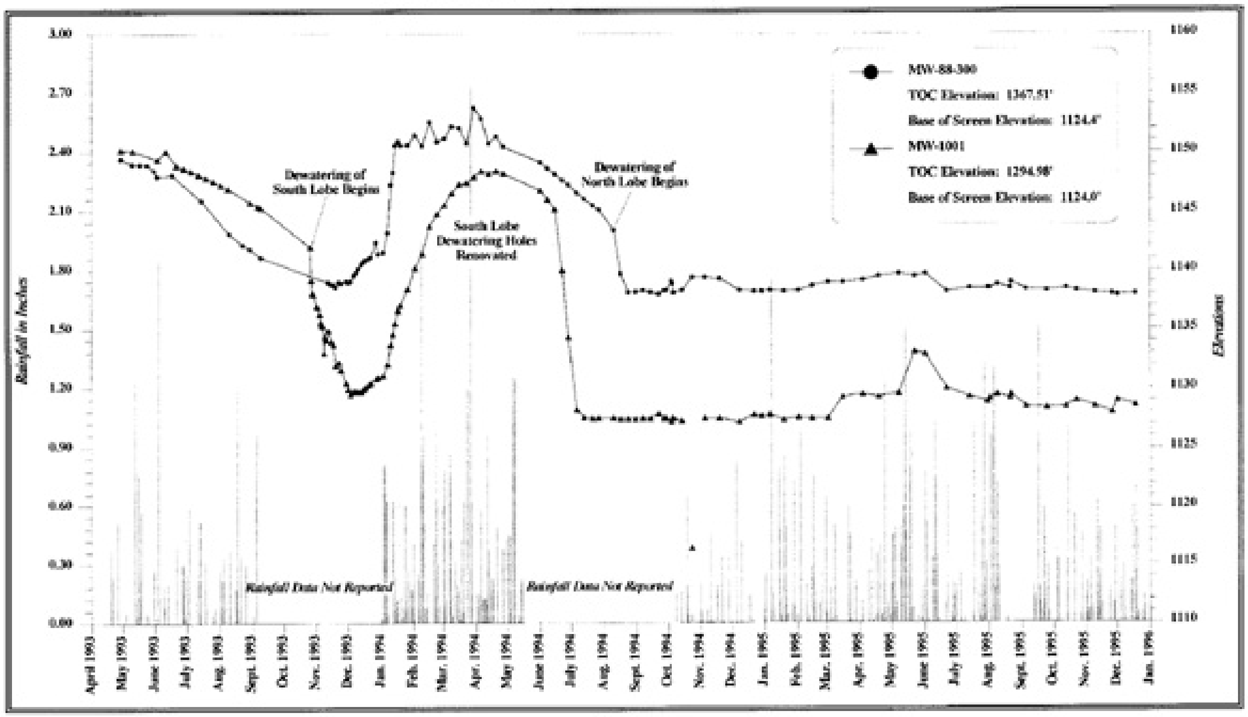
Iron concentrations in the stream were significantly raised above pre-mining levels at points a short distance downstream of the seeps. However, it was also found that the dissolved iron responded quickly to aeration, such that the iron is oxidized and precipitated within a relatively short distance upon being discharged from the seepage point.

Remedial Action

Results of the hydrologic characterization study indicated that mine dewatering to remove the driving force (head build-up) was necessary to remediate the seepage flow rates and the rise in the water table which had occurred along the valley floor below the seam outcrop position. The study also indicated, however, that water resident within the pool was of substantially better quality (less mineralized) than that issuing from the seeps, such that prevention of migration through the barrier would result in less degradation of the water. The high dissolved oxygen content, favorable pH, and overall buffering capacity of the pool water indicated that dewatering may be implemented with relatively little required treatment beyond retention to allow further oxidation and precipitation of iron prior to discharge to the receiving stream. The oxygenated nature of the pool water precluded any potential for treatment via anoxic limestone drains.

Dewatering was undertaken first at the south lobe mine pool, in the autumn of 1993. Two horizontal borings were advanced through the barrier at the lowest-elevated point of that lobe of the mine. The pool level, as monitored via an observation well, responded immediately, showing about 12 feet of decline in head over the first two months. At that time, however, a combination of partial caving and blockage of the dewatering ports in the subsurface and a period of heavy rain and snowfall drove the pool back to its original levels *(see Figure 8)*.

Figure 8
Mine Pool Fluctuations and Precipitation Data



H-7

In the summer of 1994, the south lobe dewatering ports were renovated, and the desired lowering of the pool was fully achieved within a few weeks' time. Shortly thereafter, similar horizontal borings were installed into the north lobe pool, at two different locations. One location is at the lowest elevation of that pool, but because of extensive pillar extraction in that area, there are questions as to the permeability of the workings there. In order to achieve more effective and more timely results, dewatering portals were also installed at a more updip location where no pillar extraction had occurred which could impede flow through the workings. As can be seen on *Figure 8,* the initial response to these installations was rapid. However, the only available monitoring well in the north lobe lies in a sublobe that is prevented by the structural dip from fully draining. Consequently, the continued decrease in pool level in the north lobe cannot be directly monitored below a certain point, as is reflected in *Figure 8.* Discharge rates at the two dewatering locations in the north lobe indicate that full reduction of the mine pool was probably achieved in the autumn of 1995.

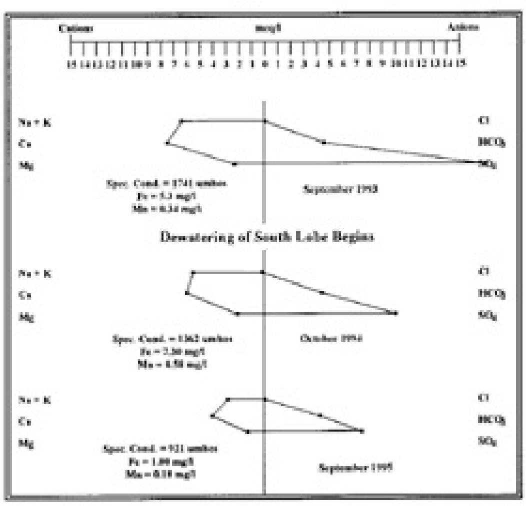
Results of Remedial Efforts

South Lobe

Removal of the hydraulic head impounded in the mine workings has produced a dramatic improvement in receiving stream quality and has alleviated the impact that had once existed on shallow residential well supplies in the valley. The shallow water table in the valley floor area has returned to pre-mining levels, several seepage points have ceased to flow, and the old "house coal" adits which continue to discharge (DEP-6 and DEP-8) now exhibit greatly reduced flow rates. In short, the pool dewatering has been extremely successful in stopping or minimizing the flow rates at the seepage points.

The diminished impact is not, however, attributable merely to reduced flow rates on the downdip side of the mine. Substantial improvements in water quality have also occurred, both in the mine pool itself and at the seepage points which continue to exhibit some discharge. A comparison of temporal water quality changes in monitoring well BH, which is situated in a localized structural depression within the mine that retains water but which is subject to "flushing" as transient water moves downdip through the mine, demonstrates the improved quality within the mine pool itself. As shown on the following notated Stiff diagrams representing samples collected in the autumn season of three successive years, the pool has undergone significant decreases in total dissolved solids (as evidenced by specific conductivity analysis), iron, manganese, and sulfates since dewatering was undertaken. Sampling in May, 1995, when more recharge to the pool was occurring (and therefore more dilution), dissolved mineral content was even lower than any of these autumn-season samples. While the water is still a calcium-sulfate type, bicarbonate content has increased proportionately while sulfate has decreased. Monitoring well MW-1001, located near the south lobe dewatering ports, exhibits a similar decrease in sulfate and total dissolved solids, and proportional increase in bicarbonate. Water discharging from the south lobe dewatering ports is similar in character, but with even less iron and manganese. The decreased contact time has, as anticipated, resulted in less overall mineralization, and significantly less dissolution of iron sulfides within the mine workings.

Figure 9
Stiff Diagrams
Autumn-Season Samples/Monitoring Well BH



The two seeps formerly identified as directly influenced by the south lobe pool, DEP-6 and DEP-8, now show distinct differences in quality. DEP-6, situated more down-dip, continues to reflect the general quality characteristics of the mine pool (strongly calcium-sulfate dominated, with relatively high iron concentrations), but exhibits a general decrease in iron, manganese, and sulfate since dewatering began. However, in contrast, water quality at DEP-8, located updip of the present pool elevation, has changed dramatically since dewatering began, such that it now exhibits little similarity to the mine pool water. The following diagrams and data show the dramatic change in quality of seep DEP-8 since dewatering began; and also provide comparison of present conditions at DEP-8, where the discharge is no longer influenced by water held in storage in the mine pool, to those at DEP-6, where some relatively minor pool retention remains.

Figure 10
Stiff Diagrams
Autumn-Season Samples/Seep DEP-8

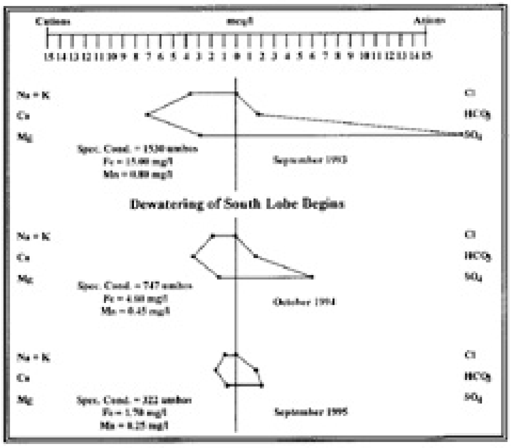
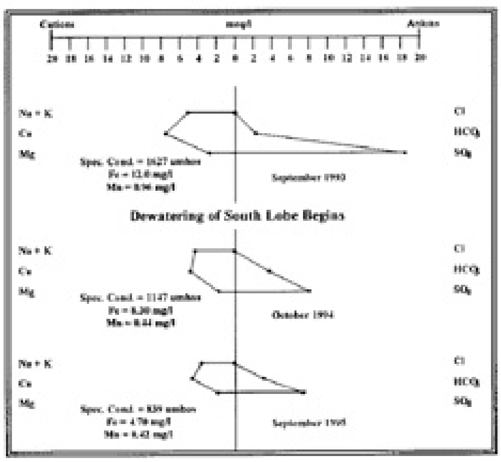


Figure 11
Stiff Diagrams
Autumn-Season Samples/Seep DEP-6



The substantial decrease in iron, manganese, and sulfate levels at DEP-8 reflect the lack of mine pool contribution to that discharge under current conditions, a circumstance directly attributable to lowering of the head in the mine pool. As long as the pool is prevented from rebuilding, DEP-8 will cease to be a point of concern for the operation.

Discharge from the south lobe dewatering boreholes bears general characteristics of the historical mine pool quality, as would be expected, but with substantially lower mineral concentrations than occurred prior to dewatering. Results of sampling in both May and September, 1995, show the discharge to be well within acceptable standards for both iron and manganese. In those sampling events, total iron concentration has ranged from 0. 18 to 0.93 mg/l, and manganese has ranged from 0. 15 to 0.24 mg/l.

Results of the periodic monitoring since 1993 confirm that the anticipated and hoped-for water quality improvements have, indeed, occurred as regards the south lobe of the mine. The former high levels of dissolved minerals, including iron and sulfate, were contributed to by retention or increased contact time in the mine workings, fluctuations in pool level, and in passage of the pool water through the coal strata itself to reach the discharge points. Anoxic conditions did not develop within the mine pool due to the rapid influx of oxygenated water that took place during storm and snowmelt events, which in turn results from subsidence fractures created by pillar extraction. The remedial action of dewatering of the pool not only has reduced (and in the case of seep DEP-8, removed) the head that formerly drove the seeps (and thereby reduced the flow rate of the seeps), but has also resulted in less mineralization of the mine water. The ultimate goal of the program has been, and continues to be, to enable infiltrating recharge to pass directly through the workings as quickly as possible, maintain established preferred flow paths, and be discharged with minimal contact time for mineralization to occur.

North Lobe

In contrast to the south lobe, in which complete dewatering was first achieved in July, 1994, the north lobe pool is believed to have just recently reached a point of near-total dewatering. The lack of a monitoring well within this lobe precludes direct assessment of water levels, but observed flow rates from the dewatering boreholes indicate that the pool attained its minimum possible level in about October, 1995. The more updip of the dewatering stations, near seep DEP-2, had ceased to flow by September, 1995. The downdip dewatering port, near seep DEP- 1, had diminished in flow to about 40 gpm in September, 1995, whereas its previous rate of flow had been several hundred gallons per minute when the dewatering activities were begun. Seep DEP- I itself had ceased to flow by October, 1995.

Treatment Requirements

At both the south lobe and north lobe dewatering sites, water from the horizontal boreholes is directed into a detention pond before being discharged to the receiving stream. At the south lobe site, the discharge directly from the dewatering ports is suitable for release, even prior to passing through the detention pond. No treatment whatsoever is presently required.

Water from the north lobe ports continues to require detention, and periodically requires a small addition of chemical treatment to reduce iron concentrations to within acceptable discharge limits. It is anticipated that, now that full drawdown of the pool has been achieved, future iron concentrations are likely to decline to resemble those of the south lobe dewatering ports. However, it is recognized that differences in transient water contact time may occur between the two lobes, due to differing degrees of pillar extraction and caving of the workings, such that geochemical conditions between the two lobes may not be identical. Future monitoring will provide additional insight in this regard.

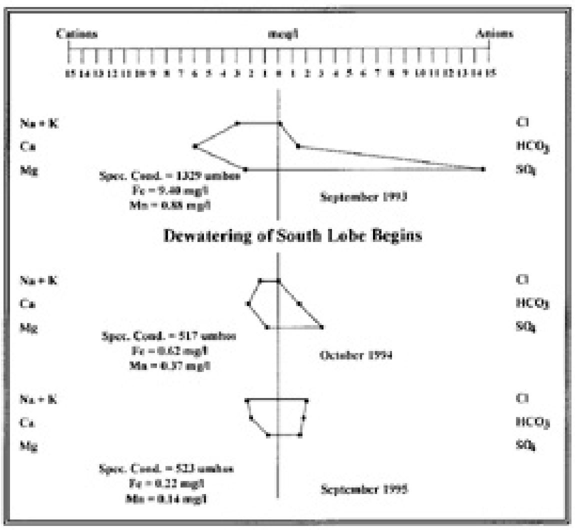
Mitigation of Impact

Previous monitoring has shown some degree of seasonality in mineral concentrations and loading rates, with a general inverse relationship because of seasonal variations in flow rates, resulting in dilution. At seasonal low flow periods prior to initiation of dewatering, dissolved mineral concentrations of the stream and its tributaries were somewhat higher than at other periods of the year. However, the total loading rate in mass per unit time was lower than in higher-flow seasons.

Comparison of overall water chemistry at the various sampling stations, aided by Stiff diagrams for visualization, very clearly demonstrates the beneficial effects of mine dewatering upon stream quality, as shown by the following examples from autumn-season sampling, when dissolved mineral concentrations are generally at their highest levels.

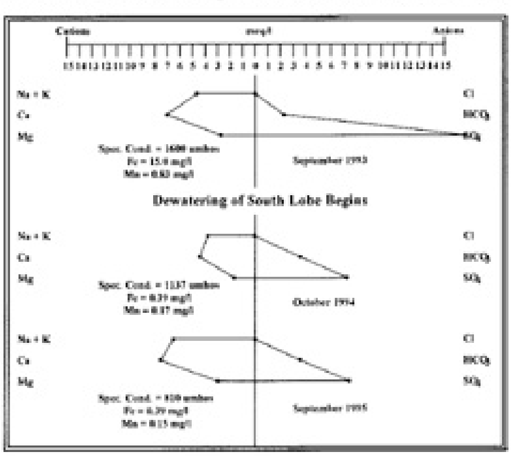
Station SW- 10 is on the main trunk of the stream, at a point just downstream of the inflow from DEP-8 *(see Figure 4)*. Comparison of SW-10 characteristics in the low-flow seasons of 1993 (before south lobe dewatering) and 1994 and 1995 (after dewatering) reveals a continual decline in the calcium and sulfate dominance that so strongly characterized the stream prior to mine dewatering, and an increase in bicarbonate. (The present increased levels of sodium and chloride at SW-10 suggest possible contribution by septic system effluent from a nearby residence.) SW-10 now appears to be completely unimpacted by water from the mine pool.

Figure 12
Stiff Diagrams
Autumn-Season Samples/Stream Location SW-10



SW- 11, located in the unnamed tributary downstream of DEP-6 and the south lobe dewatering ports, also exhibits an increase in bicarbonate constituency, but with less diminution of the calcium-sulfate dominance, as it still reflects direct influence by the remaining (but improved-quality) mine pool.

Figure 13
Stiff Diagrams
Autumn-Season Samples/Stream Location SW-11



SW- 17 and SW- 18 are located on the main trunk of the receiving stream and are just above and just below, respectively, the tributary which was formerly fed by seeps DEP-2 and DEP-3 and is currently fed by the outfall from the north pond. Although calcium and sulfate remain as dominant components, there is an overall decrease in their concentrations and an increase in bicarbonate. The impact of sodium hydroxide treatment of the north pond outfall in September, 1995, is clearly seen at S W- 18.

Figure 14
Stiff Diagrams
Autumn-Season Samples/Stream Location SW-17

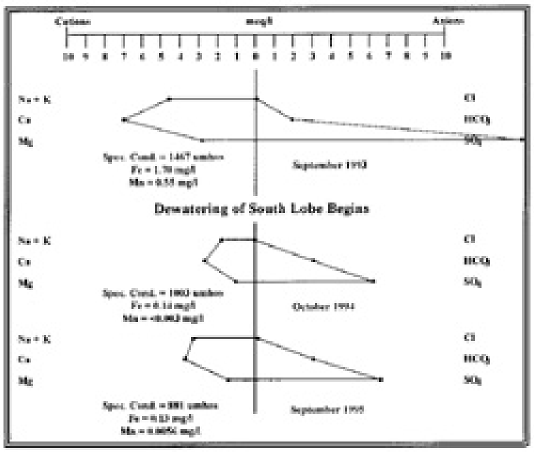
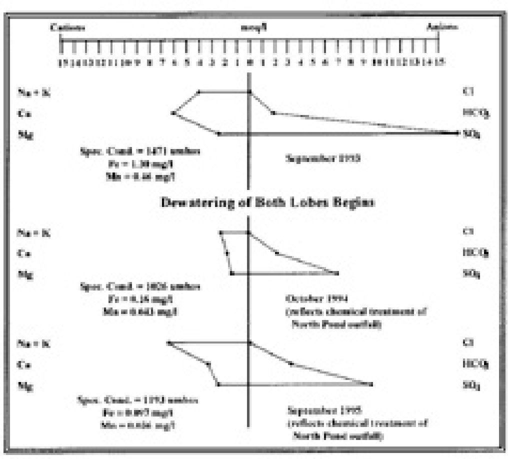


Figure 15
Stiff Diagrams
Autumn-Season Samples/Stream Location SW-18



With the change in overall water chemistry that has resulted from mine dewatering, there has been an accompanying decrease in the three parameters historically monitored as indicative of mining impact, namely iron, manganese, and sulfate.

Iron concentrations in September, 1995 were substantially lower than at any previous time for which data is available, and in fact were lower than existed prior to mining, based on the sparse available pre-mining data. The maximum iron concentration found in the receiving stream was 0.44 mg/l, at SW-12. Regulatory maximum limits for discharge are set at 4 mg/l daily maximum and 2 mg/l daily average, and the limit is not exceeded anywhere except at DEP-6 and the north lobe dewatering discharge, prior to treatment.

For that part of the stream lying upstream of the north lobe pond tributary (SW-17 and above), this dramatic reduction in iron concentrations has been achieved without chemical treatment, simply by eliminating the head in the south lobe pool and decreasing retention time of water passing through the mine cavity. Downstream from the north lobe pond tributary, chemical treatment of the north pond outflow enables the maintenance of very low iron concentrations. It is hoped and expected that water quality of the north lobe discharge will improve similarly to that of the south lobe, so that the entire remedial system may become passive in the future.

Manganese concentrations in September, 1995, were also generally at the lowest levels since the investigation began in 1993. The current levels are near to, but not below, those indicated by sparse available information to have existed prior to mining. The regulatory maximum limit for manganese discharge is 2 mg/l daily maximum and 1 mg/l daily average, and that limitation is not exceeded at any of the subject monitoring points except the north lobe discharge, prior to treatment.

While sulfate concentrations have also responded favorably to the remedial dewatering program, they have not improved as dramatically as iron concentrations. (Sulfate concentrations are unregulated, and are addressed here because of their association with overall mining-related impact rather than as a specific problematic constituent to be remediated.)

The primary influence on sulfate levels is seasonality and dilution, and the highest levels occur at low-flow periods of the year, such as late summer and autumn. Consequently, the samples collected in September, 1995 show sulfate levels slightly higher than were observed at some high-flow periods, either pre-dewatering or post-dewatering. A more meaningful comparison of September, 1995 levels to those of September, 1993 (pre-dewatering) shows that a substantial decrease in sulfate has actually occurred in the stream as a result of the remedial program. Current levels in the stream range from 75 mg/l at SW-10 (as opposed to 700 mg/l in September, 1993) to 470 mg/l at SW- 18 (as compared to 800 mg/1 in September, 1993).

Summary and Conclusions

Down-dip mining of the No. 5 Block seam in an area in Clay County, West Virginia, resulted in a post-mining subsurface impoundment that led to adverse hydrologic impacts in the valley floor and receiving stream down dip of the above-drainage coal seam outcrop. Part of that impact was simply the result of increased recharge to the stream, shallow water table, and shallow stress-relief fracture system aquifer of the valley floor; such that residential areas, lawns, and gardens became "wet", and the flow rate of pre-existing seepages from old "house coal" adits increased. However, water quality impacts also occurred, due primarily to increased dissolved iron content of the seepages above the levels that had existed prior to mining. (Acidity and pH of the seepage water remained similar to pre-mining conditions, and was not problematic.)

Hydrologic characterization established that water impounded in the mine pool displayed relatively high dissolved oxygen contents, such that anaerobic conditions were not achieved. Thus, dissolution of iron sulfides and resultant elevated levels of iron and sulfate occurred within the pool, but increased substantially as the water migrated through the down-dip coal barriers to discharge to the surface. Monitoring of water levels within the pool over time and in comparison to seasonal and temporal rainfall events confirmed that the pool was recharged quite readily by oxygenated, percolating stormwater. The investigation also found that considerable fluctuation in pool level occurred in response to precipitation events. A remedial approach was undertaken based on the concept of minimizing contact time of the oxygenated water with the subsurface environment; and especially with the coal barriers through which seepage occurred, driven by the hydraulic head of the pool.

Horizontal borings were utilized to effect drainage ports at the lowest-elevated points of the pools. The design also incorporated aeration channels and detention ponds to induce precipitation of dissolved iron before the water was discharged to the receiving stream. Chemical treatment was intermittently required during the dewatering phases, and particularly as the pools initially reached complete drawdown levels. However, since complete drawdown was achieved in the south lobe of the mine, no further chemical treatment has been required at that site and, in fact, water discharging directly from the dewatering ports meets criteria for release to the stream, without further aeration or detention. As the water quality is substantially improved over that which the impounded pool formerly exhibited, it is interpreted that the improvement is due to the creation of fully transient hydrologic conditions, minimized contact time, and minimized wetting-drying cycles in the mine and overburden strata. Fully transient conditions are believed to have just recently been achieved at the north lobe pool, and future improvements in water quality there are anticipated but remain to be confirmed. In any event, dewatering has resulted in alleviation of the increased recharge impacts to the water table and shallow aquifer, and alleviation of impact to the receiving stream. Most of the seeps have ceased to flow, and the two that remain (which also existed prior to mining) now exhibit greatly reduced flow rates and greatly improved water quality. The remedial system is, at one dewatering location, entirely passive, and may have the potential to become so at the other location in the future.

While this presentation documents what is regarded as a successful mine drainage mitigation approach, the investigation also indicates that downdip mining requirements are not always appropriate, and the practice does not always produce the theorized result, particularly if the coal seam lies above drainage levels. Impoundment of percolating waters within the workings did not, in this instance, create anaerobic conditions, and in fact, led to increased mineralization as the impounded water migrated through down-dip barriers. Water quality of the current discharge, in which fully transient conditions have been achieved and migration through the barrier has been eliminated, suggests that an up-dip mine advancement may have, in this instance, resulted in little or no adverse impact to the receiving stream or to the hydrologic system of the receiving stream valley. The results also point to the fact that mine discharge water quality experienced during rapidly transient flow conditions (including during mining) is not indicative of that which may occur after a subsurface impoundment is created.