Table of Contents

Page

9.0 Conclusions

The purpose of this study was to document the geomorphologic and hydrologic changes that result from mine subsidence and to quantify the effects on aquatic life and on the values and functions of the stream's wetland and riparian areas. In order to facilitate this assessment, Robinson Fork was selected as the stream for study. The Site Selection Report demonstrated fulfillment of all study criteria as specified in the project Contract. The June 20, 2001 letter from the BMR validated that the Department agreed with the justification for selecting Robinson Fork provided in that report. In order to meet the study objectives under the BMR contract, Earth Sciences evaluated geomorphologic conditions and stream habitats. Two areas for study were established along Robinson Fork, one within the mined area and another in an unmined area as previously described. Because of the limited premining data, the assessment of subsidence effects on the stream required a direct comparison of data between the mined and unmined stream segments. The study was divided into two components including: 1) geomorphologic and hydrologic changes; and 2) effects of those changes on riparian and wetland areas and on aquatic communities.

Although by definition, fluvial geomorphology and floral/faunal biology represent distinct disciplines, in a natural ecosystem such as the stream assessed for this study, these two fields of natural science are strongly interdependent. Although mutually dependant, the conclusions derived from an evaluation of the data provided from the geomorphologic/hydrologic and biologic phases of this study have been presented in separate sections. Essential conclusions reached from the two phases are then summarized jointly. This type of presentation allows the reader to focus on the findings for these separate yet interrelated phases of the study as a preface to the integrated summary conclusions.

As a prologue to the specific project conclusions, it is important to reiterate the point that a primary difference between the geomorphologic/hydrologic 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. This variation is primarily due to the data 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 as discussed further in Section 9.3.

9.1 Geomorphologic and Hydrologic Evaluation

Within the Robinson Fork Watershed, the main channel and associated tributaries have likely been impacted by increased erosion and/or runoff from adjacent crop and pastureland, mowed areas, roads, and domestic activities. 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 slopes. Based on field observations, these areas are mainly comprised of croplands with secondary pasturelands (idle fields and livestock grazing). Within the unmined study segment, the Robinson Fork stream valley is largely forested with minor cropland and mowed areas. Aside from one maintained area within the mined study segment, the stream flows through an area of forest and unforested floodplain.

A substantial portion of the Robinson Fork Watershed is underlain by Consol's Enlow Fork Mine. In general, the mine layout consists of gates that are 260 to 270 feet wide and intervening panels of coal that are 900 to 1,000 feet across and approximately 8,500 feet long. The panels of 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 methods was conducted during 1995 and 1996. The height of 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 stream valley containing Robinson Fork is comprised of Quaternary 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. Several points along the mined section exhibited strong positive VLF signatures. The location of two of the strongest signatures coincided with the intersection of a tributary/gully with the main channel of Robinson Fork. These same areas were identified during the lineament evaluation performed as part of this study. 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. These signatures, therefore, may be a result of the brittle and ductile fracture of bedrock units due to differential settlement (cantilever failure) between the panel and gate, although no premining data exist to confirm this. The location of two strong VLF signatures within the unmined study segment coincide with the intersection of a tributary/gully with the main channel of Robinson Fork.

Both study segments were classified as single channel and meandering although meander geometry between the mined and unmined study segments differed. Specifically, the degree of sinuosity is greater within the unmined segment. Values for wavelength, amplitude, belt width, and radius of curvature determined from meander geometry measurements reflect the decreased sinuosity exhibited within the mined study segment. Although some measured values are comparable between the two segments, maximum values are substantially greater within the mined segment (i.e., larger and fewer meanders). 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 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, bedform units within the mined area had greater surface area and volume than units in the unmined segment. Specifically, a total of 14 bedform units were mapped within the mined study segment. These units included 4 runs, 5 riffles, 1 glide, and 4 pools. In contrast, 46 bedform units were mapped for the unmined segment that included 15 runs, 11 riffles, 4 glides, and 16 pools. Therefore, over three times the amount of bedforms existed in the unmined segment. According to bankfull surface area for specific bedforms within the mined area, pools constituted approximately 36.9 percent, riffles 34.3 percent, and runs/glides 28.8 percent. Based on bankfull surface area for the unmined segment, runs/glides comprised approximately 54.8 percent, pools 29.9 percent, and riffles 15.3 percent. The average bedform length in the mined segment is over two times that of the unmined segment and the average bankfull channel width for the mined segment is over 12 feet greater. 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 have different physical dimensions than those in the unmined portion due to increased sediment load and surface water discharge. Although fewer bedforms and proportionally larger dimensions can be expected downstream of the unmined segment, the substantial variation 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 would be associated only with increases in discharge and/or other watershed factors.

The bedform data reflect an increase in the surface area of pools and riffles (especially riffles) and the loss of run/glide segment area in the mined study area. In other words, the bedform units associated with moderate flow have been transformed into units representing the low or high endpoint flow regimes. According to the mine layout and plan view of the mined channel segment, riffle dimensions may have increased on the downstream side of deep mine gates and pool dimensions have possibly been enhanced on the upstream side of these deep mine structures. 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.

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. Bank materials within both study segments consist of unconsolidated alluvial and colluvial deposits with some bedrock outcroppings. Also, the average bank height and bank slope are slightly greater within the unmined segment. This characteristic can probably be attributed to the increase in cut bank type erosional features (undercutting and resultant slumping) associated with the increased sinuosity of the unmined segment. 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 deposition 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 exists 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 sediment 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 C4-type streams. There is no evidence that either segment of channel is undergoing processes that would result in a classification change.

9.2 Assessment of In-Stream Macroinvertebrate and Fish, Wetlands, and Riparian Vegetation

The quantity and physical dimensions of channel units (riffles, races, glides, and pools) in the mined reach differed from those in the unmined reach. There were 17 channel units in the mined reach and 36 channel units in the unmined reach. Generally, channel units in the mined reach were longer, deeper, and wider than those in the unmined reach and had greater surface area and volume. Race CUs have contracted in the mined reach and pool CUs have expanded, the latter finding concurring with the results of Sidle et. al. (2000) on Burnout Creek, Utah. Additionally, two anomalous channel forms (depositional areas in pools) were observed within mined reach channel units with both being located in close proximity to gates. The identification of CUs for the biological (habitat) assessment revealed similar results as the geomorphic bedform evaluation previously discussed.

Pools CUs differed the greatest between the mined and unmined areas. More than 78 percent of the volume of the mined reach is contained within pool channel units, whereas 46 percent was found for unmined pools. Fish biomass per unit volume from all channel units combined in the mined and unmined reaches was not significantly different; however, biomass per unit volume in pool channel units was greater in the unmined reach indicating lower productivity in mined reach pools. The greater percentage of pool CUs in the mined area, and the associated reduction in the number of race CUs could account for the reduced production (biomass) of fish in the mined pools. Fish in pools rely on drift by benthic macroinvertebrates from riffle and race CUs into pool CUs as a major food source, and the reduction of these areas in the mined segment may be a major factor in limiting pool production. This contention is not supported empirically in this study.

Bank stability ratings show that bank erosion/failure are marginally different in the unmined reach (more severe) but are consistent with differences in longitudinal position (less occurrence of bedrock and greater sinuosity in unmined reach). Banks in both areas were often severely eroded and showed evidence of sloughing. This instability contributes to the chronic clay turbidity observed in Robinson Fork that is problematic and most likely exacerbated by sediment from agricultural sources and dirt and gravel roads.

The cumulative impact of various environmental stressors has produced a fish community in Robinson Fork that is composed primarily of tolerant habitat generalists (white sucker, creek chub, and blacknose dace). The reduced abundance (black redhorse, golden redhorse, northern hog sucker, central stoneroller, and rock bass) and absence (rosyface shiner, stonecat, and smallmouth bass) of species in study reaches above the reservoir (PA-647 dam) may be primarily influenced by the frequency and magnitude of overall hydrologic disturbances in Robinson Fork and its isolation from Enlow Fork. Total fish species richness in the mined reach (19) exceeded species richness in the unmined reach (14), and average fish species richness in the channel units (combined) in the mined reach was marginally greater than the unmined reach (9.83 and 7.79 respectively). 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 assemblage in this stream determined during this study is influenced by many factors, and the direct effect of subsidence cannot be separated from these other factors.

The benthic macroinvertebrate assemblages in the mined and unmined pool CUs in Robinson Fork are characteristic of a 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, indicates that it is not impaired (high diversity with several intolerant species).

The evaluation of riparian vegetation and habitat consisted of a botanical survey of the riparian area (10 m width) along each bank of Robinson Fork in both study reaches. 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 number of exotic or naturalized species were tallied for each reach from the plant lists generated from the botanical survey. Exotic or naturalized species are generally more aggressive than most native species and often invade and proliferate on sites where chronic disturbances occur and can invade sites where an acute disturbance, that can occur with subsidence, has occurred. 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).

The general botanical survey was supplemented by a more detailed analysis of the riparian plant community by establishing sampling plots (5 m x 10 m) at transects along each side of the stream in both study reaches (22 sample plots in each reach). The plot samples determined prevalent plant species (trees, shrubs, and herbaceous) in each plot (>20 percent coverage) along with the total coverage (percentage) in each plot for each layer (canopy, understory, ground cover).

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.

The riparian vegetation communities in both study reaches were very similar and riparian cover reflected the land use type with increased exotic or naturalized species on agricultural areas (frequently disturbed) and more stable, native communities on rarely disturbed areas (floodplain forested, and forested slope). Heavy deer-browsing in both study reaches was influencing the riparian community by reducing plant diversity (reduced tree regeneration, sparse understory dominated by unpalatable shrubs, and reduced ground cover).

There was no discernible 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 Molinari Wetland contains a diverse wetland plant community and appears to be saturated or inundated by a few inches of water for the majority of the growing season. The wetland is larger and more diverse (has moderate to high functional values) than most of the wetland areas (seasonal or temporary hydrology) in the Robinson Fork watershed, other than those areas that are beaver influenced.

The field where the Molinari Wetland is located is in the center of a mined panel (mined in 1996), and elevations in the upland portion of the field compared to the wetland indicate a depression at 6 feet below the upland elevation. This depressional area is most likely the result of subsidence because the expected settlement in this area (based on depth of cover and coal seam thickness) is expected to be about 6 feet. This would explain the saturated condition where the existing water table is at the surface and Robinson Fork frequently inundates the wetland during higher flows.

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.

It would not be prudent to assume that all streams and their riparian areas in Southwestern Pennsylvania respond to subsidence in exactly the same manner as that observed in Robinson Fork. Differences in land use, valley shape, stream gradient and type, stream order (size), overburden characteristics, and other factors combine to produce the physical characteristics and associated biological communities found in streams in Greene and Washington counties. Because of the limited spatial and temporal scope of this investigation, further studies with a more powerful statistical experimental design are recommended. This would facilitate extrapolation of findings to similar aquatic systems in the region.

9.3 Summary

This section summarizes the fundamental differences between the mined and unmined study segments that were determined from this study. 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 notable physical and biological differences between the two study segments, however, that are described in the following paragraphs.

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. Generally, the bedforms/channel units in the mined segment were longer, deeper, and wider than those in the unmined segment and had greater surface area and volume. Although the number and proportional dimensions of bedforms/channel units typically increase downstream due to increased sediment load and surface water discharge, the substantial variation is considered a fundamental difference in this study. It is doubtful that the significant decrease in the number of bedforms/channel units and their greater physical dimensions in the mined segment would be associated only with increases in discharge and/or other watershed factors. Consequently, data suggest that riffle and pool dimensions within the mined segment have increased and runs/glides have diminished possibly due to surface swales resulting from differential subsidence above deep mine panels and gates. It is important to note that although there were differences in the number of bedform units mapped for the geomorphologic work in comparison to the amount of channel units identified for the biologic assessment due to differing methods, the same general conclusions were drawn regarding the disparity in bedforms/channel units.

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. This condition cannot be directly confirmed. However, 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.

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 and 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.

As previously mentioned, this study has provided important and intuitive information regarding the application of current methods for conducting such studies and a substantial database that can be used as a comparative standard for streams with characteristics and deep mine conditions comparable to Robinson Fork. Broad conclusions extracted from this study that are related to project scope and applicability and that should be considered for possible future projects include the following: 1) due to the numerous variables and combinations of these variables that govern subsidence mechanics and stream characteristics, the limited scope of this study precludes its use as a comparative standard to all streams currently or potentially underlain by longwall panels; 2) the period of time for conducting this study, as determined by the contract work scope, was too short in duration to allow observation and evaluation of seasonal characteristics and long-term effects; 3) the limited length of channel to be studied as specified in the contract work scope, even though increased by two to three times in the actual study, provided statistically restricted data for only a small percentage of the mined and unmined portions of the Robinson Fork Watershed; and 4) premining geomorphologic/hydrologic and biologic data specific to the requested methods applied for this study and crucial for "before and after" comparisons, was limited for Robinson Fork, and was limited for most of the other candidate streams initially considered for this study. In addition to the previous items, investigative activities such as obtaining and comparing data from other watersheds for evaluating potential impacts in areas with varying overburden, land use, and geologic characteristics, and the quantitative analysis of predicted and actual subsidence mechanics as related to effects expected for shallow and deep cover scenarios, are necessary for a comprehensive understanding of the relationship between longwall mining and potential stream impacts. These items are discussed further in the recommendations provided in Chapter 10.0.