IMPROVING GROUND WATER QUALITY IN THE BACKFILL WITH ALKALINE ADDITIONS

by

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Abstract. Skyline Coal Company, a wholly owned subsidiary of Cyprus Amax Coal Company, initiated surface mining of the Sewanee seam of coal in Sequatchie County, Tennessee, in September, 1987, pursuant to the terms of a duly approved surface mining permit. The mine was named after an adjacent creek, Glady Fork. The engineering and geological studies conducted in the preparation of the surface mining permit application indicated that the mine could be operated with a minimum of concern for the generation of adverse impacts to the hydrological regime outside of the permit area. On July 5, 1990, however, the mine was cited for polluting Glady Fork with iron laden seeps. Shortly thereafter, comprehensive hydrogeological, geochemical, and operations management investigations were launched. Furthermore, laboratory testing procedures were scrutinized and modified to address the "siderite masking" of overburden data generated from standard acid-base accounting techniques. These investigations culminated in the preparation of a detailed Toxic Materials Handling Plan (TMHP) which incorporated "state of the art" ground water management plans and water quality assurance programs. In light of the lithologic distribution of the problematic strata and the reliance on both blast casting and dragline equipment for overburden movement, the TMHP placed a heavy emphasis on the timeliness of certain activities, the collection of detailed pre-mining information, and the application of heavy doses of alkalinity in the form of crushed limestone. The permit area has been mined out and is currently in the final reclamation phases of pit closure. Data collection from various ground water sources support the validity of the concepts and practices undergirding the TMHP. Significant alkaline recharge of the backfill ground water resource has been realized. More importantly, the alkaline additions of the TMHP have yielded substantial reductions in both iron (Fe) and manganese (Mn) concentrations in the post-mine ground water regime.[1,2,3]

Introduction

Activities aimed at the prevention or abatement of poor quality mine drainage must be based upon a well designed, fully implemented Toxic Materials Handling Plan (TMHP). The plan should be site specific in nature. Its overall effectiveness in meeting desired abatement objectives will be contingent upon the prudent factoring of key hydrogeologic, geochemical, and operational considerations into its design and field application. In this case, alkaline additions through imported limestone were a key component to the success of a TMHP developed specifically for the Glady Fork Mine. This paper will document the merits of adding limestone amendments to the backfill in coordination with surface coal mining and reclamation activities. Emphasis is placed on the benefits

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[3]Publication in this proceedings does not prevent authors from publishing their manuscripts, whole or in part, in other publication outlets.

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derived from adding the alkaline materials along identified hydrologic flow-paths in the backfill.

Statement Of Purpose

The purpose of this paper is to share the experiences of Skyline Coal Company with the coal mining industry. In particular, the writers wish to address the following points of significance:

- The methodologies involved with limestone incorporation to the backfill in synchronization with the surface mining and reclamation process require a detailed knowledge of the operation of the mine.

- Limestone additions, with respect to both quantity and placement in the backfill must be based on overburden geochemical data. These data must be routinely gathered in advance of mining.

- Time spent in identifying the post mining ground water regime and direction of flow is essential in developing concepts and defining the needed "building - blocks" to achieve overall effectiveness of the TMHP.

- The benefits of alkaline additions can be directly measured or observed by monitoring the ground water quality of the backfill.

Background

Skyline Coal Company 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 Glady Fork Mine. Mining was initiated at the Glady Fork site in September, 1987, in the lower third of the mining permit by use of endloaders and trucks. A box cut was prepared using that equipment. Once the box cut was in place, a walking dragline was placed into the sequence, and the front end loaders and overburden trucks were subsequently phased out. Cast-blasting was later introduced to the operations and subsequently the remainder of the permitted area has been developed with a combination of both dragline and cast-blasting as the primary mode for overburden movement.

The coal-bearing sequence developed at Glady Fork are Pennsylvanian Age rocks of the Crab Orchard Group. *Figure 1* shows the overburden strata to consist of the Newton Sandstone and Whitwell Shale Formations. The coal seam being mined is the Sewanee Coal Member of the Whitwell Shale Formation. The surface mine is in a broad upland divide area of the Cumberland Plateau. It lies between major drainage systems which dissect the plateau surface. The major stream adjacent to the former mine site is Glady Fork Creek.

In mid-1990, Skyline Coal began experiencing water problems at Glady Fork. The water concerns were in the form of off-site seepage emanating from the mine site into the adjacent creek. The seepage consisted of slightly acidic to alkaline, manganese (Mn) enriched, ferruginous waters. Seepage flows were defined as originating from the mine disturbance areas with movement to the creek via natural fracture systems or other stratigraphic flow paths existing in the stream buffer zone and stream bed itself. Although the overall impacts of the seepage to the adjoining streams were limited to aesthetics (red staining) and temporary benthic aquatic habitat concerns (iron sediment coatings), the discharge was defined as a pollution source to waters of the State and therefore implementation of remedial action plans was required to eliminate or minimize degradation potentials.

The range in primary water quality parameters of the seeps at the time of discharge were as follows: pH = 3.4 to 7.5; alkalinity = 0 to 121 mg/l; total iron (Fe) = 4.8 to 48.6 mg/l; total manganese (Mn) = 2.3 to 34 mg/l; and, sulfate (SO_4) = 8 to 812 mg/l.

Skyline embarked on an intensive investigative program so that enough information could be collected to identify the cause of the apparent disparity between the projected and actual water quality parameters. This information was also deemed necessary in order that a reliable materials handling plan could be developed which would satisfy both the regulatory authorities and corporate custodians. This program included extensive core drilling, testing of overburden samples, and modifying the testing procedures to account for "siderite masking" of acid/base overburden characterization objectives (Wiram, 1992), re-examining the hydrogeological and geochemical structure of the overburden, and consulting with experts in the field of mine drainage. Contrary to earlier permit findings, the additional site investigations identified potential acid-producing strata that were previously ill-defined or non-existent based upon acid/base laboratory procedures that did not account for the abundance of siderite ($FeCO_3$) common to the overburden shale sequence.

Using modified analytical procedures to account for the "siderite masking", three stratigraphic horizons in the overburden were identified as being potentially acid-producing in character. The three horizons were (listed in descending order):

1) upper shales (<5.0') at the top of the Whitwell Shale Formation;
2) lenticular sandy shales (0 - 20') within the Whitwell; and,
3) pit floor or underclay of the Sewanee Seam.

A fourth type of material, the "coal cleanings" (an admixture of coal and underclay), generated in the coal extraction process, was also identified as being acid-producing in character and was subsequently targeted for proper handling and disposal during mining.

Although the different materials were demonstrated to possess pyritic materials and a lack of inherent neutralizing potentials, the acid producing character of the various strata was only sporadic in nature. With the exception of the "coal cleanings", it was not uncommon to see both acid and alkaline characteristics within the respective strata.

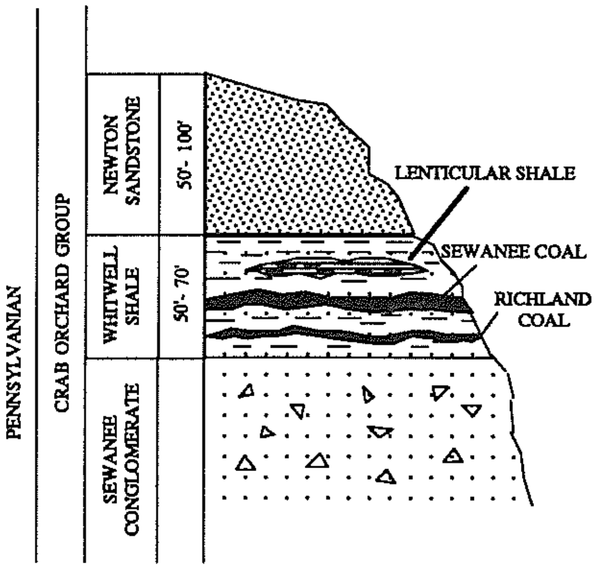
Typical ranges in % pyritic sulfur ($\%P_S$) contents and modified net neutralization potentials (MNNPs, expressed as tons of $CaCO_3$ /1000 tons material (Wiram, 1992)) for identified acid producing units were as follows:

1) Upper shales: $\%P_S$ = <0.1 to 1.64, and MNNP = -26 to +55.
2) Sandy shale: $\%P_S$ = <0.1 to 1.78, and MNNP = -48 to +14
3) Underclay: $\%P_S$ = 0.12 to 0.78, and MNNP = -19 to +20

The typical range in both $\%P_S$ and MNNP observed for the coal cleanings were 0.73% to 1.60% and -45 to -24 tons $CaCO_3$/1000 tons material respectively.

Throughout the reserve area, the lower Whitwell Shale interval above the coal seam demonstrated consistently low $\%P_S$ and was alkaline in character. The Newton Sandstone, the rock unit comprising the majority of the stratigraphic column of the coal sequence, was shown to be basically inert from the standpoint of acid or alkaline producing potentials due primarily to its indurated, quartzitic cementation. An exception to the general rule for the sandstone interval existed when, on an occasional basis, the quartzitic cementation was replaced by sparry calcite. Although the calcite cementation was sporadic in occurrence, when present, such sandstone material demonstrated excess alkalinity characteristics with MNNP values commonly in the range of 100 to 130 tons of $CaCO_3$/1000 tons material.

Figure 1
Stratigraphic Sequence in Permit Area



Eventually, these investigations, mine planning efforts, negotiations with the regulatory authorities, and protracted hearings at the administrative law level, generated a TMHP which was attributed the highest probability of success. The balance of this presentation describes the results of the application of this TMHP.

The Mining Method

Skyline's method for selectivity handling and disposing of potentially acid-producing materials involved a combination of operating techniques. Overburden movement was achieved by a combination of direct cast-blasting, tractor pushing, and dragline placement with the mine's Bucyrus-Erie Model 1300 stripping machine.

Skyline modified some phases of its traditional mining methods to accommodate the TMHP developed for the site. An important element of change was that Skyline moved the backfill-side operating bench level of the dragline from 50 feet or less off the pit floor to 85 feet above the coal. That change enhanced the machine's capabilities of handling an increasing volume of shale (i.e., problematic shale) to be placed on the bench pad as well as expanding the machine's ability to place the best shale materials in the graded backfill. Both activities were deemed important to the success of the TMHP.

The mining sequence was initiated with the cleaning of the mined out pit, placement of cleanings against the toe of the machine bench, and where appropriate, constructing a hydrologic flow-path (chimney drain) to move subsurface water off the dragline bench itself. As other sections of this paper will discuss, this phase of the mining/reclamation sequence was also the recipient of alkaline additions. The pre-blast configuration as well as the generalized geochemical characterization of the overburden are depicted in *Figure 2*.

Figure 2
Configuration of Pit Prior to Blast Cast

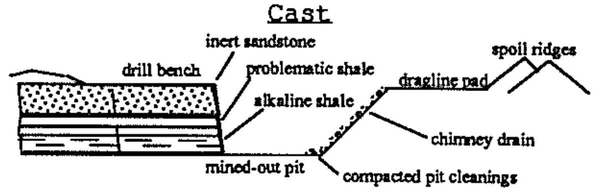
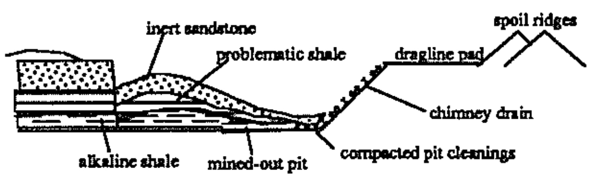


Figure 3 illustrates the position of the muck pile (shot overburden) following a normal cast-blast shot. (The shape and the distribution of the shattered rock ("the bread loaf") was established by field measurements. Thereafter, the services of blasting specialists using high speed movie cameras were also secured. An examination of the film using the "stop frame" capability of a special projector supports these initial field

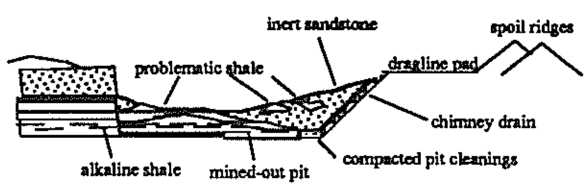
observations.) Note that the problematic shale extends across the former pit floor. However, the bulk of the acid-forming shale lies toward the highwall side of the pit and thus in a more advantageous position for selective handling with the dragline. Lastly, it is important to note that the shot rock underlying the entire length of the muck pile consists of alkaline shale materials derived from the basal section of the original overburden profile.

<u>Figure 3</u>
<u>After Blast Cast</u>



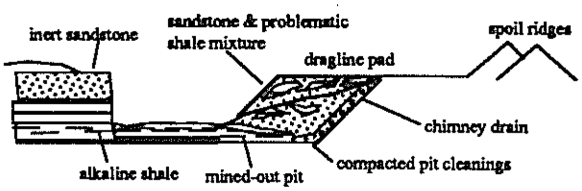
Once the overburden material was cast, tractors were used to push the upper sections of the muck pile ("the bread loaf") from the highwall side toward the adjacent backfill bank. Eventually the tractors would cut into the shattered problematic shale and the pushed material would become an admixture of problematic shale and inert sandstone. This unique configuration is depicted in *Figure 4*.

<u>Figure 4</u>
<u>After Tractor Push</u>



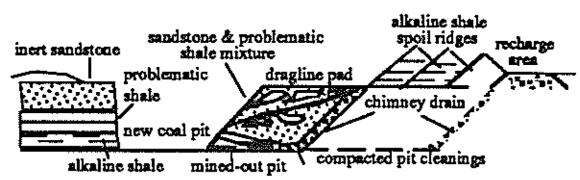
Following the tractor push of primarily inert rock materials, the dragline was used to build its dragline bench out of mostly problematic shale materials. As a practical way of providing in-field identification of the position of the problematic shale materials in the muck pile following cast blasting, stakes with notes affixed were placed along the dragline bench. Information pertaining to estimated depths to the base of the problematic materials was provided by these notes. The dragline operators would rely on the information on those stakes to control stripping depths to the base of the problematic shale. *Figure 5* shows the position of the pad relative to the other components of the mine backfill.

<u>Figure 5</u>
<u>Configuration After Building Dragline Bench</u>



Final pit excavation consisted of placing the alkaline shale materials in spoil ridges behind the machine on the dragline bench. As shown in *Figure 6*, only an extremely small portion of problematic shale materials had the opportunity of actually being cast into the spoil ridges. Overburden sampling of the graded spoil ridges at this mine proved the validity of the method. As the dragline bench has progressively moved higher into the backfill, the geochemical quality of the graded backfill interface steadily improved.

<u>Figure 6</u>
<u>Final Overburden Distribution</u>



Tractors regraded material no more than three spoil ridges behind the active cut. *(See Figure 6.)* This material was graded in lifts approximately 8 feet thick. The spoil ridges were continually worked with tractors until the area was regraded to the approximate original contour, or slightly elevated due to the swell of the overburden. Final grading was conducted parallel to the contour in sloped areas to minimize erosion and to provide a more stable surface for redistribution of topsoil.

As a summary comment, the majority of the problematic shale ended up on or directly beneath the dragline bench. At a minimum, Skyline targeted placing 90% of the acid- producing shale materials on or below the dragline bench horizon. An estimated 30 - 40% of the acid-producing materials remained permanently buried in the cast-blast profile. As will be discussed later, limestone applications above and below the direct cast-profile were designed to prevent and/or substantially minimize acid production from this zone of the backfill.

Design Objective Of Alkaline Additions

The limestone applications had to meet both interim and long-term requirements. A synopsis of the key amendment objectives follows:

1. To subdue bacterial pyritic oxidation activities and neutralize acidities generated from unavoidable reactions occurring when potentially acid-producing materials (i.e., Whitwell interface shale and lenticular sandy shale deposits, coal cleanings, underclay materials, etc.) are exposed to the atmosphere between stripping cycles to control similar reactions in these materials once disposed in the backfill.

2. To focus alkaline recharge capabilities along pre-defined hydrologic flow-paths (i.e., dragline bench, graded backfill/topsoil interface, pit floor, etc.) to enhance a long-term alkaline availability in the backfill for the purpose of counteracting unfavorable acidity build-up. (Coarse-sized ($1^1/_2$" x 0") limestone was used in order to sustain longevity of the alkaline resource.)

3. To enhance the chemical stability of siderite ($FeCO_3$) common to the shale materials comprising the overburden sequence. Limestone additions were expected to provide high alkalinity/acidity ratios in the backfill and to thus maintain favorable pH/alkaline conditions which would prevent and/or minimize the mineral dissolution of siderite constituents in the backfill.

4. To complement the in situ alkaline shale materials at the base of the muck pile. The combination of imported limestone and native alkaline shale at the base of the muck pile was to ensure the availability of alkaline products of sufficient quantity and distribution to effectively accommodate the chemical reactions and subsequent metal-loading activities that could accompany natural backfill weathering processes (i.e., "wetting" and "drying" cycles) associated with backfill ground water re-establishment.

Key Methods, Parameters, And Assumptions

1. Overburden was sampled ahead of mining on a close-spaced grid (approximately 500 feet) using air-rotary or core recovery methods. Individual samples were collected at 5-foot vertical intervals in each exploratory hole.

2. All amendment rates associated with alkaline additions to the backfill were determined by utilizing the modified neutralization potential (MNP) (Wiram, 1992) procedure for the purpose of eliminating "siderite masking". MNP was expressed in terms of tons $CaCO_3$/1000 tons of material.

3. The standard multiplication factor of 31.25 times the pyritic sulfur content was used in calculating potential acidities (PAs) of the various overburden materials. Potential acidities were expressed in terms of tons $CaCO_3$/1000 tons of material.

4. Modified Net Neutralization Potential (MNNP) was defined as the difference between MNP and PA (MNNP = MNP - PA).

5. In defining its lime requirements, Skyline Coal used a 2,300 tons/ac.-ft. factor for estimating in situ tonnages of overburden shale and pit cleanings to be encountered in stripping. This is a "Caterpillar Performance Handbook," (Edition 17, October, 1986) value. A 250 foot radius around each hole was used to estimate the total quantity of alkalinity required.

6. Limestone application rates were based on "negative MNNP" zones identified through the 5-foot sampling and testing interval in each borehole. (These were also denoted as "net deficient" zones in other communications on the subject.) Each zone was presumed to be 5 feet thick and to occupy an area reaching half the distance to each adjacent borehole (typically 250 feet). Zones demonstrating negative MNNP values equal to greater than 5 tons $CaCO_3$/1000 tons of material were selected for the subsequent calculation of limestone application rates for the area around the borehole. The limestone application rates for each 5-foot zone demonstrating negative MNNP's equal to or greater than 5 tons of $CaC0_3$/1000 tons of material were then accumulated to arrive at the total quantity of limestone applicable t the area around each borehole.

7. The alkalinity of "net neutral" zones in each exploratory hole was not factored into the limestone quantity estimation calculations.

8. Limestone application rates were based on a stone quality of 90% purity.

Alkaline Addition Placement In The Backfill

The "building blocks" needed to develop a workable TMHP relative to the following issues began to accumulate as the investigations proceeded. These "building blocks" included the following:

1. The water quality characteristics of the earlier mined and backfilled portions of the mine, as evidenced by both post-mine ground water data and off-site seepage water quality;

2. The refinement of pre-mine/post-mine positioning of potentially acid-producing materials in the stripping sequence; and,

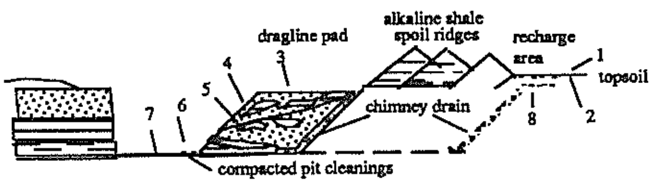
3. The establishment of a basic understanding of the hydrologic flow-paths in the backfill.

It quickly became evident that alkaline additions to the backfill would play a major part in the TMHP. These additions were to have the dual role of minimizing and/or preventing acidic reactivity in the backfill and to enhance the alkaline-loading of the reemerging ground water presence in order to meet the long-term post-mine drainage objectives following reclamation. The overall concepts for the design and planned installations of alkaline-loading mechanisms for the TMHP are credited primarily to the past research works and technical papers of Caruccio and Geidel, 1988 and 1989. The ideas and technical support for incorporating the limestone materials into the backfill in conjunction with the stripping and reclamation process stem primarily from the works of Byerly (1990) and Infanger and Hood (1980).

Eight zones in the backfill were targeted for alkaline additions. As shown in *Figure 7*, the zones of alkaline additions are (in descending order from the reclaimed surface):

1) replaced topsoil;
2) topsoil-graded backfill interface;
3) backfill-side dragline bench;
4) pit-direct cast overburden;
5) pit-direct cast understory;
6) coal cleaning;
7) pit floor underclay/shale; and,
8) surface alkaline recharge structures (SARS).

<u>Figure 7</u>
<u>Alkaline Addition Areas</u>



Because of the substantial quantities of limestone to be applied to the backfill to account for the neutralization deficiencies identified for the involved strata and to compensate for possible unforeseen short-comings in the mine's overall success at achieving total selective handling in the backfill, Skyline split the limestone application into three equal portions. Each split was placed within a specific position within the backfill. Correct proportioning in the field was assured by use of "zone of influence" boundaries marked along the dragline bench.

The three sections of the backfill receiving the limestone amendments are as follows:

1) topsoil/backfill interface;
2) backfill dragline bench; and
3) direct cast profile.

The portion of lime placed on the topsoil/backfill interface was in addition to the amount of lime already added to compensate for possible "hot-spots" identified on the graded backfill in advance of final soil replacement.

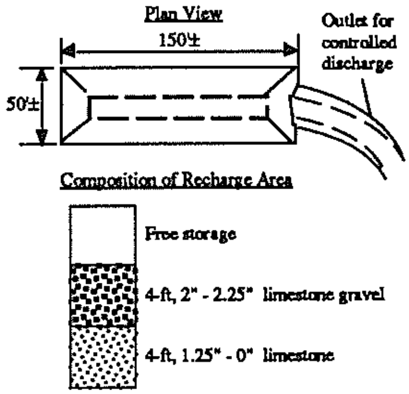
Skyline further split the lime targeted for the "direct cast profile" of the muck pile into two separate applications. Half of the required lime amount was dumped on the pit floor and spread in a uniform lift. The remaining half of the lime planned for the direct cast profile was placed and spread over the tractor push area of the muck pile.

<u>Backfill Alkaline Recharge Structures</u>

To enhance the introduction and subsequent movement of alkaline waters into and through the backfill, Skyline constructed a network of surface alkaline recharge structures (SARSs). *(See Figure 8.)* The SARSs were installed during final reclamation and were designed to afford maximum watershed inflow into the backfill. Furthermore, wherever possible, these surface features were positioned to overlay chimney drains installed in the backfill. In that manner, the potential for the alkaline/oxygen loading of the backfill ground water was enhanced. The key objective of this initiative was to induce metal precipitation within the backfill.

Typically, each SARS was first excavated and shaped to match the existing contours of the reclaimed land. Usually, this would result in a backfill excavation with volume of approximately 1.8 acre-feet. Limestone with a calcium content of 90% or greater was placed into the excavation. The first four feet of limestone consisted of a 1.25" x 0" "crusher-run" produce. The next four feet consisted of 2" x 2.5" gravel. The resulting loosely packed, bowl-shaped, recharge areas were anticipated to have a water holding capacity of 1.3 acre-feet, almost double the volume expected from the design precipitation event (2-year, 15 minute event).

Figure 8
Detail of Alkaline Recharge Facility



Ground Water Monitoring Results

The application of the TMHP is now running into its fourth year. *Figure 9* shows the general location of where the TMHP was implemented at Glady Fork. The TMHP was initiated in August 1992. Skyline Coal continued full implementation of the plan through final pit closure in 1995.

Prior to entering into a discussion of the water quality data of the mine site, it is important for the reader to understand that the basis for this paper is "ground water well" data and not "seepage" data. This is a practical off-shoot of the company's seepage abatement program which was initiated in October, 1990. At that time, the ground and surface water paths to the identifiable seeps to Glady Fork were intercepted, and as a result, the seeps have ceased to exist. The multi-source water captured in the process is being pumped back to the mine site. This method of control of the former seeps is expected to continue until the company installs a passive, wetland-based, water control system. Among the many objectives of this wetland is the accommodation of those seepage flows, should they in fact re-emerge following final reclamation of the mine site.

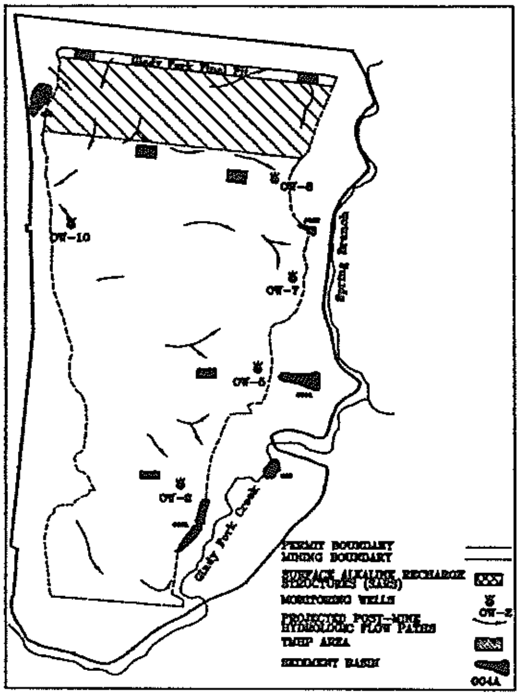
A review of the water quality trends from the majority of the backfill monitoring wells indicates an overall amelioration of the ground water associated in areas mined prior to the application of the TMHP. The improvement in ground water quality in the areas mined prior to full implementation of the TMHP initiative primarily reflects the combined benefits of contemporaneous reclamation and the backfill's inherent capabilities to control the chemical reactions which generate poor quality water. The water quality trends within and adjacent to those areas that had the direct benefits of the TMHP clearly demonstrate the prevention of significant deterioration of the ground water. The following discussions and graphic presentations summarize these observations.

Water quality data generated from five backfill ground water wells are presented here. The five wells (listed in order from south to north through the mined reserve) are OW-2, OW-5, OW-7, OW-10, and OW-8. *Figure 9* shows the respective positions of the ground water wells relative to the projected post-mine ground water flow paths in the backfill. Also, delineated on the generalized map are the TMHP and non-TMHP areas as well as locations of the installed SARS. Some discussion of the location of ground water wells relative to the SARS, TMHP area, and post-mine hydrologic flow paths is required.

- Wells OW-2, 5, 7, and 10 are similar in that they fall well beyond the boundary of the fully implemented TMHP area. These four wells reflect non-TMHP backfill conditions for approximately 90% of the total area mined at Glady Fork.As shown on *Figure 9*, ground water wells OW-2 and 5 share additional likenesses in that both are located down gradient from SARSs. The SARS up-gradient of OW-2 was installed in March, 1991. The

SARS located above OW-5 was constructed in October 1991.

Figure 9
General Location Map of Ground Water Wells, TMHP Area and SARS



- OW-7 is located approximately 1,300 feet northeast of OW-5 and along the easternmost highwall perimeter of the mined area. The well is positioned over a structural low area on the former pit-floor and is within the projected post-mine hydrologic flow-path from the TMHP area in the backfill.

- OW-8, located approximately 1,300 feet south of the final pit, is located immediately down gradient of the TMHP area and is positioned hydrologically in the backfill to effectively monitor the overall influence of the fully implemented TMHP on the ground water regime. Although OW-7 lies down gradient of OW-8, both wells are hydrologically connected in that the location of each well falls within the overall post- mine hydrologic flow pattern.

- OW 10 is offered here as a stark contrast primarily to OW-7 and OW-8. This observation well was deliberately placed in a shallow backfill area, known for its preponderance of problematic shales, and its anticipated high position in the ground water regime of the backfill. It was concluded early on, that this well would at best monitor the results of contemporaneous reclamation and possibly the influence of previous backfill/interface liming activities only. The area around this well was not the beneficiary of the direct application of the TMHP, and it had little or no chance of enjoying TMHP benefits through ground water migration.

Five ground water quality parameters are discussed here for the purpose of demonstrating the overall effectiveness of the TMHP in meeting the desired post-mine reclamation goal of minimizing backfill ground water deterioration. The five parameters to be highlighted are alkalinity, pH, sulfate (SO_4), total manganese (Mn), and total iron (Fe). With the exception to the sulfate, all the parameters chosen for comparative evaluations align with the mine's current post-mine NPDES effluent standard requirements. For sake of brevity, the comparative discussions offered below address the overall performance of the different quality parameters from a time-trend perspective. The graphic presentations provided depict a statistically computed trend line reflecting overall performance of the respective parameters as measured since initiation of monitoring at the individual wells involved.

The trend lines of the various water quality parameters presented here have been developed using a statistical software program within Harvard Graphics 2.3. The trend lines of the parameters have been statistically derived by a least squared fit of the data. The sample population of each parameter ranged from a minimum 26 to 49 data points depending on the age of installation of the respective ground at OW-7. The ground water accumulated in the vicinity of OW-7 has not only been the beneficiary of alkaline-loading from the up-gradient TMHP area, it has also been the recipient of alkaline-loading from both surface alkaline recharge as well as backfill/interface liming initiatives. These additional sources of alkaline-loading explain the observed high alkalinity levels recorded at OW-7.

Observation wells OW-5 and OW-2 are functionally similar in that both measure backfill ground water conditions at a considerable distance (3,000 feet and 4,500 feet respectively) from the TMHP area. However, both wells are positioned down-gradient of SARSs. They demonstrate alkaline-recharge in those areas of the backfill where basically no limestone additions have been made. Data derived from both wells show favorable increases on alkalinities with time. Average alkalinity levels observed for ground water at OW-5 and OW-2 are 159 mg/l and 140 mg/l respectively.

The elevated alkalinity trend observed for OW-5 reflects the dissolution of limestone within the SARS under the influence of both natural precipitation and operational pump-back recharge to the backfill. Surface water pump-back activities to the SARS above OW-5, began in late summer, 1994, and has continued to the present. Both surface and spoil ground water which accumulates in Basin 002A is routinely pumped back into the backfill to prevent basin discharge of possible non-compliant effluent. The pump-back mechanism allows for natural "air-stripping" of both iron and manganese prior to re-entry to the backfill ground water resource.

Contrary to OW-5, the overall trend line for OW-2 is flat to slightly negative. The character of this trend line reflects the long-term influence of continuous backfill dewatering activities associated with pumpage at Basin 002A and past sediment pond modifications. Changes in pond structure were implemented in the Fall of 1991 for the dual purposes of controlling pond discharge and to establish a framework for ultimately developing a permanent passive wetland system for the backfill discharge area. Basin 002A modifications resulted in significant lowering of water levels in the pond and related backfill ground water. Since modification, Basin 002A has been under a continuous pump-back mode. The continuous pumping at 002A has resulted in considerable ground water fluctuations in the adjacent backfill over time. The sustained mechanical manipulations of the ground water is primarily responsible for the trend character observed for alkalinity at OW-2.

Ground water in the vicinity of OW-10 displays a slight negative trend in alkalinity. This trend undoubtedly reflects the consumption of alkalinity in response to past and/or current natural acidification/neutralization activities in the backfill. Despite the apparent decline in natural alkalinity depicted by the graph, the inherent backfill carbonate resources appear to be effective in maintaining favorable alkalinity levels in the ground water.

Backfill Ground Water - pH

The benefits of the alkaline additions to the backfill can also be discerned from a trend line graph of pH values *(See Figure 11)* for the ground water collected from the selected wells.

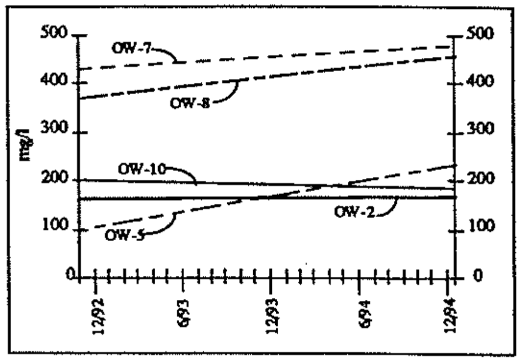
The pH values at both OW-7 and OW-8 ground water wells have remained within the 6.0-7.0 range. The slight negative trend in pH observed for OW-8 reflects pit-dewatering/final closure activities. No pH conditions have been recorded which might indicate adverse water monitoring wells involved. For example, the trend line derived for OW-8 was based upon the least number of data points (i.e., 26) per parameter due to the fact that the monitoring well in question is the younger of all the wells. Ground water well OW-2 is one of the older wells installed at Skyline Coal's Glady Fork Mine, therefore, a greater population density of data points (i.e., 49) exists for this well. The frequency of data collection of all the ground water monitoring wells discussed in this paper is monthly. Because of the population density of the data involved and the desire to present legible graphics absent data cluttering, a decision was made to present only trend line information of the various parameters at this time. It is recognized that the trend line presentations cannot be subjected to rigorous interpretation without further statistical analysis beyond which is currently offered here, however, the information provided does afford the reader with a preliminary overview of the favorable geochemical responses of adding alkaline materials to the backfill for the purpose of improving post-mine ground water quality conditions. Such transfer of information despite its preliminary nature is the ultimate objective of this paper.

Backfill Ground Water - Alkalinity

Figure 10 depicts the various alkalinity trends established for the selected wells in the backfill.

The elevated positions of the trend lines for the hydrologically connected wells OW-7 and OW-8 clearly illustrate the positive effects of the alkaline additions. Although not discernible from this simplified graph, up until March, 1994 (the date of initiation of pit dewatering for pit closure),the slope of the alkalinity trend for OW-8 was greater than that of

Figure 10
Glady Fork - Backfill Ground Water - Alkalinity

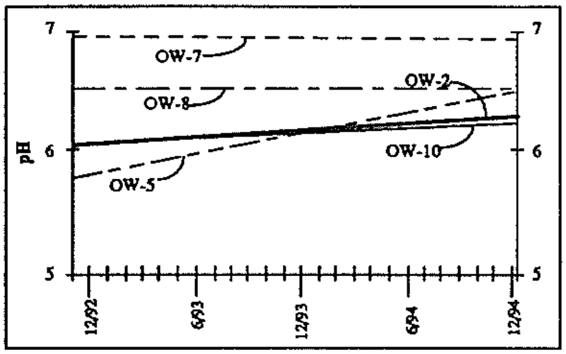


OW-7, and individual readings actually were higher that those of OW-7. Pit dewatering activities associated with final pit closure, however, lowered the next series of readings for OW-8 by an estimated 50 to 60 mg/l during the summer and fall of 1994. This temporary operational impact explains the currently observed position of the OW-8 alkalinity trend below that of OW-7. Despite these unavoidable operational manipulations, the average alkalinity value for ground water in the vicinity of OW-8 is an impressive 433 mg/l. The maximum recorded alkalinity for the 2 1/2 year time period of monitoring is 537 mg/l.

As previously mentioned, both OW-7 and OW-8 wells are positioned within the primary post-mine hydrologic flow-path in the backfill. OW-7 is located in an area which had not been subject to the TMHP. OW-8, on the other hand, is located within a TMHP area. OW-7 pre-dates OW-8 and is hydrologically down-gradient of OW-8. Despite the fact that OW-7 lies approximately 2,100 feet from OW-8, its high ground water alkalinity values reflect down-gradient migration of alkaline charged waters from the TMHP area.

North-to-south ground water movement has resulted in a significant "pooling" of alkaline-loaded waters in the structural low area in the backfill acidification activities in this part of the Glady Fork backfill.

Figure 11
Glady Fork - Backfill Ground Water- pH



The steady pH performance observed at OW-7 reflects the cumulative benefits of both recharge contributions from the SARSs and subsurface ground water recharge from the TMHP area. OW-7's distance from any significant draw-down impacts associated with pit/dewatering activities provides a further explanation of the consistency of the pH values observed at this well location.

OW-5 is located in backfill that had not been the recipient of the TMHP. It is located down-gradient of an SARS. Considering the past backfill-dewatering activities and the subsequent manipulations of the ground water regime nearby (in the vicinity of OW-2) it is apparent that the surface alkaline recharge structure up-gradient from this well has played a beneficial role in maintaining steady state pH conditions in the backfill. Evidence indicates that the backfill ground water conditions have gone from acidic pHs (<6.0) to more favorable pHs (>6.0) in less than a 2 1/2 year period following reclamation.

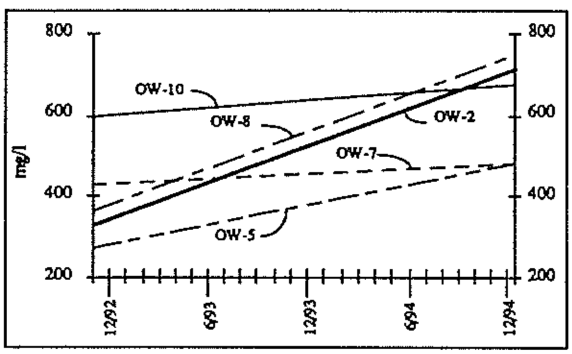
A major segment of the monitoring well-screen for OW-10 is positioned in pit cleanings. The steady pH recorded for OW-10 (pH = 6.0± range) reflects the presence of natural alkaline resources in the backfill and the benefits derived from the inundation of coal-cleanings positioned at the base of the backfill.

Backfill Ground Water - Sulfates (So_4)

The sulfate data is openly presented here for the purpose of allowing the readers to formulate their own opinions regarding possible geochemcial reactions occurring in the backfill, in particular, the case for suppression of pyrite oxidation. Commonly, observed increases in sulfate concentrations are automatically attributed to pyrite oxidation in the backfill and that sulfate concentrations are expected to decline with time if indeed pyrite oxidation is being prevented. However, the authors suggest that caution be used in the broad application of this "axiom" of AMD technology in the interpretation of the sulfate trends being presented here as well as any other backfill water quality investigations. There exist other possible sources of sulfate productivity in the backfill besides pyrite oxidation that can and most likely are contributing to the observed sulfate increases to date in the Glady Fork Mine study. In light of the marine/freshwater paleo-environment source (i.e., distributary channel/backwater embayment setting) of the former sediments comprising the overburden in the Glady Fork Mine area, other mineralogical sources of sulfates can be expected to be present. When considering the degree of overburden fragmentation involved with the mining process coupled with the past and present ground water mechanical manipulations (i.e., sediment pond dewatering, continuous spoil pump-back activities, final pit closure dewatering, etc.) of the backfill, natural increases in sulfate concentrations are expected to occur. The mere cyclic "wetting and drying" and subsequent "flushing" phenomena associated with the mechanical manipulations of the backfill ground water resource yields sulfate loading from multiple mineralogical sources.

Figure 12 depicts the various trend-lines for sulfates measured at the respective well locations in the backfill. All of the sulfate trends illustrate increases in concentrations with time. The only differences in sulfate performance between wells are in degree, as indicated by positioning of respective trend-lines on the graph, and the rate of productivity (kinetics of reactivity), as measured by the respective slopes of the individual trend lines.

Figure 12
Glady Fork - Backfill Ground Water - Sulfate (SO_4)



The sulfate trend-line for OW-7 shows elevated sulfate conditions in the backfill. The flattened slope of the line, however, reflects rather stable conditions relative to actual acid/base reactivity in the backfill. Another possible explanation for the observed flattened slope is that equilibrium conditions have been reached between a mixture of waters having varying degrees of sulfate concentrations. The sulfate performance observed here reflects the cumulative effects of recharge to the backfill ground water originating from the previously identified up-gradient SARS and the migration of ground water from the TMHP area.

The sulfate trend observed at OW-8 exhibits a response to pit-dewatering/pit closure activities. Up to March, 1994, the sulfate levels recorded at OW-8 were historically lower than those observed at OW-7 and the overall slope aspect of both trend-lines were essentially the same. Shortly after the initiation of full scale pit pumping in early March of, 1994, sulfate concentrations at OW-8 increased steadily. This is attributed to the "flushing" of the backfill materials as ground water levels in the backfill near that hole were caused to fluctuate. One significant observation that can be made from the data is that sufficient alkaline materials are present in the backfill to mitigate the effects of the acidic reactions. Thus both acid-loading and metal-loading have been minimized or prevented.

The slopes observed for the sulfate trends measured at both OW-5 and OW-2 somewhat mirror the trending sulfate levels observed for OW-8. As with OW-8, the overall sulfate trends for both wells reflect significant influences from past and present mechanical manipulations of the ground water regime. Surface water pump-back activity to the SARS up-gradient of OW-5 has induced frequent "flushing" of the backfill. Both pump-back and backfill-dewatering has significantly influenced the overall sulfate-loading in the vicinity of OW-2. Undoubtedly in both situations, some backfill acid/base reactivity has accompanied such mechanical influences. The ground water quality data supports the conclusion, however, that the overall impacts of undesired reactions have been minimized by the alkalinity releases from the SARS and the natural alkaline resources of the backfill materials.

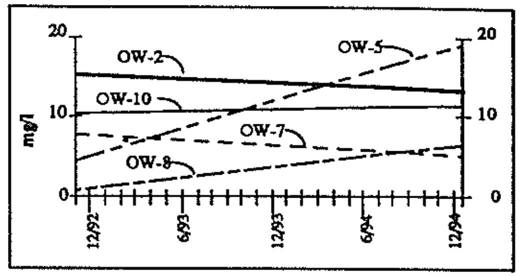
In comparison to measurements made at all other observation wells at Glady Fork, the sulfate concentrations at OW-10 have been consistently higher. The elevated sulfates coupled with the slight increase in sulfate productivity over time is associated with a backfill situation where greater than normal proportions of pyritic-bearing backfill and coal-cleanings are present and the benefits derived from fully implemented TMHP are lacking.

Backfill Ground Water - Metal Loading Fe And Mn

The benefits of alkaline additions is further evidenced by the significant reductions in metal-loading to the backfill ground water regime. Trend comparisons of metal concentrations of both Fe and Mn reveal the positive effects of the alkaline additions in preventing or significantly minimizing development of undesirable acid conditions and restraining metal dissolution in the backfill. Although the company collects both total and dissolved metal data routinely, only total values are shown here. Total iron and manganese data are presented here for the purpose of illustrating the "worst case" scenario of backfill ground water conditions. It is understood that suspended solids can conceivably create a negative bias in the metals data which is independent of the alkaline additions to the backfill, however, the idea is to present favorable conditions resulting from use of total metal information knowing that use of dissolved metal data would only show a much better case. *Figures 13 and 14* illustrate the overall trends of both metals for each of the wells under consideration here. The following discussions briefly highlight key observations made from the trend analyses provided.

Manganese (Mn). Compared to background Mn levels in the majority of the non-TMHP areas of the backfill, a significant reduction in Mn-loading is observable at OW-8. Using a calculated mean of 14 mg/l for Mn data generated at OW-10 for comparison purposes, a 3.5X to 4X fold reduction in manganese dissolution has been achieved at OW-8.

Figure 13
Glady Fork - Backfill Ground Water - Total Manganese (Mn)



This favorable reduction is noted despite the fact that the trend shown for OW-8 is negative. Over the 2.5 year time-period of monitoring at OW-8, the Mn levels have fluctuated from 1.8 to 8.1 mg/l and averaged 3.7 mg/l. As depicted in *Figure 13*, the Mn trend-line at OW-8 is climbing. This negative trend is skewed upward by recent pit-dewatering/final pit closure activities. Prior to the pit dewatering events at Glady Fork, the Mn performance fell in the range of 1.8 to 4.0 mg/l. These values are consistent with post-mine NPDES effluent discharge standards and are anticipated once again following final pit closure.

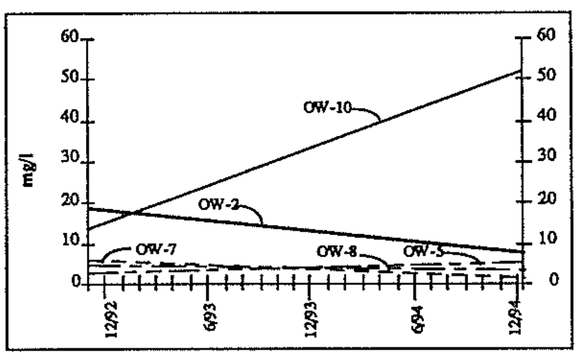
The progressive decline in Mn concentrations observed at OW-7 reflect the positive effects of highly alkaline, low Mn-bearing ground water generated in the TMHP area migrating southward toward OW-7. At OW-7, a 2.5X to 3X fold reduction in Mn levels can be observed when compared to ground water quality at OW-10. From initial monitoring at OW-7, the Mn levels have varied from 1.80 mg/l to 9.30 mg/l. The last year values cluster around 5 mg/l and are trending downward.

The continued mechanical manipulation and associated "flushing" of the backfill as a result of pump-back activities and pit dewatering have influenced the overall Mn trend-lines for both OW-5 and OW-2. Their concentrations of Mn are high. A favorable trend in Mn reductions at OW-

2 was noted following the halt of pump-back and backfill dewatering activities. This suggests that this parameter will be reduce with time once passive wetland systems are finally established and backfill pumping activities are permanently terminated.

Iron (Fe). The alkaline additions element of the TMHP has played a significant role in reducing the concentrations of iron and subsequent acid productivity in the backfill. Although it cannot be definitely proved by the information gathered to date, the positive trends in reduction of both acidity and iron levels lends support to the proposition that the alkaline additions have played a role in suppressing pyrite oxidation in the backfill. The effects of the alkaline additions on such backfill reactivity are best illustrated by observing the major reductions in Fe loading shown in *Figure 14*.

Figure 14
Glady Fork - Backfill Ground Water - Total Iron (Fe)



Using OW-10 data for comparisons, a 10X fold reduction in iron levels observed at both OW-7 and OW-8 can be tied directly to the influence of the limestone additions of the TMHP. The average Fe values observed for both OW-8 and OW-7 are 3.4 mg/l and 2.8 mg/l respectively.

As mentioned in the preceding discussions of Mn-loading, the on-going pit-dewatering/pit closure activities have caused "flushing" of the backfill and as a result have impacted the ground water quality in the vicinity of OW-8. However, despite an observed "spike" in Fe levels following the draw-down events, the overall trend is toward significant reduction of ferruginous water in the backfill.

Once final reclamation at Glady Fork is complete and the backfill ground waters receive the full benefits of the "workings" of the TMHP, Fe concentrations are expected to drop and remain below 3.0 mg/l iron on a permanent basis. Backfill water quality data collected during the interim of final pit inundation (March 1993 - March 1995) provides a technical basis in support in of such a favorable post-mine ground water quality projections. Prior to final pit dewatering, the iron levels at OW-8 averaged 2.4 mg/l. With final pit closure the post-mine ground water quality should stabilize in the 2.4 to <3.0 mg/l range.

The on-going pump-back/surface alkaline recharge activities associated with OW-5 provides a plausible explanation for the slight negative trend in iron-loading associated with this well. A reversal in trend can be expected once these operations are halted. Iron concentration trends depicted for OW-2 provides a technical basis for that expectation. As indicated in *Figure 14*, OW-2 Fe concentrations show a steady reduction over time. This favorable trend was accelerated following completion of pump-back and backfill -dewatering activities in the vicinity of that well.

When all mechanical manipulations of the backfill ground water regime are terminated, it is expected that continued declines in iron-loading will be achieved. Such favorable trends in the backfill ground water will ensure long-term effectiveness of passive wetlands designed for handling post-mine water quality discharges from the southern end (Pre-TMHP area) of the Glady Fork Mine.

Conclusions And Recommendations

In review of the overall design objectives of the TMHP, in particular the element of limestone additions, the ground water data generated from monitoring the ground water in the Glady Fork backfill indicate significant benefits have been derived. In fact, the monitoring data reflect that all of the basic design criteria and related objectives built into the TMHP are being met. The following summary highlights salient observations, interpretative inferences, and conclusions drawn from the monitoring data collected to-date.

- The alkaline additions have made significant inroads toward achieving major reductions in the concentrations of acidity, iron, and manganese. Iron concentrations in amended backfill are up to 10 times less than those in unamended backfill. While manganese levels are 2.5 - 3.0 times lower.

- The consistently high alkalinity levels recorded and the observed steady rise of ground water alkalinity with time provides substantial evidence that limestone placement along pre-determined hydrologic flow-paths in the backfill has generated the desired alkaline-loading. In areas where limestone has been added, observation wells had alkalinity concentrations that were 2 to 3 times greater than those of a well (OW-10) located in the backfill where no alkaline amendments have been made.

- Favorable alkaline-loading accompanied by reductions in metal concentrations are observed to be associated with the SARS. The ground water data from points down-gradient of the SARSs show steady increases in alkalinity and corresponding decreases in metal levels (both Fe and Mn).

- Because of the observed significant reductions in levels of acidity, iron, and manganese, it can be inferred (not proven) that limestone additions to the backfill have been effective in subduing bacterial pyritic oxidation activities during and following mining. The observed persistent high alkalinities, lowered metal contacts, and the complementing favorable pH conditions in the backfill have undoubtedly minimized or prevented pyritic oxidation reactions. Further, the same favorable water quality parameters have undoubtedly assisted in maintaining a more favorable stability field for siderite in the backfill.

Suggested Future Investigative Efforts

All of the favorable trends referenced above point to achievement of the desired long-term goal of preventing damage to the environment.

The results of the ground water data generated to-date raise technical questions, which if answered through additional on-site investigations, would expand the knowledge base for achieving workable solutions to effective AMD abatement and control. The following are suggested investigative efforts.

- The high alkalinities (400-500 mg/l range) observed as a result of the limestone additions to the backfill, suggest that the basic geochemical mechanisms of the passive anoxic limestone drains (PALDs) are at work at the Glady Fork Mine. These high levels of alkalinity can only be achieved through the accelerated dissolution of the added limestone. This in turn suggests the involvement of CO_2 in the backfill. Further investigative efforts are needed to document the role of CO_2 in the backfill and its ability to enhance the solubility of limestone.

- Further studies are needed to document the effectiveness of the limestone additions along defined hydrologic flow-paths in the backfill. Such investigative efforts should focus on development of technical guidelines which will facilitate the application of this attractive alkaline-loading method.

- Investigation and formal documentation of the workings of the SARSs are in order. Technical guidance documents should be developed subsequent to this investigation so that the application of such facilities to other mines can be better evaluated.

Conclusions

In conclusion, this paper provides documentation of the benefits of planned placement of alkaline additions to the backfill. The limestone materials added to the Glady Fork Mine in combination with the synergistic workings of all elements of the TMHP have been effective in minimizing and/or preventing acid drainage development in the backfill. Further, the fully implemented TMHP has been effective in substantially curtailing the dissolved metal concentrations in the backfill ground water regime.

Post-mine NPDES effluent standards will be achieved for the areas under the immediate influence of the TMHP. This is supported by the current ground water quality trends in the backfill. Therefore, in the unlikely event that seepage discharges were to occur from the TMHP section of the backfill, off-site damage in the form of AMD will not occur.

With respect to the southern portions of the mine where the TMHP was not applied, the benefits of alkaline-loading and metal-loading reductions derived from the TMHP area, the alkalinity contributed by the SARS, and the inherent alkaline resources within the backfill material itself positions these portions of the mine for meeting post-mine NPDES discharge objectives.

Acknowledgments

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