STREAM RECONSTRUCTION UNDER SMCRA BURNING STAR #4: A CASE STUDY[1]

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Abstract. Reconstruction of approximately eight miles of stream habitats at the Consolidation Coal Burning Star #4 Mine in Perry County, Illinois was reviewed. Important hydrologic and biologic functions were successfully restored following surface mining for coal through two large streams by reconstruction of the stream systems. Riparian and wetland habitats exceeded that which existed before mining. Stream water sulfate concentration was identified as the biggest difference between the pre-mining and post-mining stream environments with a tenfold increase as a result of mining. Data from these reconstructed streams and from other nearby reclaimed mine sites suggest that elevated sulfates may have little effect on tolerant macroinvertebrate communities but may be detrimental to sensitive macro-invertebrates and may persist for several decades.

Additional key words: coal, mining, invertebrates, fish, riparian, sulfate

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Introduction

Consolidation Coal Company surface mined the North Field of their Burning Star #4 Mine, located in Perry County, Illinois from 1982 to 1998. The mined area was approximately 3800 acres (1537 hectares) with an average pit length of 2.5 miles (4.0 kilometers) and pit advancement of 2.6 miles (4.2 kilometers). Over 30 million tons of coal was removed. Two major streams, Galum Creek with a watershed of approximately 22 square miles (57 square kilometers) of mostly un-mined land and Bonnie Creek with a watershed of approximately 14 square miles (36 square kilometers) of un-mined land flow onto and through the mine site (Fig.1).

Figure 1. Burning Star #4 Mine, North Field after reclamation. A – Boxcut Spoil, B – Final Cut Lake, C – Adjacent East Cutler Pit Wetlands

All but a very minor portion of this project occurred after the State of Illinois was granted SMCRA (Surface Mining Control and Reclamation Act of 1977) primacy in February 1983. The operations and reclamation plans therefore were processed under the newly established SMCRA permanent program regulations. The purpose of those new regulations was to provide comprehensive Federal and State environmental controls over coal mining in order to "strike a balance" between protection of the environment and the nation's need for coal as an essential source of energy (U.S. Congress 1977, Section 102[f]). With over 30 years of SMCRA implementation and renewed interest in mining impacts to streams, it is important and timely to review stream restoration projects to determine if that balance is being struck.

The mining and reclamation plan involved significant temporary diversions of both Galum and Bonnie Creeks during mining and comprehensive reconstruction of the streams during reclamation. Proposed designs were reviewed by several State and Federal agencies before a final design was approved. Designs included hydraulic and stability factors such as channel capacities, flood storage, and energy dissipation. Biological factors were also addressed including replacement of floodplain habitat, wildlife corridors, wetlands, and in-stream microhabitats such as riffles and pools.

Plan approval was conditioned upon collection of seasonal stream data including water quality and macroinvertebrate and fish communities upon project completion. Ten sampling locations were established (1 upstream sample where each creek drains onto the mine, a downstream point after the two channels converge, a point where the system drains off the site, and six sites along the reconstructed channels within the site). Each location was sampled seasonally (spring and fall) for five years from 2002 to 2006. This was the period after the stream flow was fully restored to the reconstructed channels, but before bonds were released. Some of that monitoring data is reviewed in this paper. The scope of this paper focuses on direct comparisons of post-mining upstream and downstream conditions in an effort to understand major trends and major impacts to the stream community. A more comprehensive study of all data would undoubtedly shed additional light on these impacts, and may be explored more fully at a later time.

Methods

To fulfill Consolidation Coal's requirement to monitor the streams, company biologists, Dr. Dale E. Pike and Dr. Bradford B. Owen conducted the semi-annual sampling from 2002 to 2006 and generated reports twice a year, which were submitted to the State of Illinois to meet the sampling and reporting requirement. For each of the ten sampling sites a water sample was collected and analyzed for water temperature, field pH (using a pH meter), flow (cfs), conductivity, total suspended solids (TSS), total dissolved solids (TDS), alkalinity, Fe, Mn, SO_4^{2-}, Pb, Zn, Cl^-, F^-, NO_3^-, dissolved oxygen (DO, fixed in the field), and D.O. % saturation. These evaluations of the data focused on pH, TSS, Fe, Mn, SO_4^{2-}, Cl^-, and DO. These parameters, except for DO, were selected due to their importance in the NPDES (National Pollutant Discharge Elimination System) system. Dissolved oxygen was examined to determine if any limiting conditions existed due to this parameter and to assess differences between upstream and downstream environments.

Macro-invertebrates were collected with D-frame nets and by hand picking from large rocks and other debris by Dr. Pike and Dr. Owen. According to the submitted reports, efforts were made to sample all suitable habitats at each station. Specimens collected were preserved in a formalin solution and returned to the laboratory for removal from sample debris and identification. Identifications were made with the aid of taxonomic keys in Merritt and Cummins (1996) and Pennak (1989). Reports identified taxa present (mostly to genus level). No quantitative data were recorded. Number of invertebrate taxa was used in this paper as a measure of invertebrate diversity.

Fish were collected (by Pike and Owen) by electro-fishing and/or seining. Most fish were identified, noted and released. Some specimens were retained to verify species identification using taxonomic keys in Smith (1979) and Page (1983). Nomenclature followed that used in Page and Burr (1991). Species present were reported.

Results from those reports were used to make comparisons between upstream sampling sites (the point where Galum Creek enters the site [Galum upstream] and the point where Bonnie Creek enters the site [Bonnie upstream], see Fig. 1) and the downstream sample site (where the system drains from the mine [Downstream], see Fig. 1).

Results

Reclamation of the site included grading floodplains for both Galum and Bonnie Creeks. Within these flood plains approximately 8 miles of stream channels were constructed in a meandering fashion, along with adjacent wetlands. Floodplains were planted with a variety of tree species to restore riparian habitats (Fig. 2). After these efforts were completed, flows from the creeks were routed into the reconstructed channels and the temporary diversions were backfilled. Wildlife utilization of these new habitats began immediately. The area is known today for its trophy whitetail bucks and turkeys and as a prolific waterfowl harvest area. Threatened and endangered species have been observed by the authors at this mine site including bald eagle, common moorhen, shorteared owl, northern harrier, Cooper's hawk, sharp-shinned hawk, loggerhead shrike, pied-billed grebe, least bittern, and rice rat. (Some of these species have since been delisted.) The post-mining riparian and wetland habitats exceeded that which have existed pre-mining. In addition to biological functions, hydrologic functions have also been restored including flood storage, surge protection, erosion control and sediment reduction.

Water Quality

Review of the seven selected water quality parameters identified no substantial differences in water quality between the upstream sample sites (the point where Galum Creek enters the site and the point where Bonnie Creek enters the site) and the downstream site for most parameters (pH, TSS, Fe, Mn, Cl^-, and DO). The basic water quality regime was near neutral to slightly alkaline (pH 6.9-8.4) with low TSS. Neither acidity nor excessive silt loads were problematic at this site. As Galum Creek enters the site, pH ranged from 7.2 to 8.3 with a numerical mean of 7.8. As Bonnie Creek enters the site pH ranged from 7.6 to 8.4 with a numerical mean of 8.0. At the downstream sample site pH ranged from 6.9 to 7.5 with a numerical mean of 7.2. Water pH was therefore not considered to be biologically limiting and well within the established NPDES limits of 6 to 9.

Figure 2. Post-mining restored Galum and Bonnie Creeks at Consolidation Coal's Burning Star #4 Mine in Perry County, Illinois. Low altitude oblique aerial photograph is looking toward the northwest. Photo date is October 12, 2006. A - Restored Galum Creek floodplain and riparian corridor, B – Floodplain wetlands, C – Confluence of Bonnie and Galum Creeks, D – Adjacent upland tree plantation

Total suspended solids at Galum upstream ranged from 5 to 80 mg/l, with a mean of 22 mg/l. At Bonnie upstream TSS ranged from 7 to 30 mg/l with a mean of 14 mg/l. At the downstream site TSS values ranged from 13 to 45 mg/l with a mean of 30 mg/l. All samples were within the NPDES limit of 70 mg/l, except for 1 sample at Galum upstream (un-mined) with a value of 80 mg/l. Similar to pH, TSS was not considered to be biologically limiting in this system.

Iron at Galum upstream (un-mined) ranged from 0.4 to 1.6 mg/l, except for one outlier value of 34.9 mg/l. The cause of that high value could not be explained. Mean Fe at Galum upstream was 4.3 mg/l. Bonnie upstream iron values ranged from 0.3 to 2.0 mg/l with a mean of 0.9 mg/l. The downstream site yielded Fe values ranging from 0.7 to 3.5 mg/l with a mean of 1.8 mg/l. All samples were within the NPDES limit of 6.0 mg/l, except for the high outlier mentioned above from un-mined drainage. Similar to pH and TSS, Fe was not considered to be biologically limiting in this system.

Galum upstream Mn values ranged from 0.2 to 4.5 mg/l, with a mean of 0.9 mg/l. At Bonnie upstream Mn ranged from 0.1 to 1.1 mg/l with a mean of 0.5 mg/l. Downstream Mn values ranged from 0.8 to 1.6 mg/l with a mean of 1.2 mg/l. All samples were within the NPDES limit of 2.0 mg/l, except for the 4.5 mg/l (un-mined) sample at Galum upstream. Similar to pH, TSS, Fe, and Mn was not considered to be biologically limiting in this system.

Galum upstream Cl^-values ranged from 7 to 104 mg/l, with a mean of 45 mg/l. Bonnie upstream Cl^- ranged from 15 to 44 mg/l with a mean of 30 mg/l. Downstream Cl^- values ranged from 31 to 71 mg/l with a mean of 49 mg/l. All samples were well below the NPDES limit of 1000 mg/l. All values were below National Aquatic Life Criteria of 230 mg/l for chronic effects and 860 mg/l for acute effects. Similar to pH, TSS, Fe, and Mn, Cl^- was not considered to be biologically limiting in this system.

Although dissolved oxygen (DO) is not generally considered in the coal mining water quality regulatory scheme, these values are of biological interest. Galum upstream DO values ranged from 1.4 to 9.2 mg/l, with a mean of 5.7 mg/l. Bonnie upstream DO ranged from 2.2 to 9.4 mg/l with a mean of 6.0 mg/l. Downstream DO ranged from 3.2 to 11.0 mg/l with a mean of 6.7 mg/l. No biologically significant differences were noted between downstream and upstream sites.

Sulfate was the one parameter in which significant differences occurred between the downstream and upstream environments. Sulfate at Galum upstream ranged from 14 to 417 mg/l, with a mean of 180 mg/l. Bonnie upstream sulfate values ranged from 43 to 498 mg/l with a mean of 270 mg/l. Downstream SO_4^{2-} values ranged from 943 to 2517 mg/l with a mean of 1781 mg/l. Downstream SO_4^{2-} can generally be characterized as a tenfold increase compared to the upstream environments (Fig. 3). Konik (1980) identified sulfate dominance in mine waters, replacing bicarbonate as the dominant anion in the system, as a result of mining. The Burning Star #4 data is consistent with that trend. How this increased SO_4^{2-} may affect aquatic biota will be discussed later in this paper.

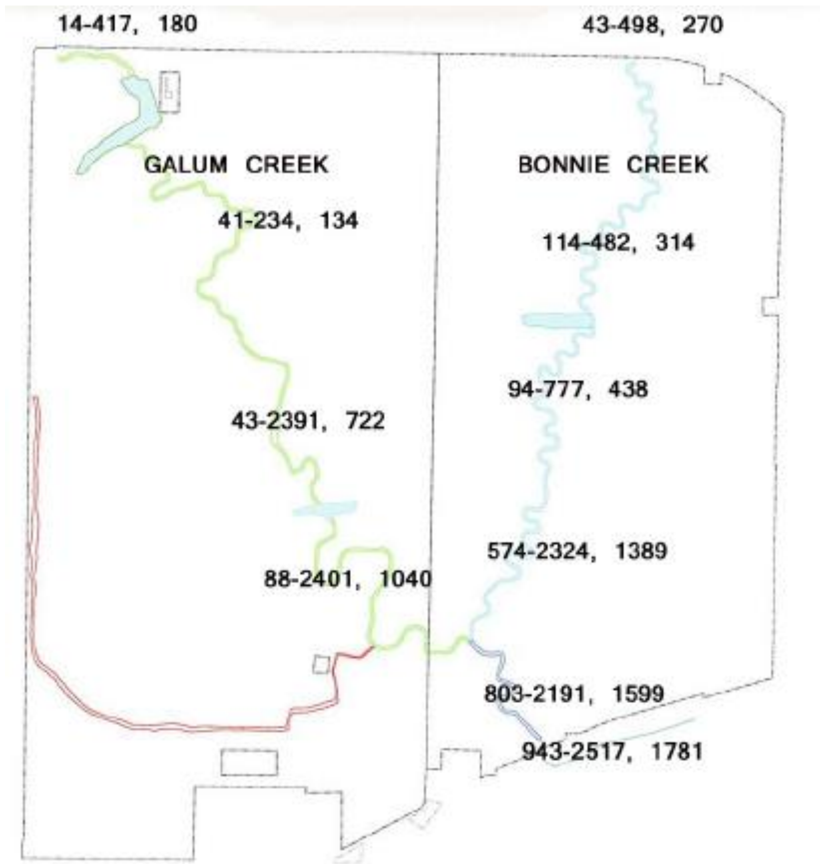

Figure 3. Sulfate values (range and mean) for 10 sampling locations at Burning Star #4 Mine 2002-2006.

Macro-invertebrates and Fish

The first level of invertebrate data analysis involved direct comparisons in number of invertebrate taxa downstream of the mine compared to the upstream (un-mined) environments. During the course of the ten sampling periods the number of invertebrate taxa at the Galum Creek upstream site ranged from 1 to 19. Bonnie Creek upstream values ranged from 3 to 26. The downstream site ranged from 3 to 27. The downstream site had the lowest number of taxa for one sampling period but had the highest number for 4 sampling periods. In general, number of invertebrate taxa downstream was comparable to the upstream sites (Fig. 4).

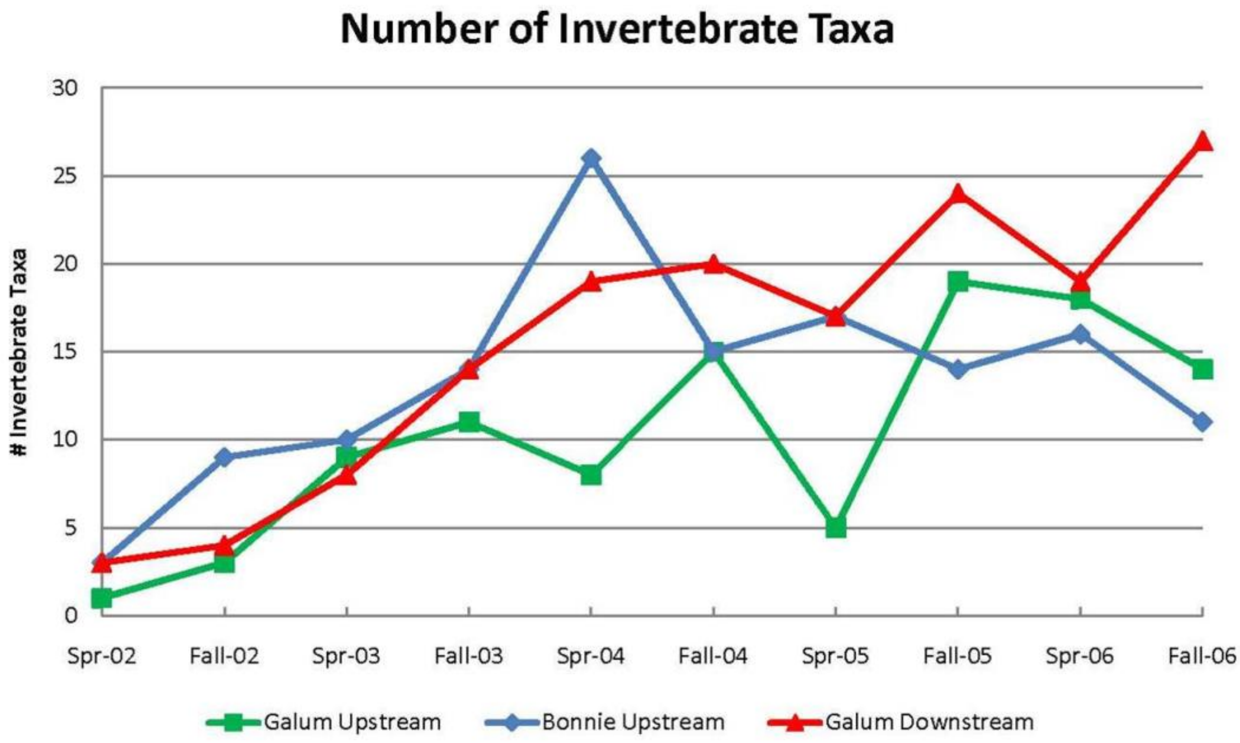

Figure 4. Number of invertebrate taxa collected at upstream and downstream stations 2002-2006.

Although sulfate values were an order of magnitude greater downstream, SO_4^{2-} does not appear to have inverse impacts on invertebrate diversity, however, additional investigation was conducted. For each of the ten sampling sites (the seven sites between the upstream and downstream sites in addition to the two upstream sites and the downstream site) the average SO_4^{2-} value for that site and the average number of invertebrate taxa for that site were plotted. Based on a least squared regression, there was not a significant correlation between SO_4^{2-} concentrations and number if invertebrate taxa ($r = 0.00009$, $P>0.09$, Fig. 5). This result supports the hypothesis that increased sulfates do not have negative effects on invertebrate diversity (by this measure).

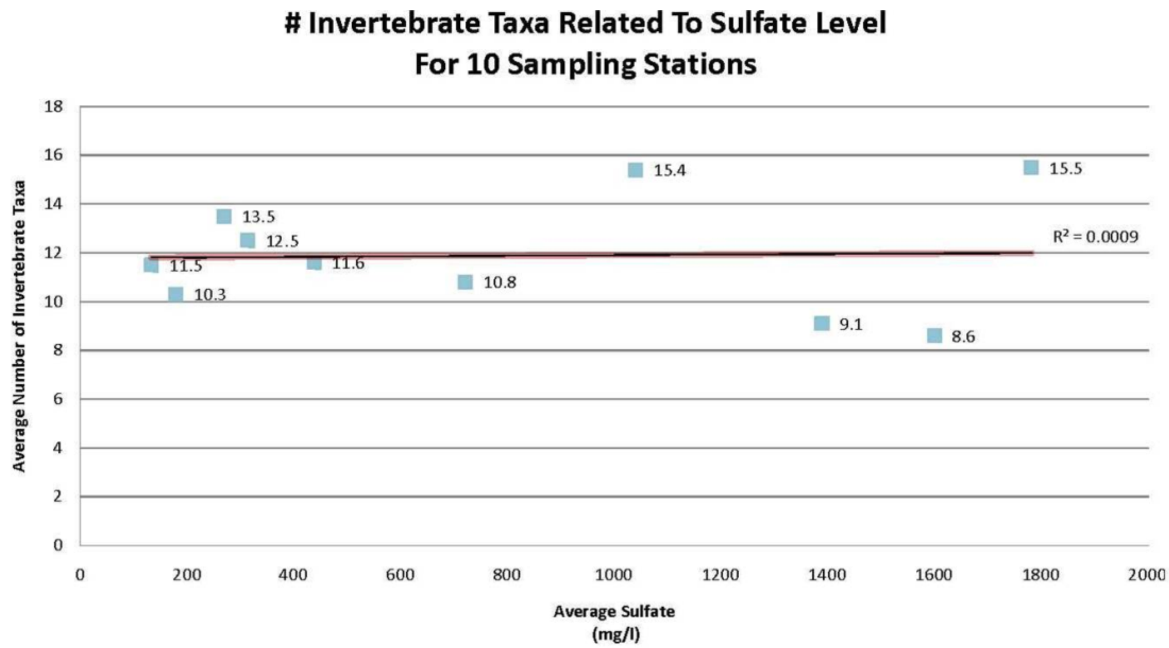

Figure 5. Mean number invertebrate taxa related to mean sulfate values for 10 sampling stations.

The Illinois Environmental Protection Agency (IEPA) lists tolerance indices for many macro-invertebrate taxa in Illinois. (IEPA 2010) Invertebrate taxa reported in this study reflect a community characterized as generally tolerant of environmental pollution. The pre-mining site and upstream watersheds were heavily impacted by row crop agriculture since settlement of the region. This probably accounts for the scarceness of sensitive species. Jenkusky et al. (1979) documented aquatic macro-invertebrates at the Burning Star #4 North Field prior to mining as part of an ecological resources survey. Their data confirm that the pre-mining aquatic macro-invertebrate community was comprised mostly of tolerant species. Occurrence of sensitive species in this post-mining system was investigated to determine if the general lack of effects from SO_4^{2-} on the invertebrate community at large applied also to sensitive species.

The IEPA tolerance scale ranges from 1 to 11. A very sensitive species would score a 1, whereas a very tolerant species would score an 11. For this study, a taxon was classified as sensitive if it had an IEPA value of 1, 2, or 3. Of the 50 taxa documented before mining by Jenkusky et al. (1979), only 1 sensitive taxon was recorded (*Gammarus sp.* with a value of 3). During the course of the ten post-mining sampling periods (2002-2006) the number of sensitive invertebrate taxa at the Galum upstream site ranged from 0 to 3. Bonnie upstream numbers ranged from 0 to 4. The downstream site ranged from 0 to 2. At Galum upstream, no sensitive taxa were collected for 4 of the 10 sampling periods. No sensitive taxa were collected at the Bonnie upstream site for 2 of the 10 sampling periods. At the downstream site, no sensitive taxa were collected for 8 of the 10 sampling periods (Fig. 6). These data suggest that sensitive species may be impacted by the higher sulfates encountered downstream.

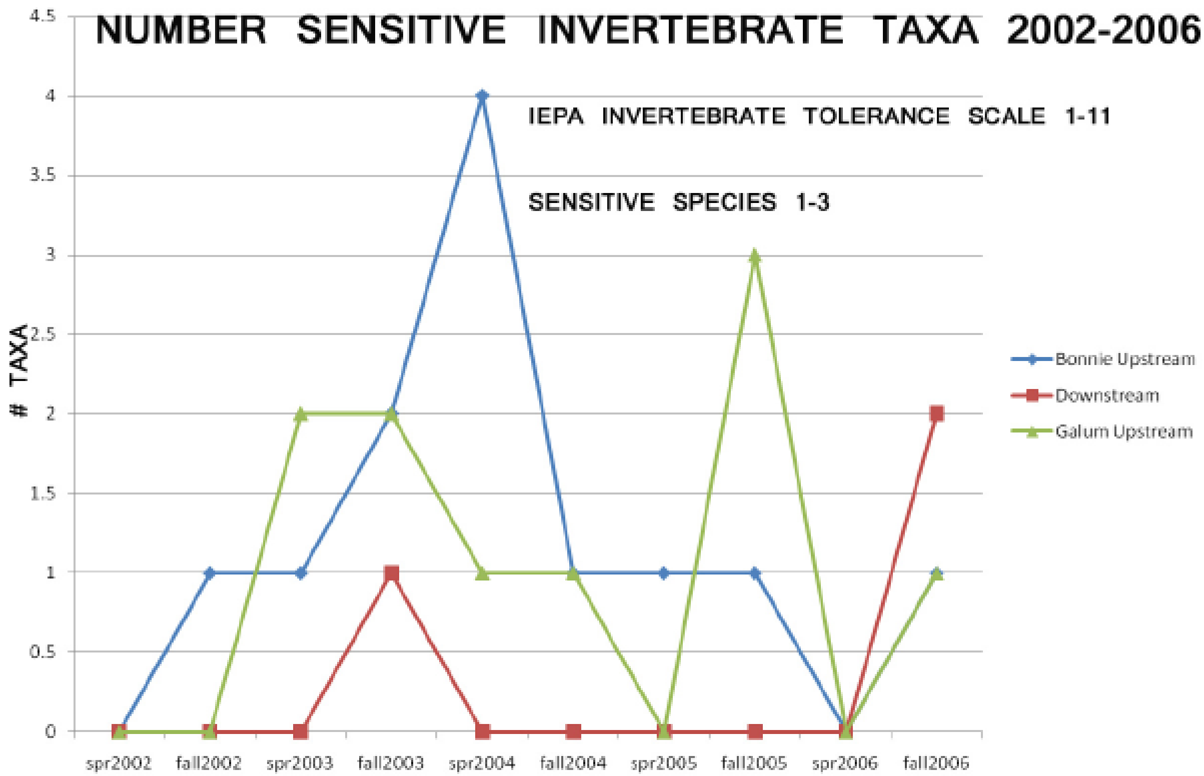

Figure 6. Number of sensitive invertebrate taxa collected at upstream and downstream sampling stations.

The relationship between sulfate concentration and number of sensitive invertebrate taxa was further investigated using a least squares regression analysis, which showed there was no statistically significant correlation between sulfates and number of sensitive taxa ($r = 0.22$, $P>0.1$) but showed a trend of decreasing taxa number with increasing sulfate concentration (Fig. 7). The upstream sites had low SO_4^{2-} concentrations and the highest number of sensitive taxa, while the downstream site had the highest SO_4^{2-} concentration and low number of sensitive taxa, suggesting an inverse relationship between SO_4^{2-} concentration and number of sensitive taxa.

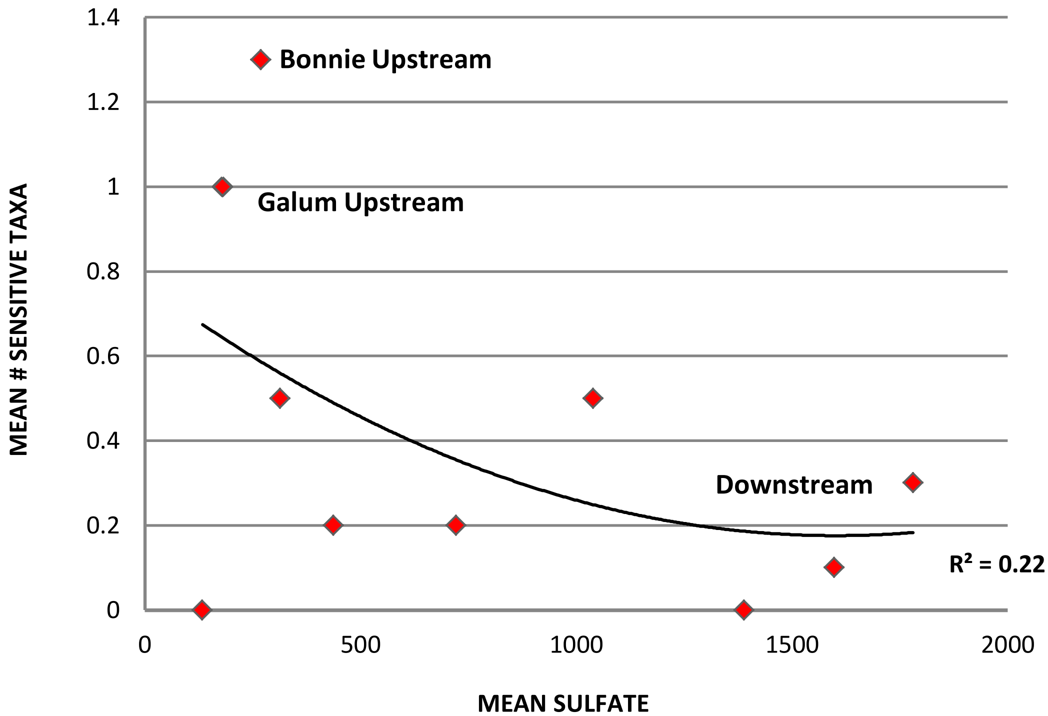

Figure 7. Mean number sensitive invertebrate taxa related to mean sulfate concentrations (mg/l) for 10 sampling stations.

The number of fish species at the Galum upstream sampling location ranged from 2 to 12. The Bonnie upstream site numbers ranged from 0 to 15. The downstream site numbers ranged from 2 to 7 (Fig. 8). Number of fish species downstream was generally between the two upstream numbers. A more thorough analysis of the fish data would undoubtedly shed additional light on restoration efforts but is not within the scope of this paper.

Discussion

The relationship between sulfate concentration and invertebrate diversity found at this site was compared with other studies of mine waters in the area. Two other studies were selected for comparison. Konik (1980) studied physical, chemical, and biological characteristics of several surface mine lakes in Perry, Fulton, and Williamson Counties in Illinois. Two of Konik's study lakes are located approximately 6 miles southeast of the Burning Star #4 site. Konik (1980) concluded that surface mine lakes with the lowest specific conductance, hardness, and SO_4^{2-} typically had the highest diversity of invertebrates, algae, and aquatic macrophytes. These data suggest that high SO_4^{2-} values could be associated with lower invertebrate diversities.

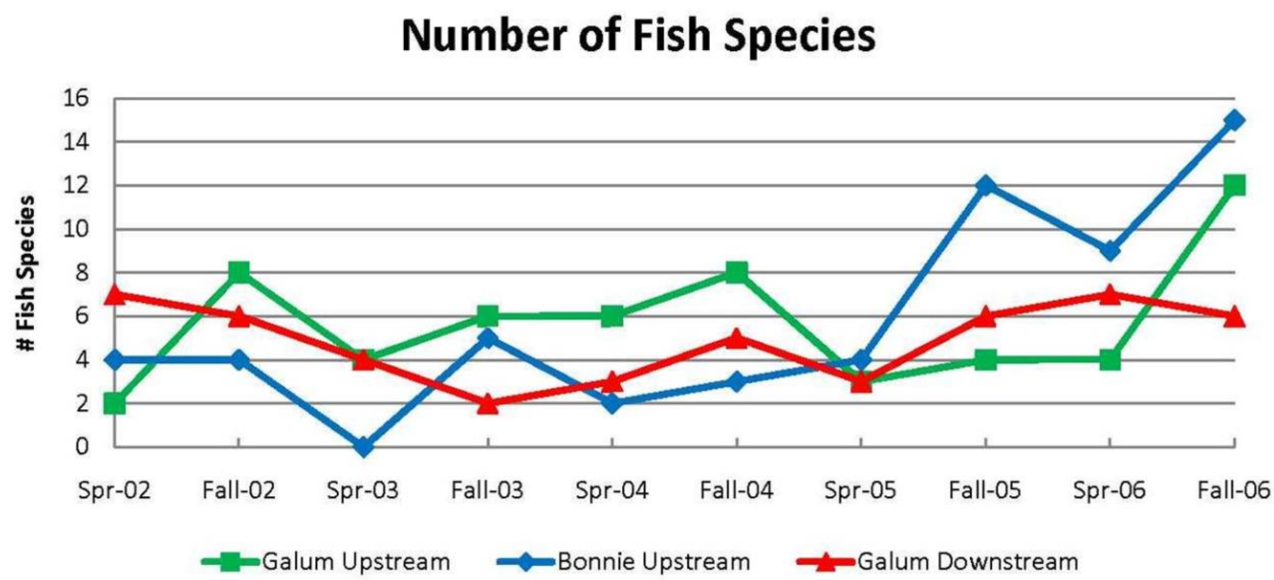

Figure 8. Number of fish species collected at upstream and downstream sampling stations.

O'Leary (1984) studied wetlands resulting from surface mining on the East Cutler Pit site located less than one mile west the Burning Star #4 site (Fig. 1). Although O'Leary's 1984 study focused on characteristics of the wetlands as waterfowl habitat, both aquatic invertebrate and sulfate data were reported that may provide insight into the relationship between SO_4^{2-} and the aquatic invertebrate community. In that study, twelve wetlands were selected for intensive study, which were each sampled in 2 locations in the fall of 1982 and the spring of 1983 for water quality and invertebrates. The 48 SO_4^{2-} values ranged from 2 to 1200 mg/l and the 48 values for number of invertebrate taxa ranged from 6 to 39. Each SO_4^{2-} value had a corresponding value for number of taxa for the same location and time. With a wide range in SO_4^{2-} values and also a wide range in number of invertebrate taxa, these data were reexamined to investigate the relationship between SO_4^{2-} values and invertebrate diversity.

A least squared regression analysis of the 48 data pairs showed a similar trend as the Burning Star #4 sensitive taxa data discussed above (Fig. 9), that is, an inverse relationship between sulfate concentration and number of taxa. At sample points with sulfates less than 100 mg/l, invertebrate taxa ranged from 10 to 39; whereas, at sample points with sulfates over 100 mg/l invertebrate taxa ranged from 6 to 15.

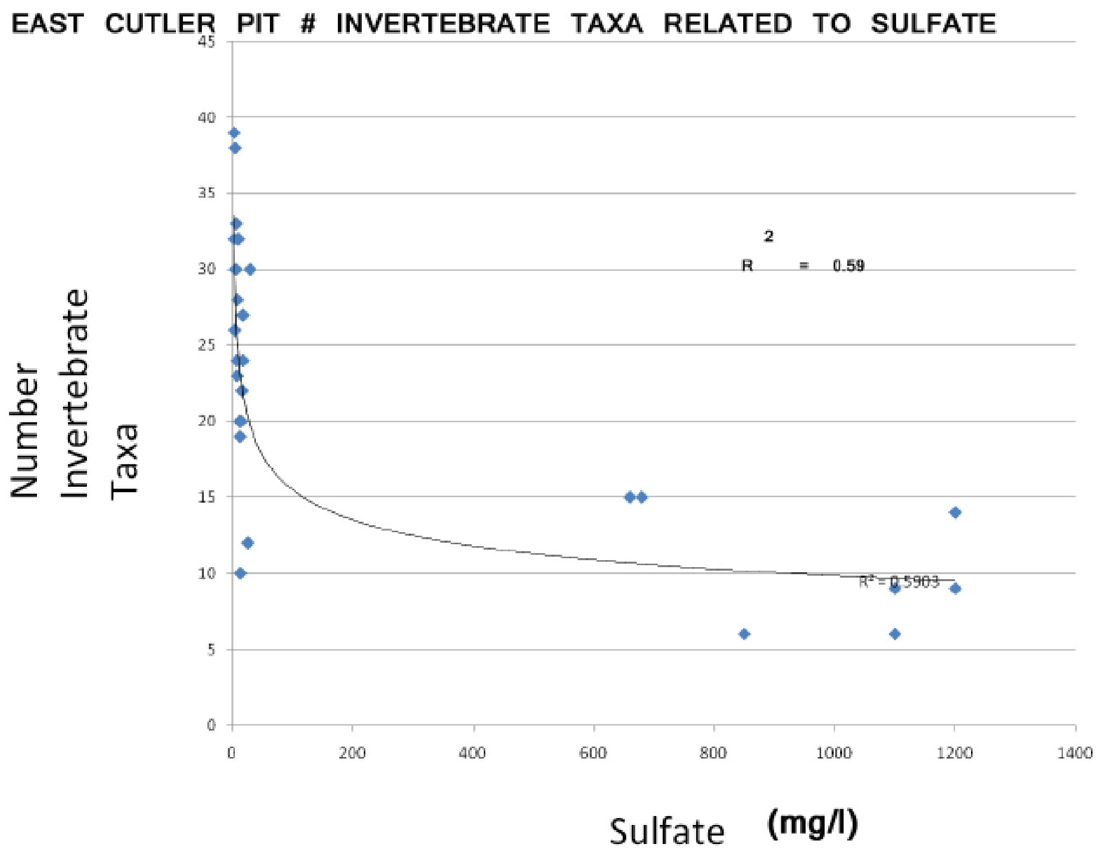

Figure 9. Number invertebrate taxa related to sulfate concentrations for East Culter Pit wetlands (data from O'Leary 1984).

The greatest change in water quality in this stream restoration project was increase in SO_4^{2-} (and its possible impacts on aquatic macro-invertebrates). Another interesting aspect is how long elevated sulfates will persist. Sulfate in the spoil should readily and eventually flush out of the system, but it is not known how much time is needed for SO_4^{2-} to return to pre-mining concentrations. At Spring Lake located a few miles from the Burning Star #4 site, Konik (1980) reported average sulfate as 1660 mg/l in 1979. In a previous study at Spring Lake Lewis and Peters (1954) reported conductivity value as 3650 µmohs/cm, and although they did not report SO_4^{2-} concentration, a rough-estimated SO_4^{2-} value would be 2693 mg/l based on the assumption that the portion of the conductivity attributed to $SO_4^{2-}$was the same in 1954 and 1979. In a sample collected by O'Leary in 2011 (unpublished), the SO_4^{2-} concentration was 592 mg/l which was a decrease of 1068 mg/l over 32 years (since 1979) which translates to a decrease of 33.4 mg/l per year. Based on the assumption that this rate of SO_4^{2-} decline was applicable to the period from 1954-1979, the SO_4^{2-} concentration for 1954 could be alternately roughly estimated at 2495mg/l, which is a figure similar to the estimate of 2693mg/l, using the first method. Using the mean of the two estimates for 1954 (2594 mg/l), along with the mean of 1660 mg/l for 1979 reported by Konik (1980) and the 2011 sample of 592 mg/l, a long term trend in SO_4^{2-} concentration for Spring Lake from 1954 to 2011 can be inferred (Fig. 10). Although the estimates of the early (1954) SO_4^{2-} are rough, tying together the historical data for this lake provides some insight into the question of how much time is needed for SO_4^{2-} to return to pre-mining concentrations. Based on the calculated decrease of 33 mg/l per year (1.3% of an initial concentration of 2594 mg/l) over 57 years at Spring Lake and the mean pre-mining SO_4^{2-} concentrations for Galum and Bonnie Creeks, the time it would take for sulfate to return to pre-mining concentrations is estimated at 68 years. Brugham et al.(1983) reported the fraction of SO_4^{2-} for 8 lakes varied from 0.0009 to 0.35 (mean 0.012) or 1.2 % per year, which is similar to the 1.3% per year for Spring Lake reported in this study.

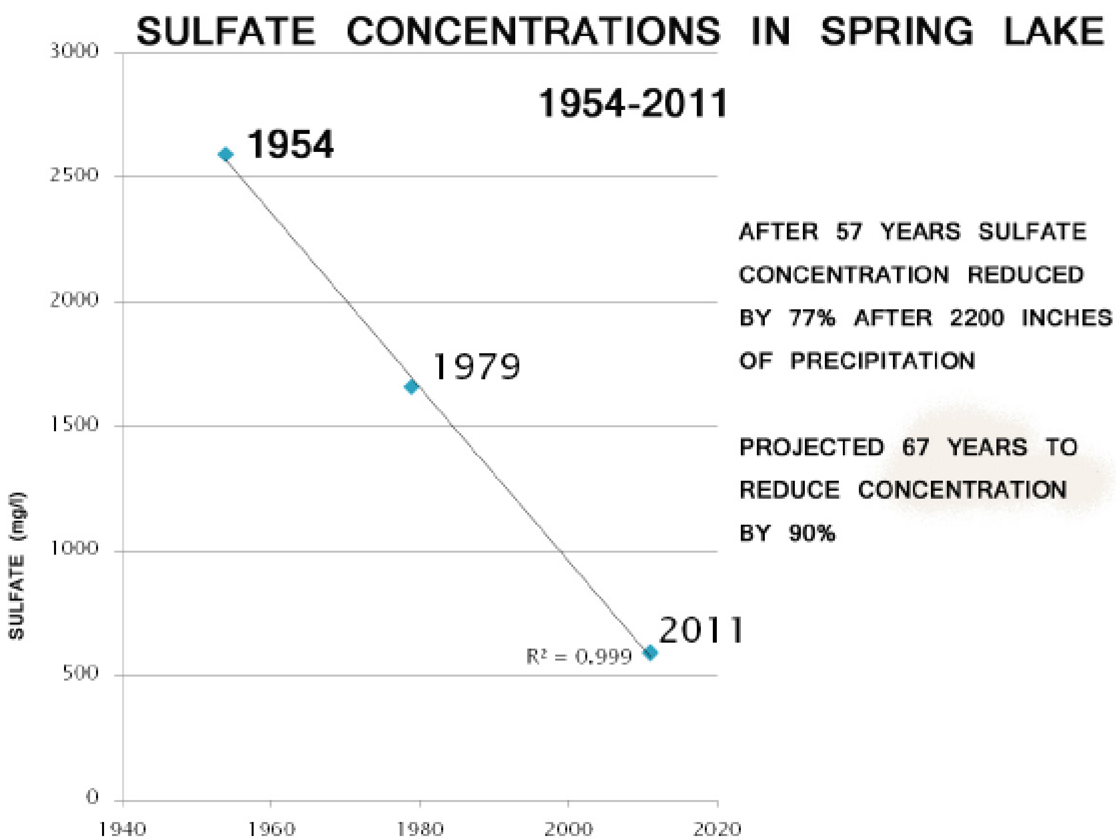

Figure 10. Sulfate concentrations in Spring Lake, Pyramid State Park, Perry County, Illinois 1954 to 2011.

Summary

The Burning Star #4 site has demonstrated that large Midwestern streams can be surface mined through with successful restoration of many important hydrologic and biological functions. A major difference in the post-mining environment compared to pre-mining is the large increase in sulfate in post-mining streams. Although this effect may be temporary, several decades, sensitive invertebrate species may be detrimentally impacted for a time. As SO_4^{2-} flushes from the system, we would expect sensitive species to gradually re-colonize. SMCRA mandates that we "strike a balance" (U.S. Congress 1977, Section 102[f]) between coal production and environmental protection. Given the long term expectation of full invertebrate community recovery, perhaps a temporary reduction in sensitive macro-invertebrates, where they are not a major part of the system before mining, is not a high a price to pay for the energy benefits from coal extraction. At the Burning Star #4 site this impact should be viewed keeping in mind the mitigative value of the improved riparian and wetland habitats (Nawrot et al. 2009).

Conclusions

Data reviewed in this paper suggest the following trends and insights.

1. Large midwestern streams can be mined through with successful restoration of the stream system including restoration of important biological and hydrologic functions.
2. Major differences in pre-mining and post-mining water quality can include large increases in sulfate concentrations.
3. Elevated SO_4^{2-} concentrations may be temporary. Eventually we would expect sulfate concentration to drop to pre-mining levels. This might take several decades.
4. Elevated SO_4^{2-} concentrations may not have detrimental effects on an aquatic macroinvertebrate community made up of mostly tolerant species.
5. Sensitive macroinvertebrate species may be detrimentally impacted by elevated sulfates.

Regulatory Implications and Recommendations

These conclusions have some regulatory implications. In cases where stream invertebrate communities could be affected by elevated sulfates, regulators need to know how significant sensitive species are in the composition of those communities. Much of the Illinois (and other

Midwestern) coal fields are so heavily impacted by past agriculture, that stream invertebrate communities can be expected to be comprised largely of tolerant species at many sites. However, in less impacted areas, sensitive species become more significant in the invertebrate community structure and greater impacts to that community would be expected from elevated SO_4^{2-}. Some temporary loss of sensitive species can probably be tolerated in the interest of striking the mandated balance between coal production and environmental protection. However, in cases where some of those species are listed under endangered species legislation great care needs to be taken to determine if elevated sulfates can cause declines in such species or interfere with recovery efforts. Endangered species legislation prohibits jeopardizing the continued existence or recovery of a listed species by reducing reproduction, numbers, or distribution. "Take" of listed species is interpreted broadly and is also prohibited without specific authorization to take either directly or in an incidental fashion. "Taking" listed aquatic invertebrates, in a coal mining context, without a specific permit to do so would constitute violations of both SMCRA (CFR 30 816.97[d]) and the [federal] Endangered Species Act (Section 9), and possibly state specific endangered species legislation. Mining companies and regulators need to be sensitive to endangered species concerns as these relate to elevated SO_4^{2-} impacts on aquatic macro-invertebrates.

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Literature Cited

Brugham, R.B., M.A. Carlson, S. Chakraverty, and M. Lusk. 1983. Post-Mining Neutralization of Acidic Surface Mine Lakes. Water Resources Center, University of Illinois Technical Completion Report B-138-I11. 96 pp.

Illinois Environmental Protection Agency. 2010. Illinois Environmental Protection Agency macroinvertebrate tolerance list and functional feeding group classification, January 2010.

Jenkusky, S., D.W. Sparling, and L.G.Nelson. 1979. Ecological resources survey of the Jamestown North area, Perry County, Illinois. Cooperative Wildlife Research Lab, Southern Illinois University, Carbondale report to Consolidation Coal Company. 83 pp.

Konik, J. 1980. Some physical, chemical, and biological characteristics of non-problem waters occurring on lands surface mined for coal. Illinois Institute natural Resources Doc. 80/14. 90 pp.

Lewis, W.M. and C. Peters. 1954. Physico-chemical characteristics of ponds in the Pyatt, Desoto, and Elkville strip mined areas of southern Illinois. Trans. Am. Fish. Soc. 84:117-124. http://dx.doi.org/10.1577/1548-8659(1954)84[117:PCOPIT]2.0.CO;2.

Nawrot, J.R., W.G. O'Leary, and P. Malone. 2009. Illinois stream restoration – opportunities for habitat enhancement: policy, principles, and practices. Geomorphic Reclamation and Natural Stream Design at Coal Mines: A Technical Interactive Forum. Bristol VA, April 27-30, 2009.

O'Leary, W.G. 1984. Waterfowl habitats provided by surface mine wetlands in southwestern Illinois. M.A. Thesis, Southern Illinois University at Carbondale. 141 pp.

Merritt, R.W. and K.W. Cummins. 1996. An Introduction to the Aquatic Insects of North America, 3rd ed. Kendall/Hunt Publishing Company. 862 p.

Page, L.M. 1983. Handbook of Darters. TFH Publications, Inc. 271 p.

Page L. M. and B.M. Burr. 1991. A Field Guide to Freshwater Fishes of North America North of Mexico. Peterson Field Guide Series; 42. Houghton Mifflin Company. 432p.

Pennak, R.W. 1989. Fresh-water Invertebrates of the United States: Protozoa to Mollusca, 3rd ed. John Wiley and Sons, Inc. 628p.

Smith, P.W. 1979. The Fishes of Illinois. University of Illinois Press. 314p.

U.S. Congress (95th). 1977. Public Law 95-87, The Surface Mining Control and Reclamation Act of 1977.