Executive Summary

This technical report was prepared by Earth Sciences Consultants, Inc. (Earth Sciences) and its technical subcontractor Sci-Tek Environmental Services Company (Sci-Tek), on behalf of the Pennsylvania Department of Environmental Protection, Bureau of Mining and Reclamation (BMR). The contents of this report provide a detailed presentation of the field methods and results associated with the Study of the Effects of Longwall Mining on Streams, Wetlands, and Riparian Areas. The study was implemented along segments of Robinson Fork that are located in West Finley Township, Washington County, Pennsylvania. Study activities were conducted in accordance with Earth Science's October 13, 2000 Technical and Cost Proposals, the BMR's Contract No. BMR-00-01 dated March 14, 2001, Earth Sciences' April 3, 2001 Task Plan, and Earth Sciences' May 3, 2001 Site Selection Report.

The primary intent of this study was to determine the effects of longwall mining subsidence on streams, wetlands, and riparian areas within a selected valley floor setting. Secondly, the study findings were to provide a means, from a broader perspective, to determine whether the results could be applied as a predictive tool to forecast consequences within other watersheds designated for future undermining. In addition, the study was intended to provide data that would assist with developing approaches for monitoring and mitigating such effects. Overall, this study has provided valuable and insightful information regarding the application of current methods for conducting such studies and has generated a substantial database that can be used as a comparative standard for streams with characteristics and deep mine conditions comparable to Robinson Fork.

Prior to proposing Robinson Fork for conducting this study, several other candidate streams were evaluated in the field and research was performed to determine the availability of historical documentation. These streams included Hoovers Run, Enlow Fork, Templeton Fork and its main tributary Rocky Run, Whitely Creek, Laurel Run, and Pursley Run. Following the evaluation, these streams were not considered for the study for reasons including disturbances from significant agricultural and grazing land, extremely low gradients that could have interfered with distinguishing potential subsidence induced pooling, lack of a local and comparable unmined control segment, insufficient historical information, and recent or ongoing in-stream restoration work. These excluding factors were either not applicable to, or were of a lesser magnitude in, the Robinson Fork Watershed. Also, although premining information was limited for the Robinson Fork Watershed, this situation existed for most of the other candidate streams. The limited availability of historical data for Robinson Fork, however, provided an opportunity for expanding the current stream database. A site selection report was then prepared and submitted to the BMR on May 3, 2001. The Site Selection Report was approved by the BMR in a letter dated June 20, 2001.

Several BMR site selection criteria, along with other criteria amended by Earth Sciences and Sci-Tek, were to be satisfied for this study and were considered during the field inspections of the candidate streams. Study area selection criteria are discussed in Section 1.3.2. According to field reconnaissance, the study segments along Robinson Fork were the most suitable for fulfilling project criteria.

Two segments along Robinson Fork were selected for study and included a mined study area and an upstream study area that has not been undermined and that is substantially beyond the expected angle of draw from deep mining subsidence. The selection of the mined and unmined study areas considered the extent of longwall mining in the watershed, and a review of the limited premining and postmining biological survey data that had been collected on the stream by government agencies and private entities. The stream segments surveyed within the mined and unmined study areas generally coincided for the geomorphologic/hydrologic evaluation and the biologic assessment. The lengths of channel surveyed for these two investigative phases, however, were slightly different due to the methods used (Rosgen, 1996 for the geomorphologic work versus Peterson and Rabeni, 2001 for the biologic work). The lengths of channel surveyed for the geomorphologic/hydrologic work were 2,068 feet (mined segment) and 3,011 feet (unmined segment). For the biological assessment, approximately 2,641 feet were surveyed in the mined segment and 2,756 feet were evaluated in the unmined segment. Lengths of channel surveyed for the fish studies were slightly less because of the applied methods, time constraints, and factors that would likely have biased the results.

Prior to initiating fieldwork, property owners contiguous to the study segments were notified of the proposed study. Access to all designated stream locations was granted. Also at this time, local watershed groups were contacted to apprise them of the study and to obtain any historical information. Although some groups expressed their opinions on stream conditions and indicated possible sources for historical information, they had no data to offer.

The program of field activities developed and implemented for this study consisted of qualitative and quantitative investigative procedures designed to provide data for assessing geomorphologic, hydrologic, and fish/in-stream macroinvertebrate characteristics as well as wetland and riparian associations along the selected segments of Robinson Fork. Geomorphologic and hydrologic work was conducted by Earth Sciences' personnel and aquatic, wetlands, and riparian vegetation work was performed by Sci-Tek's personnel.

The portion of the Robinson Fork Watershed applicable to this study covers an area of approximately 14.4 square miles (headwaters through the southern end of the mined study segment). The drainage area for the unmined segment is approximately 4,384 acres and the drainage area for the mined segment is approximately

8,920 acres. Land within the study area is primarily forested and, secondly, is associated with cropland and pasture. The town of Good Intent, that is situated approximately 0.3 linear mile south of the unmined segment and approximately 2 linear miles north-northeast from the mined segment, represents the most densely populated area within the delineated watershed. Within the Robinson Fork Watershed, the stream and tributary network has likely been impacted by increased erosion and/or runoff from adjacent crop and pastureland, maintained (mowed) areas, roads, and domestic activities. These impacting factors, however, were either of a lower magnitude, or similar, in comparison to those observed for the other candidate streams.

Upstream of the unmined study segment, Robinson Fork flows primarily through agricultural areas that are active along the valley floor, and to a lesser extent, along the valley slopes. Within the unmined segment, the Robinson Fork stream valley is largely forested with minor cropland and mowed areas. Aside from one mowed area within the mined study segment, the stream flows through an area of forest and unforested floodplain. No construction activities were observed within or near the town of Good Intent (including the study segments and upstream of these segments). Also, no other types of earth disturbance, aside from small "backyard" type gardens, were identified within the town of Good Intent. Because roadways in the vicinity of the study segments are not heavily traveled and are separated from the channel by up to 390 feet, it is not expected that the stream would be adversely impacted by hydrocarbon compounds. Also, it is not likely that these rural paved and unpaved roads receive significant amounts of deicing materials during the winter season.

Consol Pennsylvania Coal Company's (Consol) Enlow Fork Mine extends beneath a substantial portion of the Robinson Fork Watershed. In general, the mine layout consists of gates that are 260 to 270 feet wide and intervening panels of mined coal that are 900 to 1,000 feet across and approximately 8,500 feet long. The panels of extracted coal are oriented nearly perpendicular to the stream channel beneath the mined study area. In the vicinity of the mined study segment, coal removal by longwall techniques was conducted during 1995 and 1996. The height of the coal removed was between 5 and 7.5 feet. The depth to the Pittsburgh Coal varies throughout the overall study area, but is typically 530 to 545 feet below the Robinson Fork Channel Bottom.

Within both study areas, rocks of the Permian Age Washington Formation outcrop along the base of the valley occupied by Robinson Fork. Outcrops within the study areas consist of fine-grained sandstone, siltstone, and shale. The overlying Greene Formation comprises the uppermost stratigraphic bedrock unit within the study areas. Bank and channel bedrock outcrops are more prominent within the mined study segment and, where present, substantially enhance bank stability. The valley floor is comprised mainly of Quaternary Age alluvial deposits.

Lineament analysis of remote sensing imagery suggests the presence of natural bedrock fractures within and in the vicinity of the mined and unmined study segments. Locally, the orientation of valleys and streams mimic the measured joint sets within the bedrock. In addition to the lineament analysis, a very low frequency (VLF) (electromagnetic methods) survey was conducted. The location of two strong VLF signatures within the unmined study segment coincides with the intersection of a tributary/gully with the main channel of Robinson Fork. Several points along the mined section exhibited strong positive VLF signatures, two of which coincided with the intersection of a tributary/gully with the main channel of Robinson Fork. Three other positive signatures within the mined segment were identified as possible fractures, although these signatures did not correspond to any identifiable surface features. The location of the three VLF signatures, however, coincides with the boundary between a longwall panel and an adjacent gate where differential bedrock settlement and increased fractures would be expected. No premining data exist, however, to confirm whether these possible fractures are related to mining operations.

Both study segments were classified as single channel and meandering although meander geometry between the mined and unmined segments differed. Specifically, the degree of sinuosity is greater within the unmined segment. Values for wavelength, amplitude, belt width, and radius of curvature reflect the decreased sinuosity exhibited within the mined study segment. Differences in meander geometry can probably be attributed to the indigenous stream pattern because other segments of the channel exist within the unmined area that exhibit the lower degree of sinuosity observed within the mined study segment.

Overall, the number of bedforms (i.e., riffles, runs, glides, and pools) within the mined segment were significantly reduced and exhibited greater longitudinal length, depth, and bankfull width in comparison to those in the unmined segment. Also, bedforms within the mined area had greater surface area and volume than units in the unmined segment. The mean stream depth, average maximum stream depth, and average maximum water depth were also greater in the mined segment. In addition, average maximum water depths indicate that pools in the mined segment were deeper by a factor of 1.8. Because of differences in longitudinal position within the Robinson Fork Watershed, it can be expected that the bedforms in the mined segment should be fewer and have different physical dimensions than those in the unmined portion due to increased sediment load and surface water discharge. The substantial variation in the number and dimensions of bedforms between the two study segments is considered a fundamental difference in this study. Although there is no premining data regarding bedform identification and dimensions, it is unlikely that the significant decrease in the number of bedform units and their greater physical dimensions in the mined segment would be associated only with increases in discharge and/or other watershed factors. This effect, therefore, may be the result of subsidence due to longwall mining, although this conclusion cannot be verified based on the limited availability of historical information.

The bedform data reflect an increase in the surface area of pools and riffles and the loss of run/glide area in the mined study segment. In other words, the bedform units associated with moderate flow have been transformed into units representing the low and high endpoint flow regimes. Riffle dimensions appear to have increased on the downstream side of deep mine gates, and pool dimensions appear to be greater on the upstream side of gates. This may be related to the swale pattern often manifested at the ground surface due to subsidence over mined panels versus bedrock support over gates. An unusual area of bank erosion that is possibly related to subsidence is evident along Pool MSP5. This erosional feature may have resulted from a subsidence-induced increase in channel gradient along Riffle MSR7.

In relation to the previous discussion, a primary difference between the geomorphologic and the biologic study results included a variation in the number and types of mapped geomorphic bedforms as compared to the channel units identified for the biological assessment work. The variation is primarily due to the data collection objectives and the differing methodologies used (geomorphologic evaluation according to Rosgen (1996) versus the biological channel unit assessment (Peterson and Rabeni, 2001). Regarding these methods, bedforms and channel units both consist of riffles, runs, glides, pools, etc. that are defined by water depth, velocity, and turbulence. Channel units, however, also consider biological and statistical components at the subreach level and are defined at a finer scale. The number of bedforms mapped also differed from the amount of channel units identified due to the differing lengths of channel surveyed for the geomorphologic/hydrologic and biologic assessment phases. Although the stream segments surveyed within the mined and unmined study areas generally coincided, actual surveyed lengths varied due to the methods used. Additionally, bedforms could not have been correlated with channel units because of a large-magnitude precipitation event that occurred between the period of biologic and geomorphologic work. As a consequence of the precipitation event, some channel units were modified or transformed. Although differing in methodology, the geomorphologic/hydrologic and biologic phases of this study yielded the same fundamental conclusion regarding bedforms and channel units.

Flood prone areas were determined using data from surveyed transects. Areas adjacent to the mined and unmined study segments that are susceptible to flooding are similar and exhibit well-defined and extensive floodplains adjacent to banks opposite the hill slope. These data indicate that both study segments possess comparable overbank flow and floodplain depositional characteristics during periods of elevated stage.

Regarding stream bank stability, areas that are potentially vulnerable to accelerated erosion have been identified in both the mined and unmined study segments. Areas of bank instability appear to be related to natural factors or prevailing conditions in the watershed that consist of steep hydrographs after precipitation events (rapid runoff due to topography) and land use including crop and grazing lands and maintenance mowing which often result in enhanced erosion during large magnitude precipitation events. Both the mined and unmined segments exhibit problemed areas of bank instability, although banks within the mined segment are only slightly more stable in comparison to the unmined segment due to increased bank outcrops of bedrock, which greatly enhance bank stability, and decreased sinuosity. Aside from bank instability attributable to agriculture or mowing, the anomalous planimetric morphology of Pool MSP5 within the mined segment may be the result of a subsidence-related gradient increase beyond the downstream edge of a deep mine gate. Field observations indicate that within the mined and unmined segments, bank erosion and failure are resulting in the accumulation of fine sediment on channel substrate and in suspended clay turbidity following precipitation events.

Areas of aggradation within the mined and unmined segments are similar and primarily reflect point bar type deposition with lesser amounts of channel and flanking bar deposition. Aside from the accumulation of fine sediment on the channel substrate, the observed depositional processes operating within both study segments appear to reflect normal stream dynamics. Based on the lengths of channel studied, the proportional area of bank degradation within the mined and unmined segments is of the same order of magnitude, although degradational processes are marginally more active in the unmined segment. Degradation (undercutting, slumping, and back channel development) is primarily occurring along meander cut banks and other sections with relatively low bank stability. Within the mined segment, evidence suggests the incorporation of the eastern stream bank into the channel adjacent to Pool MSP1 due to channel widening. This degradational feature is possibly due to surface subsidence.

Data obtained from surveyed channel transects indicate that lateral channel bottom morphology for the two study segments is similar and exhibits a well-defined concave shape for pools with a more subtle concave to flat to slightly convex shape for riffles and runs. The morphology of the longitudinal channel profile reveals that the overall water surface slope for the mined segment was approximately 1.2 times greater than the water surface slope within the unmined segment. Additionally, the overall channel bottom gradient was nearly 1.7 times greater within the mined segment. These differences are not significant, however, considering that the water surface and channel bottom slopes within both study segments were extremely low (near or less than 0.5 percent). Available data suggest that greater slopes are characteristic between gates and that lower gradients are associated with areas overlying gates.

Mean stream depth values were moderately greater in the mined study segment and maximum stream depths were slightly higher in this segment. Insufficient data exist to definitively ascertain whether this may be associated with a normal downstream increase in channel dimensions rather than subsidence effects. The average maximum water depth within the mined segment was greater than the unmined segment. Average maximum water depth values for riffles and runs/glides were similar between both study segments, whereas pools exhibited the largest disparity (approximately 1.8 times deeper for the mined segment). Again, this may reflect typical downstream increases in channel dimensions rather than the effects of subsidence.

The average thickness of pool sediments was approximately 1.3 times greater within the mined study segment. Insufficient data exist to determine whether this increase is a result of longwall subsidence or increased sediment load due to longitudinal position. Because of the unsubstantial difference, however, it is likely that the variation is due to longitudinal position. Within riffles and runs/glides, the average thickness of channel sediments was slightly greater within the unmined segment.

According to pebble count results, the cumulative D_{50} particle size for the mined and unmined study segments is comparable, although slightly greater within the mined segment. For both segments, the overall D_{50} particle size is classified as medium gravel. With respect to individual bedform units within the mined and unmined segments, the D_{50} particle size for riffle sections is comparable (very coarse gravel), nearly equivalent for run/glide sections (medium gravel), and for pools, was slightly less in the mined section (very coarse sand) versus very fine gravel for the unmined segment. Stream power estimates indicate that the energy available for transporting sediments is greater in the mined segment and correlate with the finding that the overall D_{50} particle size for the mined segment was slightly larger than that within the unmined segment.

Entrenchment ratios for the mined and unmined study segments were of the same order of magnitude and indicate that the stream channel is slightly entrenched. Except for an elevated value of width/depth ratio obtained along Transect F-F' within the mined study segment, the ratios were comparable between the two study segments. The increase in width/depth ratio for Transect F-F' may be solely related to the specific area chosen to complete this section. Specifically, stream bank erosional and depositional processes appear to be exceptionally dynamic in this area. The width/depth ratio along Transect F-F', however, is well within the expected range of values for the Type C stream as specified by Rosgen. In general, increased width/depth ratios correspond to decreased channel stability. Values of width/depth ratio derived for both study segments correlate with the lowest expected values for this stream type as defined by Rosgen.

Mean surface water velocity within the mined segment was lower in comparison to the unmined segment. Lower surface water velocity within the mined segment may be attributed to the greater bankfull widths and depths associated with this segment. Typically, surface water discharge increases in the downstream direction due to additional contributions from tributaries and/or groundwater base flow (i.e., more watershed drainage area). As expected, surface water discharge calculations indicate that a greater volume of water exits the downstream mined segment. Both the mined and unmined segments contain sections of losing and gaining channel. Within the mined segment, there is a losing section that appears to correlate with the location of a longwall mining panel and an increase in the amount of bedrock fractures. Gains in surface water discharge seem to coincide with a segment overlying a deep mine gate. Data obtained from this study, however, are not sufficient to definitively conclude a relationship between gaining and losing sections of channel and effects from longwall mining. Within the unmined study segment, losing and gaining segments are likely related to the magnitude of bedrock fractures and their degree of communication with the stream channel.

Surface water analytical results for the monitoring points sampled during this study (SW-1 through SW-4) indicate that concentrations are within the range of historical background values previously reported by Consol. A comparison of surface water quality between the two study segments, however, reveals some differences. Specifically, levels for pH, metals, hardness, total suspended solids, nitrate, nitrite, total phosphate, and turbidity were slightly higher and fecal coliform was substantially greater in the unmined segment. Elevated levels of nutrients and other constituents within the unmined segment are likely related to increased agricultural activities upstream of this segment. Within the mined segment, reported values for total dissolved solids, alkalinity, and specific conductance were greater. The increase in alkalinity and total dissolved solids (and corresponding increase in specific conductance) for the mined segment is possibly related to greater channel input from sources along the approximate 2.4 miles that separate the two study segments. Sulfate levels generally increased downstream from Monitoring Points SW-2 through SW-4.

According to the Level II Stream Classification developed by Rosgen, both the mined and unmined study segments are categorized as a Type-C4 stream. There is no evidence that either segment of channel is undergoing processes that would result in a classification change.

The biological assessments (fish, benthic macroinvertebrates, riparian vegetation, and wetlands) in this report present the methods used to evaluate postmining values and functions of Robinson Fork and associated wetlands and riparian areas. A channel classification system was used that featured channel units (CU) (in-stream habitats consisting of riffles, races, runs, and pools) that provided an aquatic habitat classification that grouped the physical features of both study reaches of Robinson Fork (mined and unmined) by common factors (ranges of depth and velocity) and substrate type that influence biological processes and aquatic biota (benthic macroinvertebrates and fish).

The use of this habitat classification system based on CUs was developed in Ozarkian streams (Peterson and Rabeni, 2001; McKenney, 1997) and was shown to be applicable on streams in southwestern Pennsylvania.

The hypothesis is that, if the physical characteristics of CUs (number, dimensions, and distribution) are modified following subsidence, then there may also be associated effects on aquatic biota.

Comparisons of the composition of CUs within the mined and unmined reaches required fish and benthic macroinvertebrate sampling. The defined CUs in both study reaches were sampled for fish by electrofishing (725 meters in length in the unmined reach and 687 meters in length in the mined reach). These lengths were determined to be the minimum required to obtain an adequate number of CUs in each study reach for comparison. An additional five stations (60 meters to 180 meters in length) from other locations on Robinson Fork were also sampled for fish to better characterize the fish assemblage in the watershed. Fish were weighed in the study reaches only (biomass).

Benthic macroinvertebrate sampling was conducted in three representative pool CUs and three representative riffle CUs in each study reach. This resulted in a total of 30 samples (D-frame net) in each of the study reaches. Collected benthic macroinvertebrates were identified and enumerated, and established metrics to assess the condition of the benthic macroinvertebrate assemblages in each study reach were applied to the data and compared.

The evaluation of riparian vegetation (10 meters in width along each bank) consisted of a botanical survey along each study reach where existing tree, shrub, and herbaceous species were identified and listed. Exotic and naturalized plant species on the botanical survey list were highlighted in each reach.

A more detailed evaluation of the riparian vegetation consisted of the establishment of 11 transects equally spaced along each study reach. The transects extended perpendicular to both banks, creating a total of 22 sample plots (5 meters by 10 meters) in each study reach of Robinson Fork. Vegetation analysis consisted of the identification of prevalent species in each plot (>20 percent coverage) resulting in a list of the prevalent species (trees, shrubs, and herbaceous) in each reach along with their frequency of occurrence in sample plots.

The land use type (agriculture, floodplain herbaceous, floodplain forest, floodplain sloped forest) was also tabulated (areal coverage) for each sample plot and reported as total percentage of land use type for each study reach.

The evaluation of wetland resources in each study reach consisted of inspection of National Wetland Inventory (NWI) mapping and delineation of any wetland areas identified on the mined reach using the three-parameter approach (soils, vegetation, and hydrology). Color aerial photography of a delinated wetland

(Molinari Wetland) in the mined study reach was obtained for years that included premining and postmining of the area and were interpreted.

CUs were identified in the field within each study reach and tested for accuracy using statistical analysis and calculation of the Froude (Fr) number (cross-sectional data). The CU classification determined that the unmined reach contained 36 CUs (12 riffles, 11 races, 10 pools, and 3 glides) while the unmined reach contained 17 CUs (7 riffles, 4 races, 5 pools, and 1 glide). In general, the unmined reach contained twice as many CUs as the mined reach containing, therefore, greater aquatic habitat heterogeneity. The average CU in the mined reach was roughly twice as long as those in the unmined reach, was 1.4 times wider, had 3.4 times greater surface area, and 6.3 times more volume. The identification of CUs for the biological (habitat) assessment revealed similar results as the geomorphic bedform evaluation previously discussed.

The fish sampling effort revealed that 30 species of fish inhabit the Robinson Fork Watershed. This assemblage is diverse compared to similar-sized streams in Greene and Washington counties. A comparison of the fish assemblage reported in this study compared to historical studies revealed that the fish community (common and abundant species) has not significantly changed in recent years. The historical fish surveys completed in Robinson Fork (1976) were conducted at least 17 years before longwall mining was initiated in the watershed (1993).

The mined study reach contained 19 fish species and the unmined reach contained 14 fish species. The white sucker and creek chub (both tolerant-habitat generalists) dominated community composition in both reaches (total biomass).

The benthic macroinvertebrate assemblages in the mined and unmined pool CUs in Robinson Fork are characteristic of an eutrophic, low-order, warm water stream in this region where species diversity is low and the number of individuals of each taxa present is reduced. The riffle CUs in both study reaches have similar benthic macroinvertebrate diversity (39 taxa in the mined reach and 33 taxa in unmined reach). The examination of other metrics for benthic macroinvertebrates indicates moderate impairment in both reaches (dominance by tolerant midge fly larva and somewhat tolerant caddisflies, mayflies, and aquatic beetles). These findings are similar to those for the fish community and indicate that Robinson Fork is impaired and supports an aquatic biota that is suboptimal. This impairment is observable in both the unmined and mined study reaches. Recent benthic macroinvertebrate sampling by the DEP below dam and reservoir PA-647 indicates that the stream is impaired (Unassessed Waters), but fish sampling, as part of that study, indicate that it is not impaired (high diversity with several intolerant species).

The observed plant species checklist (trees, shrubs, and herbaceous) resulted in a similar riparian plant community in both reaches with most listed plant species occurring in both the mined and unmined reaches. The mined reach contained 234 total plant species and the unmined reach contained 246 total plant species. The unmined reach contained 42 exotic or naturalized plant species (17 percent of total plant species observed), and the mined reach contained 61 exotic or naturalized species (25 percent of total plant species observed).

Land use types consisted of agriculture (frequently mowed areas), floodplain herbaceous, floodplain forested, and floodplain forested slope. These land use types represented cover types that ranged from frequently disturbed (agriculture) to moderately disturbed (floodplain herbaceous) to rarely disturbed (floodplain forested and forested slope). The types of land use had similar areal coverage along both study reaches, although agricultural land use was higher in the unmined reach, and floodplain forested slope was higher in the mined reach. All of the land use types in the watershed and in both study reaches represent characteristic land uses in rural areas in the region where the disturbance regime is high ranging from plowed areas for row crops and abused pastures to rapid runoff from forested slope areas where heavy deer-browsing has reduced the ground layer and understory.

There was no discernable difference in the riparian plant communities that could be attributed to subsidence. No trees along the mined reach showed reduced vigor, other than several trees that were situated on bank areas that were being undercut by elevated discharges in the stream.

The wetland investigation on the floodplain in the mined reach did not indicate that any wetland areas existed that exhibited reduced wetland hydrology that would occur from a loss of the hydrologic regimen that would reduce the size and functional values of the wetland. There was no indication that jurisdictional wetland area was lost because of dewatering resulting from undermining. One wetland area within the mined study segment, however, exhibits evidence of enhancement as discussed in the proceeding paragraph.

The Molinari Wetland, 0.73 acre in size, was identified and delineated as a jurisdictional wetland on the floodplain of Robinson Fork in the mined reach. The wetland is situated in a field that was recently farmed (pasture) and is now reverting to old field habitat. An examination of premining and postmining aerial photography along with a thorough investigation of soils and hydrology (water table) in the field indicates that a small wet area may have been present in the center of the existing wetland before mining (seasonal seepage from adjacent slope). Subsidence in this area appears to have increased the size of this wetland area (enhancement).

The wetland contains many prevalent hydrophytic plant species that are indicative of an early succession stage (broad-leaf cattail, sweetflag, marsh seedbox, and creeping jennie) in the region where recent hydrological alterations have occurred. The probable enhancement of the Molinari Wetland presents a situation where several natural and anthropogenic influences are operating. A natural seep area in the field created a wet spot that was located in the center of a mined panel. This mined panel is at the intersection of three natural bedrock fractures (lineaments) – see Sheet 20. This circumstance most likely resulted in the large depressional area within an area of anticipated maximum subsidence which caused the enhancement observed in the Molinari Wetland.

Study results indicate that most indices evaluated for the geomorphologic/hydrologic and biologic phases exhibited little (within reasonable tolerance limits) or no variation between the mined and unmined study segments. There were some fundamental physical and biological differences between the two study segments, however, that include the following:

- There is a substantial difference between the mined and unmined study segments regarding the number and dimensions of bedforms mapped for the geomorphologic work as well as the channel units identified for the biologic assessment. This variation may be attributable to subsidence related to longwall mining, although the limited premining database precludes verification.

- Due to possible subsidence-related channel widening, the east bank of Pool MSP1 within the mined segment may be undergoing incorporation into the channel. Also within the mined segment, a possible subsidence-induced gradient increase along Riffle MSR7 may be causing atypical bank erosion within Pool MSP5.

- Although the mined and unmined study segments contained losing and gaining sections, the losing section of channel within the mined segment may be associated with its location above a panel where bedrock fractures due to subsidence should be most prominent. Although there are bedrock fractures identified by VLF that do not correspond with the local fracture pattern in the mined segment, and may be subsidence related, this condition cannot be directly confirmed.

- Fish biomass per unit volume in pool channel units was greater in the unmined reach indicating lower productivity in mined reach pools. The reduced production of fish in the mined pools could be attributed to the greater percentage of pool surface area in the mined segment and associated reduction in run/glide channel units. It cannot be definitively concluded, however, that this condition is related to subsidence.

- Results of benthic macroinvertebrate sampling indicate moderate impairment in both study segments. These findings are similar to those for the fish community and indicate that Robinson Fork is impaired and supports an aquatic community that is suboptimal. It cannot be definitively concluded, however, that this condition is related to subsidence.

- While the occurrence of subsided reaches in Robinson Fork has created a significant change in aquatic habitat types (channel units), the structure of the fish and benthic macroinvertebrate assemblages in the stream determined during this study are influenced by many factors, and the direct effect of subsidence cannot be separated from these other factors. Of these factors, the primary influence is probably related to agricultural operations with possible contributions from unpaved roads, mowed/maintained areas, and other domestic activities.

- Circumstantial evidence (no premining wetland studies) indicates that a wet spot in a field on the floodplain in the mined reach (center of panel) has been enhanced (increase in size and change in hydrology regimen) because of subsidence. The wetland is saturated at the surface or has shallow inundation for the majority of the growing season. Permanently saturated wetlands are rare in the Robinson Fork Watershed (usually beaver induced) with most wetland areas having temporary or seasonal wetland hydrology.

This report should only be used as a standard for the comparison of streams that possess characteristics similar to the segments studied along Robinson Fork because of the limited scope and duration allocated for this project, due to the numerous variables that govern subsidence mechanics and stream characteristics, and considering the myriad of effects that combinations of these variables may have on a stream. Controlling variables include, but are not limited to, geologic and hydrogeologic characteristics, channel and valley gradient, overburden thickness, thickness of coal extracted, stream order, and land use.

In order to derive a comprehensive set of comparative standards, additional studies that are broader in scope and duration need to be developed and implemented along streams of differing characteristic. For such studies, thoughtful technical planning in the developmental stage is necessary to eliminate the generation of technically, spatially, and temporally limited data.

Although this study has identified variation between the mined and unmined segments, the statistically limited database cannot be used with absolute certainty to conclude whether these changes are attributed solely to subsidence and/or are related to anthropogenic disturbances. These disturbances include increased erosion and/or runoff from crop and pasturelands, mowed areas, roads, and domestic activities. Therefore, approaches for mitigation and monitoring are not currently recommended.

To supplement the current database and compensate for the lack of crucial premining data, additional studies are recommended along the unmined segment of Robinson Fork as a preface to broader studies conducted in other watersheds with dissimilar characteristics. The unmined segment will provide an ideal “before and after” evaluation of the potential effects of longwall mining since detailed premining data has already been provided from this study. With a few exceptions, the recommended study would duplicate the work conducted within the unmined segment as detailed in this report. The recommended study could be conducted in conjunction with broader studies in dissimilar watersheds for more expeditious data gathering.

Following the recommended additional study, approaches for monitoring and mitigation could then be developed if appropriate. Also, reliable information with respect to expected impacts within similar subsided areas and the types of critical premining data that may need to be collected for postmining comparisons could be generated.