Stream Restoration – Long Term Performance: A Reassessment

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Karl Williard[1], Blair Borries[1], Timothy Straub[2], Donald Roseboom[2], Clayton Nielson[1], and Veronica Kelly[1]

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[1]Southern Illinois University Carbondale, Department of Forestry, 1205 Lincoln Drive,
Carbondale, IL 62901; williard@siu.edu, 618 453 7478
[2]United States Geological Survey, Illinois Water Science Center, Urbana, IL 61801

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Abstract

In the 1980s, three of the largest stream relocations in the United States occurred as a result of surface mining in southern Illinois. Bonnie, Galum, and Pipestone Creeks in Perry County, Illinois were restored to the same location with many of the same physical attributes that were present prior to surface mining. Immediately after restoration, the streams were sampled over five years for water quality, fish, and macroinvertebrates. This study sought to determine the long-term (20 to 30 years post restoration) success of the stream and wetland restoration efforts by focusing an assessing whether form and function had been restored in these ecosystems.

This study conducted post-restoration water quality and biological community sampling, and also evaluated stream stability, hydraulics, riparian wildlife habitat, and riparian soil quality. Also, the study investigated incline pits connected to 2 of the streams affected hydraulic and sediment relationships and the biotic communities.

Overall, the stream and riparian estoration appears to have been successful. Few water quality issues were identified. Current water quality was similar to 5 years post restoration. Though, Bonnie and Galum Creeks showed increasing water temperatures along the length of both restored stream segments due to a lack of canopy cover over the stream channels. Also, Bonnie Creek contained some groundwater seeps that were a likely source of sulfate to the stream.

Riparian wetland soil quality was essentially fully recovered to natural reference wetland conditions. Comparisons of soil organic matter, bulk density, and soil nitrogen to natural wetlands showed few differences in the surface 15 centimeters, a result that is rarely encountered in studies comparing restored to natural wetlands. However, soil organic matter and soil nitrogen were lower in 15-30 cm depth suggesting that these depths take longer to recover. Hydric soil indicators as well as wetland vegetation were found in the wetlands restored on mined ground. An assessment of riparian wildlife habitat indicated that the restored

riparian corridors were of similar value to wildlife as a natural riparian corridor.

Despite the success of restoring soil and water quality in the riparian systems, instability was found in several reaches in all three streams. Pipestone Creek had mainly stable stream banks, but had a very low gradient combined with over wide channel dimensions and as a result, nearly all of the riffle substrate was buried in fine sediments. Galum Creek had mostly stable stream banks as well, but had a similarly low stream gradient and few riffles. The riffles that were present were buried with fine sediment. Bonnie Creek showed the most instability. Stream banks were sometimes steeper than 1:1 horizontal distance:vertical distance in the outer bends which is steeper than the natural angle of repose for soils as well as steeper than the design conditions. This suggests that Bonnie Creek is still adjusting to the relocation. Several rock structures were assessed and found to be failing due to flanking or because the stream power was too high. In Bonnie and Galum Creeks, most of the elevation drop in the channel occurs at a few discrete locations rather than spread out across the length of the channel.

The effects of the incline pits appeared to be mixed. The incline pit on Galum Creek served as an effective sediment trap. However, the current fish community was not restored to one that approximated a natural community, but rather one that supported more lentic instead of lotic species. The macroinvertebrate communities appeared to be less affected by the incline pits and more closely represented the community in Little Galum Creek, the natural reference stream that was sampled.

In summary, the relocation of Bonnie, Galum, and Pipestone Creeks were the largest of their kind associated with mine reclamation. The restoration of wide accessible floodplains with wooded riparian corridors and sinuous streams were a large improvement from the straight-line diversion channels that were common historically. While riparian processes were relatively quickly restored and water quality was maintained at near pre-mining conditions, in-stream processes and form have taken longer to recover. This study has generated multiple recommendations for future stream and riparian restoration following mining or other significant landscape disturbances. Stream shading via riparian plantings should be an initial high priority. Riffles could be more frequent so that all the fall in the stream bed doesn’t occur in a relatively short distance. Nearby stable reference streams could be used to help design the profile, plan form, and cross-section dimensions of the proposed restored stream. Stream banks could be less steep to encourage the growth of stream bank vegetation. Inner meander bends could be much gentler and at the apex of a bend, the channel should be wider with the inner bank of the meander bend lower to allow for flow across the meander during bankfull events. Incline pits should probably be disconnected from the flowing stream to ensure that lentic or lacustrine species do not dominate. Large woody debris could be saved during clearing and used as stream structure to provide both grade control and aquatic habitat.

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Introduction

Surface mining drastically alters the landscape and as current (2011) worldwide coal production exceeds 7 billion metric tons per year (US EIA 2012), it has become essential to understand the impacts and the processes that may lead to the restoration of streams and adjacent riparian ecosystems impacted by coal mining. Early strip mining accessed shallow coal and occurred over a small area, but as technology increased the size and power of excavation equipment, the size and impact of surface mines grew (Chenoweth et al 2009). Large-scale surface mines in southern Illinois extracted coal from depths of 70 – 95 feet or more during the late 1970s and 1980s. The resulting effects were large open strip cuts that extended >1.5 miles in length (Nawrot et al. 2010). Smaller tributaries, creeks, and streams often required relocation around these active surface mines. Post-disturbance monitoring of the physical, chemical, and biological processes of the stream community is required through the Federal Surface Mining Control and Reclamation Act of 1977 (PL 95-87). When surface mining disrupts the riparian vegetation and wetland habitat, it must be enhanced, restored, or replaced to promote fish and wildlife habitat along the affected stream (sec. 816.97).

The restoration of riparian areas and streams is important due to their influence on water quality, water quantity, local and regional terrestrial wildlife, and aquatic life within and far beyond the mined area. The sources of hydrology in a restored surface mined stream include upstream watersheds, groundwater, and overland flow. While the upstream watershed and regional groundwater flow paths may be outside the control of a surface mine undergoing reclamation, overland flow filtering through a restored riparian buffer can undergo significant transformations. Stream stability is a balance of sediment transport and deposition; a system out of balance can cause negative effects both upstream and downstream. Riparian ecosystems also have specific roles in landscape-level ecosystems. They function as important linear corridors connecting habitats as well as providing important habitat themselves. The importance of streams goes beyond the bed and banks and they cannot be adequately studied as a simple linear feature. This study aims to provide a comprehensive look at the stream and riparian systems of three of the largest perennial stream restorations on surface mined lands: Pipestone Creek, Galum Creek, and Bonnie Creek. It presents a cross-section of the wildlife habitat, aquatic life, as well as the abiotic features of the riparian and stream ecosystem including water quality, soil quality, stream hydraulics, and sediment transport.

The restored riparian areas include three of the largest streams relocated during the process of surface mining in North America to date. Forty km of streams, 400 hectares of riparian area, and 200 hectares of wetlands were identified post-mining (Figure 1). Incline pits, remnants of ramps which led to the exposed coal seam during active mining, were left in the path of all three of the relocated creeks. The in-stream deepwater features are unique to the surface mined landscape and may provide sediment attenuation benefits, but may also have consequences to the migration of aquatic life. Now, after several years of recovery, these riparian systems provide an opportunity to evaluate the long-term effectiveness of stream and wetland restoration efforts following surface mining.

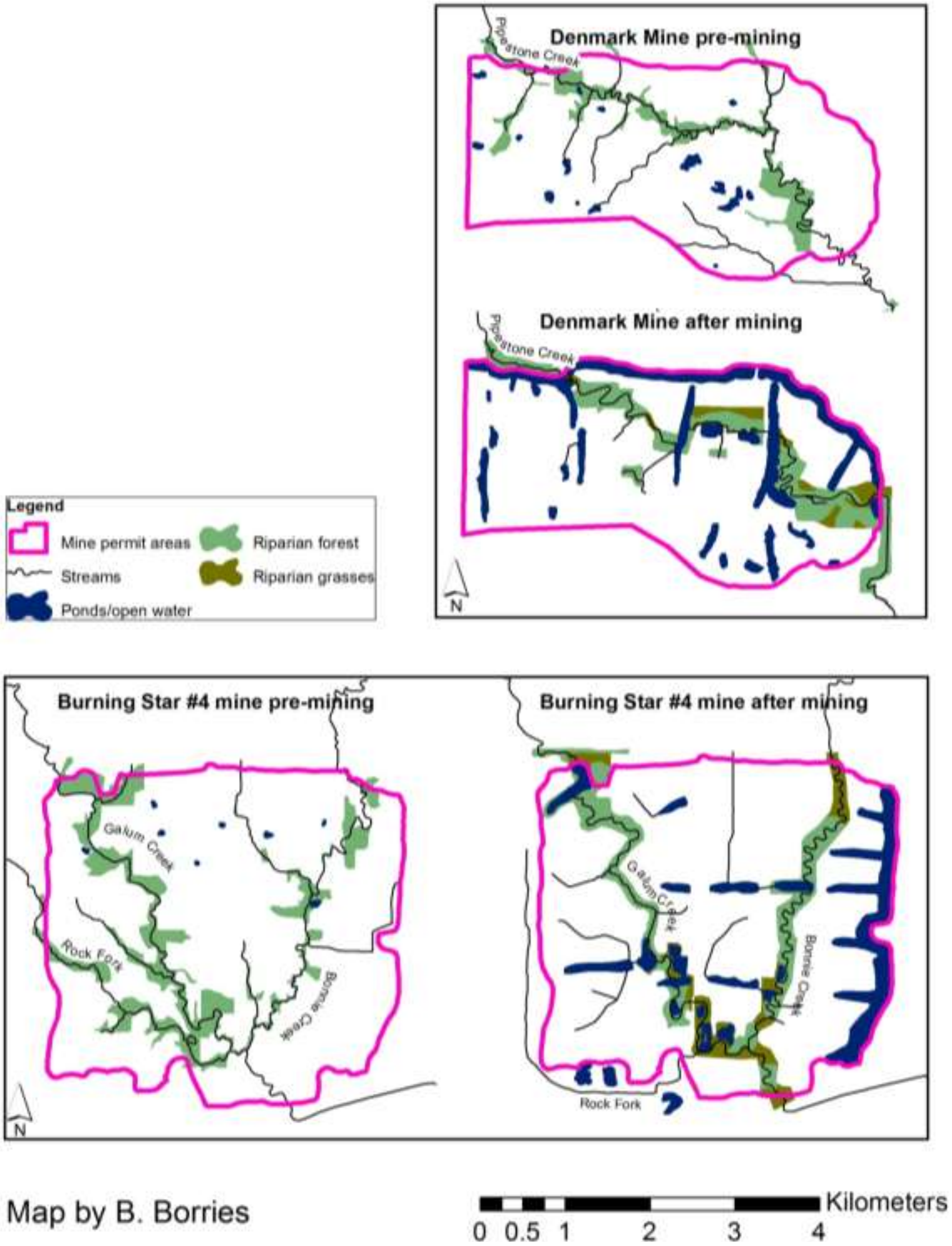


Figure 1. Hydrography and riparian features at Burning Star #4 and Denmark Mines before and after mining. Mining at the Denmark mine (right) and BS4 (below) caused drastic alterations in hydrography and landscape. Most of the stream length was replaced following restoration, but with a different pattern. There was also an increase in open water and riparian area.

WATER QUALITY, AQUATIC LIFE AND SURFACE MINING

The impact of surface mining on water quality varies from profound to insignificant depending on the water quality parameter in question. Nutrients are generally low in streams. When nutrient levels are high they affect drinking water uses and aquatic life (Lampert and Sommer 1997), but in most cases surface mining does not increase the nutrient levels in streams. Total dissolved solids (TDS) measures the sum of the concentrations of major ions. TDS is associated with mining effluent and is considered a stressor to aquatic communities (Bodkin et al 2007) at levels as low as 1050 mg L^{-1} (Kennedy et al 2004). It has been shown, however, that individuals ions such as Ca^{2+}, SO_4^{2-}, Mg^{2+}, and K^+ are more strongly correlated to macroninvertebrate biotic metrics (# number of EPT taxa, % dominant taxa, number of taxa, number of collector taxa) than TDS (Timpano 2010). SO_4 is produced in mined areas when weathering of pyritic material is increased due to the crushing of formerly consolidated shales. Macroinvertebrates must maintain an ionic balance through osmoregulation and SO_4 can disrupt this balance leading to decreases in fitness and survival (Pond et al 2008). The impact of SO_4 is affected by chloride (Cl) and hardness concentrations (Soucek and Kennedy 2005). Cl concentrations above 25 mg L^{-1} increase the toxicity of SO^4 and hardness concentrations above 100 mg L^{-1} decrease the toxicity. Illinois has developed water quality criteria for SO_4 based on the concurrent Cl and hardness concentrations, but regardless of the levels of either sets a maximum allowable concentration at 2,000 mg L^{-1} (Illinois Water Pollution Control Board 2009). Total Suspended Solids (TSS) is a measure of the inorganic and organic particulates that remain suspended in the water column as long as the load is more than the streams capacity to entrain and move the particles. At high levels, TSS affects stream primary productivity by reducing light penetration (Wood and Armitage 1997), fine solids impact filter feeding macroinvertebrates by clogging their collecting nets (Aldridge et al. 1997), and through scouring may dislodge aquatic insects more rapidly from substrate. It affects fish by increasing risk of bacterial infection (Redding et al. 1987), increasing mortality especially in juveniles (Newcombe and MacDonald 1991), and decreasing feeding efficiency (Newcombe and MacDonald 1991). Excess TSS also leads to sedimentation of important habitats by smothering gravels beds and clogging interstitial spaces (Wood and Armitage 1997). TSS downstream of surface mines may be increased long-term or short-term as a result of surface mining in areas under original forest cover, but in the Midwest, where row crops often dominate the land cover, TSS may decrease downstream of surface mines following reclamation. This may be due to an increase in permanent cover or the presence deep incline and final cut basins that are formed when ramps and mining pits are left to fill with water. Acidic mine drainage, a byproduct of pyrite oxidation that occurs when pyritic overburden is crushed mobilizes metals (Clements et al 2008) such as iron (Fe), manganese (Mn), and Zinc (Zn) that are directly toxic to fish at high levels. They may affect transport mechanisms across fish gills, cross link with DNA, and displace essential ions causing changes in essential proteins (Gerhardt 1992).

The restoration of water quality in the stream was evaluated for Galum, Bonnie, and Pipestone Creeks through samples collected during two periods: immediately following mining, and 5 years (Galum and Bonnie Creek) or 15 years (Pipestone Creek) later (2012–13). These data were analyzed to detect trends and to compare post-mining conditions to a limited amount of pre-mining data and upstream “control points”. Storm samples were collected using automated samplers to determine the total sediment load entering and leaving the incline pits. This sampling assessed whether the incline pits had a significant sediment attenuation effect on downstream reaches.

STREAM HYDRAULIC, SEDIMENT TRANSPORT AND SURFACE MINING

Assessing stream hydraulics and sediment transport is useful in quantifying the physical characteristics of a stream system and aids in the understanding of the stability of the restored channels. From Mackin (1948), a stable river is one in which, over a period of years, slope is delicately adjusted to provide just the velocity required to transport the available water and sediment supplied from the drainage basin. Lane (1955) further discussed the balance in stream systems between the quantity and size of sediment, and the quantity of water and slope of the channel. If the quantity of water or slope of the channel are too excessive for the sediment size and load, the channel will likely erode. Conversely if the quantity of water or channel slope are too low for the sediment size and load, the sediment will likely deposit.

In the design of stream restoration projects, sediment continuity should be considered to help maintain the stability of the channel. Also, channelized agricultural ditches generally have a relatively high sediment transport capacity and load. Restoration projects downstream of agricultural ditches should take these factors into consideration in the design of streams and floodplains. Lastly in the case of the incline pits (remnants of surface mining), depending on the configuration of the incline pits and connection to the stream, sediment can drop out in the pits. The hydraulic and sediment assessment provides insight on the combination of incline pits, re-meandered channels, and riffle construction in the restored mine areas.

The hydraulic and sediment assessment was completed using both qualitative and quantitative techniques. The field data collection included photographic documentation, stream-channel surveying, and bed material sampling at each restoration area for stream reaches both upstream and downstream of the most upstream incline pit. Hydrologic assessment utilized the USGS Streamflow Statistics (StreamStats) website to determine 2, 10-, and 100-yr flows (http://water.usgs.gov/osw/streamstats/illinois.html) for rural Illinois watersheds (Soong and others, 2004; Ishii and others 2010). Also, an examination of flow records from the nearby USGS streamgage 05597500 (Crab Orchard near Marion, Ill. http://waterdata.usgs.gov/il/nwis/nwisman/?site_no=05597500&agency_cd=USGS) was completed to determine the number of large flood events (2-yr or greater) that occurred in the area since restoration. The gage was also used to obtain hydrographs for model input.

Hydraulic and sediment modeling for the selected reaches utilizing the Hydrologic Engineering Center, River Analysis System model (HEC-RAS) (U.S. Army Corps of Engineers, 2010) to summarize velocity, stream power, shear stress, and size of bed materials moved for various flood magnitudes throughout the stream reaches. Also, the one-dimensional, quasi-unsteady sediment transport capabilities within the HEC-RAS (Version 4.1.0) were used to model changes in peak sediment concentration between upstream and downstream of incline pits for the 2- and 10-yr floods.

WILDLIFE HABITAT AND SURFACE MINING

Streams and riparian zones support important functions for wildlife, even if their form has been altered from historic conditions (Nawrot et al. 2010, Walton 2012). Wildlife habitat is affected both directly and indirectly by the ecological processes that take place both above and beneath the ground. Healthy stream corridors aid in physical (hydrological and geomorphological), chemical, and biological landscape-level processes such as transporting water from the watershed to the channel; traveling through the channel, floodplains, and sediment, and eventually delivering water to the local landscape (Fischenich 2006, Scott et al. 2009). Geomorphological processes slowly change and rearrange riparian landscapes by moving woody debris and sediment to create new land forms and provide structural habitat for wildlife (Church 2002, Brierley 2006). Biological processes produce and sustain diverse habitats to support vigorous aquatic and riparian biotic communities, aiding in maintaining natural predator-prey relationships and genetic diversity, thereby helping to preserve healthy physiological conditions in riparian zones (Ehrenfeld 2000, Fischenich 2006).

Succession describes the natural process of how plant and animal communities change over time after a disturbance, and knowledge of successional changes to riparian zones following restoration is important. Changes in vegetation structure and age promote biodiversity and ecological vigor, which is important to the long-term adaptation of ecosystems. By planting native species important to wildlife in the surrounding area, restoration efforts often “jump-start” succession (Walton 2012). Wildlife will colonize particular habitats once the vegetation within those areas meets their habitat requirements. Through establishment of native plant communities and construction of similar substrates, it is reasonable to expect that wildlife will utilize previously mined and restored habitats as they would similar habitats on undisturbed sites (Zipper et al. 2011, Walton 2012). One way of gauging whether reclamation was successful is to compare the vegetative communities of reclaimed land with those of nearby land that was not disturbed by mining.

To assess this project objective, we quantified habitat quality for wildlife on restored stream corridors, using a focal group of southern Illinois wildlife species to indicate a set of commonly-measured habitat variables that are of importance to those species. Wildlife species and species-groups chosen included mammals, birds, reptiles, and amphibians. Birds, of course, are not restricted to any one habitat patch but move about freely. The other species groups included carnivores, herbivores, and omnivores; may be terrestrial, aquatic, or aerial; may use both in-stream habitats and wooded corridors; or may spend part of their lives in water and part on land. This set of species and variables included wildlife that have large and small home ranges and may migrate, disperse, or neither. Species included were white-tailed deer (*Odocoileus virginianus*), bobcat (*Lynx rufus*), river otter (*Lontra canadensis*), beaver (*Castor canadensis*), white-footed mouse (*Peromyscus leucopus*), deer mouse (*P. maniculatus*), water snakes (*Nerodia spp.*), testudines (terrestrial and aquatic turtles), anurans (frogs and toads), migratory birds, ground-nesting birds, raptors and bats. Here, we review specific habitat needs for these focal species and species-groups; variables mentioned are those we measured in this study.

Some focal wildlife species are habitat generalists, while others have more specific habitat requirements. Canopy cover, for instance, is important for a wide array of different species and has been measured for habitat studies of bobcats (Kolowski and Woolf 2002), beaver (Cox and Nelson 2009), white-footed mice (Nupp and Swihart 2001), Nerodia species (Cross and Peterson 2001, Pattishall and Cundall 2009), salamander species (Faccio 2003), birds (Saab 1999, Batten and Lawler 2006), and bats (Watrous et al. 2006). Canopy cover has been shown to be an ecological indicator and is useful for distinguishing different plant and animal habitat, and assessing forest floor microclimate and light conditions (Jennings et al. 1999, Lowman and Rinker 2004). Ground cover such as grasses, herbaceous plants, leaf litter, woody debris, rocks, and bare ground provide substrate, foraging areas, and low cover for many smaller wildlife species such as the white-footed mouse (Adler and Wilson 1987), salamanders (Faccio 2003), Nerodia species (Cross and Peterson 2001, Pattishall and Cundall 2009), anurans (Anderson et al. 1999), and both aquatic and terrestrial turtles (Fuselier and Edds 1994, Converse and Savidge 2003, Rizkalla and Swihart 2006). As the summer days get longer and hotter, terrestrial turtles have an increased need for thermoregulatory sites; herbaceous ground cover and shrub structure can help provide shade (Converse and Savidge 2003). Ground cover also has been measured for bobcats (Kolowski and Woolf 2002), river otter (Bowyer et al. 1995), and migratory birds (Saab 1999).

Variation in vertical foliage structure is a measurement of the density of vegetative cover for habitat suitability for wildlife and can be used for assessing habitat quality for deer (Griffith and Youtie 1988), white-footed mice (Nupp and Swihart 2001), and bobcats (Kolowski and Woolf 2002). Wildlife use vertical vegetation for cover, as it provides camouflage within the forest. Dense foliage under the forested canopy makes flight less navigable, so vertical vegetation may exclude some avian species, such as larger raptors, from areas with dense understory.

Understory and overstory stem densities are important habitat characteristics selected by river otters and beaver (Bowyer et al. 1995, Cox and Nelson 2009). Reforested areas on restored streams provide higher-quality habitat than areas with agricultural and grasslands for the river otter. Jeffress et al. (2011) found that river otter (*Lontra canadensis*) occupancy increased with increasing forested areas along riparian corridors. Otter presence may be positively correlated with the presence of fish, their main prey, because fish abundance often increases in areas of woody debris (Angermeier and Karr 1984), which is linked to the amount of forested cover along banks and within riparian areas. Trees and the hard or soft mast they produce provide sustenance for ground-nesting birds such as wild turkey (*Meleagris gallpavo*), small mammals like the white-footed mouse, and larger herbivores such as white-tailed deer. Peak acorn production and densities of white-footed mice were highly correlated indicating the importance of mast to small mammals (Ostfield 1996).

Ectothermic species such as aquatic turtles, water snakes, salamanders, toads, and frogs have smaller home ranges, limited dispersal capabilities, and require heterogeneity within their habitat so that they may move from areas of higher or lower temperatures for thermoregulation (Walton 2012). Complexity of stream bank substrates have been measured for water snakes (Cross and Peterson 2001, Pattishall and Cundall 2009) and aquatic turtles (Fuselier and Edds 1994), as these provide cover and basking areas. Submerged aquatic vegetation at the edge of banks also provides cover for aquatic turtles, along with seasonal breeding habitat for toads, frogs, and salamanders. A variety of habitat features such as herbaceous ground cover, leaf litter, and decaying logs equip salamanders with the necessary microclimate conditions on the forest floor (Maser et al. 1988, Faccio 2003).

Aerial species such as birds and bats are not necessarily dependent on any specific habitat patch given their ability to fly, but still have specific habitat needs. Trees provide bats with roosting sites in the form of natural and excavated cavities, exfoliating bark, top-outs, splits, and fissures. Live tree species supporting higher number of bat roosts include shagbark hickory, black locust, and sugar maple, while American elm and oak trees were selected for when dead (Waltrous et al. 2006). Migratory birds and raptors also use snags for perching and roosting. Other significant habitat features for Neotropical migrants include the amount of canopy cover, understory and overstory stem densities, and the presence of cavities (Saab 1999, Batten and Lawler 2006).

The recovery of an ecosystem and its processes post-mining and after land reclamation is influenced at multiple spatial scales; therefore a multi-scale assessment of restored stream buffers is necessary. These restored streams benefit wildlife by providing not only the much needed site-level habitat (hereafter, called “microhabitat”), but also by providing landscape-scale habitat (hereafter, called “macrohabitat”) connectivity. Riparian buffers can successfully work as corridors to link patches with other corridors, and increase biodiversity of vegetation and wildlife by providing space and allowing for perceived safe movement from one fragmented patch to the next (Henry et al. 1999, Schuller et al. 2000, Grillmayer 2002). Corridors are especially important in a habitat matrix that is highly fragmented and dominated by agricultural land (Lovell and Sullivan 2006). Fragmentation has a strong and negative effect on wildlife demographics and movements due to the reduction in the amount of habitat, the increase in the number and isolation of habitat patches, and the decrease in habitat patch size (Fahrig 2003). Sensitivity to habitat fragmentation is generally based on a particular species’ ability to survive and persist in local patches and to recolonize patches by being able to move across a landscape (Hanski 1998, Etienne and Heesterbeek 2001).

While wildlife species have different microhabitat requirements, larger species need more room to move and disperse, and these larger areas support higher biodiversity and allow for adaptation within a changing landscape (Cagnolo et al. 2009). The physical arrangement and surface area of cover types within the landscape such as forest, mixed understory, and grasslands are all important habitat types and aspects to be measured for the wide array of species that inhabit the local area, move, and disperse within the corridor of the restored stream buffer.

Research on stream restoration has been ongoing by the Cooperative Wildlife Research Laboratory at Southern Illinois University since the early 1980s (Nawrot et al. 2009), but not much is known about how wildlife respond to reclamation in riparian areas. Scientists and land managers must understand the roles that habitat quality and landscape connectivity play in the movement of wildlife over the greater landscape as a naturally-functioning riparian ecosystem provides important habitat and serves as a corridor for individual animals to disperse from one area of suitable habitat to the next (Boutin et al. 2003, Lees and Peres 2008). We assessed restored streams from a wildlife habitat perspective, to provide information to guide future stream restorations. Our specific objective was to provide an assessment of the microhabitat quality and macrohabitat connectivity features of riparian corridors for wildlife following stream restoration. Data were collected via microhabitat measurements at specific plots and a landscape-level evaluation of macrohabitat was performed using GIS to assess habitat connectivity around restored streams.

RIPARIAN WETLANDS AND SURFACE MINING

The importance of wetlands to many ecosystem functions is a result of their unique chemical, hydrologic, and biological properties (Mausbach 1994). The biodiversity within wetlands is substantially higher than fully aquatic or upland habitats (Aber et al 2012). In addition, the high degree of biological productivity found in wetlands and the selection pressures found only in their varying hydrologic regime has resulted in a wetland biota that is not found in any other ecosystem (Gibbs 1995). The combined effects of wetlands as patches of unique species and their intrinsically high biodiversity underlies their importance for maintaining diversity at a landscape scale (Gibbs 2000). Wetlands areas are also hotspots for denitrification (Groffman et al 2008) typically existing concomitantly with soils high in organic matter and being found in low areas that receive runoff or groundwater through-flow. They have also been found to be sinks for phosphorus mobilized during storm events (Mitch and Gosselink 1993). The role of wetlands in flood abatement and maintenance of consistent flows during dry periods has an estimated value of as much as $1.3 billion a year in the U.S. alone (Zedler and Kercher 2005; Dahl 2011). High productivity and soil conditions that promote carbon storage have led to wetlands being identified as natural areas of importance for carbon sequestration (Zedler and Kercher 2005).

Wetlands cover only 9% of the global land surface, but their importance to numerous ecosystem functions is disproportionate to their relative land cover (Zedler and Kercher 2005) and their loss has been tremendous. It is estimated that almost half of the U.S. wetlands have been lost since European settlement due to drainage or filling (Dahl 2011). Surface mining has affected over 130,000 ha of land in Illinois with the majority occurring in southern Illinois. Wetlands in southern Illinois are commonly associated with riverine systems and are formed by fluvial and other hydrologic processes. They may occur as oxbows (ponds formed from abandoned river channels) or are found where the upland intersects the floodplain. Surface hydrology inputs to these depressions and flat areas within the floodplain include runoff and overbank flow. As the lowest point in the landscape, groundwater inputs to these wetlands often occur as groundwater flowing from the upland is intercepted before flowing through to the stream (Lindbo & Richardson, 2001).

A number of studies have compared restored wetland soil nutrient properties (SOM, C, N, and P) and soil physiochemical properties (bulk density (ρ_b), gravimetric soil moisture (GSM), pH, soil texture) across chronosequences and to natural wetlands. Differences between restored wetlands and natural wetlands were most significant in SOM (Meyer et al 2008; Campbell et al 2002; Cole et al 2001), and to a lesser extent in C (Hunter et al 2008, Meyer et al 2008) and N (Hunter et al 2008; Meyer et al 2008). ρ_b tends to be lower in restoration sites while GSM is higher in natural wetlands (Hunter et al 2008; Meyer et al 2008; Campbell et al 2002). pH tends to be higher in restored wetlands (Meyers et al 2008; Johns et al 2004). Differences in soil texture have been found between natural and restored wetlands (Campbell 2002) suggesting less about the natural recovery processes in wetlands and more about the selection of the restoration site. Soil properties have been shown to trend towards the natural condition (Hart and Davis 2011; Meyer et al 2008) except for soil texture which does not appear to increase or decrease significantly over time (Hart and Davis 2011; Johns et al 2004; Moreno-Mateos et al 2012; Meyer et al 2008). Approaches to restore wetlands to their natural hydrologic regime, redox status (Hart and Davis 2011), and vegetation communities have been successful. Dikes and land contouring activities can be used to establish a controlled water level, and plantings are often incorporated into wetland restoration to promote biodiversity in hopes that natural regeneration will ultimately maintain the community (Meyer et al 2008). Hossler et al (2012) showed no differences in the plant communities and hydrologic regime in restored versus natural wetlands in Virginia.

Before SMCRA established a requirement to return land to its original contours, land affected by mining contained many depressional wetlands as well as emergent wetlands along the perimeter of final cut lakes. More recently, wetland creation has been promoted on reclaimed mines and is now incorporated into the reclamation plan (Nawrot 2011). Depressional wetlands created after mining have been evaluated in Alabama, Texas, and Southern Illinois. Johns et al (2004) observed mined wetlands to have half the SOM as natural wetlands in Texas. Hart and Davis (2011) observed an increase in C and N across a chronosequence of wetlands at the same mine. On the other hand, Sistani et al (1995) and Cole and LeFebvre (1991) found SOM to be higher or comparable to nearby natural wetlands in Alabama and southern Illinois, respectively. Cole and LeFebvre (1991) also found the soils to be slightly alkaline and to have levels of P comparable to natural wetlands. No studies to date have evaluated mined wetlands found in the riparian area of major intermittent or perennial drainages. While research on wetlands restored on non-mined soils is extensive, little research exists on the soil properties of wetlands created on mined soils. No studies to date have addressed riparian wetlands restored in mined soils. Continued expansion of the research on mined wetlands can lead to better design and construction practice.

Research evaluated soil properties in the mined riparian wetlands with a focus on nutrient properties to address whether or not these wetlands are equivalent to natural wetlands. Other related soil physiochemical properties were evaluated along with vegetation and hydrology to support these results and explain the processes that are essential to the recovery or maintenance of soil nutrient pools.

Executive Summary

During the 1980s, three of the largest stream relocations with an intent to restore natural function in the United States occurred as a result of surface mines in southern Illinois. Bonnie, Galum, and Pipestone Creeks located in Perry County, Illinois were relocated during surface mining and later restored to the same location and with many of the same physical features as had existed prior to surface mining. Immediately after restoration, the streams were sampled over five years for water quality and biological communities. Between 15 (Bonnie and Galum Creek) and 25 years (Pipestone Creek) after the final sampling round, this study sought to determine if stream and wetland form and function had been restored and why or why not.

This study repeated the post-restoration water quality and biological community sampling, and also evaluated stream stability, hydraulics, riparian wildlife habitat, and riparian soil quality. Large incline pits were left to fill with water inline of the restored stream segments. This connection to a lacustrine habitat was not naturally found in streams within the region. The study investigated how these incline pits affected hydraulic and sediment relationships and the biotic communities.

At first glance, the stream restoration appears to have been successful. Few water quality issues were identified. Specific conductivity, Total Dissolved Solids (TDS), and sulfate levels were high at the upstream control point for Pipestone Creek due to upstream and unrelated mining activity, but these levels tended to be lower toward the end of the restored stream segment. Bonnie and Galum Creeks also had few water quality issues and had similar water quality to the upstream controls except for water temperature which increased along the length of both restored stream segments due to a lack of canopy cover over the stream channels. Visible groundwater seeps were found at the furthest downstream sampling point along Bonnie Creek. Initially, the current sampling was conducted above the seeps, but during

the final round of sampling an additional sample was collected downstream of the seeps and elevated levels of specific conductivity and sulfate were found suggesting the presence of contaminated groundwater that resulted from the weathering of sulfur containing bedrock material.

Riparian wetland soil quality was also almost fully recovered to natural reference wetland conditions. Comparisons of soil organic matter, bulk density, and soil nitrogen to natural wetlands showed few differences in the surface 15 centimeters, a result that is rarely encountered in studies comparing restored to natural wetlands. However, soil organic matter and soil nitrogen were lower in 15-30 cm depth suggesting that these depths take longer to recover. Hydric soil indicators as well as wetland vegetation were found in the wetlands restored on mined ground. An assessment of riparian wildlife habitat indicated that the restored riparian corridors were of similar value to wildlife as a natural riparian corridor. Habitat analysis indicated that riparian buffers within the 3 restored streams contained a matrix of forested patches intermixed with young understory trees, and grassy/herbaceous areas; beyond those patches riparian buffers were surrounded by primarily agriculture, which is generally less-suitable year-round habitat for wildlife. Had these areas remained unrestored or otherwise planted entirely to row-crop agriculture, wildlife habitat value would be considerably limited.

Despite the success of restoring soil and water quality in the riparian systems, instability was found in several reaches in all three streams. Pipestone Creek had mainly stable stream banks, but had a very low gradient combined with over wide channel dimensions and as a result, nearly all of the riffle substrate was buried in fine sediments. Aquatic vegetation colonized the stream bed and greatly slowed water velocities. Galum Creek had mostly stable stream banks as well, but had a similarly low stream gradient and few riffles. The riffles that were present were buried with fine sediment. Bonnie Creek showed the most instability. Stream banks were sometimes steeper than 1:1 horizontal distance:vertical distance in the outer bends which is steeper than the natural angle of repose for soils as well as steeper than the design conditions. This suggests that Bonnie Creek is still adjusting to the relocation. Deposition is occurring in the inner meander bends causing the point bars to grow which forces stream flow against the outer bank. Several rock structures were assessed and found to be failing due to flanking or because the stream power was too high. In Bonnie and Galum Creeks, most of the elevation drop in the channel occurs at a few discrete locations rather than spread out across the length of the channel.

The effects of the incline pits appeared to be mixed. The incline pit on Galum Creek served as an effective sediment trap. Even though the incline pits can support a sportfish nursery habitat, they give preference to lacustrine fish species that end up dominating the flowing lotic portions of the stream. Fish sampling showed that the fish community was not restored to one that approximated a natural community, but rather one that supported more lentic instead of lotic species. The macroinvertebrates seemed to be less affected by the incline pits and more closely represented those found at Little Galum Creek, the natural reference stream that was sampled. One exception was the absence of Gomphidae species. Species of dragonflies in the family Gomphidae are riffle dwelling predators and were only found in Little Galum Creek. They were absent from all the mined streams presumably due to the lack of appropriate riffle habitat.

The restoration of Bonnie, Galum, and Pipestone Creeks were the largest and first of their kind. They attempted to restore floodplain, riparian, and in-stream processes to the values that existed prior to mining. The creation of a wide accessible floodplain with a wooded riparian corridor and a sinuous stream was a large improvement from the straight-line diversion channels that were common historically. While the floodplain and riparian processes were quickly restored and water quality was maintained at near pre-mining conditions, in-stream processes have taken longer to recover given the restoration techniques used. This assessment has yielded multiple recommendations for future planning of stream restoration following mining. Stream shading should be established within the first decade after reconnection. Riffles should be much more frequent so that all the fall in the stream bed doesn't occur in a relatively short distance. Nearby stable reference streams should be used to help design the profile, plan form and cross-section dimensions of the proposed restored stream. Stream banks should be gentler to encourage the growth of stream bank vegetation. Inner meander bends should be much gentler and at the apex of a bend, the channel should be wider with the inner bank of the meander bend lower to allow for flow across the meander during bankfull events. Incline pits should probably be disconnected from the flowing stream to ensure that lentic or lacustrine species do not dominate. Large woody debris could be saved during clearing and used as stream structure to provide both grade control and aquatic habitat. All in-stream structures should be fully keyed into stream banks to prevent flanking during flood events.

Experimental

Study Area

Location

Research was conducted at two mined (Bonnie and Galum Creeks) and one unmined (Little Galum Creek) riparian areas in Perry County, Illinois (Figure 2). The mined riparian areas are found within the former Burning Star #4 North (BS4N) mine. Bonnie Creek drains approximately forty square kilometers where it makes confluence with Galum Creek which drains approximately fifty km^2near the southern limit of the BS4 permit boundary where it makes confluence with Bonnie Creek. All three streams are within the Galum Creek watershed (HUC 0714010609) ultimately draining to the Mississippi River via the Big Muddy River.

Climate

The climate of Perry Illinois is temperate with hot summers and cool winters with average temperatures of 25°C and 1°C, respectively. The annual precipitation,112 cm, exceeds evaporation by 18 cm (Based on data recorded at DuQuoin, IL 1971-2000). The typical growing season is generally from April to October (Williams et. al., 2009). During 2012, a drought affected the study area. At its peak, 100% of Perry County was considered to be in a condition of “extreme drought” (Drought Mitigation Center 2012). Beginning on September 1st, a number of rain events occurred and by October 19th, the drought in Perry County had been reduced to a D0 intensity or “abnormally dry” (Drought Mitigation Center 2012)

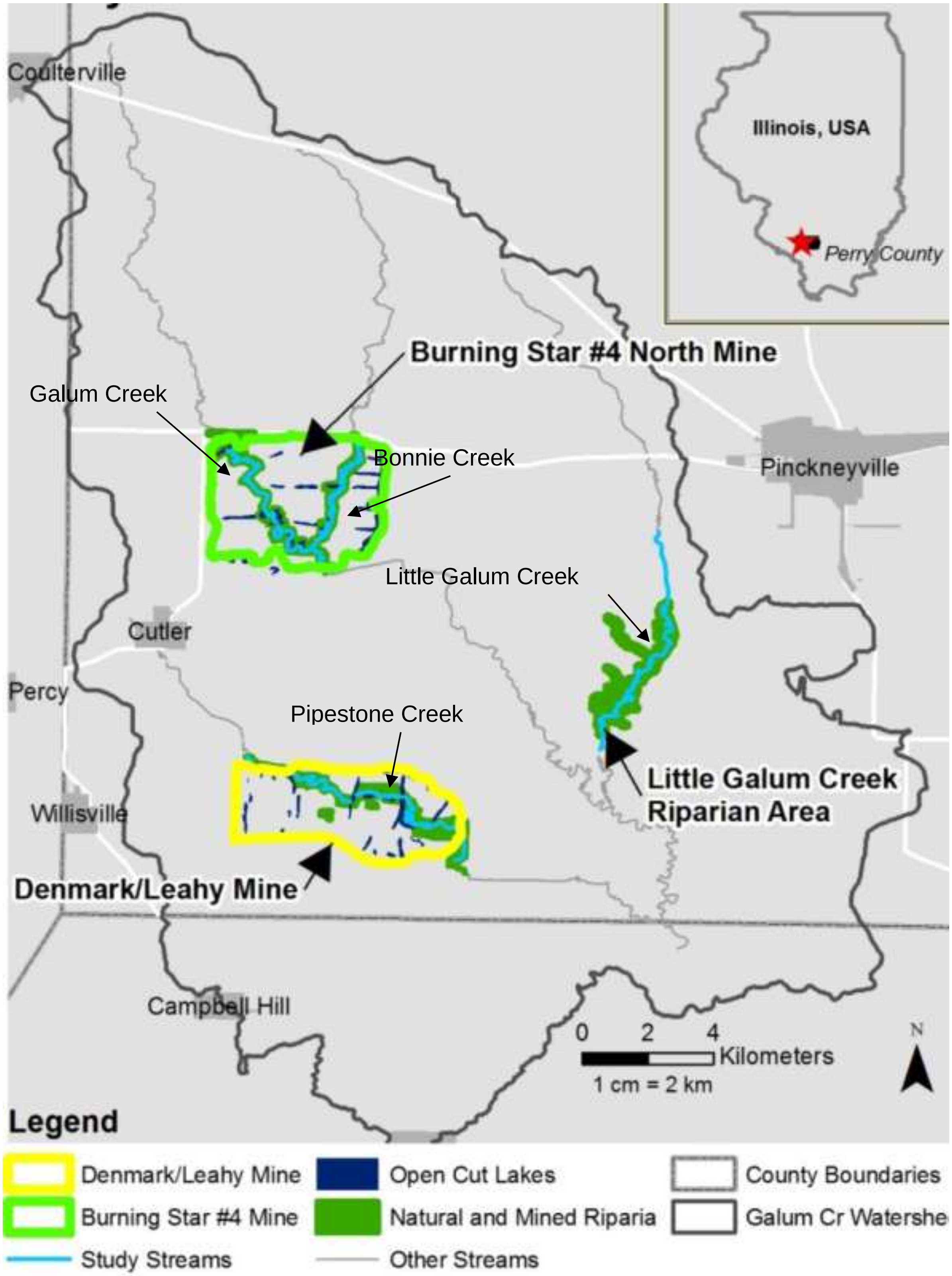


Figure 2. Locations of study area, BS4N mine, Denmark Mine, and Little Galum Creek riparian area in Perry County, IL.

Natural Geology and Soils

The surficial geology and topography of the study area is defined by the Illinoisan glaciations and subsequent eolian forces that began approximately 150,000 years ago. Perry County is comprised of loess covered layers of glacial clays and tills. Below 6-12 m of glacial clays and tills, the subsurface geology is defined by the Pennsylvanian depositional environments (Smith 1958). Changes in the depositional environment resulted in vertically repeating interbedded stratas called cyclothems. The cyclothems are 21-30 m thick and are composed of sequences of shale, limestone, coal, underclay, and sandstone. An idealized cyclotherm is shown in Figure 3. All elements are rarely found in a given column due to the lateral discontinuities shown in the model to the right of the column. Major coal seams found in the cyclothems at BS4N include the Danville (no. 7), Herrin (no. 6), and Springfield (no. 7) units (Jacobson 2000). Riparian floodplain soils within the reference site are of the Bonnie-Belknap association (Raveill 1982) as were the soils within the mined study areas prior to mining (Jenkusky et al. 1979). Bonnie and Belknap soils are soils found in the floodplain with high water tables and have alluvium as a parent material. Bonnie series soils described in Perry County were classified as Fine-silty, mixed, acid, Typic Fluvaquents. Belknap series soils described in Perry County were classified as Coarse-silty, mixed, acid, mesic Fluvaquentic Endoaquepts (Williams et. al., 2009).

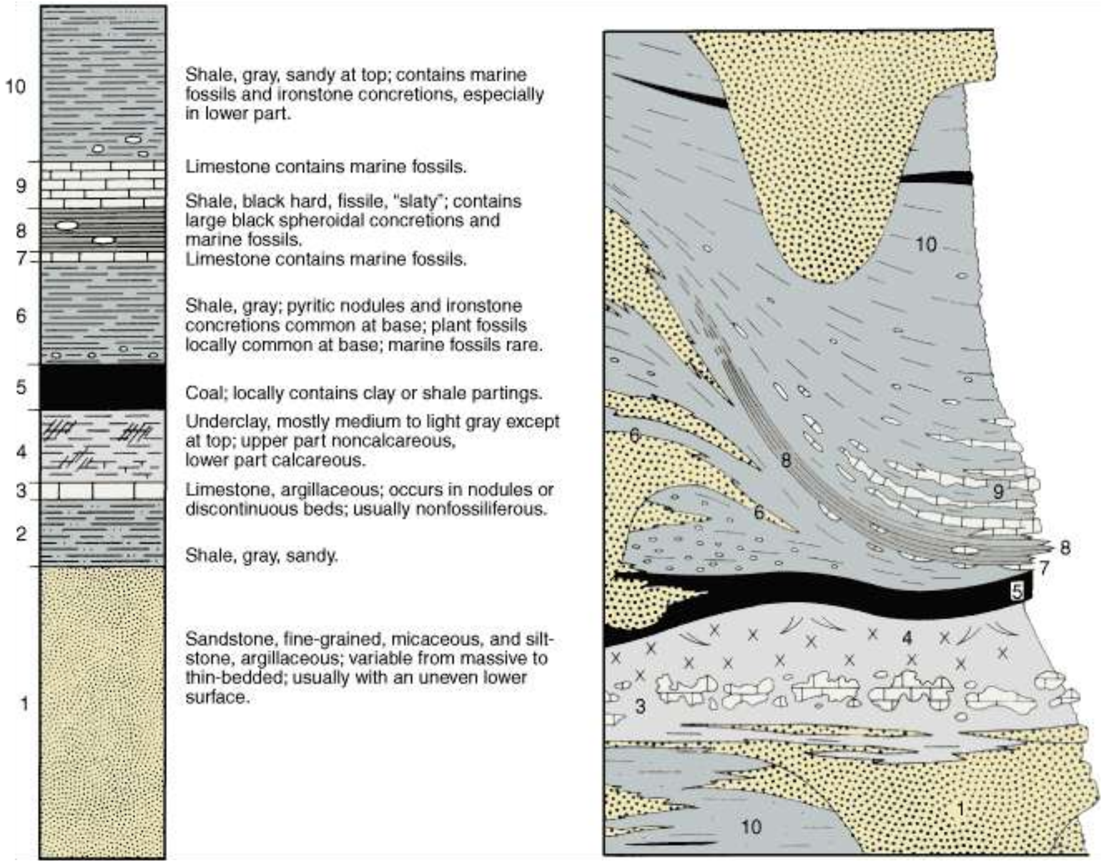


Figure 3. Idealized Pennsylvanian cyclotherm (Jacobson 2000).

Natural Flora and Fauna

In Perry County, the current and pre-mining land cover is dominated by row crop agriculture (*Zea mays*, *Glycine max*, and *Triticum aestivum*). Cropland occupies 70% of the land while forested areas comprise 16%. Jendusky et al. (1979) conducted a flora and fauna survey of the Burning Star #4 area in 1979. Dominant natural communities included bottomland forests in the floodplain, upland forests on the adjacent slopes, and post oak flats or prairies at the tops of hills. Vegetation in bottomland forests were dominated by boxelder (*Acer negundo)*, sugar maple (*Acer saccharum*), and river birch (*Betula nigra*). Common understory plants included stinging nettle (*Laportea Canadensis*) and jewel weed (*Impatiens capensis*). The occurrence of these typical wetland plants indicate a prevalence of wetland conditions within the bottomland forests *Quercus alba* (white oak) and *Quercus velutina* (black oak) were the most common species in the slope/upland forests and in the post oak flats. Understory in the upland areas was dominated by *Podophyllum peltatum* (mayapple), *Parthenocissus quinquefolia (*Virginia creeper), and *Ulmus americana (*American elm*).* A few prairies were surveyed on the site and were comprised of *Andropogon gerardii (big blue stem)*, *Sorghastrum nutans (*Indian grass*)*, *Elymus Canadensis* (Canada wild rye*)*, *Panicum virgatum (*switchgrass*)*, and *Spartina pectinata (*prairie cordgrass)*.* From 1981–82, a floral survey of the Pyramid Park area, which included a portion of the Little Galum riparian area, identified the dominant trees as *Acer saccharinum, A. saccharum, B. nigra, Carya cordiformis, Fraxinus americana, Fraxinus pennsylvanica, Quercus macrocarpa,* and *U. americana*. Shrubs included *Lindera benzoin*, *Hydrangea arborescens, Staphylea trifolia, Euonymus atropurpureus,* and *Asimina triloba*. The most common herbaceous species were *Rudbeckia laciniata, Impatiens biflora, Aster lateriflorus, Leersia virginica, Elymus virginicus, Galium aparine, Erigenia bulbosa, Plox divaricata, Claytonia virginica,* and *Ranunculus septentrionalis.* Many herbaceous plants in the bottomland understory are considered spring ephemerals and only have aboveground biomass during the early spring (Raveill 1982).

Fishes within the upper and middle Big Muddy River basin were described by Smith (1971) as being “only the most ecologically tolerant and tenacious species of fishes.” Siltation, dessication during drought periods and oil field/industrial pollution were listed as causative factors for poor water quality throughout most of the basin (Smith 1971). Studies of Bonnie Creek (1983-1985) and Galum Creek (1979) conducted before mining and studies of Little Galum Creek (IDOC 1985, Carney 1991) support these conclusions with few exceptions. The ecologically tolerant green sunfish (*Lepomis cyanellus)* made up half of the fish collected in fall of 1983 at Bonnie Creek. Other dominant species (in order of occurrence) include bluegill

(*Lepomis macrochirus),* redfin shiner (*Lythrurus umbratilis)*, golden shiner (*Notemigonus crysoleucas),* creek chub (*Semotilus atromaculatus),* red shiner (*Cyprinella lutrensis),*and blackstripe topminnow (*Fundulus notatus).* Although, tolerant species clearly dominated Bonnie Creek, a rotenone survey conducted during fall 1985, revealed the presence of 31 native species. Included were less tolerant species including ribbon shiner (*Lythrurus fumeus*), creek chubsucker (*Erimyzon oblongus*), blackspotted topminnow (*Fundulus olivaceus*), bluntnose darter (*Etheostoma chlorosomum*) and slough darter (*Etheosoma gracile)* (IDOC 1985). Samples from Little Galum Creek contained those fish species as well (Sauer 1985, Carney 1991). The faunal similarity between pre-mining Bonnie Creek and Little Galum Creek is due to the presence of fishes that are associated with flowing water habitats with woody structure, i.e., those species listed as less tolerant above plus the more common creek chub (*Semotilus atromaculatus*), redfin shiner (*L. umbratilus*) and pirate perch (*Aphredoderus sayanus*) . No species unique to Galum Creek were found during a 1979 survey and numbers of individuals were not reported (Jenkusky et al. 1979).

Macroinvertebrates at the Bonnie, Galum, and Little Galum Creeks were also indicative of moderately disturbed streams in the study area. Most genera were tolerant to a variety of conditions and included Asellus, Gammarus, *Caenis,* aquatic coleopterans, and midges (chironomidae). Other notable species found in significant numbers at Bonnie Creek include stoneflies from the genus *Perlesta*, found at two sites along Bonnie Creek; and mayflies from the genus *Hexagenia* (IDOC 1985). At Little Galum, odonata diversity was high and included the following genera: *Dromogomphus, Aeshna, Argia, and Ennalagma* (Sauer 1985). Galum Creek possessed much of the same species with some additional genera not found at the other two creeks including *Cheumatopsyche, Tropisternus, Berosus, and Enochrus* caddisflies (Trichoptera) and a species of the Elmidae (riffle beetle) family (Jenkusky et al. 1979).

Mining and Reclamation

The Denmark mine affected a total of 1914 ha and removed nearly 40 million metric tons of coal at depths ranging from 10 – 24 m until the mine ceased production in 1991 (Myers and Chenowith 2009). Pipestone Creek was originally diverted along the north and west boundaries, but beginning in 1979 and advancing behind the active pit, a new channel was dug through the mined area using a small dragline and given a meandering configuration. The final stream length was 7.4 km and had a sinuosity of 1.45. A riparian buffer of either grasses or trees was established along the entire length of the creek through the mine with the exception of a section of the original diversion that was left intact along the eastern boundary. In 1991, the relocated meandering Pipestone Creek was reconnected to its upstream watershed. The relocated channel is now managed through Pyramid State Park under the name the Denmark Unit (Nawrot et al 2011).

The BS4N mine was operated by the Consolidation Coal Company (now Consol Energy, Inc.) from 1983-1997 during which time 30,000,000 metric tons of coal was extracted from a depth of 9-33 m below the surface. The total surface area affected was 1659 ha (Myers and Chenowith 2009). The first pit (boxcut) was opened along the western edge of the mine boundary and advanced east while reclamation followed immediately behind (Anderson 1987). Draglines with 84 m^3 and 38 m^3 capacity buckets were used to remove the overburden and strip the coal, respectively (Consolidation Coal Company 1979).

Ervin Anderson (1987), an engineer for Consol described in detail the reconstruction of the Bonnie and Galum Creek channels and riparian areas at BS4N. The channel dimensions and floodplain were designed so the floodplain would be inundated during a 2 year design storm. Of the 58.68 ha of floodplain, 55.44 ha were planted with green ash, river birch, bald cypress, hickory, silver maple, pin oak, sycamore, and sweet gum to replace 1:1 bottomland forest that was cleared during mining. Riparian corridors (floodplain and adjacent upland areas) averaging 200 m and 170 m wide was established along Galum and Bonnie Creeks, respectively. Planned wetlands were created by adding subsoil and topsoil to depression areas found in the spoil and graded to create islands and water zones ranging from 0.1 to 3 m in depth so that approximately 70% of the water zone was 0.1 to 1.5 m in depth. Concrete spillways connecting the wetlands to the adjacent channel were created to control water levels while allowing the floodwaters to enter the wetlands (Anderson 1987). In 2001, portions of the diversion channel were backfilled and new sections of Bonnie and Galum Creeks were dug to connect the relocated channels to their upstream watershed and to Galum Creek downstream of BS4N (Nawrot et al 2011). In 2002, Consol was awarded the OSM National Award for innovative reclamation practices for its work at the BS4N site (Nawrot et al 2011). Figure 4 tracks the progression of the active pit and the soil reconstruction that occurred behind it. The ages shown in the figure were estimated from aerial photos and from information provided in Anderson (1987).

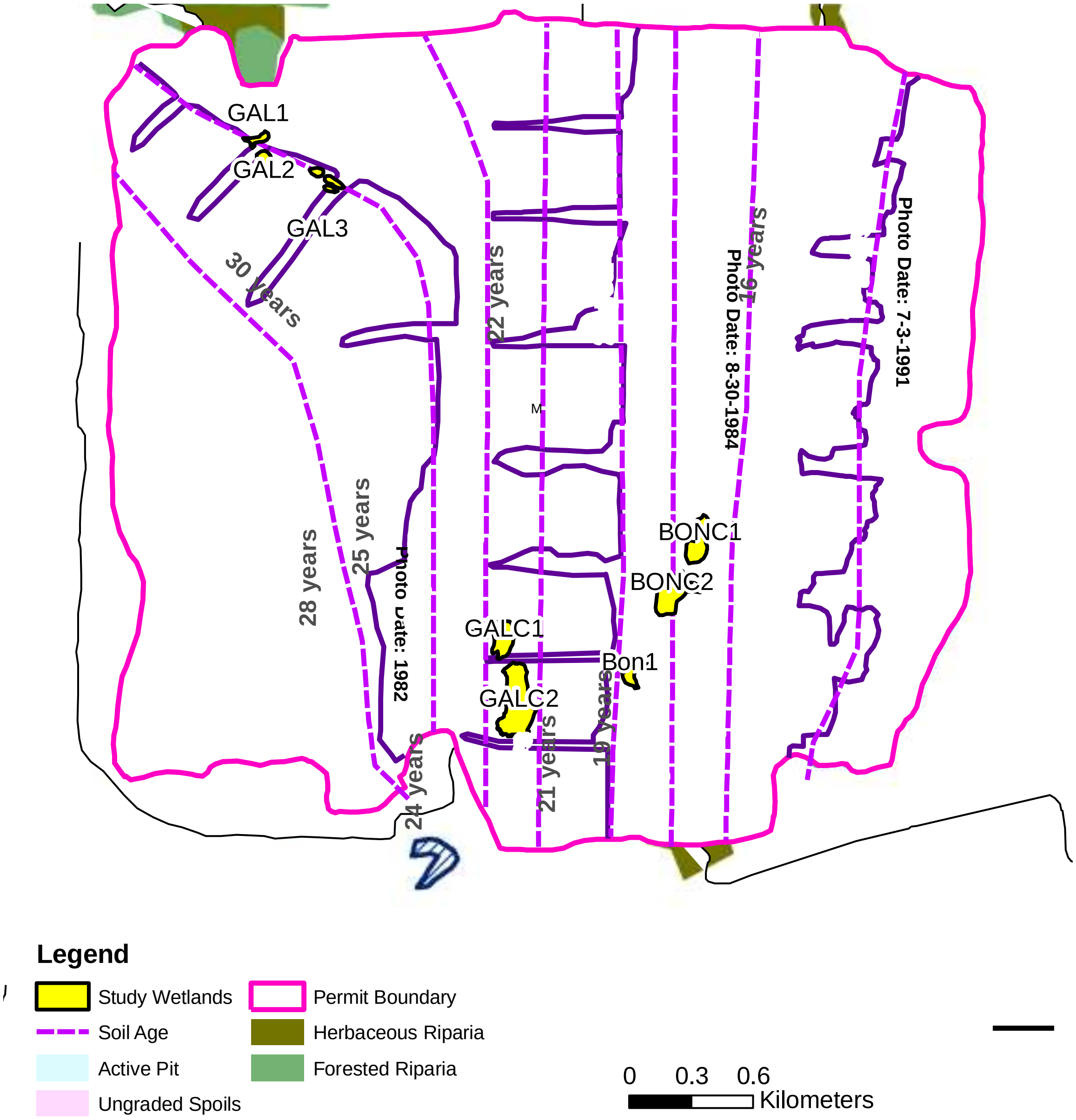


Figure 4. Soil age from aerial photos and Anderson (1987) at BS4N Mine.

Post-mining Geology and Soils

The final geology at surface mines in Southern Illinois is dependent on the character of the overburden and the reclamation/mining techniques used. Pedogenic horizons were segregated prior to mining and graded atop the remaining overburden that consisted of the crushed consolidated cyclotherm units overlying the deepest layer of coal that was extracted (Springfield, no. 7). When the consolidated cyclotherms are exposed to oxygen at the surface or are mixed into the segregated topsoil and subsoil, weathering of previously inert elements of the cyclotherms occurs. Coal within Pennsylvanian age cyclotherms is generally high in sulfur as a result of periodic inundation by the brackish Pennsylvanian sea that soaked the ancient peat with water high in sulfates and dissolved solids (Oertel 1980). Oertel (1980) discovered several cyclotherm units above and near the Herrin #6 coal seam at the nearby Captain and Burning Star #4 south mines that produced water high in total dissolved solids during leachate tests. Four of these units, located at depths of 6.3-7.5 m (Greenish black, calcareous, thin bedded shale), 11.3-12.5 m (medium to dark gray laminated shale), 15.4-15.9 m (black thin bedded shale with abundant pyritized fossils), and 18.9-19.8 m (silty, medium gray, very thinly bedded shale) below the subsoil produced water high in higher than normal (for the groundwater of the area) concentrations of chloride, zinc, and manganese. The leachate tests produced results similar to groundwater collected from wells established in nearby mine spoils (Oertel 1980).

Reconstructed minesoils were reflective of the original soil, but with higher bulk density and an initial lack of soil structure (Indorante 1981). At BS4N and Pipestone Creek, the riparian minesoils were classified as members of the Lenzberg (Fine-loamy, mixed, active, calcareous, mesic Haplic Udarents) and Swanwick (Fine-silty, mixed, active, nonacid, mesic Alfic Udarents) soils series (Williams et al., 2009).

Hydric soils and other indicators of wetland hydrology were found in the planned wetland areas and in the bottomland forest established in the floodplain of BS4N. For this study, the wetlands were classified as mined planned wetlands (MPW) or mined bottomland forest wetlands (MBFW) based on the reclamation plan. MPWs at BS4N are palustrine unconsolidated bottom (PUBGx) wetlands with an outer perimeter that meets the classification for seasonally inundated palustrine emergent marsh (PEMC) (Cowardin 1979). Water levels in the MPWs are controlled by concrete lined spillways and groundwater connections to the adjacent waterway. Most of the wetland area remains inundated year round except during droughts. There is a lack of persistent vegetation in the substrates that are only exposed during droughts. MBFWs are palustrine forested wetlands (Cowardin 1979) found in the flat areas of the floodplain where a hardwood forest was established as part of reclamation or through natural forest regeneration of an area reclaimed as “herbaceous wildlife,” a term used in the permit maps to describe areas planted with a mixture of grasses and forbs. The watershed to wetland area ratio of the MBFWs is much larger than the MPWs. MBFWs received considerable hydrologic input from runoff and from flooding.

Study Methods

WATER QUALITY

Stream grab sampling at the Denmark Mine began in June 1992 at three locations along the restored Pipestone Creek channel: R-1, R-2, and R-3. Sampling was also conducted above and below the restored channel at points L-7 and L-3. Conductivity, pH, D.O., and temperature were measured in the field and turbidity, TSS, TDS, total and dissolved iron, manganese, and sulfate were measured at first by MSL labs and later by Standard Laboratories. In 2002, Pike Environmental Consulting began sampling of the restored Bonnie and Galum Creek channels. Monitoring was conducted at two control points (GLA and BCA) and three sample points along Bonnie Creek: BCB2, BCB3, BCB4. Three points were also sampled along Galum Creek: GLC2, GLC3, and GLC4. Sampling was conducted once during the spring and once during the fall from 2002-2006. During the sampling of the reconstructed channel, pH, temperature, conductivity, and D.O. were measured in the field using a YSI model 556 water quality meter;

and TSS, TDS, Alkalinity, Acidity, SO_4, NO_3, Fl, Cl, Fe, Mn, Zn, and Pb were analyzed by Standard Laboratories (Freeburg, IL).

As part of this study, water quality grab samples were collected during winter, spring, and fall of 2012 and during the spring of 2013. Water quality sampling locations were selected from sampling that was done from 2002-2006 at the Burning Star #4 mine and from 1992–95 at the Denmark Mine. Samples were collected at the approximate sample location as L-7, R-1, R-2, R-3, and L-3 along Pipestone Creek used from 1992–95 (Figure 5); at the approximate sample locations of BCA, BCB2, BCB3, BCB4 along Bonnie Creek used from 2002-2006; and at the approximate sample locations of GLA, GLC2, GLC3, and GLC4 (Figure 6). The approximate locations were estimated from aerial photos and drawings provided in the monitoring reports since no geographic coordinates were available. A high amount of variability was identified at sample points BCB4 and GLC4 and attributed to visible groundwater seeps present at the sampling locations. Samples collected 2012-2013 were taken upstream from the seeps while it seemed that the 2002-2006 samples were collected downstream of the seeps. During the April 2013 sampling rounds, samples were collected both above and below the seeps to identify the magnitude of the variability due to the seeps.

During the 2012-2013 assessment, samples were collected in the center of the channel during high flow or at the thalweg during low flow. A YSI probe #7 was used to measure pH, water temperature, and conductivity and a YSI was used to measure D.O. Two samples were immediately placed on ice. A third was acidified using 2-3 mL of Nitric Acid. Two sample bottles including the acidified sample were sent to Standard Laboratories (IL) and analyzed for alkalinity, Fe, Mn, Pb, and Zn.

Water quality grab samples were analyzed for chemical and physical parameters via the reported methods (Table 1). Some analytes were tested in the SIUC FLOW lab (Carbondale, IL) and some were tested by Standard Labs (Freeburg, IL).

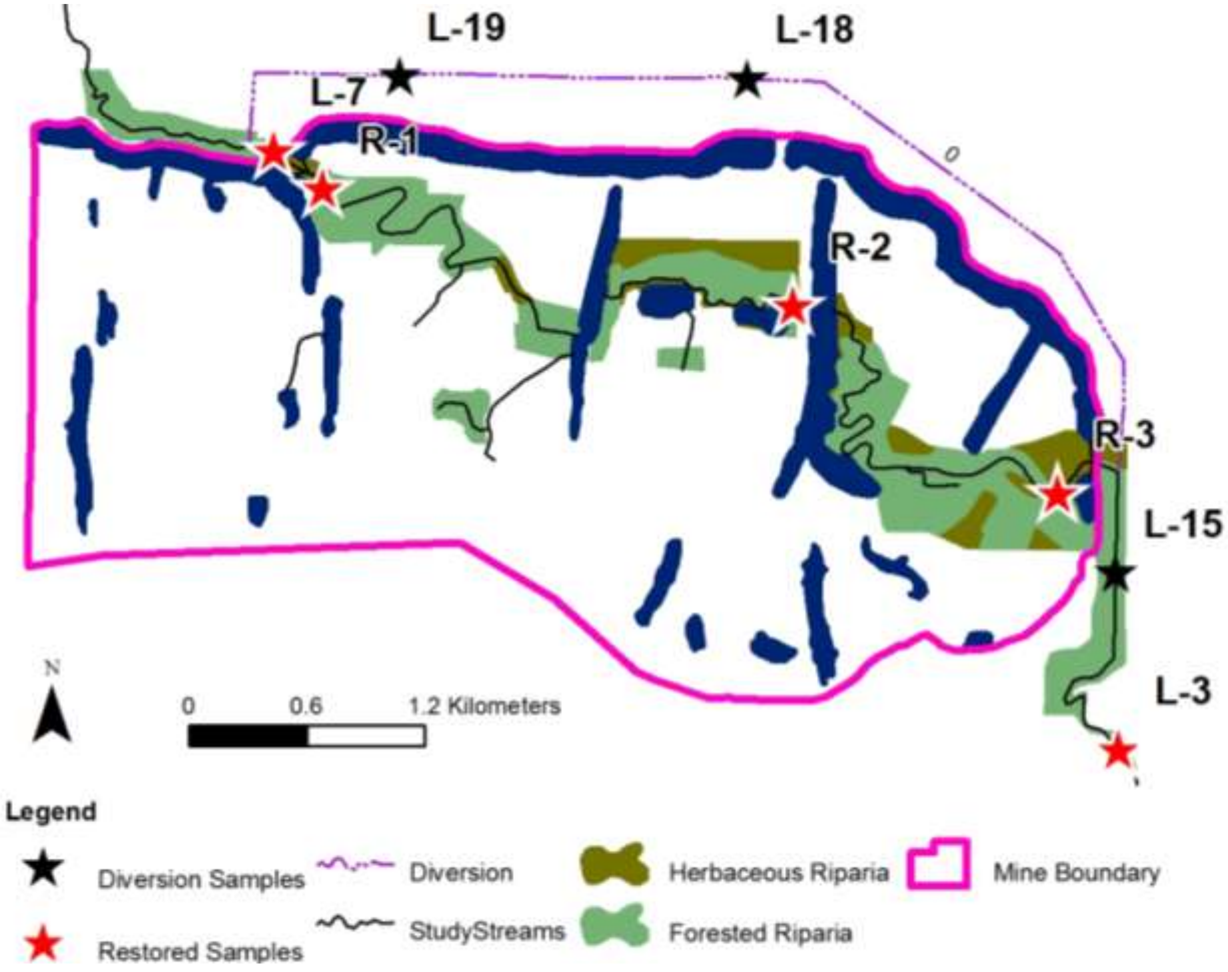


Figure 5. Water quality grab sample locations at Denmark Mine.

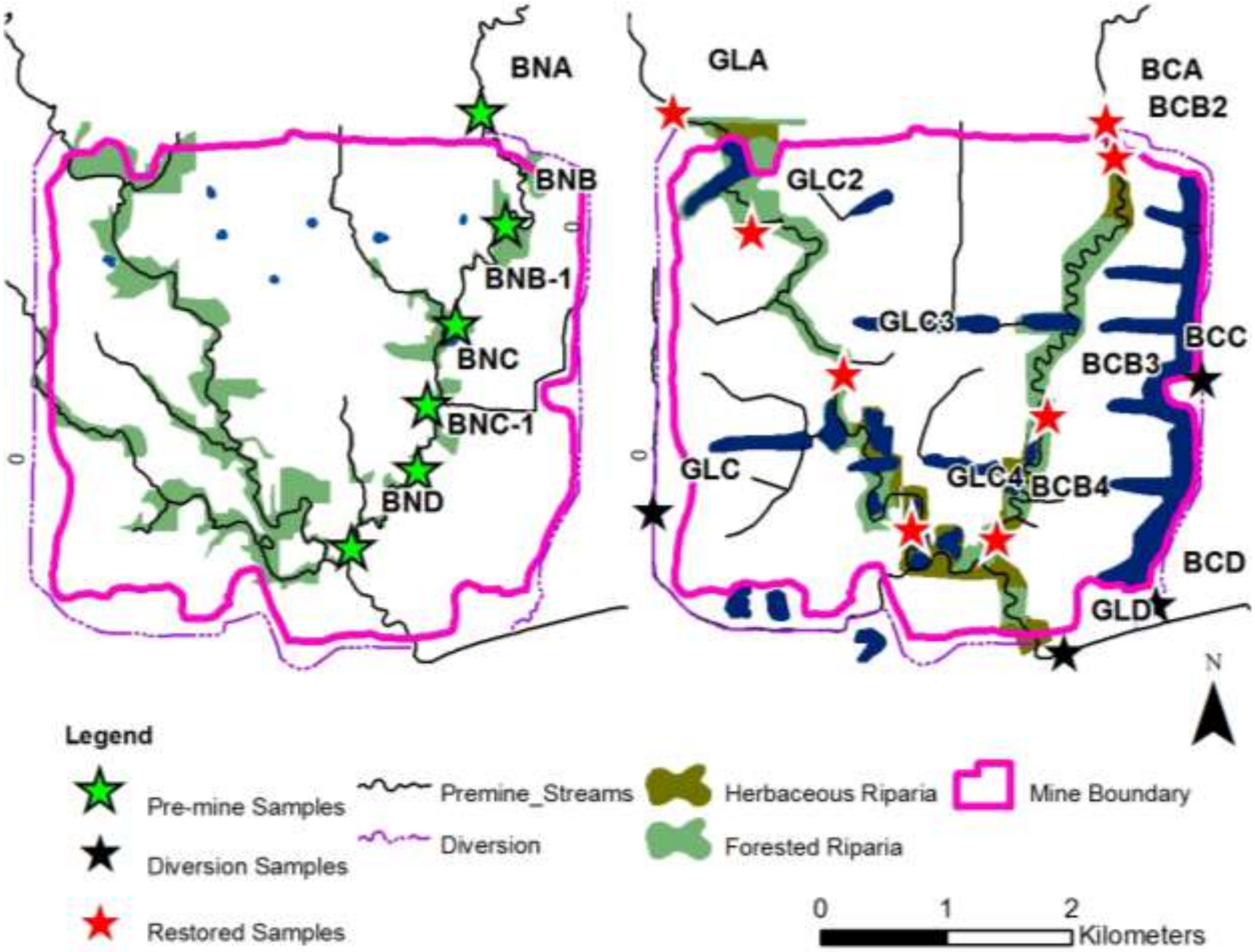


Figure 6. Current and historic water quality grab sample locations at BS4N Mine.

Table 1. Water quality parameters and methods of analysis.

Analyte	Method	Lab
Alkalinity	SM 2320 B – Titration*	Standard Labs
Chloride	EPA 300.1 Ion Chromatography **	FLOW (SIUC)
Fluoride	EPA 300.1 Ion Chromatography **	FLOW (SIUC)
Iron, total	EPA 200.7 ICP **	Standard Labs
Manganese, total	EPA 200.7 ICP **	Standard Labs
Zinc	EPA 200.7 ICP **	Standard Labs
Nitrate	EPA 300.1 Ion Chromatography **	FLOW (SIUC)
Sulfate	EPA 300.1 Ion Chromatography **	FLOW (SIUC)
Total Dissolved Solids	SM 2540 C*	FLOW (SIUC)
Total Suspended Solids	SM 2540 D*	FLOW (SIUC)

* methods used are from Eaton and Franson (2005)

** methods used are from USEPA (2000)

Water quality was analyzed to determine if there were any significant trends over time. To normalize the data, the data from the sample points along each creek were subtracted from their respective upstream control. The Mann-Whitney-Wilcoxon test was performed in SAS to test for step-trends in the data over time.

BCA was used as the control on Bonnie Creek. GLA was used as the control for Galum Creek. L-7 was used as the control for Pipestone Creek. All three controls were located in an unmined section of their respective creeks. The controls on Bonnie and Galum do not have any upstream mining impacts. The control on Pipestone Creek was located downstream of many older mines that were completed before the passage of SMCRA. It has many characteristics of non-acidic mining affected waters including high SO_4, TDS, and conductivity concentrations.

STORM EVENT SUSPENDED SOLIDS SAMPLING

Sediment sampling stations were established above and below the most upper inline incline pit on Galum Creek and the only inline incline pit on Bonnie Creek to measure the total influent and effluent sediment of storm events. ISCO 6712 and 3700 autosamplers (Lincoln, NE) were used to collect samples at 24 irregular intervals during storm events. The intervals were determined based on the duration of the rain and runoff. Samples were collected once every hour during the rising limb and at the peak of each hydrograph and once every 2-3 hours during the falling limb. A stilling well with a Global Water WL16 Level Logger (College Station, TX) transducer was installed near each sampling station to collect stage data that was matched to the sediment levels. During February of 2012, topographic data were collected using a Real Time Kinetic (survey-grade) GPS unit at several cross-sections above and below the two pits to get elevations of the gauging stations so they could be compared.

Water samples collected at the sediment stations by the ISCO autosamples were analyzed for Total Suspended Solids (TSS) similar to SM 2540 D (Eaton and Franson 2005). The method was adapted for samples with large particles sizes. The entire sample was poured in a beaker on a stirring plate. A vortex was maintained and a pipette was used to collect 100 mL of sample. The 100 mL sample was passed through a 0.45 µm filter which was subsequently dried and weighed to get the total solids in the sample. A sand/fine split was conducted on samples taken during the second storm event. The 100 mL samples were first passed through a 0.0625 mm screen. The water that passed through the screen was then poured through a 0.45 µm filter to measure the total amount of solids <0.0625 mm in diameter (fines). The screen was washed into a basin with DI water and the wash water was then poured through a 0.45 µm filter to measure the total amount of solids >0.0625 in diameter (sands).

MACROINVERTEBRATE SAMPLING

Macroinvertebrates were sampled in the original post restoration monitoring sites in May 2012 and September 2012 by SIU personnel. Little Galum Creek was sampled at two sites (LGA and LGD). Galum Creek was sampled at three sites (GLA-control, GLC2, and GLC3). Bonnie Creek was sampled at the BCA, BCB2, BCB3, and BCB4 monitoring sites. Pipestone Creek was sampled at the L-3, R-1, R-2, and R-3 monitoring sites. Little Galum Creek, Galum Creek, and Bonnie Creek were sampled with pipestove cores. Pipestone Creek was sampled with pipestove cores, a ponar sampler, and a surber smapler.

FISH SAMPLING

Fish sampling was led by IDNR Fisheries staff with assistance from other IDNR personnel along with SIUC, USGS and OSM. We employed two 20 ft x 4 ft minnow seines (1/4" mesh) and exhaustively sampled all available habitats within each of the eight fish sampling stations (station lengths varied from 300 to 420 ft in length and included representative pool, riffle and run habitats where available). Larger fish were identified, measured (TL) weighed (g) and release alive; smaller specimens (minnows, young sunfish etc) were preserved in 10% formalin for later identification in the laboratory.

HYDRAULICS AND SEDIMENT TRANSPORT

The three relocated streams did not have USGS stream gages on them, StreamStats (http://water.usgs.gov/osw/streamstats/illinois.html) was used to determine 2-, 10-, and 100-yr flows for rural Illinois watersheds (Soong and others, 2004; Ishii and others 2010) (Table 2). These flow values are useful for two aspects of the project. The first is as input data to the HEC-RAS steady-state hydraulic model to determine various hydraulic and sediment transport properties throughout each stream reach and for a wide range of flow conditions. The flow values are not adjusted for the reach downstream of the incline pits. This gives the worst case scenario of flow values in those reaches because the incline pits will have an influence on flow because of the storage in each pit.

Secondly, for the HEC-RAS sediment transport modeling, the input data includes a hydrograph for the quasi-unsteady state modeling. In this case the StreamStats flow values were used to adjust hydrograph data from a nearby USGS streamgage 05597500 (Crab Orchard near Marion, Ill. The corresponding 2-, 10-, and 100-yr flows for this streamgage were 47, 110, and 219 m^3/s, respectively. On September 6–7, 2009 and January 21-24, 1999, the Crab Orchard Creek streamgage recorded approximately a 2- and 10-yr flow, respectively. The hydrograph flow values for these floods were then adjusted using a ratio of the flow values for each magnitude flood to obtain a representative hydrograph at each of the sites. For example, the 2-yr flow at a site determined from StreamStats is divided by the approximate peak 2-yr flow at the gage to get a ratio. Then the gage hydrograph is multiplied by that ratio to scale the gage hydrograph to the site.

Table 2. Drainage area and flow values determined from StreamStats for the upstream extent of each restoration site.

Parameter	**Galum**	**Bonnie**	**Pipestone**
Drainage Area (km^2)	9.07	5.91	2.11
2-yr Flood (Q2) (m^3/s)	41.6	35.7	15.1
10-yr Flood (Q10) (m^3/s)	94.3	83.0	34.8
100-yr Flood (Q100) (m^3/s)	173.3	157.2	64.8

Also, an examination of flow records from the nearby Crab Orchard Creek streamgage was completed to determine the number of large flood events (2-yr or greater) that occurred in the area since restoration (Figure 7). As recently as 2010 and 2011, the streamgage has recorded 10-yr floods, and in 2008 recorded a greater than 100-yr flood showing that each site has experienced large floods since being built.

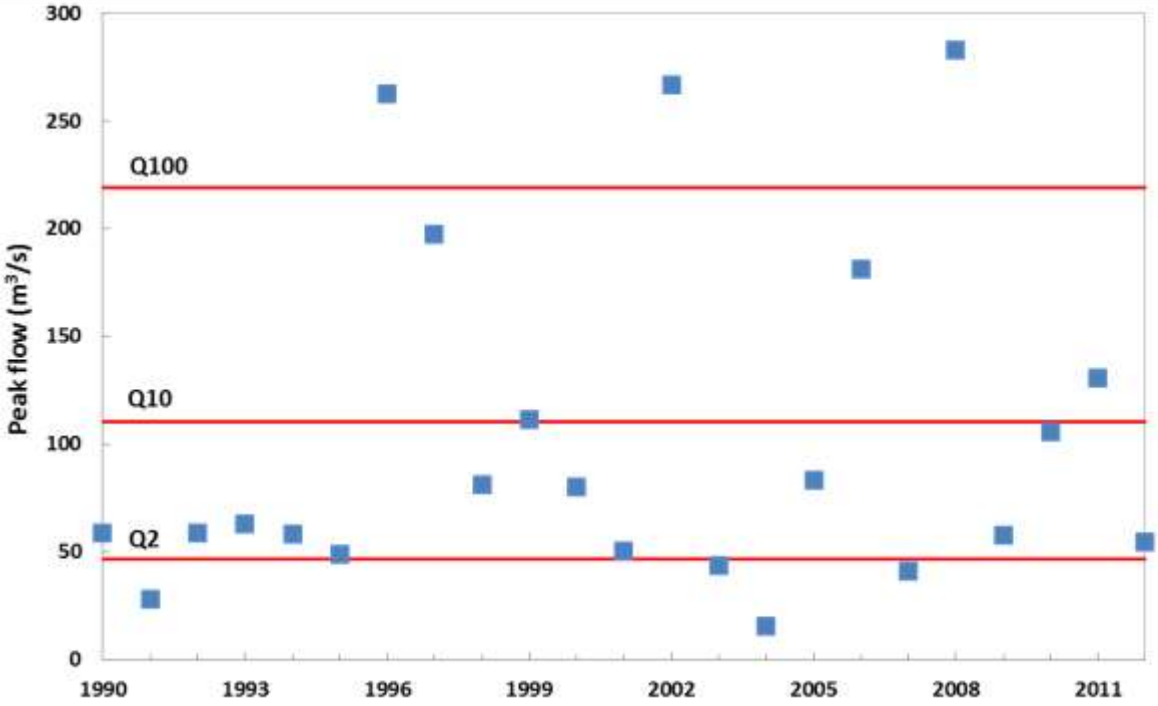


Figure 7. Annual peak flows at station number 05597500, Crab Orchard Creek near Marion, IL, from 1990 to 2012.

Before modeling the stream systems, they were qualitatively assessed from photographic documentation (Figures 8, 9, and 10), thalweg elevations in each reach, and the median bed material sizes upstream and downstream of the incline pits. The aerial views show three distinct restoration practices. Galum Creek has gentle meanders intermixed with occasional tight, elongated meanders and was built in-line with an incline pit (Figure 8). Bonnie Creek has very regular tight, sinusoidal meanders and also was built in-line with an incline pit (Figure 9), but has a much shorter contact time with the pit as compared to Galum Creek. Pipestone Creek has a similar meander style to Galum Creek, but differs from both Galum and Bonnie Creeks in that the incline pit is connected to the stream only by means of a side-channel weir (Figure 10). Overall, from the on-ground photos, Galum Creek, Pipestone Creek, and the downstream reach of Bonnie Creek appear relatively stable. Some bank erosion exists on the upper end of Galum Creek, but this reach was closest to an upstream agricultural ditch and highway bridge. Stability problems were apparent in the photos on the upstream reach of Bonnie Creek. Additional images from an aerial video taken from a helicopter in 2005 are shown in Appendix A. The images include the full reach of Bonnie from the confluence with Galum all the way to the intersection with Route 154. This includes the extent shown in 8 and gives a more comprehensive look at the reach. Also, a more quantitative discussion of stability is included in the Hydraulic and Sediment Modeling Methods and Results section.

The stream cross-section surveying and bed material sampling was completed in February 2012. Over 60 cross sections were surveyed and over 20 bed material samples were collected from the three sites. The cross-section survey was completed with a Trimble Global Positioning System (GPS). The survey consisted of mostly channel and near-bank points, but also included some flood plain points to help verify existing topographic data collected in 1997. The bed material sampling consisted of representative samples across the extent of the main channel approximately 15 cm deep. A full particle size analysis was completed on each bed material sample.

Hydraulic and sediment modeling help to quantify the physical stream assessments. Hydraulic modeling was completed for the selected reaches utilizing the HEC-RAS model (U.S. Army Corps of Engineers, 2010) to summarize steady-state velocity, shear stress, stream power, and size of bed materials moved. The flows used in each stream included a low flow (8.5 m^3/s), and the 2, 10-, and 100-yr flows (Q2, Q10, and Q100, respectively) for each stream as denoted in the Hydrology section.

The average main-channel shear stress and stream power for each site were determined in the model using the following equations and shows how slope and channel dimension are integral to the model results:

$\tau_{ch} = \gamma R_{ch} S_f$
where
τ_{ch} = main-channel shear stress
γ = the specific weight of water
R_{ch} = main-channel hydraulic radius ($R=A_{ch} / P_{ch}$)
S_f = average reach friction slope

$\omega_{ch} = \tau_{ch} V_{ch}$
where
ω_{ch} = main-channel stream power
V_{ch} = the main-channel velocity

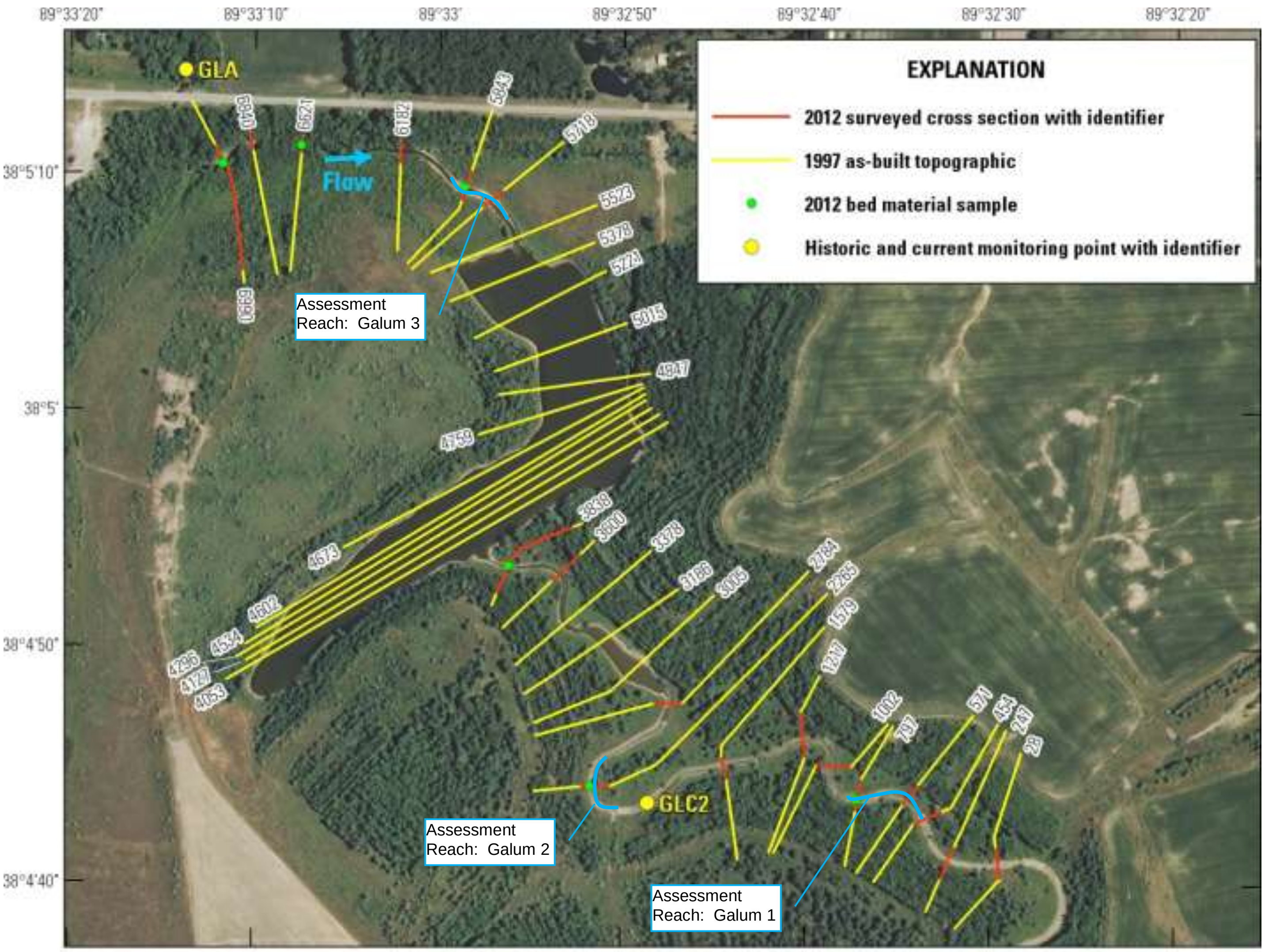
Also, to approximate the size of bed materials moved for various flows throughout the stream reaches Shields (1936) determined the threshold conditions for incipient motion of noncohesive material. Julien (1998) summarized in graphical and tabular format a Highway Research Board (1970) study relation between critical shear stress and median grain size on a flat surface (Table 3). Note that for a large range of particle sizes (sand-cobble), the critical shear stress value in Pascals is nearly equivalent to the particle size diameter that can be moved at that shear stress. Lastly, the entrenchment ratio was determined by dividing the top width (TW) at the 100-year flows by the main-channel TW at the 2-year flows, and gives some indication of whether the channel is entrenched.

Nine stream approximately 100 m segments were also analyzed both quantitatively and qualitatively for stream geomorphic and in-stream channel habitat parameters. Gradient, bank height, bank angle, pool depth, pool length, and number of riffles in each segment were determined using the surveyed cross-section and profile data. Rapid bioassessment protocol (RBP) scores were determined based on the May 2012 sampling event. The locations of the nine stream segments are shown in Figures 8, 9, and 10.

Table 3. Critical shear stress of various particle sizes (excerpt from Julien,1998).

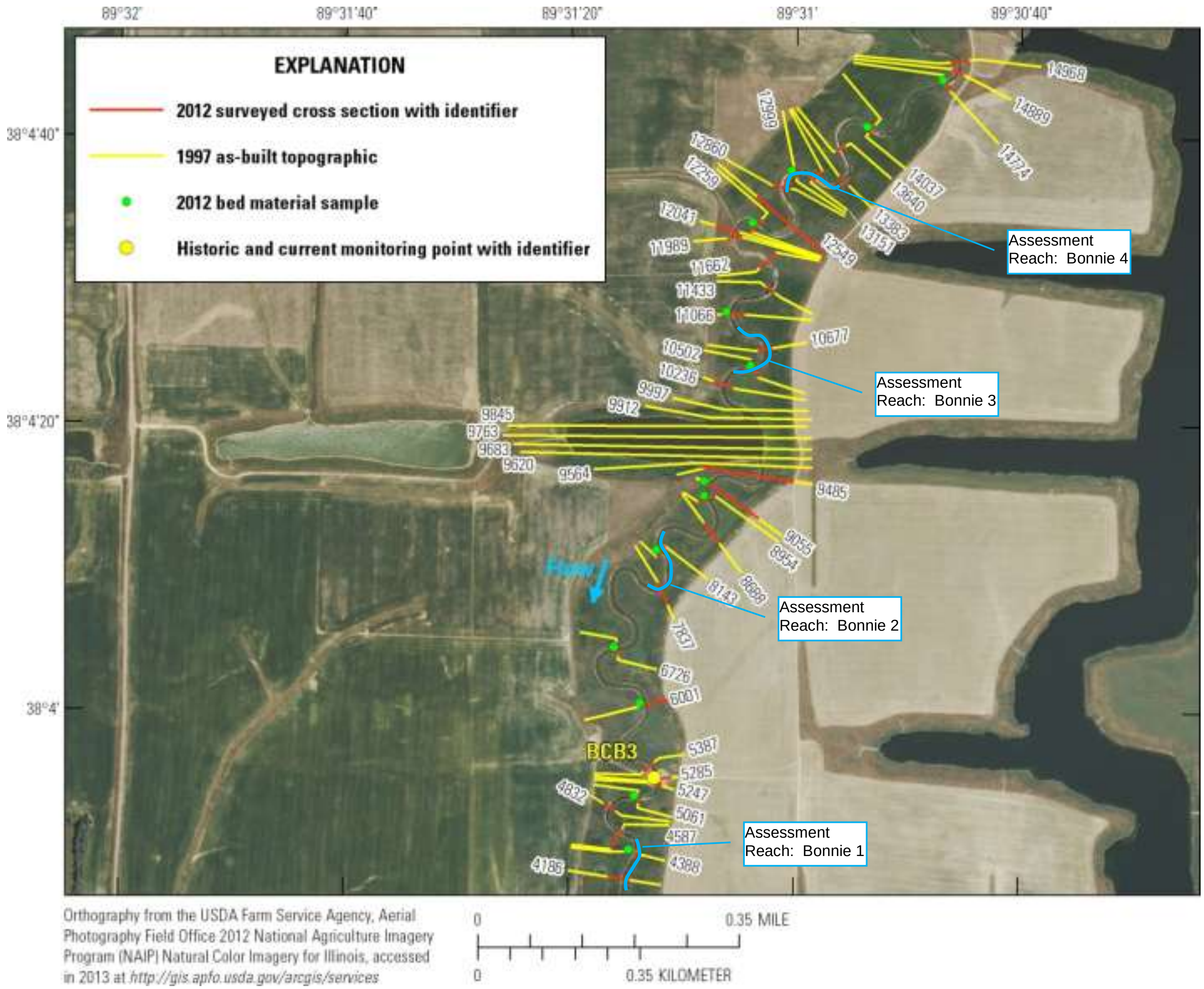
Class name	Diameter (mm)	τ_c (Pa)
Boulder		
Very large	>2,048	1,790
Large	>1,024	895
Medium	>512	447
Small	>256	223
Cobble		
Large	>128	111
Small	>64	53
Gravel		
Very coarse	>32	26
Coarse	>16	12
Medium	>8	5.7
Fine	>4	2.71
Very fine	>2	1.26
Sand		
Very coarse	>1	0.47
Coarse	>0.5	0.27
Medium	>0.25	0.194
Fine	>0.125	0.145
Very fine	>0.0625	0.11
Silt		

Coarse	>0.031	0.083
Medium	>0.016	0.065



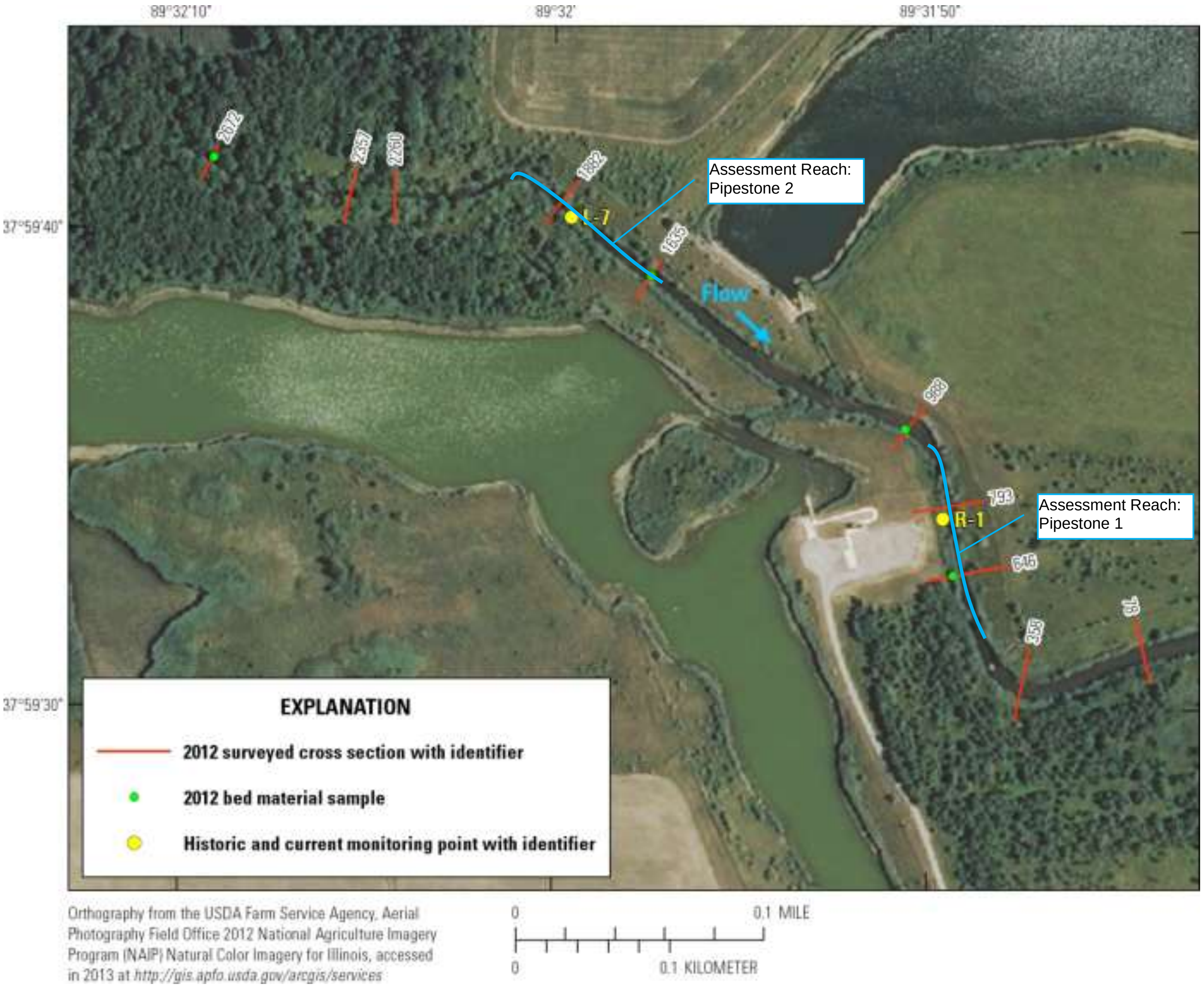
Orthography from the USDA Farm Service Agency, Aerial Photography Field Office 2012 National Agriculture Imagery Program (NAIP) Natural Color Imagery for Illinois, accessed in 2013 at *http://gis.apfo.usda.gov/arcgis/services*

Figure 8. Galum Creek surveyed cross sections and cross section extents obtained from topographic data, along with bed material and biologic monitoring points.



Orthography from the USDA Farm Service Agency, Aerial Photography Field Office 2012 National Agriculture Imagery Program (NAIP) Natural Color Imagery for Illinois, accessed in 2013 at *http://gis.apfo.usda.gov/arcgis/services*

Figure 9. Bonnie Creek surveyed cross sections and cross section extents obtained from topographic data, along with bed material and biologic monitoring points.



Orthography from the USDA Farm Service Agency, Aerial Photography Field Office 2012 National Agriculture Imagery Program (NAIP) Natural Color Imagery for Illinois, accessed in 2013 at *http://gis.apfo.usda.gov/arcgis/services*

Figure 10. Pipestone Creek surveyed cross sections, along with bed material and biologic monitoring points.

WILDLIFE HABITAT

Microhabitat

A list of focal wildlife species known to inhabit the study area was used to determine a set of 41 habitat variables to measure (Table 4). During 13 July-28 September 2012, habitat measurements were taken at 200 plots at Galum Creek (*n* = 45), Bonnie Creek (*n* = 35) Pipestone Creek (*n* = 47), and Little Galum Creek (*n* = 73) sites. Ground cover was measured by a modified version of the step-point method (Evans and Love 1957); steps were walked on 3 parallel 20-m transects spaced 10-m apart. Each step was classified to 1 of the 8 following cover types: bare ground, herbaceous (i.e., forb and grass), rock, woody debris, grass, shrub (stems <1.5 m in height), ground litter, or phragmites. Percent canopy cover was measured with a densiometer at the center of plots, held at elbow height, and facing each cardinal direction. Visual obstruction was measured by the average percent of a 1.5-m cover pole obscured from 10 m away in each cardinal direction (Griffith and Youtie 1988). The cover pole was divided into 3 sections: low (<0.5 m), mid (0.5-1.0 m), and high (1.0-1.5 m) with each section consisting of 10 5-cm sections. Understory and overstory stem densities were measured by the number of woody stems >1.5 m in height and>7.5 cm dbh for overstory trees or <7.5 cm dbh for understory trees. Trees counted were within arm's length of the same 3 transects as walked for ground cover. While categorizing overstory and understory stem densities, we also categorized whether the tree produced hard mast or soft mast. Hard-mast species were oak, hickory and American beech (*Fagus grandifolia*); other masting trees fell into the soft mast category. While walking transects, all downed logs within an arm's length were classified as either >7.5 cm or <7.5 cm and given a decay class ranking from 1-5 (adaptation from Maser et al. 1979). Class 1 logs had intact bark with twigs present and a portion of the tree was still elevated on support points above the ground. Class 2 logs had intact bark, twigs were absent and the texture of the tree was slightly softened; the tree was still elevated but sagging slightly. Class 3 logs had traces of bark, but no twigs, with the tree resting on the ground. Class 4 logs had no bark or twigs with the entire tree on the ground. Class 5 logs were oval-shaped, soft and powdery, and red-brown to dark-brown in color with the entire tree on the ground. Tree species with exfoliating bark, cavities, fissures, snags, and top-outs were also noted because they provide habitat for birds, bats, and other wildlife. Bank vegetation was categorized as the cover type that was the most prominent of the 8 cover types used as categories for ground cover.

Table 4. Microhabitat variables and description of sampling methods conducted at restored and unmined stream sites in Perry County, Illinois, during July–September 2012.

Variable	Description and Method	Citation
Overall vertical vegetation	Average percent of a 1.5-m high cover pole obscured from 10 m away in each cardinal direction. Cover pole divided by 30 5-cm sections. Data were recorded as the percentage of 5-cm sections obscured (>50%) by vegetative or structural cover.	Griffith and Youtie 1988
Low vegetative cover	Average percent of low portion (<0.5 m) of cover pole obscured by vegetative or structural cover.	Griffith and Youtie 1988
Mid-height vegetative Cover	Average percent of middle portion (0.5-1.0 m) of cover pole obscured by vegetative or structural cover.	Griffith and Youtie 1988
High vegetative cover	Average percent of high portion (1.1-1.5 m) of cover pole obscured by vegetative or structural cover.	Griffith and Youtie 1988
Bare ground cover	Same as herbaceous cover except for bare ground.	Evans and Love 1957
Herbaceous ground cover	Number of hits/number of steps x 100 using the step-point method. Steps were walked on 3 parallel, 20-m transects. Hits were identified as steps along the transect that resulted in the tip of one's shoe covering herbaceous ground cover.	Evans and Love 1957

Grass cover	Same as herbaceous cover except for grass cover.	Evans and Love 1957
Rock cover	Same as herbaceous cover except for rock cover.	Evans and Love 1957
Log/woody debris	Same as herbaceous cover except for log/woody debris	Evans and Love 1957
Litter cover	Same as herbaceous cover except for areas covered by leaf litter.	Evans and Love 1957
Shrub cover	Percent cover of shrub stems measured on the 3 20-m transects described above. Sampled height range was 1.5 m.	Evans and Love 1957
Canopy cover	Measured with densiometer at center of plots; held 30-45 cm from body at elbow height, facing each cardinal direction.	Kolowski and Woolf 2002, Pattishall and Cundall 2009
Understory stem density (USD)	Number of woody stems >1.5 m in height and <7.5 cm dbh counted within same 3 arm's-length transects as those used for ground cover (each covering 34 m^2)	Kolowski and Woolf 2002
Overstory stem density	Number of woody stems >7.5 cm dbh counted within 3 arm's-length transects. Transects used were same as USD.	Kolowski and Woolf 2002
Downed logs >7.5cm	Visual count, then assign decay class	Faccio 2003, Saab 1999
Downed logs <7.5cm	Visual count, then assign decay class	
Log decay class	1 = freshly fallen, supported above soil by branches 2 = structurally sound, bark covered 3 = relatively intact, beginning to rot and lose bark, resting on soil 4 = soft with little bark remaining 5 = almost completely incorporated into the soil	Maser et al. 1979
Hard/soft mast	Visual account of species 1=Soft Mast, 2=Hard Mast	Nupp and Swihart 2006
Roost tree	Number of standing dead snags=S and top-outs=TO	Watrous et al. 2006
Cavities/bark/split	Presence of tree species with loose bark, cavities, and splits	Watrous et al. 2006

Submerged vegetation	Y/N; Visual presence	Fuselier and Edds 1994
Bank cover	Percentage; categories same as those used for ground cover	Pattishall and Cundall 2009

We first tested for differences in variable values among our 4 study sites using Kruskal-Wallis ANOVAs and used the Wilcoxon Two-Sample Test for pairwise comparisons when overall ANOVAs were significant. We then assessed correlations among significant habitat variables using Spearman rank correlations, to further consider only uncorrelated variables ($\alpha = 0.05$). All statistical analyses were performed using SAS 9.3.

Macrohabitat

We assessed macrohabitat conditions for restored sites only (Galum Creek, Bonnie Creek, Pipestone Creek). ArcMap 10.0 was used to make all land cover computations and Microsoft Excel 2010 was used to calculate area, perimeter, and distance calculations (Table 5). Land cover boundaries of the riparian area for streams were derived by hand digitizing a high-resolution base-map layer using UTM coordinate system PCS: NAD 1983 CORS96 UTM Zone 16N. We classified land cover polygons into 1 of 7 different cover types within the restored stream buffer at each study site: forest, mixed understory, grass, open water, wetland, mowed areas, and roads. Forested areas consisted of primarily tree cover, while mixed understory was comprised of scattered understory trees interspersed with grass or herbaceous cover that, under normal and historic conditions, would mature to hardwood forest. Open water included incline pits and ponds, while wetlands were shallow and/or ephemeral water bodies. The snapping tool in ArcMAP was used while constructing land cover polygons to ensure that all features created were connected to each other, and the tracing tool was used to make new shapes that followed the borders of the previously-drawn features. After all polygons were constructed, the dissolve geoprocessing tool in ArcMap was used to reduce the number of polygons by connecting adjacent boundaries of identical land cover. The geometry calculator within the attribute table was used to calculate surface area (ha) and edge length (km) for the 7 different cover types. The maximum and minimum widths (m) of polygons were determined by measuring from edge to edge for shapes that were approximately as long as wide and through the center for longer, more narrow corridors. Connectivity of patches was determined by the average distance of gaps between patches of forest, mixed understory, grass, and wetland cover types. Average patch connectivity was calculated by the average distance between patches of the same cover types, for example, from one patch of forest to the next. These variables were used to assess quality of macrohabitat for wildlife without a statistical comparison among sites.

Table 5. Macrohabitat variables assessed at restored stream sites in Perry County, Illinois, 2012-13.

Variable	Description
# Patches	Total number of patches of the same cover type occurring at the same stream
Total patch area	Total area (ha) of forest, mixed understory, grass, wetlands, open water, roads, or mowed area
Total edge	Total perimeter (m) of forest, mixed understory, grass, wetlands, open water, roads, or mowed area patches
Patch distance	Distance (m) to nearest patch of the same cover type
Mean patch distance	Mean distance (m) to nearest patch of the same cover type
Maximum patch distance	Maximum width (m) across patch
Minimum patch distance	Minimum width (m) across patch

Riparian Wetland Soils Sampling

Twelve wetland sites at the BS4N and Little Galum Creek riparian area were chosen for assessment, including four MPWs, four MBFWs, and four un-mined natural wetlands (NWs) (Table 6) (Figure 11). Twelve MPWs exist at BS4N according to the final as-built reclamation plan submitted in 2005. Ten MPWs are located adjacent to Galum Creek and two are adjacent to Bonnie Creek. The two MPWs adjacent to Bonnie Creek were selected to provide a representation of more recently constructed soils (~15 years ago). Two MPWs with similar morphology were chosen from the riparian corridor of Galum Creek to represent earlier constructed soils (~25 years ago). Approximately 120 ha of riparian buffer was reconstructed at the two mines (Nawrot 2011), but only selected areas exhibit wetland characteristics during field investigations. Contiguous forested wetland areas within the Bonnie or Galum riparian areas >0.1 ha were considered for site selection. Three sites were identified within the Galum riparian area but only one site that met the criteria above could be found along Bonnie Creek. The Little Galum Creek riparian area was chosen as a representation of natural wetlands that were found at the BS4N prior to mining. Five NW sites were identified within the state property boundary and four were selected that were easily accessible via trails. The NWs were selected so that transects could include PFO1A (temporarily inundated) and PFO1C (seasonally inundated) areas. Wells and IRIS tubes were installed in each wetland to verify that hydric conditions were being met. Within each transect block a monitoring well screened to 50 cm below the mineral soil surface was installed late March through early April 2012, and monitored every two weeks from April 16th – November 31st 2012. From December 2012 – April 2013, the water levels were monitored once a month. At each sample point samples were collected using a 5 cm auger and split into surface 15 cm and 15-30 cm depths. A second sample was taken from the surface 10 cm using an impact driven corer. IRIS tubes were created according to Jenkinson and Fransmeier (2005). From April 16–18, 2012, IRIS tubes were inserted into the soil at each upper sample point by first creating a pilot hole with a 1.27 cm diameter soil push probe. On November 26, 2012 the tubes were removed and stored in a cool dry area for future analysis.

Table 6. Wetland sampling area locations, soil age, size, and watershed area.

Wetland area	Treatment Class	Lat (dd)	Long (dd)	Soil Age (years)	Size (km^2)	Watershed (km^2)
GAL1	MBFW	38.080518	-89.546028	28	0.00321	0.0408
GAL2	MBFW	38.078802	-89.542034	28	0.00465	0.0123
GAL3	MBFW	38.079559	-89.545478	28	0.00105	0.0525
GALC1	MPW	38.058720	-89.532437	25	0.00936	0.0287
GALC2	MPW	38.055909	-89.531824	25	0.03390	0.0551
BON1	MBFW	38.057239	-89.525484	21	0.00867	0.0347
BONC1	MPW	38.062799	-89.521813	19	0.01120	0.0672
BONC2	MPW	38.060407	-89.523414	19	0.01230	0.7870
LGAL1	NW	38.018040	-89.439554	N/A	0.01210	0.0370
LGAL2	NW	38.017704	-89.436491	N/A	0.00873	0.0235
LGAL3	NW	38.026255	-89.435087	N/A	0.00204	0.0126
LGAL4	NW	38.026991	-89.431518	N/A	0.00250	0.0136

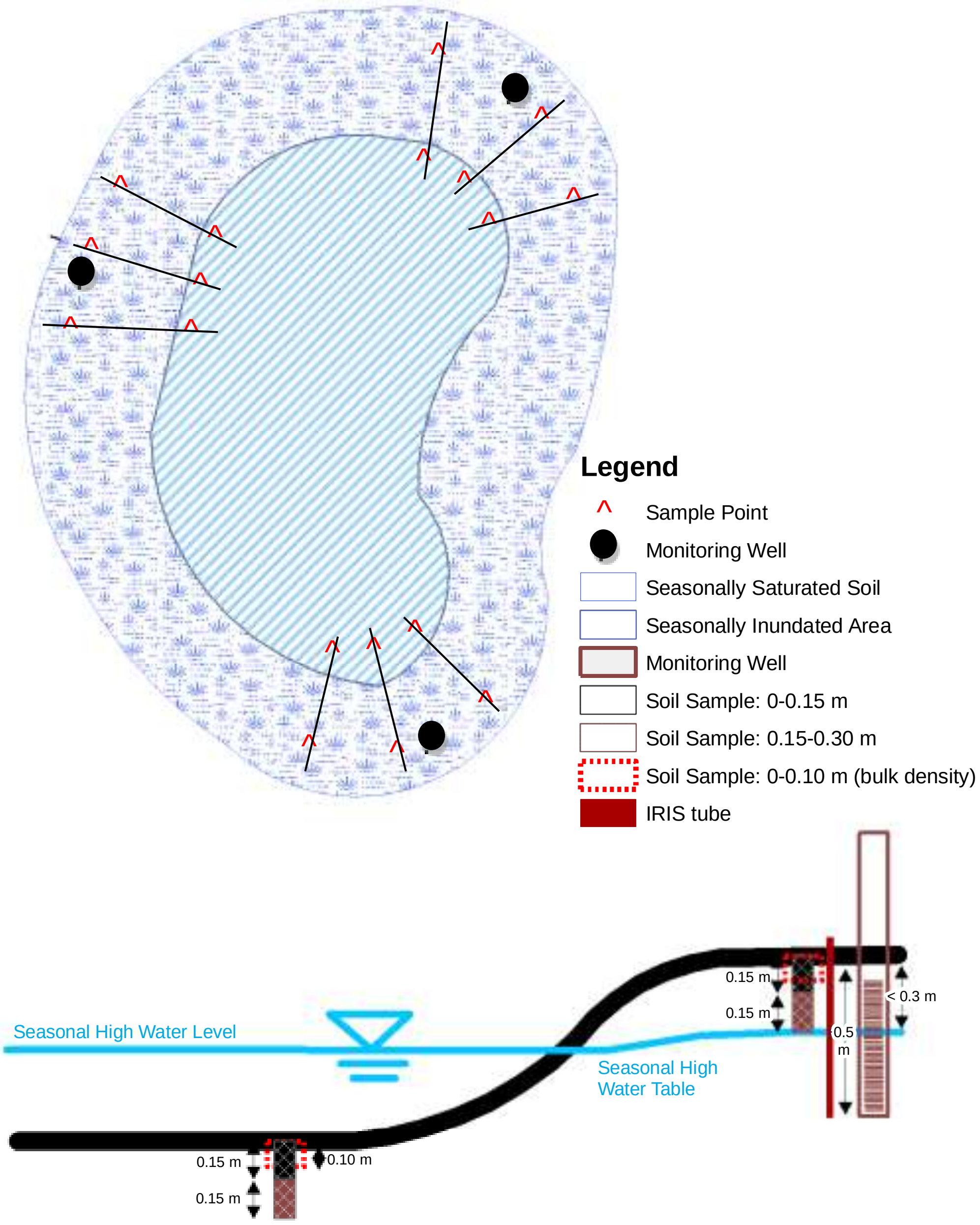


Figure 11. Wetland sampling plan in cross-section and planimetric views.

Soil samples collected via auger were air-dried, ground with a Dynocrush soil crusher (Custom Laboratory Equipment, Inc., Orange County, FL), and sieved through a 1 mm sieve. A transect was randomly selected from each block by drawing sample ID's from a box and all four samples from the selected transect were analyzed for soil texture. At least 100 g from each of the 432 samples was separated and shipped to Brookside Laboratories (New Knoxville, OH) where samples were analyzed for pH (McLean 1982) and SOM (Schulte and Hopkins 1996). Percent Carbon and Nitrogen and the C:N ratio was analyzed using a thermo C:N autoanalyzer (Milan, Italy) via dry combustion. (Jones 2001). The hydrometer method was used for soil texture analysis (Jones 2001).

Gravimetric soil moisture (GSM) and bulk density (ρ_b) was calculated from the measurements of the soil sample taken with the impact driven corer. GSM was calculated by dividing the wet soil weight minus the oven dry weight by the oven dry weight. ρ_b was calculated by dividing the oven dry weight by the volume collected using the corer (231.67 cm^3). Previous studies comparing restored wetlands to natural wetlands have identified difference based on elevation and soil depth, thus soils samples were split into different depths and into lower or upper sample points. Samples were compared to the equivalent depth and sampling location among treatment groups, producing four tests for each parameter that was measured at both depths and at both sample locations: upper surface 15 cm, upper 15-30 cm depth, lower surface 15 cm, and lower 15-30 cm depth. Outliers were identified as all samples that were more than three standard deviations different from the mean of each depth and sample location. pH, SOM, total C (%), total N (%), C:N ratio, bulk density, and soil texture were analyzed with SAS using a general linear model (GLM) procedure with multiple comparisons of treatment. A post-hoc Tukey's test was used in cases of significant treatment effect, in order to determine which treatment comparisons were significantly different. Residuals from the ANOVA procedure were visually compared to a normal quantile plot to determine normality of data. Percentage values (C, N, SOM, and soil texture) were transformed using the arcsin (square root) transformation to meet the assumptions of ANOVA. N and C/N did not meet ANOVA assumptions after transformation and removal of outliers. N and C/N were compared using the

Kruskal-Wallis rank based test. In cases of significant treatment, the N and C/N values were rank-transformed and a post-hoc Tukey's test was used to determine which treatments were significantly different.

Results and Discussion

WATER QUALITY

Water from the upstream watershed constitutes the main source of hydrology in the restored streams. However, as the restored streams pass through the mined areas the processes affecting in-channel and overland flow contribute increasingly to the water quality. Sample points along the restored channel reflect between 0.3 km^2 and 20 km^2 of runoff from surface mined lands. The runoff passes primarily through the restored riparian buffers and large incline pits. Groundwater seeps in a few locations cause discrete changes in the water quality over a small distance. Water quality is also affected by processes occurring in-channel including sediment processes within the restored channels and several large incline pits constructed inline of stream flow.

The most current water quality data was assessed first to determine if water quality in the relocated stream segments was different than that of the unmined control segments. Water quality was measured during four sampling periods. One sampling period (1/27/12) reflected a large storm event. Flows ranged from 50 cubic feet per second (CFS) at the upstream control of Bonnie Creek (BCA) to 85 CFS at R-2 along the restored channel of Pipestone Creek. The other three sampling events were during baseflow or low flow. During the sampling event on 5/7/12, flow at many sample points along Bonnie and Galum Creek was restricted to interstitial movement between pools.

Sampling within the study area represents a large span of time across multiple sampling points and reaches, but the current water quality data by itself only provide a snapshot in time, rather than a continuous record. Although, the data are comprehensive, the lack of a continuous record of several years makes the use of statistical analyses based on sample point location less accurate and reliable. Instead, the range of water quality values between the control points and the sample points located along the relocated streams were compared to identify hot spots of good or poor water quality. Historic water quality prior to surface mining is also provided as a benchmark for water quality in the region.

To determine if any parameter increased or decreased since the original post-mining sampling, the data were normalized and tested for significant step trends. The data were normalized to remove seasonal variation by subtracting the value for each parameter from value of the control, thus providing the deviation from the control at each sample point along the relocated channels. The majority of the parameters that showed step trends with time occurred at the BCB4 sample point where considerable sample variability was found due to the presence of visible groundwater seeps coming from the bottom of the channel. When one sample downstream of the seeps was substituted for the sample taken upstream of the seeps during the 2012-2013 sampling, the test for step-trend was no longer significant except for sulfate.

Historic Pre-Mining Stream Water Quality

A water quality survey of Bonnie (Sauer 1985) and Little Galum Creeks (Saurer 1985) measuring water temperature, pH, D.O., conductivity, TSS, TDS, Alkalinity, total Fe, Mn, and SO_4 was conducted in 1983-1984. Little Galum was also monitored again in 1985 and in spring 1987. In 1983, mining had begun at the BS4N area, but Bonnie Creek had not yet been diverted or cleared of vegetation. Between two and four stations along Bonnie Creek were monitored once in the spring and once in the fall each year. Along Little Galum Creek, 1-3 stations were monitored once each spring and fall. Only two samples at Bonnie Creek were reported as being outside the limits of the Illinois Pollutions Control Board’s “general use” range (Illinois Pollution Control Board 2009) when the streams were flowing (low D.O. was reported at several sites that were nearly dry and consisted only of stagnant pools). A sample near the upstream limit of Bonnie in the BS4N area had a pH of 5.6 but was not considered directly lethal to aquatic life. Samples high in SO_4 (1120 mg L^{-1}), conductivity (2050 µs cm^{-1}), and TDS (1821 mg L^{-1}) taken in October 1983 indicate possible runoff from the adjacent mining. Monitoring at Little Galum Creek revealed SO_4 and TDS levels above the "general use" limit at the time (500 mg L^{-1} for sulfates and 1000 mg L^{-1} for TDS) indicating possible historic mining impacts. Levels did not exceed the current standard for sulfate or TDS. The range of values reported in the two studies is shown in Table 7. Both streams were characterized in the report as being moderately disturbed, but with an intact pool-riffle sequence and riparian corridor.

Table 7. Summary of 1983–85 water quality from six locations along Bonnie Creek and two locations along Little Galum Creek.

	Bonnie Creek		Little Galum Creek	
	Min	Max	Min	Max
Water temperature (°C)	15	24	11	19
pH	5.4	7.8	7.6	8.9
D.O. (mg L^{-1})	1.6	11.3	4.6	10.7
Conductivity (µs cm^{-1})	260	2050	550	1200
TSS (mg L^{-1})	22	158	4	36
TDS (mg L^{-1})	181	1821	380	1450
Alkalinity, as $CaCO_3$ (mg L^{-1})	30	224	89	183
Iron, total (mg L^{-1})	0.45	4.3	0.12	0.7
Mn (mg L^{-1})	0.13	3.00	0.03	1.52
SO_4 (mg L^{-1})	38	1120	165	715

Stream Water Quality 2012–13

Based on a snapshot survey of water quality at grab sample locations at the control points and along the restored channels, water quality in the restored streams was similar to water quality at the unmined control points, and to the historic water quality prior to mining (Tables 8, 9 and 10). However, several parameters were different at the further downstream sample points along the restored streams. This is mostly consistent with the post-restoration monitoring snapshot which showed the water quality to be similar to other nearby streams with the exception of a few parameters.

Even as much as thirty years after restoration (Pipestone Creek), a few parameters indicated lower water quality than nearby streams. Maximum water temperature was higher within the restored channel of Bonnie, Galum, and Pipestone Creek. The increased water temperature is likely a result of the increased solar radiation from reduced canopy cover within the restored streams compared to the unmined control points. The incline pits may have contributed to the increased temperature by providing more surface area to absorb solar radiation compared to a natural linear stream feature. Maximum values for specific conductivity and sulfate were higher in the restored stream than the control when the sample was taken from the alternate BCB4 location (BCB4A) downstream of the groundwater seep. On the other hand, the maximum values for specific conductivity and sulfate were nearly the same in Galum Creek even when the samples were collected downstream of the visible seeps. During the post-restoration monitoring these values were much higher at the GLC4 sample point than the control point and may indicate some dilution of the polluted groundwater over time.

Some parameters showed the potential for improved water quality within the restored streams. Bonnie Creek had maximum nitrate levels in the restored stream that were slightly lower than at the control, and Galum Creek had considerably lower maximum nitrate values, though the control point was never above the water quality standard for nitrate-N in Illinois of 10 mg L^{-1}. Maximum sulfate, total dissolved solids, and specific conductivity levels were considerably lower at the control point immediately downstream from the restored Pipestone Creek. Although this sample point is located on an unmined reach, it reflects water quality immediately upstream and seems to indicate that sulfate and other dissolved ion concentrations decrease along the restored Pipestone Creek.

Table 8. Summary of 2012–13 water quality along Bonnie Creek.

	Bonnie Creek Control (BCA)				Bonnie Creek Restored Channel (BCB2, BCB3, BCB4)			
	Min		Max		Min		Max	
Water temperature (°C)	3.9	1/27/12	23.1	9/11/12	3.9	BCB2 1/27/12	27.2	BCB4 9/11/12
pH	6.72	5/7/12	7.77	4/5/13	6.44	BCB4 5/7/12	8.52	BCB3 4/5/13
D.O. (mg L^{-1})	2.3	5/7/12	13.2	1/27/12	4.6	BCB3 5/7/12	14.9	BCB3 4/5/13
Specific Conductivity (µs cm^{-1})	191	1/27/13	696	9/11/12	160	BCB4 1/27/12	3348	BCB4A 4/5/13
TSS (mg L^{-1})	31	5/7/12	62	4/5/13	20	BCB2 5/7/12	94	BCB4 1/27/12
TDS (mg L^{-1})	257	9/11/12	648	4/5/13	200	BCB2 1/27/12	792	BCB2 5/7/12
Alkalinity, as $CaCO_3$ (mg L^{-1})	74	1/27/12	164	5/7/12	48	BCB2 1/27/12	158	BCB2 5/7/12
Chloride (mg L^{-1})	9.7	4/5/13	25.4	5/7/12	8.7	BCB4 1/27/12	49.2	5/7/12
Fluoride (mg L^{-1})	0.15	1/27/12	0.34	4/5/13	0.14	BCB2 1/27/12	0.48	BCB4A 4/5/13
Nitrate (mg L^{-1})	0.59	1/27/12	2.4	9/11/12	0.33	BCB4 5/7/12	1.97	BCB3 9/11/12
SO_4 (mg L^{-1})	93	9/11/12	402	4/5/13	85	BCB4 1/27/12	1047	BCB4A 4/5/13
Iron, total (mg L^{-1})	0.6	4/5/13	3.11	1/27/12	0.81	BCB2 5/7/12	5.66	BCB3 1/27/12
Mn (mg L^{-1})	0.15	1/27/12	0.25	4/5/13	0.08	BCB3 9/11/12	1.03	BCB2 5/7/12
Zn (mg L^{-1})	0.02	5/7/12	0.04	9/11/12	0.02	BCB2 4/5/13	0.05	BCB3 9/11/12

Table 9. Summary of 2012–13 water quality along Galum Creek.

	Galum Creek Control (GLA)				Galum Creek Restored Channel (GLC2, GLC3, GLC4)			
	Min		Max		Min		Max	
Water temperature (°C)	3.8	1/27/12	18.8	9/11/12	4.1	GLC2 1/27/12	26.5	GLC2 9/11/2012
pH	6.67	5/7/12	7.54	4/5/13	6.44	BCB2 5/7/12	8.05	GLC4 9/11/12
D.O. (mg L^{-1})	6.2	5/7/12	12.9	1/27/12	6.8	GLC4 5/7/12	12.6	GLC2 1/27/12
Specific Conductivity (µs cm^{-1})	183	1/27/13	525	4/5/13	97	GLC2 1/27/12	620	GLC4A 4/5/13
TSS (mg L^{-1})	29	9/11/12	88	5/7/12	8	GLC3 5/7/12	103	GLC2 1/27/12
TDS (mg L^{-1})	191	1/27/12	503	4/5/13	155	GLC2 1/27/12	429	GLC3 5/7/12
Alkalinity, as CaCO$_3$ (mg L^{-1})	62	1/27/12	156	4/5/13	34	GLC3 1/27/12	116	GLC3 5/7/12
Chloride (mg L^{-1})	10.0	9/11/12	26.5	5/7/12	5.5	GLC2 1/27/12	36	GLC3 5/7/12
Fluoride (mg L^{-1})	0.15	9/11/12	0.25	5/7/12	0.15	GLC2 1/27/12	0.27	GLC2 5/7/12
Nitrate (mg L^{-1})	0.23	4/5/13	3.54	5/7/12	0.43	GLC3 9/11/12	0.93	GLC2 5/7/12
SO$_4$ (mg L^{-1})	70	1/27/12	254	4/5/13	21	GLC2 1/27/12	255	GLC4A 4/5/13
Iron, total (mg L^{-1})	0.70	4/5/13	3.76	1/27/12	0.45	GLC3 9/11/12	6.49	GLC3 1/27/12
Mn (mg L^{-1})	0.17	1/27/12	0.341	5/7/12	0.03	GLC3 9/11/12	0.306	GLC2 9/11/12
Zn (mg L^{-1})	0.02	1/27/12	0.04	9/11/12	0.01	GLC3 9/11/12	0.04	GLC2 9/11/12

Table 10. Summary of 2012–13 water quality along Pipestone Creek

	Pipestone Creek Control (L-7: upstream, L-3: downstream)				Pipestone Creek Restored Channel (R-1, R-2, R-3)			
	Min		Max		Min		Max	
Water temperature (°C)	5.8	L-3 1/27/12	24.3	L-3 5/8/12	5.7	R-1 1/27/12	26.1	R-2 5/8/12
pH	6.99	L-3 1/27/12	7.96	L-3 5/8/12	7.05	R-1 1/27/12	7.83	R-3 4/5/13
D.O. (mg L^{-1})	4.3	L-3 5/8/12	13.0	L-3 4/5/13	5.9	R-3 5/8/12	14.2	R-2 4/5/13
Specific Conductivity (µs cm^{-1})	963	L-3 1/27/12	3820	L-7 5/8/12	682	R-2 1/27/12	3629	R-1 9/13/12
TSS (mg L^{-1})	31	L-3 1/27/12	189	L-7 5/8/12	19	R-1 1/27/12	497	R-1 5/8/12
TDS (mg L^{-1})	1203	L-3 1/27/12	3021	L-7 5/8/12	841	R-2 1/27/12	2900	R-1 5/8/12
Alkalinity, as $CaCO_3$ (mg L^{-1})	166	L-3 4/5/13	398	L-7 5/8/12	116	R-2 1/27/12	394	R-1 9/13/12
Chloride (mg L^{-1})	5.7	L-3 4/5/13	29.9	L-7 9/13/12	0.4	R-1 4/5/13	37.9	R-2 9/13/12
Fluoride (mg L^{-1})	0.21	L-3 1/27/12	0.40	L-7 9/13/12	0.2	R-2 1/27/12	0.38	R-1 9/13/12
Nitrate (mg L^{-1})	<0.05	L-3 4/5/13	0.80	L-7 9/13/12	<0.05	R-3 4/5/13	1.38	R-1 4/5/13
SO_4 (mg L^{-1})	639	L-3 1/27/12	2100	L-7 5/8/12	744	R-1 1/27/12	4669	R-1 9/13/12
Iron, total (mg L^{-1})	0.70	L-7 4/5/13	1.32	L-3 1/27/12	0.38	R-3 9/13/12	3.44	R-2 9/13/12
Mn (mg L^{-1})	0.20	L-3 9/13/12	1.57	4/5/13	0.10	R-3 9/13/12	1.44	R-2 9/13/12
Zn (mg L^{-1})	0.02	R-2 1/27/12	0.06	L-7 4/5/13	0.02	R-2 1/27/12	0.06	R-2 9/13/12

Analysis of Water Quality Step Trends with Time

Comparison of post-restoration water quality and 2012-2013 water quality

Water from Bonnie and Galum Creeks was analyzed for temperature, pH, conductivity, TSS, TDS, Alkalinity, Fe, Mn, SO_4, Zn, Cl, Fl, NO_3, and DO during two time periods (2002–2006 and

2012–13). Separate analyses labeled BCB4A and GLC4B respectively indicate where the samples taken below groundwater seeps were used in the place of the sample taken above the seeps during the April 2013 sampling. Only those parameters where the test for step trend resulted in $p<0.1$ are shown in Table 11.

Water quality data from two sample periods at each sample point along Bonnie Creek revealed significant differences ($\alpha=0.05$) between sample periods for several of the parameters at sample point BCB4 and for TSS ($p=0.0449$) at BCB3. pH ($p=0.0134$), conductivity ($p=0.0087$), TDS ($p=0.0066$), Alkalinity ($p=0.027$), Mn ($p=0.0055$), SO_4 ($p=0.0066$), Zn ($p=0.0415$), Cl ($p=0.0272$), and Fl ($p=0.0066$) were significantly different between the two time periods. However, when the alternate BCB4 sample point was included in the analyses labeled BCB4a for pH, conductivity, and SO_4, only data for SO_4 still had showed a significant difference between the two time periods. No additional analysis for TDS, Alkalinity, Mn, Zn, Cl, or Fl data were conducted using the alternate sample point. Water quality data from two sample periods at each sample point along Galum Creek revealed significant differences ($\alpha=0.95$) between sample periods for TDS ($p=0.0372$) and Mn ($p=0.0415$) at GLC2. Water quality data from two sample periods at each sample point along Pipestone Creek revealed significant differences ($\alpha=0.95$) between sample periods for TSS ($p=0.023$) and Mn ($p=0.023$) at L-3.

Results from the data alone suggest a shift in the water quality at BCB4 towards being more representative of the control (Figure 12, Figure 13, and Figure 14). Mean pH at sample point BCB4 from 2002-2006 (-0.55 ± 0.13) was 0.79 units lower than in 2012-2013 (0.24 ± 0.22). This suggests a shift in the deviation from BCA at BCB4 from more acidic water than the control in 2002-2006 to more basic water in 2012-2013. However, when the alternative sampling location was substituted during the April 2013 sampling, the mean deviation in pH in 2002-2006 was only 0.32 units lower than during the 2012-2013 sampling(-0.23 ± 0.39) and the distributions were not significantly different ($p=0.2794$). The same pattern is suggested in the conductivity data. When the alternative sampling location data were included in the step trend comparison, the difference between the two time periods was no longer significant. The BCB4A analysis still showed an increase of 751.4 ± 644.13 µs cm^{-1} compared to the control, a value closer to the mean of the 2002-2006 data (1914.5 ± 460.24). Only the data for SO_4 maintained a significant difference when the alternate sampling location data were included. The mean deviation from the control during 2002-2006 was 853 ± 236.7 mg L^{-1} whereas the BCB4 data from 2012–13 showed a mean deviation of -25.05 ± 45.79, a complete reversal in the SO_4 concentration with respect to the control. When BCB4a was analyzed, the difference between the two time periods was still significant ($p=0.0174$), but the mean deviation at BCB4 (171.35 ± 159.77) became positive again. Deviation from the control in TDS, alkalinity, Mn, Zn, Cl, and Fl also appeared to decrease during the 2012-2013 time period compared to the 2002-2006 sampling, however, no data were available from the alternate location and so it cannot be determined if the 2012-2013 data would still be significantly different from the 2002-2006 data if water from the alternate sampling location was analyzed.

Other significant differences in the parameters tested were found among Bonnie Creek sample points at BCB3 (Figure 15) and among Galum Creek sample points at GLC2 (Figure The mean increase of the concentration of TSS with respect to the control decreased during the 2012-2013 sample period at BCB3 (-272.5 ± 61.19) compared to the 2002–06 period (25 ± 5.47). TDS at GLC2 increased from the 2002-2006 (-272.5 ± 61.19) during the 2012–13 sampling, but the mean (-61.25 ± 27.6) still showed a decrease with respect to the control. Mn at GLC2 also increased compared to the 2002-2006 (-0.27 ± 0.07). However, the 2012-2013 mean (-0.07 ± 0.05) still indicated a negative departure from the control.

Data from sample point L-3 indicated a reduction in both TDS and Mn during the 2012–13 sampling compared to the 1992–95 sampling (Figure 17). Mean deviation from 1992–95 of TSS (26.4 ± 18.29 mg L^{-1}) at L-3 went from showing a positive change with respect to the control, to showing a mean decrease in TDS concentration (-49.83 ± 21.66 mg L^{-1}) during the 2012–13 time period. The same was true for the Mn data at L-3. Mean Mn deviation at L-3 during 2012–

13 (-0.69 ± 0.33 mg L^{-1}) showed a negative deviation from the mean, whereas in 1992–95 the mean deviation (0.18 ± 0.11 mg L^{-1}) was positive.

Table 11. Summary of statistical comparisons of water chemistry between sampling periods.

		Bonnie Creek		Deviation from BCA	
				2002-2006	2012-2013
Sample Point	Parameter	χ2	p	mean ± s.e	mean ± s.e
BCB4	pH	6.112	0.0134	-0.55 ± 0.13	0.24 ± 0.22
BCB4A	pH	1.1699	0.2794	-0.55 ± 0.13	-0.23 ± 0.39
BCB4	Conductivity (μs/cm)	6.881	0.0087	1914.5 ± 460.24	34.65 ± 143.07
BCB4A	Conductivity (μs/cm)	2.881	0.0896	1914.5 ± 460.24	751.4 ± 644.13
BCB3	TSS (mg L^{-1})	4.0238	0.0449	25.0 ± 5.47	3.62 ± 5.84
BCB4	TDS(mg L^{-1})	7.3846	0.0066	1380 ± 391.4	22.75 ± 62.47
BCB4	Alkalinity (mg L^{-1})	4.8921	0.027	139.0 ± 31.50	-18.25 ± 14.42
BCB4	Mn (mg L^{-1})	7.7143	0.0055	0.34 ± 0.11	-0.16 ± 0.12
BCB4	SO_4 (mg L^{-1})	7.3846	0.0066	853.0 ± 236.7	-25.05 ± 45.79
BCB4A	SO_4 (mg L^{-1})	5.6538	0.0174	853.0 ± 236.7	171.4 ± 159.8
BCB4	Zn (mg L^{-1})	4.1538	0.0415	0.04 ± 0.01	0 ± 0.01
BCB4	Cl (mg L^{-1})	4.875	0.0272	13.6 ± 3.76	0.85 ± 1.75
BCB4	Fl (mg L^{-1})	7.3846	0.0066	0.18 ± 0.03	-0.04 ± 0.05

		Galum Creek		Deviation from BCA	
				2002-2006	2012-2013
Sample Point	Parameter	χ2	p	mean ± s.e	mean ± s.e
GLC4	pH	2.8846	0.0894	-0.3 ± 0.12	0.13 ± 0.17
GLC4B	pH	1.8462	0.1742	-0.3 ± 0.12	0.06 ± 0.22
GLC2	TDS(mg L^{-1})	4.3412	0.0372	-272.5 ± 61.19	-61.25 ± 27.60
GLC2	Mn (mg L^{-1})	4.1538	0.0415	-0.27 ± 0.07	-0.07 ± 0.05
GLC4	SO_4 (mg L^{-1})	3.4286	0.0641	1165 ± 260.3	-32.98 ± 12.37
GLC4B	SO_4 (mg L^{-1})	2.881	0.0896	1165 ± 260.3	-16.61 ± 8.81
GLC2	Cl (mg L^{-1})	2.8846	0.0894	0 ± 0.14	-0.32 ± 0.20

		Pipestone Creek		Deviation from L-7	
				1992-1995	2012-2013
Sample Point	Parameter	χ2	p	mean ± s.e	mean ± s.e
L-3	Temperature (°c)	2.721	0.099	0.40 ± 1.03	0.2 ± 0.76
L-3	TSS (mg L^{-1})	5.000	0.023	26.4 ± 18.29	-49.83 ± 21.66
R-3	Fe (mg L^{-1})	3.756	0.053	-0.50 ± 0.15	0.06 ± 0.12
L-3	Mn (mg L^{-1})	5.000	0.023	0.18 ± 0.11	-0.69 ± 0.33

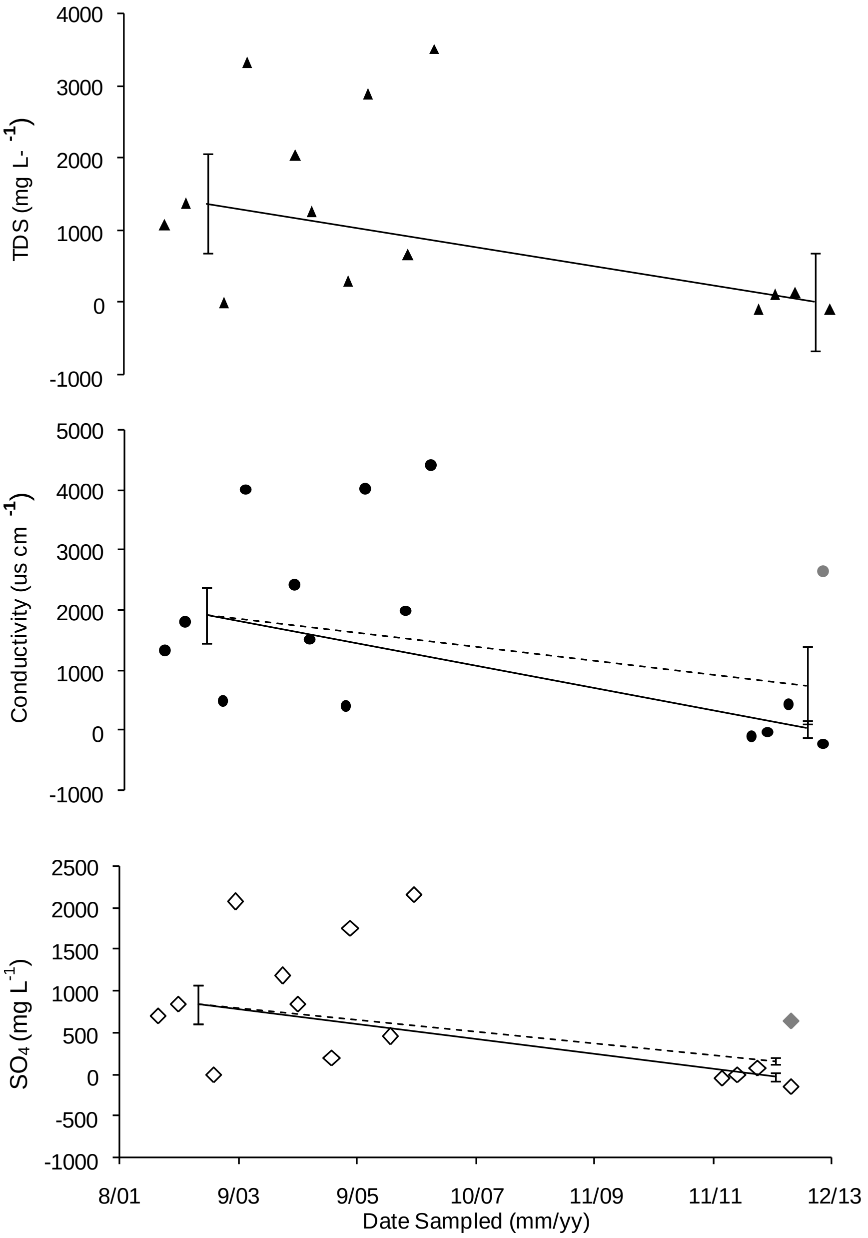


Figure 12. Comparisons between two sampling of deviations from the control in TDS (top), Conductivity (middle), and SO_4 (bottom) at BCB4 periods. Significant step trends are shown. Dashed lines show the step trend with the alternative sample location. Gray data points represent data from the alternate points.

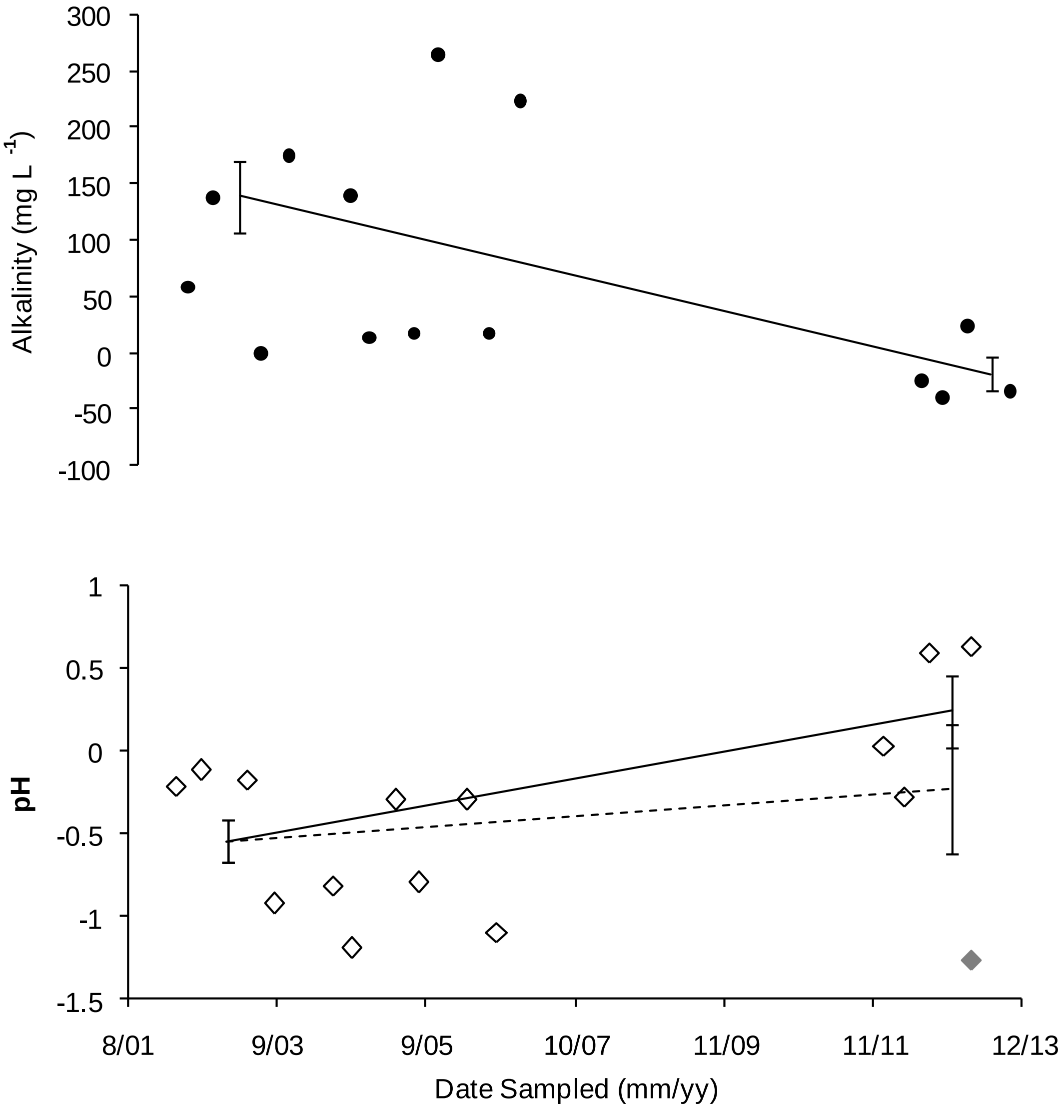


Figure 13. Comparisons between two sampling periods of deviations from the control in Alkalinity (top), and pH (bottom) at BCB4. Significant step trends are shown. Dashed lines show the step trend with the alternative sample location. Gray data points represent data from the alternate points.

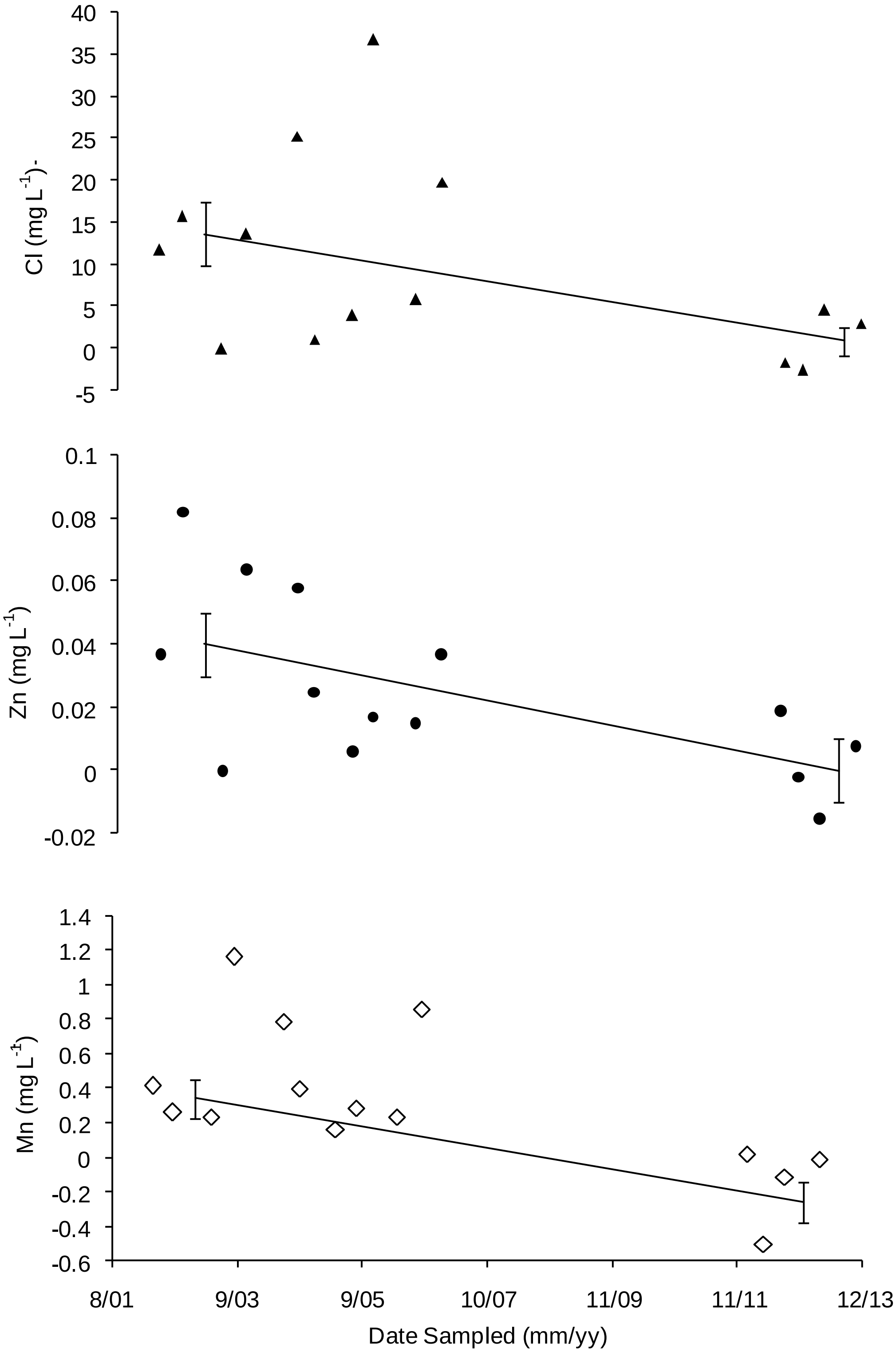


Figure 14. Comparisons between two sampling periods of deviations from the control in Cl (top), Zn (middle) and Mn (bottom) at BCB4. Significant step trends are shown.

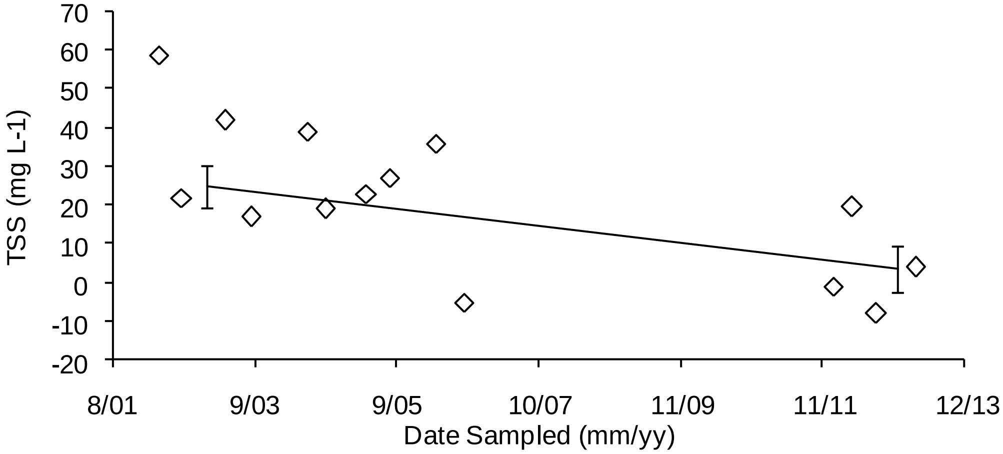


Figure 15. Comparisons between two sampling periods of deviations from the control in TSS at BCB3. Significant step trends are shown.

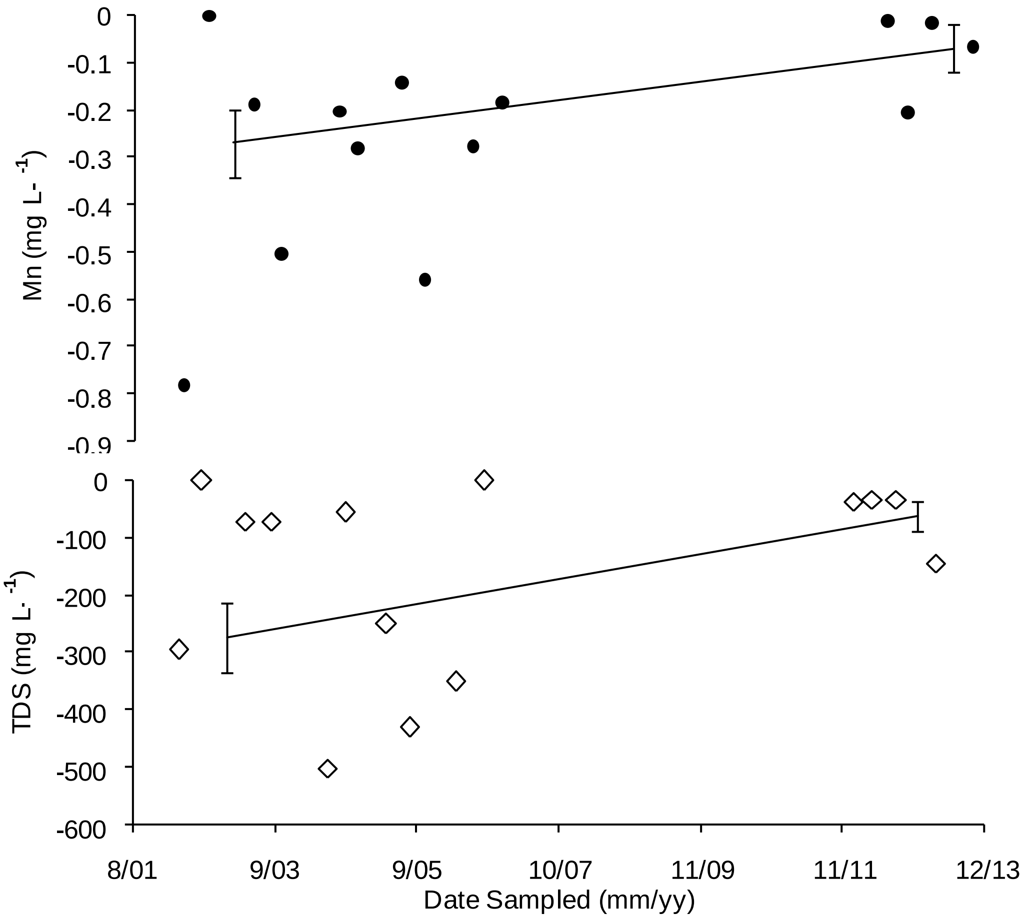


Figure 16. Comparisons of deviations from the control in Mn (top), and TDS (bottom) at GLC2 between two sampling periods. Significant step trends are shown.

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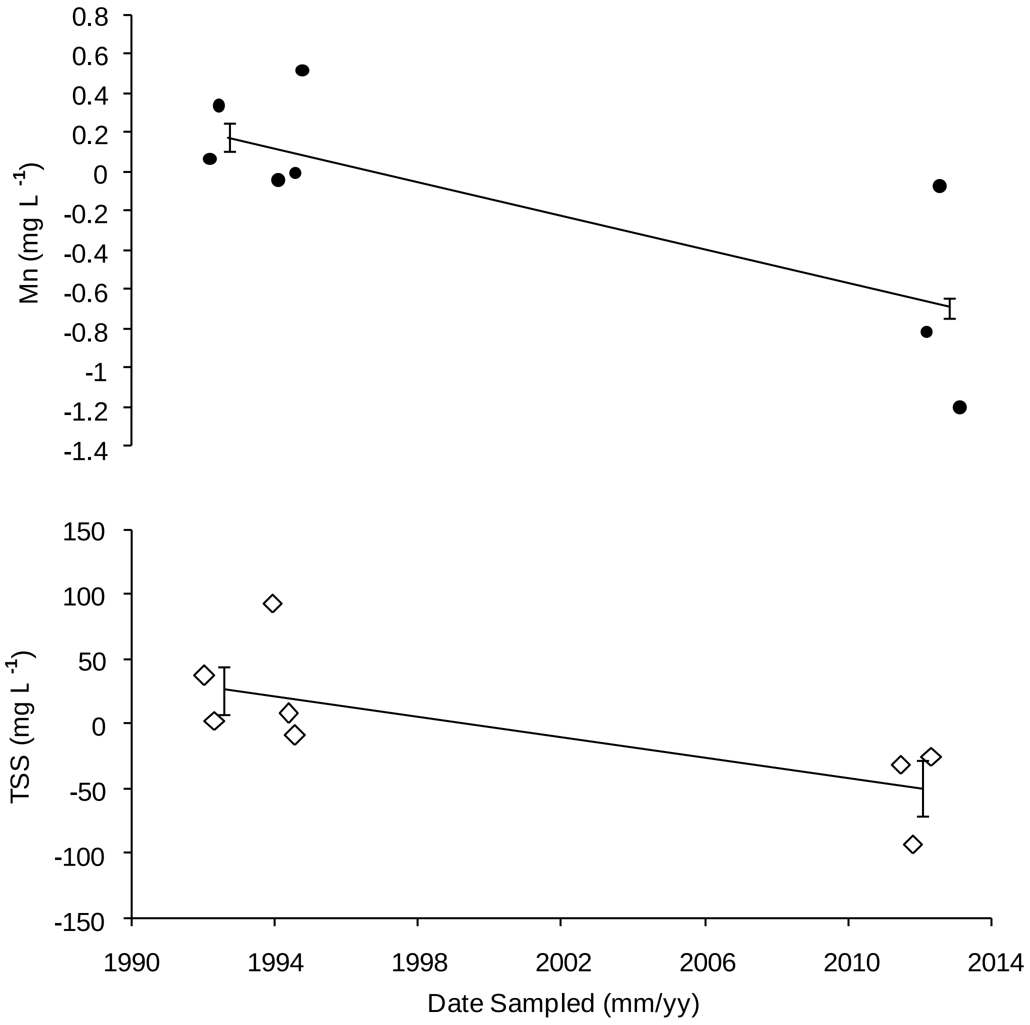

Figure 17. Comparisons of deviations from the control in Mn (top), and TDS(bottom) at L-3 between two sampling periods. Significant step trends are shown.

An unintended result of the large variability found in sampling at and around the BCB4 and BCB4A sample points was that it underscored the importance of groundwater contributions to chemistry in reclaimed mined streams. Many studies have shown elevated dissolved ions, increased conductivity, and elevated metals concentrations to be common in mined watersheds even years after reclamation has been completed (Hopkins et al 2013, Pond et al 2008, Palmer et al 2010), but an assessment of whether the longitudinal change within a stream is gradual or sudden is often lacking. During baseflow near BCB4, water quality had a completely different character depending on less than 10 m difference in the sample point location. This indicates a sudden rather than gradual change in stream chemistry along the length of a mined stream. Fritz et al (2010) observed Fe precipitates coating stream beds in perennial sections of streams restored in valley fill mining operations along with significant increases in conductivity. Similar conditions were found immediately downstream of perennial seeps at Bonnie and Galum Creeks. Metals (such as Fe, Mn, and Zn) appear elevated in coal mined streams receiving groundwater when spoils are weathered and acid producing materials mobilize the metals (Gerhardt 1993, Brabet 1984). Reduced conditions in groundwater can keep the metals in solution even when pH is circumneutral until oxidized conditions in the surface water result in precipitation. Elevated conductivity and dissolved solids (SO_4 and Cl) are also the result of weathering of previously consolidated aquifer materials. Oertel (1980) identified several strata capable of producing waters with high levels of SO_4 and other dissolved solids at mines adjacent to BS4N (Burning Star #4 South and Captain mines) near the coal seam and several meters above it. These strata, if crushed and placed in groundwater recharge zones following mining would explain the source of the groundwater contamination at BS4N.

Sampling was only performed during baseflow and after small rain events with a return interval less than one year so it was not possible to analyze the data for performance during large rain events. Nonetheless, there appears to be little change with time or along the length of the relocated streams when overland flow is the source of stream flow.

While the information presented in this study provides preliminary data characterizing the behavior of mined streams for several years after restoration, it leaves many questions only partially answered. Due to the sampling variability at BS4N, strong conclusions cannot be made even on the limited amount of data provided. This highlights the need for better description of methods during post-restoration monitoring. The use of sub-meter accuracy or equivalent global positioning systems and the inclusion of coordinates of the locations in the methods sections is recommended. In general, sampling should be avoided at points in streams where seeps are present because concentrations can change drastically depending on the vertical or horizontal positioning of the sampling or collection devices making consistent monitoring difficult. Effective monitoring requires many years of data and specifics can be easily lost even after a few years. Sampling of the streams only during baseflow and after small storms has limited conclusions to only those made about only the small storms which were sampled. Regardless of the number of samples taken, no conclusions about stability during bankfull or larger storm events can be made unless substantial sampling during these times is conducted.

AQUATIC COMMUNITY SAMPLING

Macroinvertebrates

Macroinvertebrate sampling at the original post-restoration monitoring points along Bonnie, Galum, and Pipestone Creek was conducted in May and September of 2012. Conditions were extremely dry during most of the summer of 2012, but during the May sampling some interstitial flow remained between pools and flow had been present only a few days prior to sampling. A major storm event occurred at the end of August and typical baseflow conditions were present during the sampling that took place in mid-September of 2012.

The full results of the macroinvertebrate sampling are provided in the Appendices. The total taxa collected ranged from 12 at L-3, the unmined downstream control point for Pipestone Creek during the May 2012 sampling to 27 at R-3 along the restored Pipestone Creek during the September 2012 sampling and at GLC3 along the restored Galum Creek during the May 2012 sampling. An IBI could not be calculated for the sampling because a qualitative presence/absence survey was conducted similarly to the post-restoration sampling methods.

Much information can be gained by discussing the assemblage that was collected. At Pipestone Creek, predators were the most common species, especially those with a “clinging” or “sprawling” habit. These included dragonfly species from families such as Coenagrionidae and Libellulidae. There was only one species of Trichoptera collected along Pipestone Creek during each sample round and each time the Trichopetera species was found at only one sampling point. Most Trichoptera species are found in swift moving waters such as riffles. Their near absence from Pipestone Creek is reflective of the lack of suitable riffle habitat in the studied reaches. Despite the near absence of this order, the macroinvertebrate community at sample points R-1, R-2, R-3 were fairly diverse during one or both sampling rounds. Five species of Anisoptera and five species of Coleoptera were found at R-3 during the September 2012 sampling, making it and the unmined sample point at LGD the most diverse.

Bonnie and Galum Creek had a macroinvertebrate community more representative of unmined streams in the area. Six species of Ephemeroptera were present at the restored Bonnie Creek sample points. Trichoptera were present at several sample points along Bonnie and Galum Creek during the May and September sampling rounds. Macroinvertebrates collected from the restored sections of Bonnie and Galum Creek were reflective of the control points, but were somewhat different than the monitoring point LGD along Little Galum Creek. The control points along Bonnie and Galum immediately upstream of the mine had considerable impacts from row crop agriculture. Much of the original riparian area had been cleared and at the Bonnie Creek sample point, the channel appeared to have been channelized. The sample point LGD along Little Galum Creek is found within Pyramid State Park and has a mostly undisturbed riparian corridor with no apparent channelization or stream bottom disturbance. However, it still shows signs of upstream impacts including entrenchment and bank erosion. The most unique aspect of the macroinvertebrates found at Little Galum Creek compared to the mined sites is the presence of two species of dragonflies from the Gomphidae family. These species are predators that burrow in riffle substrate. They were not found at any other site, likely due to the lack of a suitable riffle substrate within the studied areas. Substrate in Little Galum Creek consisted of clean gravel approximately 3–5 cm in diameter. Woody material was also found embedded into the riffle potentially enhancing the habitat.

Fish

In all, 26 species of fish (all native) and two hybrid sunfish taxa were collected. As in previous reports (Carney 1990), the diverted streams were dominated by lacustrine (lake-dwelling) fish species undoubtedly owing to their hydrologic connection to nearby surface mine impoundments. Galum and Bonnie creeks were both routed through lakes during their 1980’s permanent relocations and Pipestone Creek receives flow from two adjacent lakes during overflow events. Conversely, the “control” stream, Little Galum Creek, features a relatively natural channel flowing through unmined land with no such hydrologic connections. As a result, Little Galum’s fish community featured more lotic (flow adapted) species, including five stream species (creek chub, central stoneroller, sand shiner, white sucker, pirate perch) not collected from the three relocated streams (Table 12).

The Index of Biotic Integrity (Karr, 1981, Karr et al. 1986) as revised by Smogor (2000) was applied to all fish samples in an effort to assess the overall “health” of the streams as reflected by fish samples. IBI scores reflected depauperate conditions in most sites, ranging from 17 (out of possible 60) in upper Bonnie Creek to 43 (“Moderate”) in upper Little Galum (Table 12). Care should be taken when interpreting these data, however, as minnow seining is a relatively inefficient method compared to the gear (electric seine) utilized in calibration of the IBI. High water conductivity associated with the mined streams precluded use of electrofishing sampling methods. With minnow seining however, general patterns can be implied, such as the relative lack of minnows and benthic invertivores in the diverted streams along with the abundance of sunfish.

Four commonly stocked sportfish species (largemouth bass, white crappie, black crappie, and bluegill) along with two lacustrine forage species (gizzard shad, brook silversides) collectively accounted for 22- 93% of the fish collections from the six relocated stream stations compared to 7% and 1% at Little Galum. While the relative abundance of sport species in the diversions may bode well for anglers, very few of these fish (a single three lb channel catfish in lower Galum and a handful of 6-7” bluegill in upper Pipestone) could be considered “catchable”. In fact, all of the 112 crappie collected were less than 10” in length and all of the 125 largemouth bass were less than 12”. At best, these relocated streams could be serving as “nursery” habitats where young sportfish could grow and flourish in the absence of large predators. Previously stated concerns about the fragmentation of stream habitat by routing them through lakes may have some validity based on our data. Both Galum and Bonnie had substantially fewer species upstream of their respective lakes than in downstream samples (10 upper vs 15 lower species in Galum, 6 upper vs 16 lower in Bonnie). Meanwhile, the “free-flowing”

Pipestone Creek relocation actually had more species (9 vs 5) in its upper station although overall diversity was low throughout the stream. No crappie were collected above either lake, while 109 appeared below. Similarly affected species included shortnose gar, gizzard shad, suckermouth minnow, redfin shiner, and channel catfish. Likely, the relative permanence of stream flow below such large impoundments enhanced habitat conditions.

In summary, the three stream relocations appeared to show some recovery in fish abundance and diversity as compared to samples taken from straight, “temporary” diversions (Carney 1990, Sauer 1985). However, they fall well short of pre-mining data from natural stream segments and show lower biotic integrity than the unmined control stream. Despite some 25 years post diversion, habitat features important to stream fishes (i.e. mature riparian timber, instream woody debris) are still lacking relative to undisturbed stream habitats. One potential benefit of connecting streams through impoundments may be providing sportfish nursery habitat, but this likely comes at the expense of a balanced, lotic fish community with access to contiguous stream habitat.

Table 12. Fishes collected by IDNR Fisheries staff in minnow seine survey of mining impacted streams of the Galum Creek watershed, Perry Co, IL, July 2013.

	GALUM CREEK		BONNIE CREEK		PIPESTONE CK		LITTLE GALUM CK	
	7/18/2013	7/19/2013	7/18/2013	7/18/2013	7/19/2013	7/19/2013	7/31/2013	7/31/2013
SPECIES	Upper	Lower	Upper	Lower	Upper	Lower	Upper	Lower
Shortnose gar				2				
Gizzard shad		3		32				
Creek chub							16	
Central stoneroller							4	
Suckermouth minnow				1			1	
Redfin shiner		2					7	214
Ribbon shiner								1
Red shiner	22	27	25	19				5
Bluntnose minnow		16	2	7			10	5
Sand Shiner							8	
White sucker								1
Channel catfish		1		1				
Yellow bullhead	3			3			3	
Pirate perch								1
Blackstripe topminnow	110	106	3	105	2		5	2
Blackspotted topminnow					3		14	9
Mosquitofish	15	5		4				1
Brook silversides	24	1	4	22	33	59		
Black crappie	0	1		44	1			
White crappie	0	10		54	2			
Largemouth bass	8	9	8	87	2	3	6	2
Warmouth	0	1				1		
Green sunfish	10	5	4	2	4		6	
Bluegill	15	14		25	48	6		
Bluegill x longear SF	0	0	4		1			
Longear sunfish	1	3		1	22	4		1
Unidentified SF hybrid					1			
Johnny darter	2	0					8	4
Total individuals	210	204	50	409	119	73	88	246
Total species (excl. hybrids)	10	15	6	16	9	5	13	12
IBI			17	30			43	31
extrapolated IBI	24	26			20	18		

EFFECTS OF INCLINE PITS ON SUSPENDED SOLIDS CONCENTRATIONS

Suspended solids (SS) were evaluated above and below two incline pits that intersect the relocated sections of Bonnie and Galum Creeks during two storm events. The sample collected at unequal intervals across a storm event were analyzed for SS and the total (TSS) was used in a repeated measures mixed model analysis to determine if there was a significant treatment effect on suspended solids concentrations. A sand-fine split was also conducted on sample taken during the second storm event. The results are presented in Figures 18, 19, 20, and 21.

There was no significant difference (p=0.4519) between means of TSS taken from samples below the incline basins versus above. There was however, a significant time effect (p=0.0001) and a significant time x treatment interaction effect (p=0.0252). Additional patterns can be observed in the stage and SS graphs for the storm events. In the Bonnie Creek samples, levels of SS began increasing as the hydrograph increased at both upstream (BU) and downstream (BD) sample locations, but peaked much earlier and fell much sooner than the hydrograph. In the Galum Creek samples there was a distinctly different pattern between the sediment levels above and below the incline pit. In the downstream samples (GD), the sediment concentrations were consistently much lower than the upstream samples (GU), but also peaked much later and remained consistently higher than concentrations during the rising limb of the hydrograph even near the end of the falling limb. Samples at Galum Creek were higher upstream of the basins during both storm events, but at Bonnie Creek, the concentrations were higher upstream in the November storm event and lower during the February storm event.

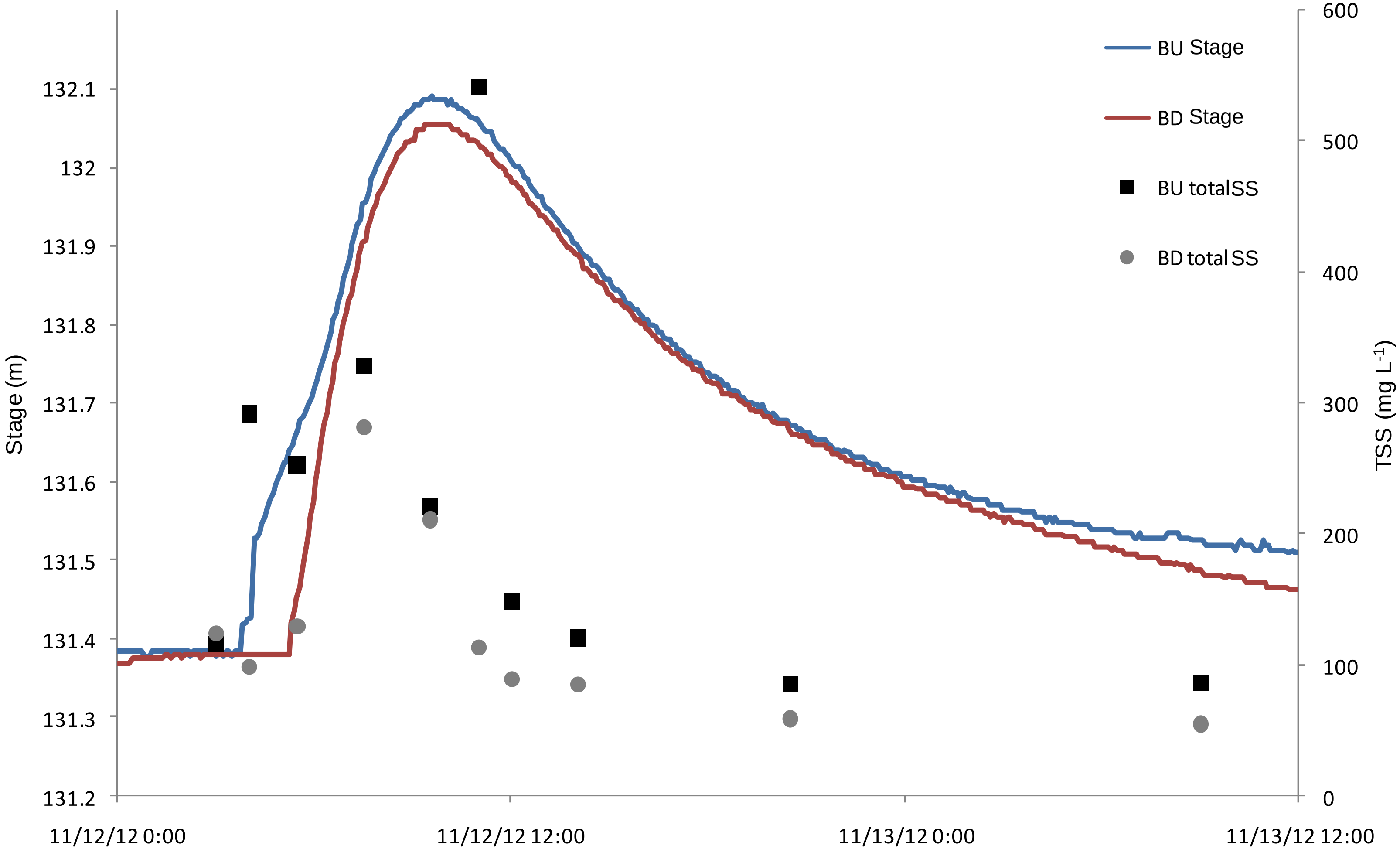

Figure 18. Stage and Suspended Sediment Concentrations upstream (BU) and downstream (BD) of an incline pit along Bonnie Creek During the November 2012 Storm Event.

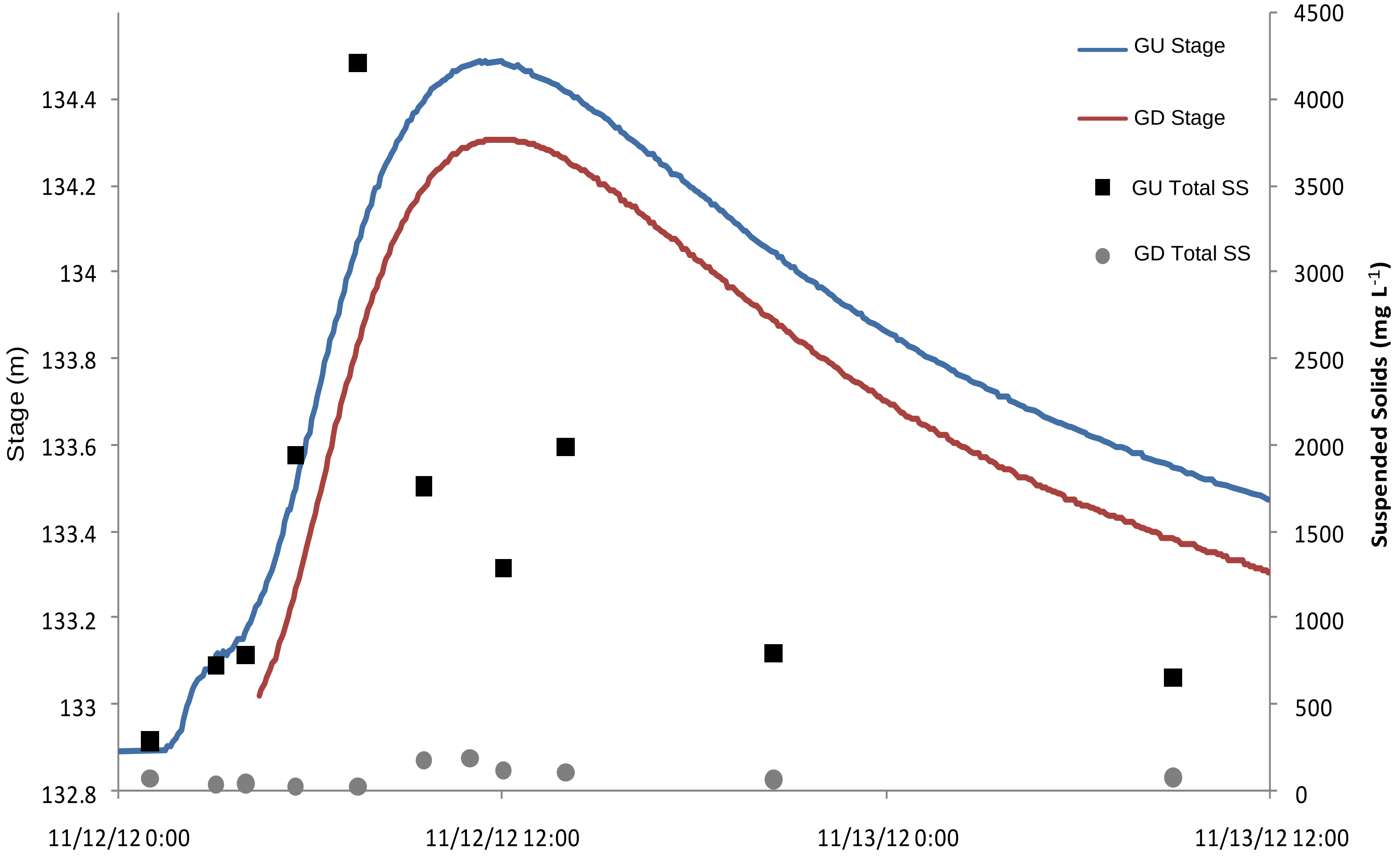

Figure 19. Stage and Suspended Sediment Concentrations upstream (GU) and downstream (GD) of an incline pit along Galum Creek during the November 2012 Storm Event.

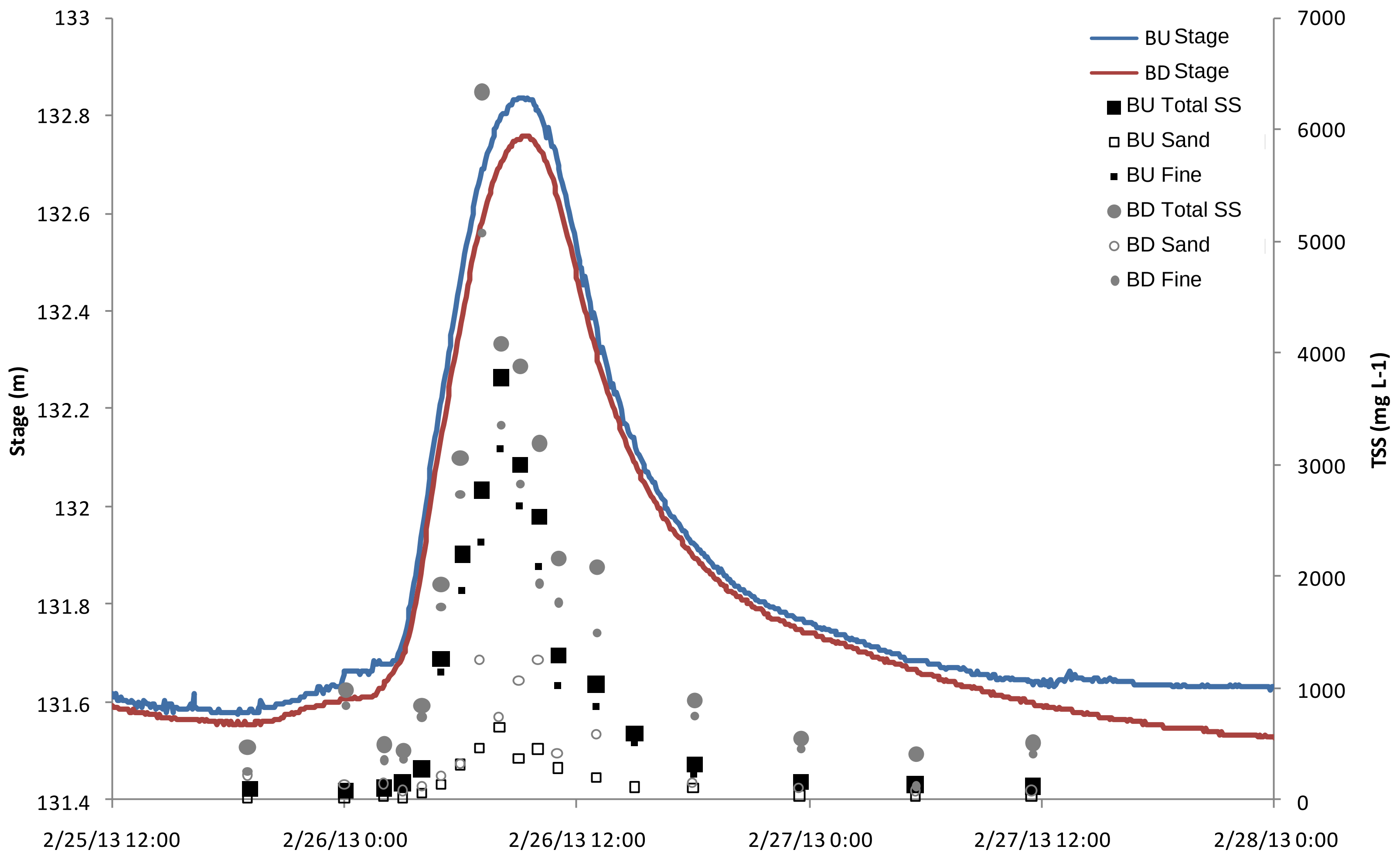

Figure 20. Stage and Suspended Sediment Concentrations upstream (BU) and downstream (BD) of an incline pit along Bonnie Creek during the November 2012 Storm Event. Sand and fine sediment concentrations are also shown as empty circles/squares and smaller scaled circles/squares respectively.

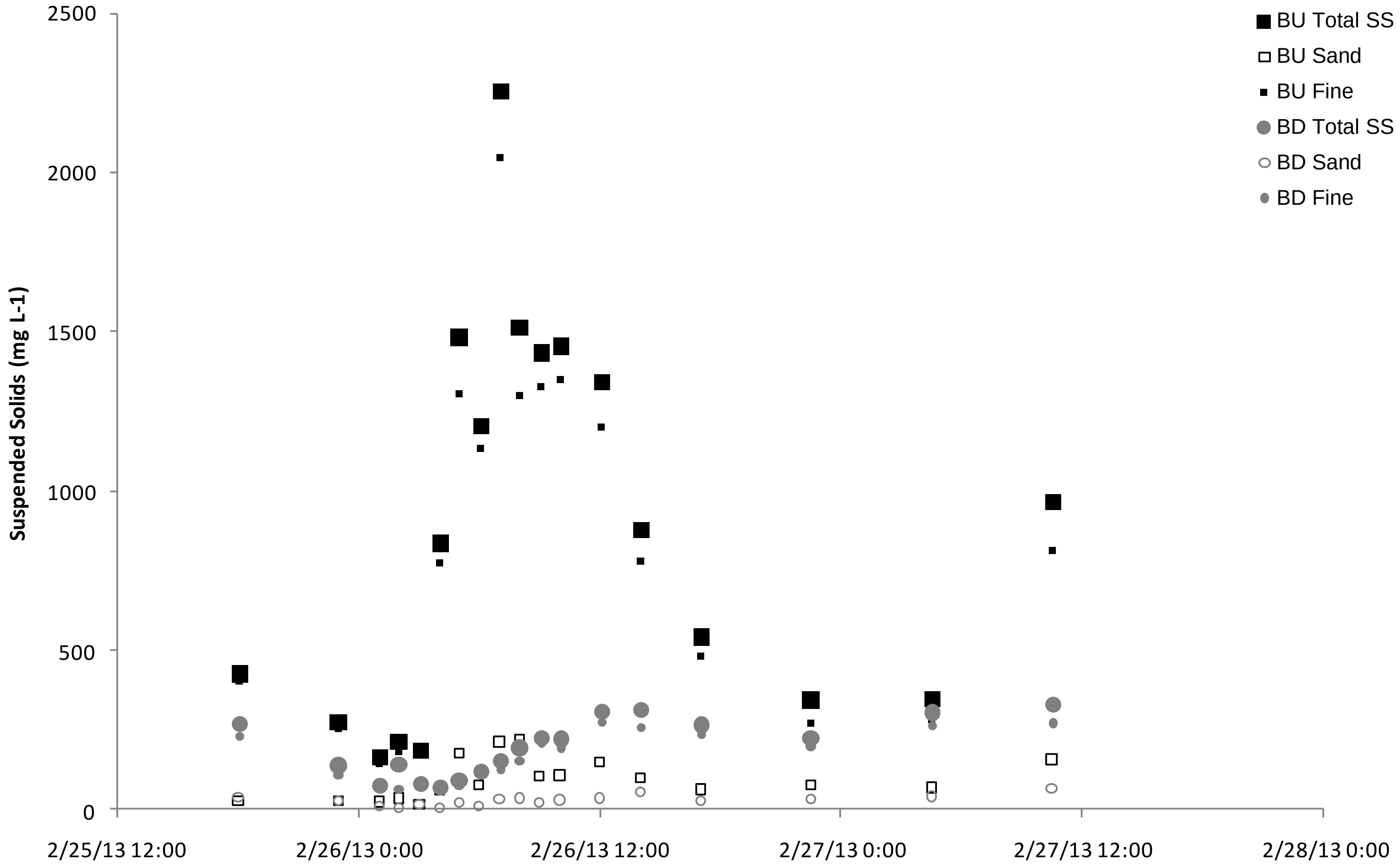

Figure 21. Suspended Sediment Concentrations upstream (GU) and downstream (GD) of an incline pit along Galum Creek during the November 2012 Storm Event. Sand and fine sediment concentrations are also shown as empty circles/squares and smaller scaled circles/squares respectively. No stage data are available.

The influence of incline pits on TSS was similar to other studies when only the Galum Creek pit was considered (McElligot 1984, Gerard 2005), but overall there was no difference in the level of TSS when both pits were considered. Nawrot (2011) suggested the use of incline pits as a way to remove sediments from upstream agricultural areas, but the results showed an increase in TSS downstream of Bonnie during the second storm event. This can be explained by the contribution of sediment laden waters by the Lost Prairie Creek watershed to an adjacent and hydrologically connected incline pit that only discharges during wet seasons or extreme events. The Lost Prairie Creek watershed is two km^2 and is almost entirely cropland. There is little to no riparian vegetation and the length that runs through the mined area was reclaimed as a straight rock-lined channel with no herbaceous or woody riparian buffer. These results show that the incline pits are not an adequate replacement for upstream watershed restoration efforts such as riparian plantings. However, the Galum Creek incline pit was highly effective at reducing TSS including both the sand and fine fractions.

GEOMORPHIC STREAM ASSESSMENT

Qualitative Assessment

Before modeling the stream system, the geomorphology can be qualitatively assessed from photographic documentation (22, 23, and 24), thalweg elevations in each reach (Figure 25), and the median bed material sizes upstream and downstream of the incline pits (Figure 25). The aerial views show three distinct restoration practices. Galum Creek has gentle meanders intermixed with occasional tight, elongated meanders and was built in-line with an incline pit (Figure 22). Bonnie Creek has very regular tight, sinusoidal meanders and also was built in-line with an incline pit (Figure 23), but has a much shorter contact time with the pit as compared to Galum Creek. Pipestone Creek has a similar meander style to Galum Creek, but differs from both

Galum and Bonnie Creeks in that the incline pit is connected to the stream only by means of a side-channel weir (Figure). Overall, from the on-ground photos, Galum Creek, Pipestone Creek, and the downstream reach of Bonnie Creek appear relatively stable. Some bank erosion exists on the upper end of Galum Creek, but it also the closest to an upstream agricultural ditch and highway bridge. Stability problems are apparent in the photos on the upstream reach of Bonnie Creek. Additional images from an aerial video taken from a helicopter in 2005 are shown in Appendix A. The images include the full reach of Bonnie from the confluence with Galum all the way to the intersection with Route 154. This includes the extent shown in Figure 23 and gives a more comprehensive look at the reach. Also, more quantitative discussion stability is included in the Hydraulic and Sediment Modeling Methods and Results section.

The thalweg elevations of each stream reach show that the reaches in Galum and Pipestone Creeks are relatively flat compared to Bonnie Creek (Figure25). These differences will play a role in the modeling results where they will be combined with the channel dimensions and characteristics, but here give a qualitative look among the three streams. In particular the reach of Bonnie Creek upstream of the incline pit is sloped as much as 0.005 m/m along the chute (location is at cumulative channel length 2,250 to 2,650 m in Figure). Similar slopes exist on Bonnie Creek at and near the road crossing at location cumulative channel length 600 m in Figure25.

The median bed material sizes upstream and downstream of the incline pits show that the incline pits trap at least the coarser sand and gravel material. Pipestone Creek shows the least amount of influence of the incline pit most likely because of the side-channel weir connection to the incline pit. Also, from other mine reclamation projects upstream of the study reach, the Pipestone Creek has incline pits that are in-line with the stream and could also be a factor in the relatively smaller particle sizes in the system as compared to Bonnie and Galum Creeks.

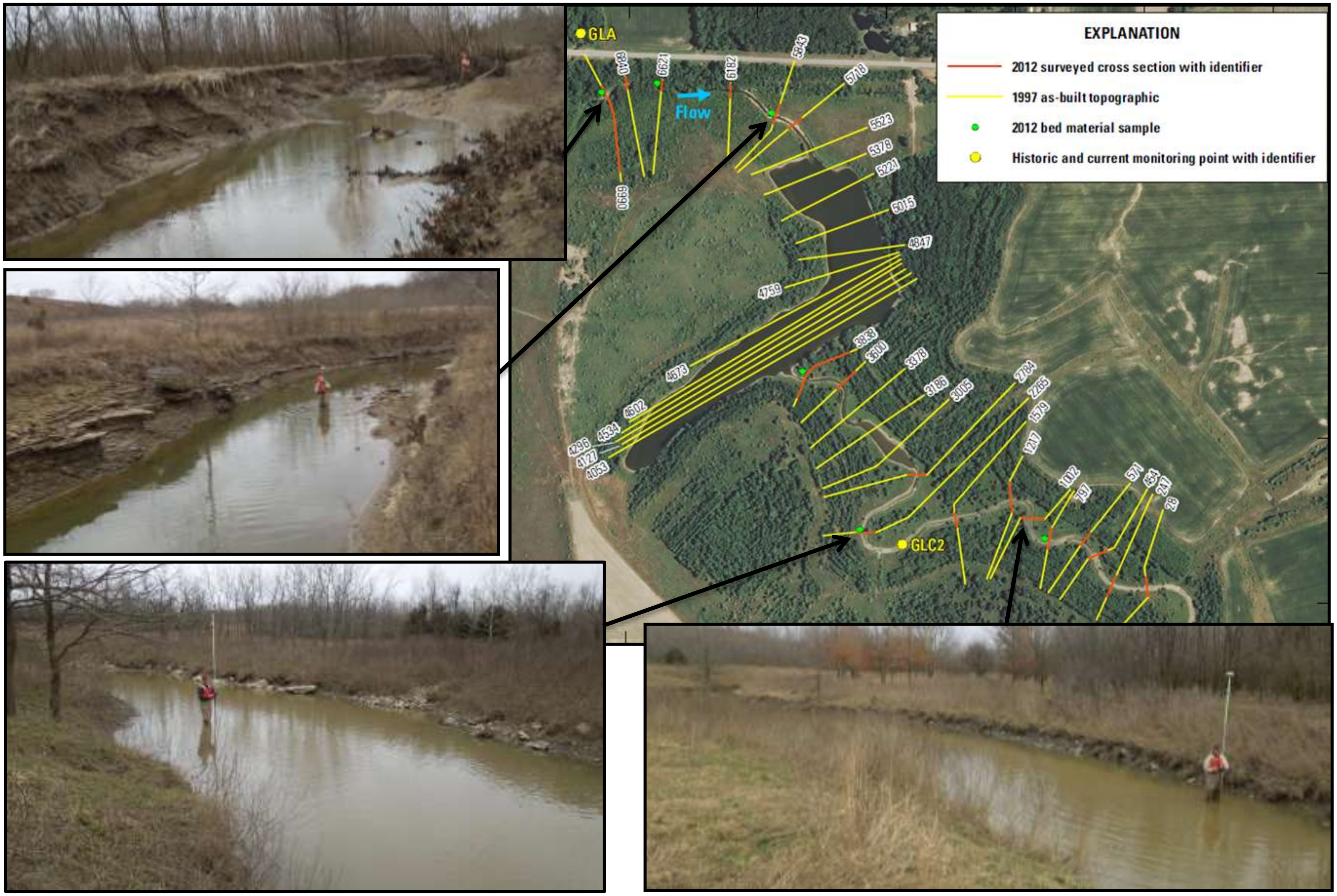

Figure 22. Photographic documentation of Galum Creek.

Figure 23. Photographic documentation of Bonnie Creek.

Figure 24. Photographic documentation of Pipestone Creek.

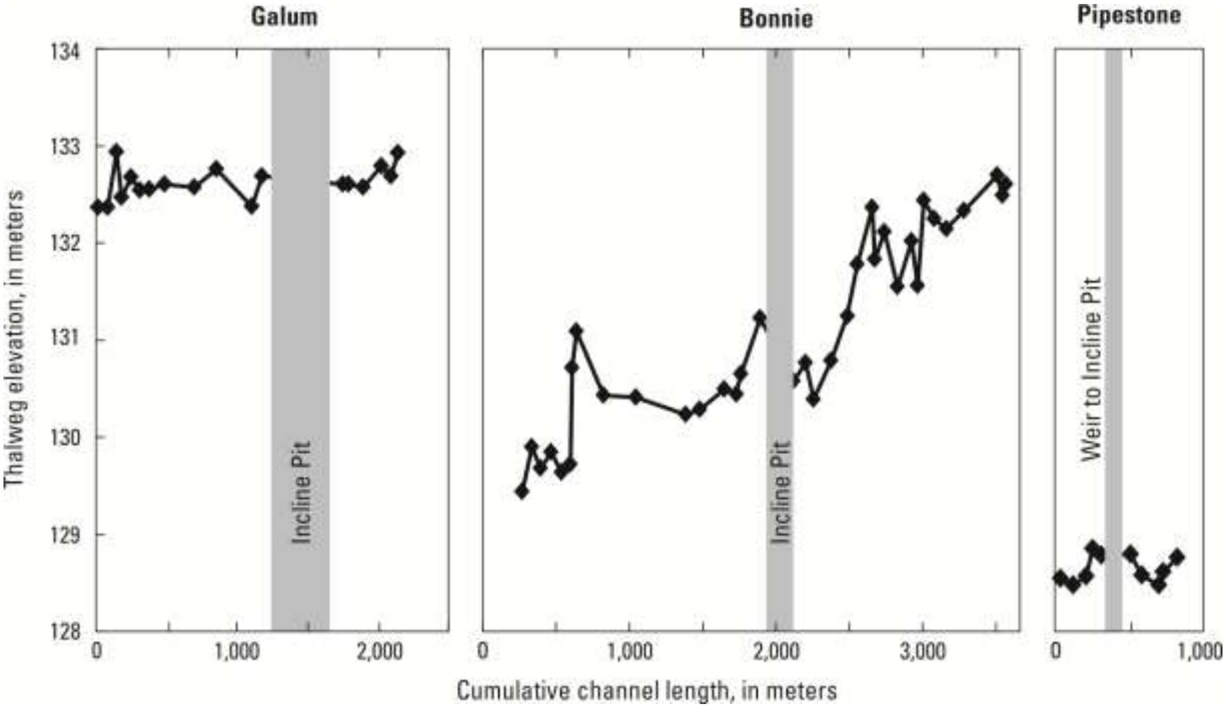

Figure 25. Thalweg elevations of Galum, Bonnie, and Pipestone Creeks surveyed reaches. Elevations are referenced to the NAVD88 datum.

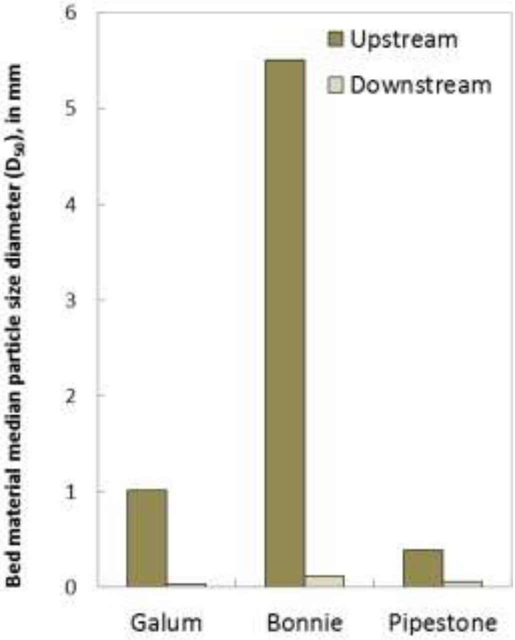

Figure 26. Bed material median particle size diameter for Galum, Bonnie, and Pipestone Creeks upstream and downstream of the incline pit in each stream. Taken from the first sample upstream and downstream of the incline pit, except in the case of Galum Creek where the first sample downstream of the pit was a constructed riffle, so the second sample downstream was used.

Geomorphic Field Measurements and In-Stream Habitat Assessment

Several geomorphic measurements were determined from the surveyed cross-sections along approximately 100 m study reaches (Table 13). These include gradient, bank height, bank angle, pool depth, pool length, riffle number, and sinuosity. Measurements such as stream gradient, bank height, and bank angle are important for understanding the stability of a stream. Stream banks that are too steep prevent the growth vegetation and are highly erodible. A stream will generally continue to erode and adjust until a stable bank angle is achieved. When the bank height is high, a steep bank is even more prone to erosion and instability. Similarly, when the gradient is too steep, the erosive power of the stream is great and the stream bed will erode. If the gradient is too low siltation, aggradation, and sedimentation will occur leading to the loss of important riffle and pool habitat.

Stream instability is reflected in the steep outer bank angle of all the reaches studied along Bonnie Creek. These angles, ranging from 1.1 (horizontal distance to vertical distance or H:V) to 1.525 are steeper than the channels were originally designed (between 2 and 3 H:V) and are steeper than the angle of repose for loose soil (about 1.8 H:V). The inner bank angle through the bends ranged from 1.29 to 4.96. The gentler slopes of the inner bank angle suggest that sediment is depositing in the inner bend leading to a gentler slope and pushing flow to the outer bend causing erosion and instability.

Along Galum and Pipestone Creeks, stream instability was less severe or the streams were nearly stable. Stream bank angles were genereally 3 H:V or flatter with the exception of study reach Galum 1 where the bank angles were 1.8 and 1.65 for the inner and outer banks respectively. This reach is located at the most upstream end of the restored stream. The channel through this reach resembles more of a diversion channel. The stream banks are very high and steep and there are rock outcroppings present that are normally below the surface. Although the stream banks are mostly stable in the reaches studied along Galum and Pipestone

Creek, the gradient is very low in all the Galum Reaches and within the Pipestone 2 study reach. As a consequence, deposition was increased here and riffle habitat if present was buried in fine sediment. In the Pipestone Creek study reach, aquatic vegetation colonized the stream bottom.

Table 13. Geomorphic Stream Measurements.

Reach	Gradient (%)	Bank Height (m)	Inner Bank Angle (H:V)	Outer Bank Angle (H:V)	Pool-depth (m)	Pool-length (m)	riffle number (count)	Sinuosity (ratio)	buffer width (m)
Bonnie 1	0.05%	2.27	1.795	1.16	0.8	>100	0	1.07	
Bonnie 2	0.02%	2.56	3.36	1.415	1.17	>100	0	1.82	
Bonnie 3	0.80%	2.67	1.29	1.525	1.1	>100	0	1.6	
Bonnie 4	0.20%	2.42	4.96	1.1	1.25	60	1	1.75	
Average	**0.27%**	**2.48**	**2.85**	**1.30**	**1.08**	**60.00**	**0.25**	**1.56**	
Galum 1	0.01%	1.975	4.035	3.395	0.68	80	1	1.18	
Galum 2	<0.01%	2.34	4.18	3.55	0.62	>100	0	2.3	
Galum 3	0.02%	2.92	1.8	1.65	0.63	>100	0	1.03	
Average	**0.02%**	**2.41**	**3.34**	**2.87**	**0.64**	**80.00**	**0.33**	**1.50**	
Pipestone 1	0.40%	2.63	3.06	4.025	1.86	75	1	1.13	
Pipestone 2	0.02%	3.215	4.335	2.97	2.09	>100	0	1.06	
Average	**0.21%**	**2.92**	**3.70**	**3.50**	**1.98**	**75.00**	**0.50**	**1.10**	
Overall Average	**0.19%**	**2.55**	**3.20**	**2.31**	**1.13**	**71.67**	**0.33**	**1.44**	

Broad-scale habitat was assessed using the EPA-RBP visual assessment method. The study reaches were scored based on ten criteria (Table 14). All streams scored moderate to poor with score ranging from 71 to 142 out of 200 possible. Most commonly, epifaunal substrate/available cover had the lowest score. Very little deadfall was present in the channels and riffles were only present in three of the study reaches. Epifaunal substrate and available cover was commonly limited to rootlets and overhanging vegetation along the edges of the water. Pipestone Creek scores were higher due to the presence of abundant aquatic vegetation within the channel. Otherwise, channel instability, lack of vegetative protection, and sediment deposition commonly resulted in the study reaches having low RBP scores. Bonnie Creek study reaches commonly scored low due to instability and lack of vegetative protection. Pipestone Creek received the lowest scores for sediment deposition. Fine sediments had buried all riffle substrate originally present at the study reaches. The highest score for all study reaches was the score based on riparian vegetative zone width. All streams had a buffer of greater than 18 m. Although, it was composed of younger forest it still provided many vital riparian habitat and water quality functions.

Table 14. RBP Visual Habitat Assessment Scores.

	Bonnie 1	Bonnie 2	Bonnie 3	Bonnie 4	Galum 1	Galum 2	Galum 3	Pipestone 1	Pipestone 2
Epifaunal substrate /available cover	7	6	6	8	12	8	5	15	14
Pool Substrate Characterization	11	10	8	9	11	11	3	17	15
Pool variability	12	12	12	10	13	11	7	11	12
Sediment Deposition	12	12	10	5	11	12	6	5	5
Channel Flow	14	13	12	7	12	14	5	18	19
Channel Alteration	18	18	18	18	18	18	11	18	18
Channel Sinuosity	6	10	8	9	7	13	5	6	5
Bank Stability (L and R)	14	15	11	4	14	16	6	18	18
Vegetative Protection (L and R)	13	14	11	6	12	14	5	18	18
Riparian Vegetative Zone Width	18	18	18	18	18	18	18	18	18
Total	125	128	114	94	128	135	71	144	142

HYDRAULICS AND SEDIMENT TRANSPORT

Assessment of Rock structures

Typical rock structures and conditions at each restoration site are shown in Figures 27 to 30. The Galum Creek rock structure is still intact and functioning similar to a natural rock riffle. There are some indications of the flow cutting around the structure, but it has not completely flanked the structure at this point. The stability of the structure could be improved by adjusting the design to include keying the structure into the bank as is generally recommended for constructed rock structures. Keying the rock structure into the bank is extending and burying rock into the banks at least 5 m, but the length may vary depending on the size of the stream. An example of a rock structure being keyed into the bank is shown in Figure31. Additionally, determining the correct height for the structure is important to maintaining the stability of a rock structure. If the structure is built too high, causing the flow to be too constricted, stability problems can result. These stability problems will be discussed further in the Hydraulic and Sediment Modeling Methods and Results section.

As discussed above, a combination of structure height and not keying the structures into the banks are most likely the causes of stability problems upstream of the Bonnie Creek incline pit (Figure 128) and at the road crossing downstream of the Bonnie Creek incline pit. The two examples shown in Figure 18 appear to be built more like grade control (upstream structure on top image in Figure 18) and a rock chute (downstream structure on bottom image in Figure 18) as opposed to a natural riffle. Also, note the photo in Figure 23 near cross section 11662 within the rock chute structure. The modeling results will help further illustrate the physical characteristics near these structures. The Bonnie Creek rock structure

Figure 29) shows both a lower structure and overall streambank, however the structure could still be keyed in further to help prevent potential future flanking.

The Pipestone Creek rock structure was very stable with no signs of flanking. However, the structure was overgrown with vegetation (Figure 30). This vegetation could be because of the overall generally milder slope of the reach. Also, Pipestone Creek has incline pits that are in-line with the stream (upstream of the study reach) that could also be a factor in that the flows that the site experience are less than what was designed. The lower flows would also allow vegetation to encroach on the design channel.

Figure 27. Galum Creek rock structure in 2011 at cross section 454 and location cumulative channel length 138 m. Top photo is looking downstream at the structure, the middle photo is looking across the structure, and the bottom photo is looking upstream at the structure.

Figure 18. Bonnie Creek rock structures between cross sections 11662 and 12860 and location between cumulative channel length 2,500 and 2,900 m. Top photo is looking upstream at both structures (2005 flight), the middle photo is looking downstream at the structure at cross section 12860 (2005 flight), and the bottom photos are looking downstream at the structure at 12860 (2006 and 2011).

Figure 29. Bonnie Creek rock structure in 2011 approximately 50 m downstream of cross section 4186 in.

Figure 30. Pipestone Creek rock structure in 2011 (looking upstream) at cross section 793 and location cumulative channel length 241 m.

Figure 31. Example of a rock riffle that is keyed into the bank to help prevent the flow from flanking the structure. Top photo is looking across the channel and bottom photo is taken from the opposite bank looking upstream.

Hydraulic and Sediment Modeling

The resulting water surface, velocity, shear stress, stream power, and entrenchment ratio are presented for each stream in Figures 32, 33, and 34. The scales are the same for each stream and figure so that the three streams can be compared more easily with each other. Generally natural streams in the Midwest with stream power values above 35 newton/meter-second indicate a possible stability problem. Similar to the more qualitative assessment of the physical characteristics, Galum Creek, Pipestone Creek, and the downstream reach of Bonnie Creek appear relatively stable and are generally below the stream power value of 35 newton/meter-second. Elevated stream power values do exist on Galum Creek near a riffle that is protected with larger bed and bank material. Stability problems that were apparent in the photos on the upstream reach of Bonnie Creek are consistent with simulated stream power values above 35 newton/meter-second for the Q10, Q100, and sometimes Q2. The elevated stream power values are also consistent with stability problems observed near the over steepened road crossing at channel length 600 m. In both areas on Bonnie Creek there is larger rock for protection, but the values are such that instability exists where structures are not keyed in, and anywhere that there is not protection of rock. As previously mentioned, the critical shear stress value in pascals is nearly equivalent to the particle size diameter that can be moved at that shear stress and gives further evidence for the assessment of observed conditions and stability. However, the entrenchment ratios for all three restoration sites are generally above 3, meaning that they are not overly entrenched.

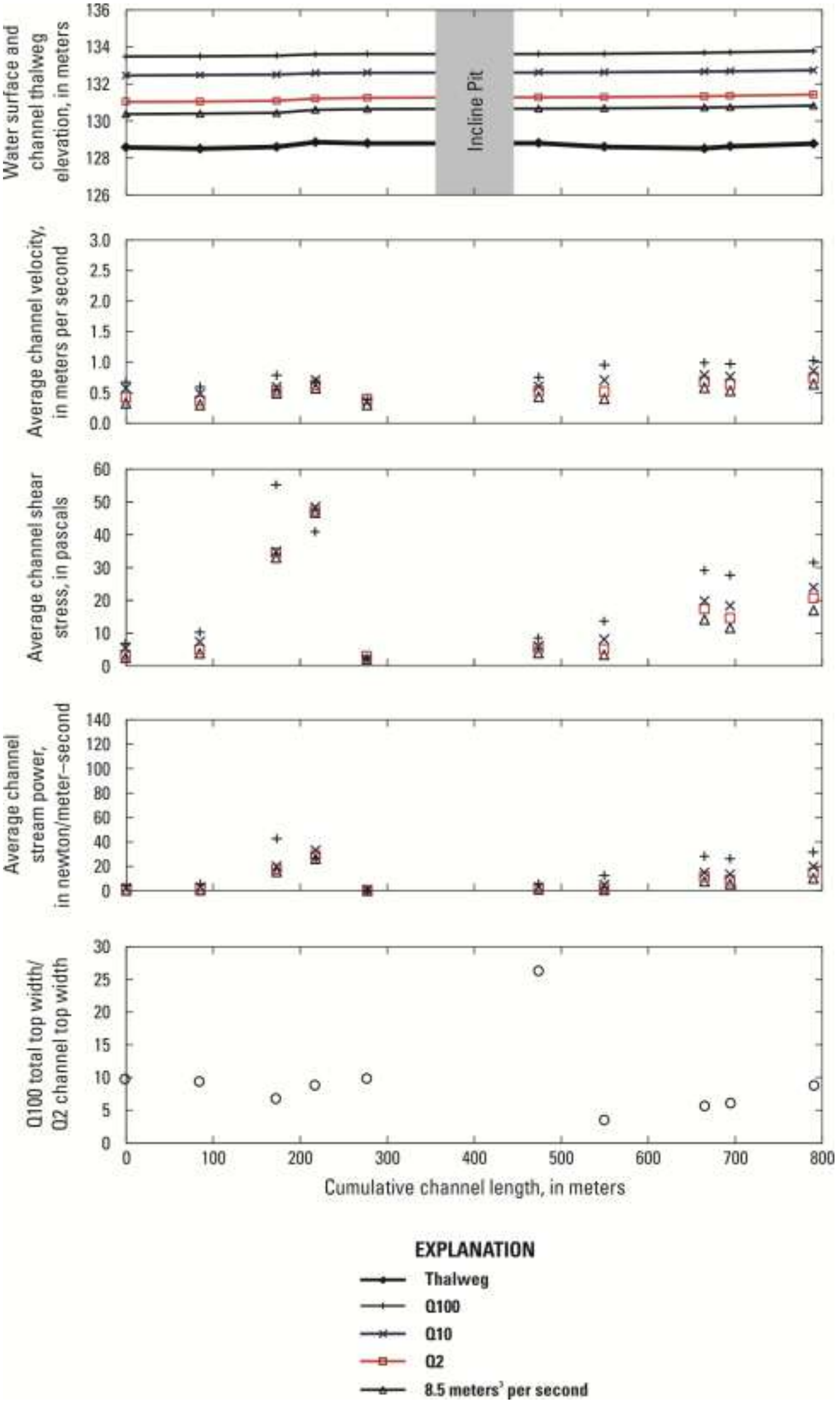

Figure 32. Galum Creek modeled water surface, velocity, shear stress, stream power, and entrenchment ratio.

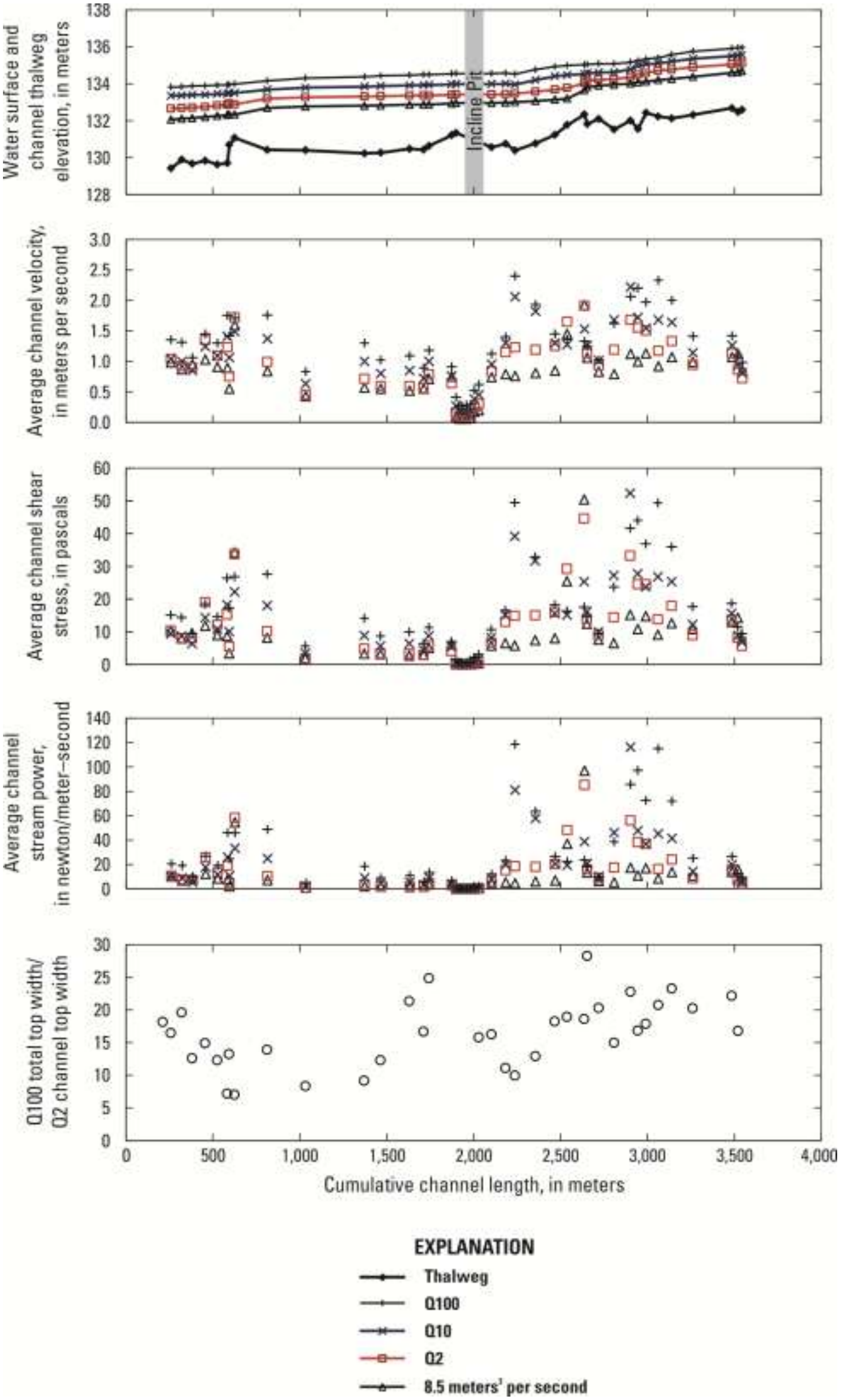

Figure 33. Bonnie Creek modeled water surface, velocity, shear stress, stream power, and quasi-entrenchment ratio.

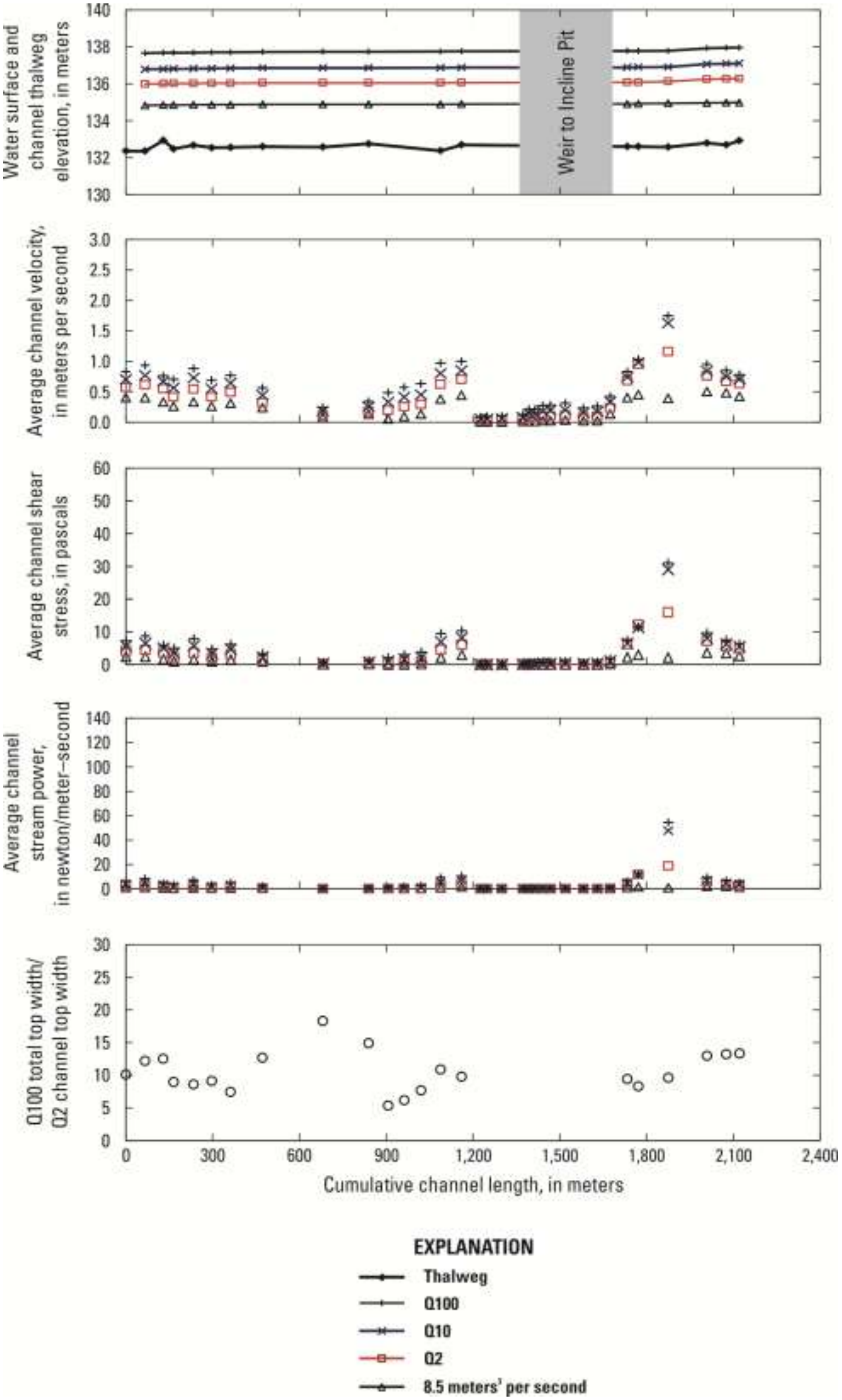

Figure 34. Pipestone Creek modeled water surface, velocity, shear stress, stream power, and quasi-entrenchment ratio.

Lastly, the one-dimensional, quasi-unsteady sediment transport capabilities within the HEC-RAS model were used to simulate changes in peak sediment concentration between upstream and downstream of the incline pits for the 2- and 10-year floods. The HEC-RAS options of the Laursen-Copeland transport function, Exner 5 sorting method, and the Ruby fall velocity methods were selected. Bed material samples taken by the USGS in 2012 were assigned to representative cross sections within the model. The results show that Galum Creek, which has the longest transport time through an incline pit, has the greatest reduction in peak sediment concentration (Figure 35). Pipestone Creek, which is only connected to an incline-pit by a side-channel weir, had the least reduction. With both Bonnie and Galum Creeks the reduction was smaller for the larger flood value.

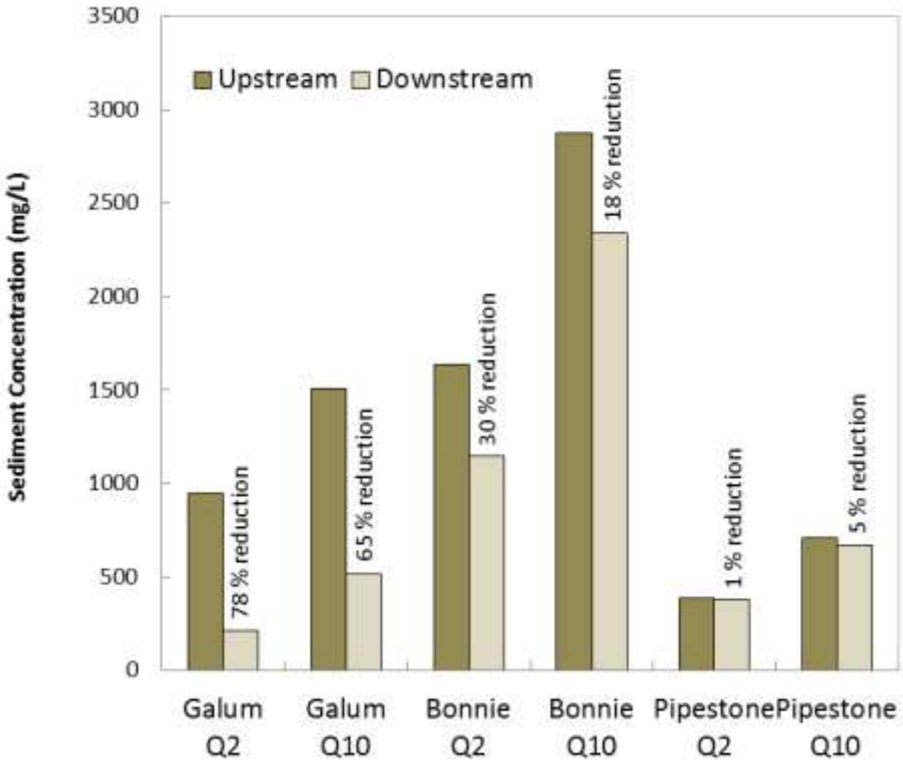

Figure 35. Peak sediment concentration upstream and downstream of the incline pits in Galum, Bonnie, and Pipestone Creeks.

WILDLIFE HABITAT

This 30-year-post-mining assessment of habitat quality for wildlife within the restored riparian buffers of Galum, Bonnie, and Pipestone Creeks has demonstrated that reclamation practices may be having a positive effect on restoring previously-mined lands by converting them back into much needed wildlife habitat. Previous research has shown that reclaimed mine lands provide ample and suitable habitat for the many species of wildlife in the Midwest, including common, threatened, and endangered species (Lannoo et al. 2009, Zipper et al. 2011). Our results indicate that these restored riparian buffers are comparable to that which might be found on lands that have not previously been exposed to surface mining. These successful restoration processes, such as reforestation of the riparian buffers, combined with planting native grasses, shrubs, and herbaceous plants, aid in sustaining the wide diversity of wildlife species that disperse throughout, reside within, or migrate through southern Illinois.

Microhabitat

Overall, microhabitat differences were very minor among sites. Of the 41 microhabitat variables measured (Appendix A), 27 did not differ among sites ($0.0593 \leq P \leq 0.8825$). Fourteen variables differed among sites ($0.0001 \leq P \leq 0.0140$): canopy cover, low vertical vegetative cover, mid-height vertical vegetative cover, overall vegetative cover, understory and overstory stem densities, understory soft mast, overstory soft mast, overstory hard mast, bare ground, herbaceous ground cover, log-woody debris ground cover, grass cover, and leaf litter cover. Four of those variables were uncorrelated (Table 15): canopy cover, overstory hard mast, bare ground, and herbaceous ground cover (χ^2 = 10.618-73.595, df = 3, P = <0.0001-0.014). Canopy cover was lowest at Bonnie Creek, moderate and similar at Galum Creek and Pipestone Creek, and highest at Little Galum Creek. Herbaceous ground cover did not differ among Bonnie Creek, Pipestone Creek, and Little Galum Creek, and was significantly lower at Galum Creek. Bare ground cover was similar at Galum Creek, Little Galum Creek, and Bonnie Creek, with Bonnie Creek and Pipestone Creek values overlapping. Overstory hard mast was similar between Little Galum Creek and Galum Creek, but Galum Creek overstory hard mast overlapped with Bonnie Creek and Pipestone Creek.

Table 15. Differences in microhabitat variables among restored and unmined stream sites in Perry County, Illinois, July–September 2012. Little Galum Creek was the unmined control site. Different letters following mean ± SD values indicate pairwise differences among sites.

Variable	Galum Creek *n* = 45 plots	Bonnie Creek *n* = 35 plots	Pipestone Creek *n* = 47 plots	Little Galum Creek *n* = 73 plots
Canopy cover	0.37 ± 0.34 B	0.22 ± 0.35 C	0.37 ± 0.40 B	0.85 ± .09 A
Herb. ground cover	0.09 ± 0.10 A	0.31 ± 0.24 B	0.21 ± 0.16 B	0.19 ± 0.10 B
Bare ground cover	0.09 ± 0.10 A	0.31 ± 0.24 B	0.21 ± 0.16 B	0.19 ± 0.10 B
Overstory hard mast	0.07 ± 0.08 A	0.04 ± 0.04 A,B	0.01 ± 0.03 B	0.06 ± 0.10 A

Site-level microhabitat variables that were measured for this study were chosen for the general wildlife species and groups of species that are known to inhabit southern Illinois. Approximately 80-88% of the ground cover and forest understory at all 4 creeks was composed primarily of grasses, herbaceous, and litter cover which means that they all provide important low cover for small mammals, reptiles and amphibians (Adler and Wilson 1987, Cross and Peterson 2001, Nupp and Swihart 2001, Pattishall and Cundall 2009). Mammal runs were present at the northern end of Bonnie Creek, even in the mowed area, and predated turtle shells were also found with that area, providing evidence that those and other wildlife use this predominately grassy corridor. Overstory stem density is an important habitat characteristic for large mammals, small mammals, aquatic mammals, reptiles, amphibians, and birds (Anderson et al. 1991, Bowyer et al. 1995, Saab et al. 1999, Nupp and Swihart 2001, Kolowski and Woolf 2002, Pattishall and Cundall 2009), and did not differ between restored and unmined streams. We similarly found no differences among streams for vertical vegetative cover, which is important for large, small, and aquatic mammals (Bowyer et al. 1995, Nupp and Swihart 2001, Kolowski and Woolf 2002). In fact, most site-level variables we measured did not differ between restored and unmined sites, indicating that microhabitat for wildlife can indeed rebound 30 years following stream restoration.

Differences in microhabitat among sites were likely due to differences in forest age among sites, such that the forest at the unmined Little Galum Creek site was considerably older than the restored stream sites. Little Galum Creek had the highest percent canopy cover at 85%, more than double that of the restored streams and there was a much greater likelihood of encountering snags, cavities, and mature trees with fissures and loose bark such as shagbark hickory (*C. ovata*), black locust (*Robinia pseudoacacia*), sugar maple (*A. saccharum*), and sycamore (*Platanus occidentalis*).

While taking field measurements around these restored wetland areas, we observed great egrets (*Ardea alba*) perched in mature baldcypress trees (*Taxodium distichum*), double-crested cormorants (*Phalacrocorax auritus*) drying their wings on snag structure that had been placed in the water, deer browsing on new growth, and birds perched on trees that will eventually grow together and blend into a closed-canopy forest. These restored riparian buffers were full of young oak and hickory trees that with time will mature into healthy hardwood bottomland forest similar to that observed at the reference site. Wildlife species will benefit at different times from early-successional habitat in restored stream corridors (Walton, 2012). During succession, grasslands change to mixed understory, and mixed understory transitions to mature closed canopy forest where soft mast recedes and hard mast tree species begin to shade out the ground vegetation. Some wildlife species will benefit from the change, move about, and begin to colonize new areas, and other species will leave and find early-successional habitat that will suit their needs over time (DeGraaf and Yamasaki 2003; Walton, 2012).

Macrohabitat

Forest cover was the highest represented land cover type at both Galum Creek and Pipestone Creek with 50% and 39%, respectively, and Bonnie Creek was lowest at 25%; Bonnie Creek had a higher proportion of grass cover at 44% (Table 16). Mixed understory cover was not different across restored stream sites, occupying approximately 17-18% of riparian buffers, while wetlands comprised between 3-7% of riparian buffers. Approximately 99% of restored riparian buffers consisted of forests, mixed understory, grasslands, ponds and other ephemeral wetlands; the remaining 1% was of a mowed area at Bonnie Creek and roads that cross the restored stream buffer.

Table 16. Surface area (ha) and proportion (%) of land cover patches within the restored stream buffers in Perry County, Illinois, 2012-13.

	Galum Creek		Bonnie Creek		Pipestone Creek	
Land Cover Class	ha	%	ha	%	Ha	%
Forest	94.63	0.50	20.21	0.25	101.48	0.39
Mixed Understory	34.53	0.18	14.25	0.18	43.57	0.17
Grass	38.68	0.20	35.50	0.44	65.86	0.26
Open Water	9.72	0.05	3.70	0.05	25.91	0.10
Wetland	12.35	0.06	2.17	0.03	17.55	0.07
Roads	0.37	0.00	0.12	0.00	2.63	0.01
Mowed	---[a]	---	5.28	0.06	--- [a]	---

[a] Cover type not present.

Minimum and maximum patch widths varied among restored stream buffers (Table 17). Galum Creek had the longest grass corridors of the 3 restored streams ranging from 135-5,167 m for maximum widths and 4-166 m for minimum widths. Forested areas at Galum Creek ranged from 143-1,407 m at maximum widths and 10-203 m for minimum widths, and mixed understory patches were 146-1,884 m at maximum widths to minimum widths of 6-105 m. Bonnie Creek's grass corridors ranged from 223-2,348 m at maximum widths to minimum widths of 4-11 m, while forest patches were smaller than the other 2 streams, at 32-675 m at a maximum width to 2-32 m at a minimum width. Pipestone Creek had the largest patch widths for forested areas (range = 283-2,294 m), and grassy areas (range = 107-3054 m).

Patch connectivity varied across streams (Table 17). Forested patches were least connected at Pipestone Creek, (range = 22-1,561 m apart), while forests at Galum Creek were the most connected (range = 8-153 m apart). Mixed understory patches were the most connected at Galum Creek (x = 178   293 m apart) and the least connected at Pipestone Creek (x = 516   856 m apart). Grass patches were the most connected at Bonnie Creek and the least connected at Galum Creek. The 6 wetland patches at Pipestone Creek were 5-4,549 m apart and the 6 wetland patches at Galum Creek were 96-823 m apart. Bonnie Creek only had 2 wetlands, which were 146 m apart.

Table 17. Attributes of land cover patches within restored stream buffers in Perry County, Illinois, 2012-13.

Land Cover Class	# Patches	Total Surface Area (ha)	Max. Patch Distance (m)	Min. Patch Distance (m)	Patch Distance (m)	Patch Distance (x ± SD)
Galum Creek						
Forest	16	94.63	143-1407	10-203	8-153	51 ± 49
Mixed Understory	7	34.53	146-1884	6-105	16-835	178 ± 293
Grass	15	38.68	135-5167	4-166	5-915	215 ± 324

Wetland	6	12.35	219-504	16-57	96-823	353 ± 346
Deep Water	4	9.72	265-1008	19-84	---[a]	---
Roads	2	0.37	94-270	14-11	---	---
Mowed Area	0	---	---	---	---	---
Bonnie Creek						
Forest	15	20.21	32-675	2-32	5-346	82 ± 105
Mixed Understory	14	14.25	64-960	3-49	5-1340	302 ± 399
Grass	10	35.50	223-2348	4--11	2-264	57 ± 97
Wetland	2	2.17	157-184	39-73	146	146 ± 0
Deep Water	1	3.70	434	84	---	---
Roads	4	0.12	34-143	3-7	---	---
Mowed Grass	2	5.28	456-520	12-23	---	---
Pipestone Creek						
Forest	15	101.48	283-2294	5-167	22-1561	480 ± 467
Mixed Understory	15	43.57	280-1484	4--46	5-2568	516 ± 856
Grass	20	65.86	107-3054	5-151	5-571	105 ± 162
Wetland	6	17.55	118-1055	3-161	5-4549	1682 ± 2225
Deep Water	3	25.91	321-2238	44-73	---	---
Roads	5	2.63	157-1949	4-9	---	---
Mowed Area	0	---	---	---	---	---

[a] No data.

Riparian buffers within the 3 restored streams contained a matrix of forested patches intermixed with young understory trees, and grassy/herbaceous areas; beyond those patches riparian buffers are surrounded by primarily agriculture, which is generally less-suitable year-round habitat for wildlife. Had these areas remained unrestored or otherwise planted entirely to row-crop agriculture, wildlife habitat value would be considerably limited.

Corridor connectivity within grasslands and herbaceous areas aids in the dispersal of seeds across the landscape which maintains biodiversity in native plant populations, and also enhances the rates in which insects colonize fragmented grasslands, providing a food source for both birds and other wildlife species alike (Collinge 1998, Damschen et al. 2006). Grasslands and herbaceous ground cover also provide nest sites for grassland nesting birds and important cover and shelter for local species of small mammals, reptiles, and amphibians (Fuselier and Edds 1994, Nupp and Swihart 2001, Ingold 2002, Faccio 2003). Bonnie Creek had the highest proportion of grassland and herbaceous cover and the most grassland and herbaceous patch connectivity, followed by Galum Creek and then Pipestone Creek, all of which provide adequate grassland connectivity across the landscape.

Early-successional mixed-understory forests provide valuable habitat for large, small, and aquatic mammals; reptiles and amphibians; offers nest sites for migratory birds; and connects with the larger patches of maturing riparian forest on our study areas (Anderson et al. 1991, Bowyer et al. 1995, Saab et al. 1999, Nupp and Swihart 2001, Kolowski and Woolf 2002, Pattishall and Cundall 2009). Disturbance-dependent species thrive in these earlier successional forests because successional process mimics natural disturbance (Litvaitis 2001). Mixed understory patches had the highest connectivity at Galum Creek. Bonnie Creek had less connectivity in its mixed understory cover, but its mature forests were much more connected, with forested patch distances ranging from 5–346 meters which helps compensate for the lack of connectivity in mixed understory forests. Pipestone Creek’s mixed understory and forested areas were the least connected of the 3 restored streams, but still provide connectivity and valuable wildlife habitat for the species that live within the riparian area.

Neotropical migrants have higher nest success when they are able to utilize interior forest cover and avoid effects of nest predation by cowbirds along forest edges, therefore larger tracts of contiguous forest are preferable to combat the loss of interior forest breeding habitat (Robinson et al. 1995). Forested patches at Galum Creek were the most connected, allowing for wildlife to move about and disperse as necessary for survival. Although forests at Pipestone Creek were the least connected of the 3 restored streams, the buffer still provides valuable wildlife habitat. Interestingly, 2 of the most isolated forest patches at Pipestone Creek, which were 1,312–1,561 m from the next forested patches, represented almost one-third of the total forested habitat available within the riparian buffer at Pipestone Creek and were the least connected forest patches at all study sites.

Ponds and ephemeral wetlands provide important breeding habitat for the 7 different frog species, 2 toad species, and 5 salamander species that have been documented in Perry County, Illinois (Illinois Natural History Survey 2012). The greatest reason for amphibian population declines is habitat loss and fragmentation (Cushman 2006), so we were interested in connectivity of wetland patches on our study sties. Semlitsch (2008) described the core habitat for 11 species of amphibians in 13 studies where 50% of the population stayed within 93 m of the breeding sites, 95% stayed within 664 m, and 99% of amphibian movements were made within 852 m of the natal pool. The 6 wetlands at Galum Creek had patch distances that ranged from 96-823 m (x =353 ± 346) apart, the 2 wetlands at Bonnie Creek were 146 m apart, and Pipestone Creek had 6 wetlands, 4 of which ranged from 5–372 m apart. This indicates that all of these wetlands within the restored riparian buffers lie within suggested and are likely used by dispersing amphibians.

Statistical evaluations of the means and distributions of soils samples from the three treatment classes showed significant difference in three of the four measures of soil nutrient pools: SOM, N, and C/N. C was the only measure where no significant differences were found among the three treatment classes.

Samples taken from surface 15 cm showed the least amount of significant differences among the three treatment classes for SOM. SOM (Figure 36) soil pools in samples taken from the surface 15 cm at upper transect locations in the three treatment classes were not significantly different. Mean SOM in the surface 15 cm samples from the lower sample points was significantly different (p<0.0001) among the three classes. Mean SOM in the MPWs was on average 38% lower (1.62 ± 0.21 %) than the NW (2.61 ± 0.13 %) and 34% lower than the MBFW (2.47 ± 0.10 %). However, SOM in the NW and MBFW was not significantly different at the upper or lower sample points in the surface 15 cm. Differences among treatment groups in SOM were much greater in the samples taken from 15-30 cm depth than in the surface 15 cm. Mean SOM (

Figure in the 15-30 cm depth from the upper (p<0.0001) and lower sample points (p<0.0001) was significantly different among the three classes and between each of the three classes in paired comparisons. Mean SOM at the upper sample points in the MPWs (1.35 ± 0.07 %) was 6% lower than the mean in the MBFWs (1.43 ± 0.06 %) and 22% lower than the mean in the NWs (1.74 ± 0.07 %). Mean SOM in the MBFWs was 18% lower than the mean in the NWs. Mean SOM at the lower sample points in the MPWs (0.95 ± 0.08 %) was 36% lower than the mean in the MBFWs (1.48 ± 0.10 %) and 48% lower than the mean in the NWs (1.83 ± 0.08). Mean SOM in the MBFWs was 19% lower than the mean in the NWs.

N pools were significantly different among the treatment groups in the surface 15 cm at the upper (p=0.0098) and lower (p<0.0001) sample points. Mean N (

Figure 37) was 13% lower in surface 15 cm of the MPWs (0.110 ± 0.007 %) than the NWs (0.126 ± 0.004 %) at the upper sample points and was 46% less at the lower sample points (MPW=0.074 ± 0.096 %, NW=0.136 ± 0.007 %). Distributions of N in the NWs and MBFWs were not significantly different at the upper or lower sample points in the surface 15 cm. Similarly, mean N was 8% lower in the MPWs than the MBFWs (0.12 ± 0.004 %) in the upper sample points and 41% lower in the MPWs than the MBFWs (0.125 ± 0.006 %) in the lower sample points. C/N ratios (

Figure) followed a similar pattern to N with significant differences only being found between the C/N distributions of MPWs and MBFWs and MPWs and NWs in the surface 15 cm at the upper ($p<0.0001$) and lower (<0.0001) sample points. Among the upper sample points, mean C/N ratio in the MPWs (15.00 ± 0.57 %) was 34% higher than the NWs (11.17 ± 0.19 %) and 29% higher than the MBFWs (11.59 ± 0.18 %). Among the lower sample points, mean C/N ratio in the MPWs (20.66 ± 1.55 %) was 34% higher than the NWs (11.38 ± 0.28) and 29% higher than the MBFWs (11.42 ± 0.15 %).

N pools (

Figure 37) were significantly different among the treatment groups in the 15-30 cm depth at the upper ($p<0.0001$) and lower ($p<0.0001$) sample points and between each of the three classes in paired comparisons of rank transformed data. Mean N at the upper sample points in the MPWs (0.051 ± 0.004 %) was 25% lower than the mean in the MBFWs (0.068 ± 0.002 %) and 41% lower than the mean in the NWs (0.087 ± 0.003 %). Mean N in the MBFWs was 22% lower than the mean in the NWs. Mean N at the lower sample points in the MPWs (0.044 ± 0.005 %) was 37% lower than the mean in the MBFWs (0.070 ± 0.004 %) and 51% lower than the mean in the NWs (0.089 ± 0.004 %). Mean N in the MBFWs was 21% lower than the mean in the NWs. C/N ratios (

Figure 38) followed a slightly different pattern than N with significant differences being found between the C/N distributions among all the treatment groups in the 15-30 cm depth at the upper (p<0.0001) and lower (<0.0001) sample points. However, while each treatment class mean of the rank transformed C/N ratios was significantly distinct in the upper sample points, only the MPWs was different from the MBFWs and NWs in the lower sample points. Rank transformed C/N ratios in the MBFWs and NWs in the lower sample points were not significantly different. Mean C/N at the upper sample points in the MPWs (18.88 ± 1.68 %) was 53% higher than the mean in the MBFWs (12.31 ± 0.47 %) and 82% higher than the mean in the NWs (10.38 ± 0.11 %). Mean C/N in the MBFWs was 19% higher than the mean in the NWs. Mean C/N at the lower sample points in the MPWs (21.022 ± 1.49 %) was 47% higher than the mean in the MBFWs (14.27 ± 1.25 %) and 102% higher than the mean in the NWs (10.39 ± 0.18 %). The mean of the rank transformed C/N ratios in the MBFWs was not significantly different than the NWs in the lower sample points.

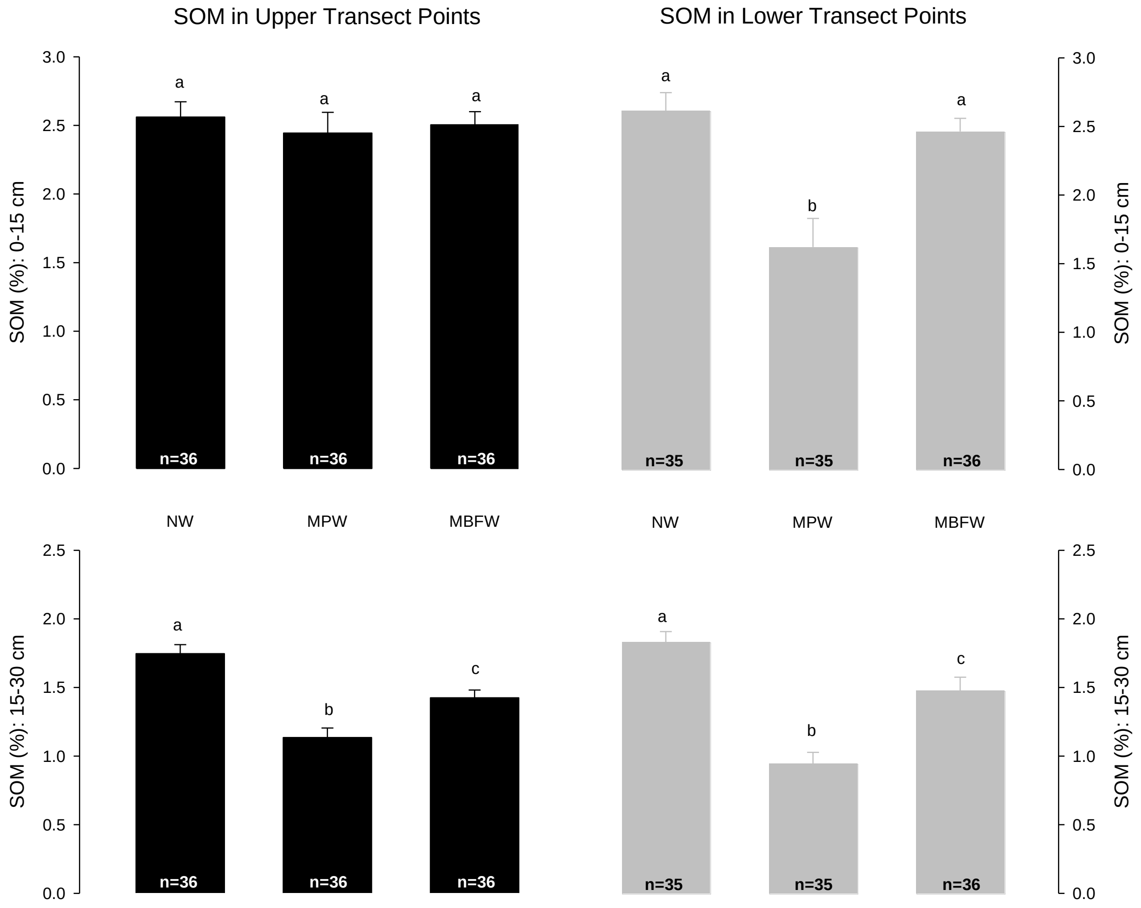

Figure 36. SOM Means with S.E. Among Treatment Classes and Sampling Locations. Treatments within the same sample location that have the same letter were not significantly different at α=0.05

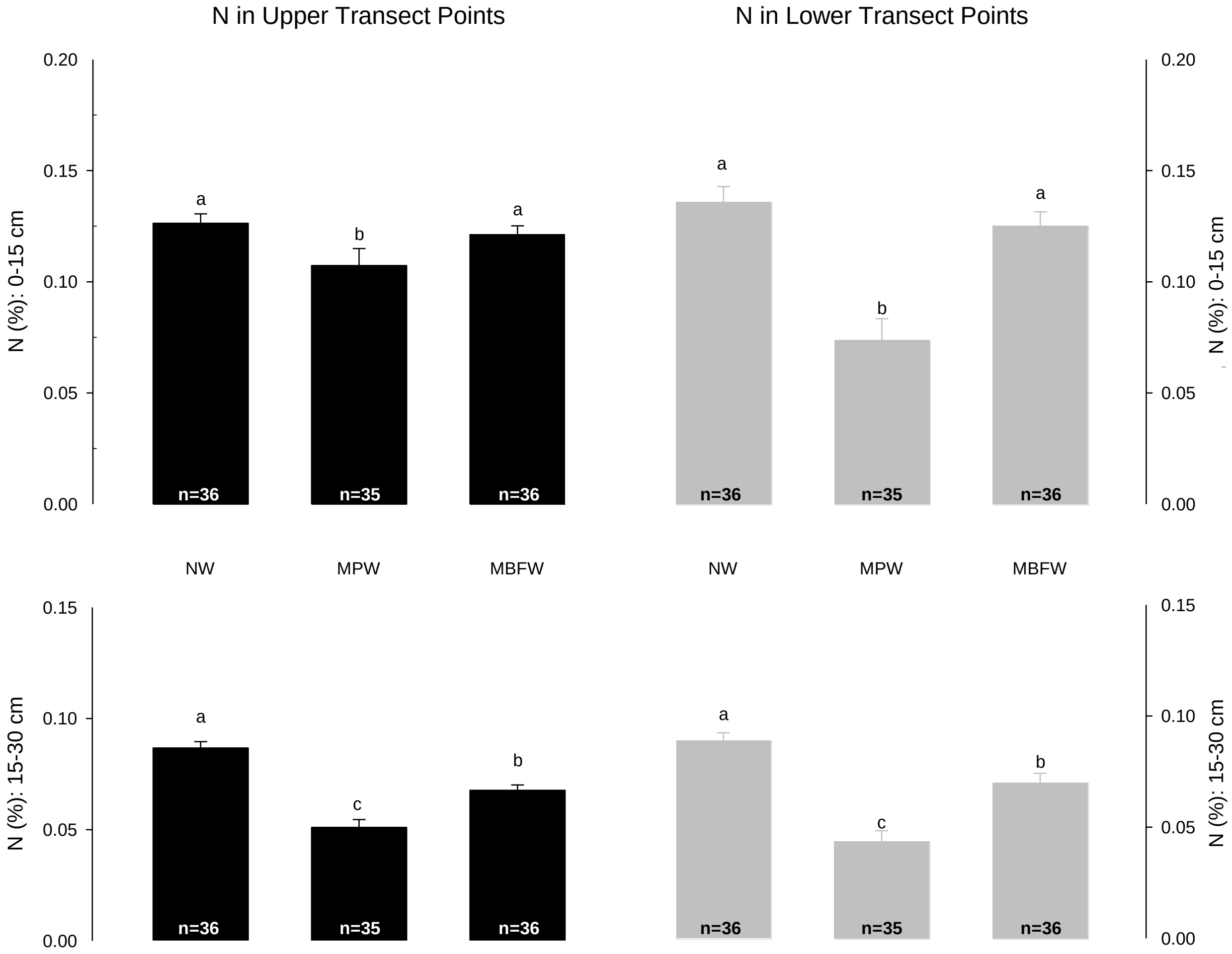

Figure 37. Soil N means with S.E. among treatment classes and sampling locations. Treatments within the same sample location that have the same letter were not significantly different at α=0.05

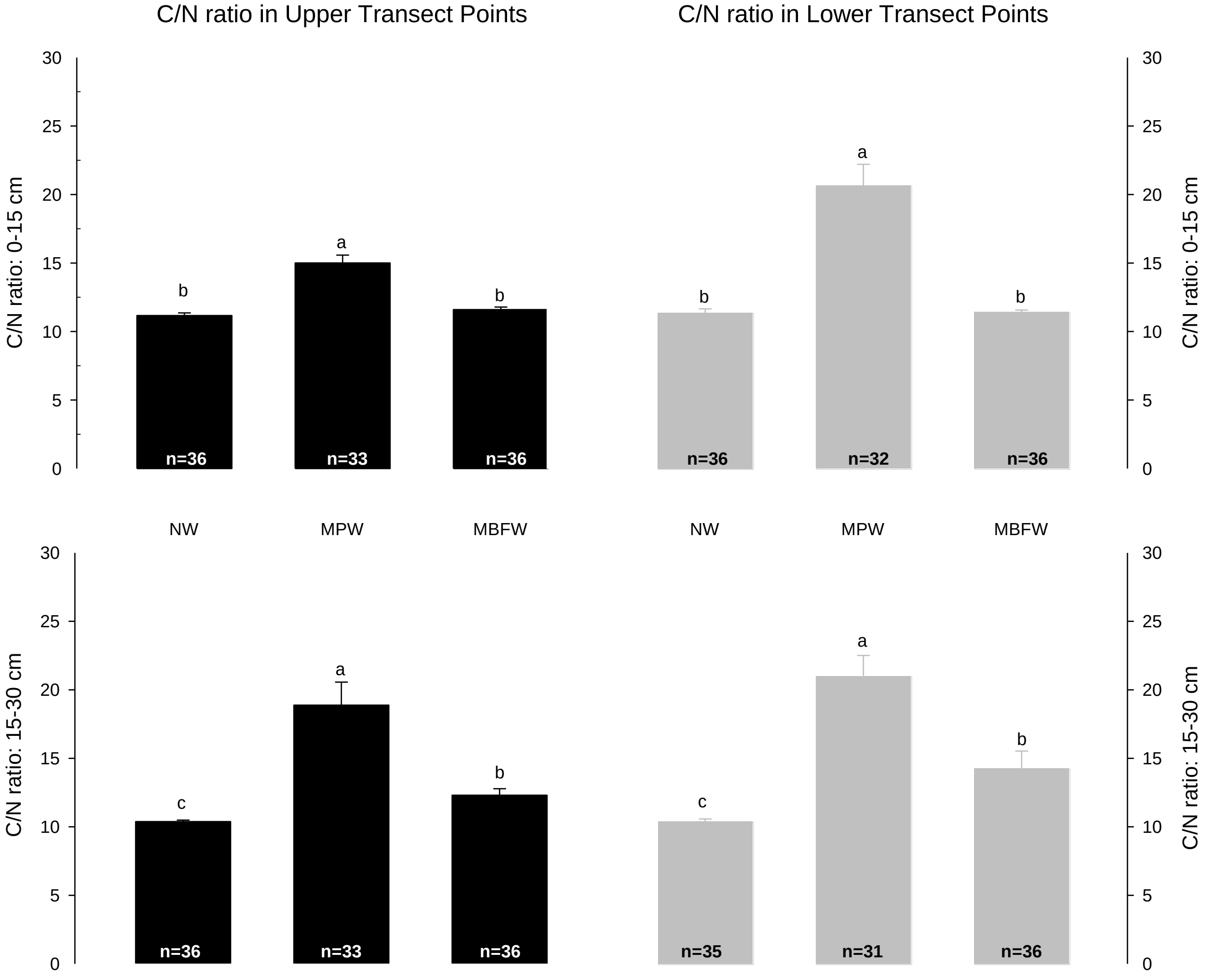

Figure 38. Soil C/N ratio means with S.E. among treatment classes and sampling locations. Treatments within the same sample location that have the same letter were not significantly different at α=0.05

Samples taken from upper sample points showed the least amount of significant differences among the three treatment classes for ρ_b (Table 18). There was no significant difference among treatments. The means ranged from 0.9 ± 0.02 g/cm in the NWs to 0.92 ± 0.01 in the MBFWs and 0.92 ± 0.02 in the MPWs. Differences among the pb means in the lower samples, however, were highly significantly ($p<0.0001$) among the three classes. Mean ρ_b in the MPWs (1.62 ± 0.21) was 26% lower than in the MBFWs (0.89 ± 0.01b) and 32% lower than the MBFW (2.47 ± 0.10). means in the NWs and MBFWs were not significantly different.

Differences between GSM means in the upper and lower sample points were found to be highly significant (Table 18). In the upper transect, mean GSM in the MPWs (13.82 ± 0.85 %) was 27% lower than in the MBFWs (15.35 ± 0.67 %) and 19% lower than in the NWs (18.93 ± 0.83 %). In the lower transect, GSM means in the MPW and MBFW (18.44 ± 1.17) were significantly different from the mean GSM of the NWs but were not significantly different from each. The mean GSM in MPW (16.02 ± 1.43 %) was 34% lower than in the NWs and the mean GSM in the MBFW s (18.44 ± 1.17) was 24% lower than in the NWs(24.24 ± 1.49 %).

Samples taken from the surface 15 cm indicated a significant difference in %Clay (p=0.0482) and %Sand (p=0.0063) in the lower sample points but in the upper sample points a significant difference was found among treatments for %Sand (p=0.0016) but not for %Clay (Table 18). The means of the three classes in the upper sample points for %Clay were 30.78 ± 2.14 % (NW), 27.07 ± 1.35 % (MPW), and 27.24 ± 1.54 % (MBFW). Mean %Sand of MPWs (32.82 ± 3.27 %) in the surface 15 cm of the upper sample points was 62% higher than MBFWs (20.29 ± 1.84) and 79% higher than NWs (18.35 ± 2.93 %). There was no significant difference for %Sand in the MBFWs versus the NWs. In the lower sample points mean %Sand in the MPWs (33.28 ± 3.11 %) was 85% lower than in the MBFWs (18.03 ± 2.81 %) and 81% lower than in the NWs (18.36 ± 4.03 %). Mean %Sand in the MBFWs was not significantly different than mean %Sand in the NWs. Among the lower sample points, mean %Clay in the MPWs (23.49 ± 2.17 %) was 23% lower than in the MBFWs (30.32 ± 1.48 %) and 25% lower than in the NWs (31.16 ± 3.05 %). Mean %Clay in the MBFWs was not significantly different than mean %Sand in the NWs.

Samples analyzed for soil texture taken from the 15-30 cm depth (Table 19) indicated a significant difference in %Sand (p=0.0179) but not %Clay (p=0.0979) whereas in the lower sample points a significant difference was found among treatments for %Clay (p=0.0359) but not for %Sand (p=0.1094). The means of the three classes in the upper sample points for %Clay were 31.8 ± 2.46 % (NW), 27.41 ± 1.6 % (MPW), and 25.15 ± 2.07 % (MBFW). Mean %Sand of MPWs (32.82 ± 3.27 %) in the 15-30 cm depth of the upper sample points was 81%

higher than NWs (18.13 ± 4.05 %). There was no significant difference for %Sand in the MBFWs (21.23 ± 1.64) versus the NWs or in the MBFWs versus the MPWs. In the lower sample points mean %Clay in the MPWs (22.84 ± 1.2 %) was 28% lower than in the NWs (31.54 ± 2.86 %). Mean %Clay in the MBFWs (26.43 ± 2.01) was not significantly different than mean %Clay in the NWs, nor was it different from the mean %Clay in MPWs. Among the lower sample points, mean %Clay in the MPWs (23.49 ± 2.17 %) was 23% lower than in the MBFWs (30.32 ± 1.48 %) and 25% lower than in the NWs (31.16 ± 3.05 %). Mean %Clay in the MBFWs was not significantly different than mean %Sand in the NWs.

The recovery or maintenance of soil nutrient pools following wetland restoration on mined lands at levels equivalent of natural wetlands may suggest the replacement of function. SOM and C were equivalent among treatment groups in the surface 15 cm especially in the upper elevation sample points, but one or both of the mined wetland treatment groups were significantly lower in N in both sample point locations and sample depths. This is similar to other studies on restored wetlands (Meyer et al., 2008). The recovery/maintenance of SOM and N at levels comparable to NWs in the surface 15 cm and C at all depths and sample locations, however, has not been reported in restored wetlands except on mined lands in the Midwest (Cole 1991). Two possible explanations for these unique results are the age of the wetlands and the source of the reclaimed soils. Many studies have reported on restored wetlands that are less than 20 years old (Meyer et al 2008; Bruland and Richardson 2006; Campbell et al 2002) although a few have reported on older wetlands and still did not show recovery of soil nutrient properties to natural levels (Hossler et al 2011; Ballantine and Schneider 2009). Wetlands at BS4N ranged from 19-28 years old. Significant positive step trends in SOM and N over a chronosequence were only found in the surface 15 cm at the lower sampling points of the MPWs. No significant linear trends were found in C by soil age. This suggests that other variables such as the properties of the source soil or vegetation were more responsible for the variability in SOM and C than soil age at least after the first 18 years. Relocation of soils for the purpose of wetland restoration is not a common practice outside of surface mining reclamation. Many restoration projects occur on upland sites (Campbell et al 2002) or at locations where the soil nutrient pools have been depleted through cultivation (Tivy 1987) or other anthropogenic impacts. Pre-mining ecological investigation indicated the presence of many areas under natural cover including bottomland forests, upland forests, and prairies. If used as a source, soils from these areas would have likely been higher in SOM, N, and C than an area under cultivation. Yet, the lower levels of N seen in the surface 15 cm in the upper sample points of the MPW when SOM was equivalent to the NWs shows the importance of the more transient nature of N in the environment compared to SOM which is more recalcitrant.

Table 18. Summary of bulk density and hydrologic properties in study wetlands.

Upper Sample Points			NW	MPW	MBFW
	F value	p	mean ± s.e	mean ± s.e	mean ± s.e
	0-10 cm				
ρ_b (g cm^{-3})	$F_{2,104} = 0.35$	0.706	0.9 ± 0.02a	0.92 ± 0.02a	0.92 ± 0.01a
GSM(%)	$F_{2,104} = 10.34$	<0.0001	18.93 ± 0.83a	13.82 ± 0.85b	15.35 ± 0.67a

Lower Sample Points			NW	MPW	MBFW
	F value	p	mean ± s.e	mean ± s.e	mean ± s.e
	0-10 cm				
ρ_b (g cm^{-3})	$F_{2,104} = 57.53$	<0.0001	0.85 ± 0.02b	1.12 ± 0.02a	0.89 ± 0.01b
GSM(%)	$F_{2,104} = 11.18$	<0.0001	24.24 ± 1.49a	16.02 ± 1.43b	18.44 ± 1.17b

Table 19. Summary of soil physical and chemical properties in study wetlands.

Upper	0-15				
			NW	MPW	MBFW
	F value	p	mean ± s.e	mean ± s.e	mean ± s.e
Sand(%)	F2,33=7.90	0.0016	18.35 ± 2.93b	32.82 ± 3.27a	20.29 ± 1.84b
Clay(%)	F2,33=1.39	0.2628	30.78 ± 2.14	27.07 ± 1.35	27.24 ± 1.54
	15-30				
			NW	MPW	MBFW
	F value	p	mean ± s.e	mean ± s.e	mean ± s.e
Sand(%)	F2,32=4.27	0.0179	18.13 ± 4.05b	32.19 ± 3.5a	21.23 ± 1.64ab
Clay(%)	F2,32=2.50	0.0979	31.8 ± 2.46	27.41 ± 1.6	25.15 ± 2.07
Lower Sample Points	0-15 cm				
			NW	MPW	MBFW
	F value	p	mean ± s.e	mean ± s.e	mean ± s.e
%Sand	F2,32=5.97	0.0063	18.36 ± 4.03b	33.28 ± 3.11a	18.03 ± 2.81b
%Clay	F2,33=3.33	0.0482	31.16 ± 3.05a	23.49 ± 2.17b	30.32 ± 1.48a
	15-30				
			NW	MPW	MBFW
	F value	p	mean ± s.e	mean ± s.e	mean ± s.e
%Sand	F2,33=2.37	0.1094	25.55 ± 4.65a	37.71 ± 3.54a	26.12 ± 5.56a
%Clay	F2,32=3.70	0.0359	31.54 ± 2.86a	22.84 ± 1.2b	26.43 ± 2.01ab

Conclusions

The BS4N and Denmark Mines were among the first mines to attempt to reclaim entire streams and adjacent riparian areas. Now more than 30 years later, they provide a glimpse into the future of recent and future mines that have adopted what is now a widespread practice required by new interpretations (Leibowitz et al 2008) of regulations such as the Clean Water Act and SMCRA. Based on many of the water quality, wetland soil quality, hydraulic and stream stability, and wildlife habitat parameters measured, the stream and riparian system has been restored to a level comparable to that of an unmined area. However, there are a few exceptions, namely those parameters that will take much longer to recover such as canopy cover and deeper soil properties. In addition, several sections of both Bonnie and Galum Creek still show signs of instability. A groundwater seep found along Bonnie Creek also shows the influence of groundwater pollution on the surface water quality. The incline pits provided some sediment retention benefits, but also affected the fish population. The fish communities were more similar to those found in lentic or lacustrine habitats rather than lotic habitats.

The recovery of in-stream water quality to comparable natural levels (except where groundwater contamination is influential) should be considered in tandem with the recovery of the adjacent riparian wetlands. The presence of equivalent levels of nutrient pools in the surface 15 cm have promoted the growth of riparian vegetation and likely has selected for microbial communities important for nutrient cycling and retention. Hydrologic investigation showed that the wetlands were regularly inundated, even more so than the reference riparian wetlands which suffer somewhat from the negative effects of stream entrenchment. On the other hand, though the hydraulic modeling of the Bonnie Creek incline pit showed that it was capable of reducing sediment concentrations by as much as 30%. Storm event sampling indicated an increase in sediment concentration downstream during some storm events. This was due to the contribution to the downstream sediment load by the Lost Prairie Creek agricultural drainage ditch. Although this channel drains approximately 6 km^2, no riparian buffer was restored and so it contributed substantial sediment loads which overwhelmed the sediment retention capacity of the incline pit along Bonnie Creek. This underscores the need to restore riparian buffers along smaller as well as larger streams relocated during surface mining.

Permanent diversion channels in the Galum Creek drainage produced in-stream fish habitat that approximates a natural stream in many respects. Creation of a sinuous channel through a low floodplain planted with riparian trees created the basic elements needed to helped hasten the return of fish habitat to the surface mine landscape. The process of habitat development is still underway as indicated by the paucity of in-stream woody cover typical of the pre-mining stream condition. Shading provided by a forested riparian zone also is critical to fishes. Warm water temperatures are limiting to fishes in summer, especially the more sensitive stream species. A channel design and reclamation plan that promotes stream shading is critical to successful recolonization by those faunal elements. Riparian buffers on smaller tributary streams discussed previously will not only reduce sediment input into the receiving stream but also serve to help decrease summer water temperatures. Riparian buffers also serve as important habitat corridors for wildlife.

The addition of floodplain wetlands along Galum Creek was an exceptional habitat feature for wildlife but the benefits to fishes were not evident in this limited sampling effort. Routing of streams through final cut and incline lakes however proved detrimental to native stream fishes. Stream dwelling fishes are adapted to seasonal and episodic variations in stream flow that, in turn, reduce the presence of species adapted to lentic conditions. It appears that when that flow variation is reduced the lake inhabitants gain an advantage and can dominate the fish fauna, perhaps because they have a nearby source population in the adjacent lakes. Those lakes may also limit immigration by stream species from upstream or downstream habitats. Fish community differences were reflected in Index of Biotic Integrity scores which were higher in the unmined Little Galum Creek. An overflow connection like that on Pipestone

Creek may reduce those effects on the stream fish community. If we define restoration as a return to a condition that more closely resembles a historical species assemblage, then the reclamation of stream segments in the Galum Creek drainage would have likely been more successful if the stream channels were independent of mine lakes.

Despite the inclusion of a regularly accessed floodplain, riparian wetlands, and the orientation of the incline pits inline of the restored channel to attenuate sediment and flows, the streams still showed considerable instability. Higher gradient reaches of Bonnie Creek were severely eroded with outer meander stream banks steeper than 1:1. Lower gradient reaches of Galum and Pipestone Creek experienced heavy siltation that buried the riffle material. The incline pits did offer some sediment and flood attenuation. The upstream Galum pit which had the longest flow path was found to reduce the sediment concentration by 78% during modeling. Significant reduction of sediment concentration was also observed during the storm event sampling. The other pits were less effective. According to the HEC-RAS model, the Bonnie pit reduced sediment concentration by 30%, but during storm event sampling this effect was negated by storm events that carried runoff from agricultural field and an agricultural ditch through an adjacent basin that was connected to the Bonnie pit. During wet season storm events, the basin is overcome by this additional input and the sediment concentration increases across the pit.

Natural streams that have not been significantly impacted by humans are able to balance the transport of sediment so that there is not a significant amount deposited or eroded from a stream segment. Heterogeneity in the stream profile provide necessary habitat for aquatic life that needs a moderated thermal and flow regime. Naturally formed deep pools in meander bends can provide refuge during storm events and dry periods. Stream shading provides the thermal insulation necessary to keep temperature low during hot periods which keeps dissolved oxygen high. The incline pits designed inline of the restored stream channels provide refuge during dry periods and cooler water temperatures deep beneath the surface.

However, the habitat within the pits is only available to fish species that are adapted to a lacustrine habitat. Lotic habitat within the restored stream channels was lacking. There was often little in the form of epifaunal cover or substrate suitable for aquatic habitat. Siltation occurred in lower gradient reaches and erosion occurred in higher gradient reaches. During dry periods, lotic-adapted species did not find refuge in the incline pits, but lentic-adapted species became dominant in the streams. This resulted in a fish community that was different from the fish communities in nearby unmined streams.

Despite falling short in providing the habitat necessary to reestablish a fish community that approximates what was present prior to mining, the three stream restorations show promise for the future. Riparian wetlands, water quality, and riparian wildlife habitat were restored to a similar condition as pre-mining. Wide riparian buffers, a wide floodplain, and natural meanders are absent from many of the streams in the region, especially where row crop agriculture is prominent. None of the streams that were sampled prior to mining or the unmined control points had excellent aquatic habitat or aquatic communities which is reflective of the surrounding watersheds in general. There is much potential and need for stream restoration in the Illinois Coal Basin region. Surface mining may provide the impetus for large-scale restoration such as what occurred at Bonnie, Galum, and Pipestone Creeks.

Stream restoration has advanced significantly thanks to early attempts such as these. Stream restoration techniques used today collect extensive data on “reference reaches” that have desirable characteristics such as good aquatic habitat, stream stability, and balanced sediment transport. If a high quality reference reach had been used to design these streams, they would have likely been designed with more frequent riffles, less tortuous riffles, gentler sloping stream banks, and deeper, wider pools. These characteristics may have solved many of the stability issues experienced in Bonnie, Galum, and Pipestone Creeks. The more frequent riffle areas would have resulted in more habitat and the stream bed elevation would have dropped slowly over the length of the channel rather than all at once in just a few places. By creating gentler sloping banks throughout, and pools with a lower inside bank height that sloped much more gently to create a point par, much of the erosive force would have been taken off the outer bank of the meander bend and distributed throughout the channel. The incline pits provide excellent riparian habitat and support sportfish which is often desirable to landowners after reclamation, but they can provide these functions without being connected to the restored stream channels. There may even be potential for flood and sediment attenuation greater than that which was modeled at the offline Pipestone Creek incline pits given appropriate engineering and design. Aquatic habitat in streams restored on surface mines would also benefit greatly from the addition of large woody debris (which could often be collected during the initial clearing stages prior to mining) and the more immediate establishment of canopy cover over the stream channel to provide thermal insulation.

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Appendix A. Macroinvertebrate sampling results from Galum, Little Galum, Bonnie, and Pipestone creeks in May 2012 and September 2012.

May 2012 Sampling			Little Galum Creek (unmined)		Galum Creek		
Order	Family	Genus-Species	LGA	LGD	GLA (Control)	GLC2	GLC3
Phylactolaemata (Entoprocta)	Plumatellidae	Plumatella sp.				x	
Oligochaeta(Annelida)	Lumbriculidae				x		
	Naididae	*Chaetogaster sp.*					
		unk sp.	x				
Hirudinea (Annelida)	Glossiphoniidae	*Helobdella unk sp.*					x
		Helobdella triserialis					x
		Placobdella sp.					x
Pelecypoda (Mollusca)	Corbiculidae	*Corbicula fluminea*			x		
	Sphaeriidae	*Musculium sp.*					x
		Pisidium sp.			x		
		Sphaerium sp.		x	x		x
Gastropoda (Mollusca)	Physidae	*Physella sp. (uk1)*	x	x	x	x	x
Cladocera (Crustacea)	Bosminidae	*Bosmina sp.*					x
Calanoida (Crustacea)	Diptomidae	*Diptomus sp.*			x		
Amphipoda (Crustacea)	Dogielinotidae	*Hyalella azteca*			x	x	x
Decapoda	Cambaridae	*Cambarus sp.*				x	x
		Orconectes sp.	x		x	x	x
Ephemeroptera	Unk sp.		x				x
	Baetidae	*Callibaetis sp.*	x		x		
		Neocleon sp.					
		Procloeon sp.					
	Caenidae	*Caenis sp.*		x	x	x	x
	Heptageniidae	*Stenonema sp.*		x	x	x	x
	Leptophlebiidae	*Leptophlebia sp.*					
Odonata	Aeshnidae	*Aeshna sp.*		x			

		Basiaeschna janata	x				
		Nasiaeschna pentacantha					
	Gomphidae	*Hagenius brevistylus*		x			
		Progomphus sp.		x			
	Macromiidae	*Macromia sp.*			x		x
	Corduliidae	*Somatochlora*			x		
	Libellulidae	*Libellula sp.*			x		
		Sympetrum sp.					x
	Coenagrionidae	*Argia sp.*		x	x	x	
		Enallagma sp.	x	x	x	x	x
		Ischnura sp.					
Plecoptera	Perlidae	*Neoperla sp.*			x		
Hemiptera	Corixidae	*Trichocorixa sp.*		x		x	x
		unk sp.				x	
		Sigara sp.					
	Nepidae	*Ranatra sp.*				x	
	Geriidae	*Trepobates sp.*					x
		Aquarius sp.					
	Veliidae	*Microvelia sp.*					
Coleoptera	Dysticidae	*Derovatellus sp.*		x			
		Eretes sp.					x
		Hydrotrupes sp.	x				
		Laccophilus sp.			x		
		Thermonectus sp.				x	
	Haliplidae	*Peltodytes sp.*					
	Gyrinidae	*Dineutus sp.*			x		
		Gyrinus sp.					
	Elmidae	*Dubiraphia sp.*				x	
		Stenelmis sp. 1		x			
		Stenelmis sp. 2			x		
	Carabidae	*unk sp.*					
	Hydrophilidae	*Berosus sp.*					x

		Cymbiodyta sp.		x			
		Spercheidae					
	Scirtidae	*Elodes sp.*					
	Staphylinidae	*unk sp. 1*			x	x	
		unk sp. 2	x				
Megaloptera	Corydalidae	*Chauliodes sp.*					
Trichoptera	Hydropsychidae	*Cheumatopsyche sp.*	x		x		x
	Philopotamidae	*Chimarra sp.*					
	Molaunidae	*Molauna sp.*				x	x
	Rhyacophilidae	*Rhyacophila*					x
Diptera		*unk. Pupa*				x	
	Tipulidae	*Tipula sp.*	x				
	Chironomidae	Chironominae (subfamily)	x	x	x	x	x
		Orthocladiinae (subfamily)	x		x		
		Tanypodiinae (subfamily)	x	x	x	x	x
		Diamesinae (subfamily)					
	Chaoboridae	*Chaoborus sp.*	x			x	x
	Culicidae	*Aedes sp.*	x				
	Simuliidae	*Simulium sp.*	x	x	x		x
		Total Taxa	17	16	26	20	27

May 2012 Sampling			Bonnie Creek			
Order	Family	Genus-Species	BCA	BCB2	BCB3	BCB4
Phylactolaemata (Entoprocta)	Plumatellidae	Plumatella sp.				
Oligochaeta(Annelida)	Naididae	*Chaetogaster sp.*				x
		unk sp.		x		
Hirudinea (Annelida)		*Placobdella sp.*				x
Pelecypoda (Mollusca)		*Pisidium sp.*				x
		Sphaerium sp.		x		x
Gastropoda (Mollusca)	Physidae	*Physella sp. (uk1)*	x	x	x	x
Decapoda		*Orconectes sp.*		x		
Ephemeroptera	Baetidae	*Callibaetis sp.*			x	
		Procloeon sp.		x		
	Leptophlebiidae	*Leptophlebia sp.*				x
		Basiaeschna janata		x		
		Nasiaeschna pentacantha			x	
	Corduliidae	*Somatochlora*		x		
	Libellulidae	*Libellula sp.*	x			
	Coenagrionidae	*Argia sp.*	x			
		Enallagma sp.	x	x	x	x
		Ischnura sp.	x		x	x
Hemiptera	Corixidae	*Trichocorixa sp.*				x
		unk sp.				x
		Sigara sp.		x		
	Nepidae	*Ranatra sp.*			x	
	Geriidae	*Trepobates sp.*				
		Aquarius sp.		x		
	Veliidae	*Microvelia sp.*	x			
	Haliplidae	*Peltodytes sp.*		x		
	Gyrinidae	*Dineutus sp.*				x
		Gyrinus sp.	x			
	Elmidae	*Dubiraphia sp.*			x	

		Stenelmis sp. 1	x			x
	Carabidae	*unk sp.*			x	
	Hydrophilidae	*Berosus sp.*		x		x
		Spercheidae	x			
	Scirtidae	*Elodes sp.*			x	
		unk sp. 2			x	
Megaloptera	Corydalidae	*Chauliodes sp.*		x		
Trichoptera	Hydropsychidae	*Cheumatopsyche sp.*	x		x	x
	Philopotamidae	*Chimarra sp.*				x
Diptera	Chironomidae	Chironominae (subfamily)	x	x	x	x
		Orthocladiinae (subfamily)	x			
		Tanypodiinae (subfamily)	x		x	x
		Diamesinae (subfamily)		x		
	Chaoboridae	*Chaoborus sp.*	x			
	Simuliidae	*Simulium sp.*			x	x
		Total Taxa	14	15	14	18

May 2012 Sampling			Pipestone Creek									
Order	Family	Genus-Species	L-3 Qual	L-3 PONAR	L-3 Surber	R-1 Qual	R-1 PONAR	R-2 Qual	R-2 PONAR	R-3 Qual	R-3 PONAR	R-3 Surber
Annelida	Naididae	*Chaetogaster sp.*										
		Pristius sp.		120	11		1080		160		400	86
Pelecypoda (Mollusca)	Corbiculidae	*Corbicula fluminea*	x	80							40	
	Sphaeriidae	*Musculium sp.*		120	11		40	x	40		160	
		Sphaerium sp.		40								
Gastropoda (Mollusca)	Physidae	*Physella sp. (uk1)*	X	120	11		40	x	80		40	54
		Physella sp. (uk2)							40			
Nematoda	Rhabditidae	*Rhabditis sp*			40							33
Ostracoda	Unknown sp.											22
Cladocera (Crustacea)	Daphniidae	*Simocephalus sp.*					80					
Amphipoda (Crustacea)	Dogielinotidae	*Hyalella azteca*	x			x	3800	x		x	40	
Decapoda	Cambaridae	*Cambarus sp.*			11							
Ephemeroptera	Baetidae	*Callibaetis sp.*				x						
		Baetis sp.						x				
		Neocleon sp.					40					
	Caenidae	*Caenis sp.*					40	x	40	x		
	Heptageniidae	*unk sp.*	x									
		Stenonema sp.					40					
Odonata	Aeshnidae	*Anax sp.*										40
		Basiaeschna janata						x		x		
		Nasiaeschna pentacantha				x						
		unk sp.					40					

	Calopterygidae	*Hetaerina sp.*	x							x		
	Coenagrionidae	*Argia sp.*				x				x		
		Enallagma sp.	x	40		x	160	x	80	x	480	97
		Ischnura sp.					80	x		x	40	22
Hemiptera	Corixidae	*Trichocorixa sp.*			180			x				11
		unk sp.						x		x		
	Hydrometridae	*Hydrometra sp.*						x				
	Geriidae	*Rheumatobates sp.*					40					
	Saldidae	*Salda sp.*				x						
Coleoptera	Dysticidae	*Coptotomus sp.*	x									
	Elmidae	*Dubiraphia sp.*		40				x	40	x		
		Stenelmis sp. 1	x		43	x	40		40			11
		Stenelmis sp. 2				x	40					
	Carabidae	*unk sp.*	x									
	Hydrophilidae	*Berosus sp.*				x						11
		Hydrochara sp.						x		x		
	Scirtidae	*Elodes sp.*	x			x		x				
		Scirtes sp.	x									
	Staphylinidae	*unk sp.*	x									
Megaloptera	Corydalidae	*Chauliodes sp.*				x				x		
	Sialidae	*Sialis sp.*										
Trichoptera	Hydropsychidae	*Cheumatopsyche sp.*						x				
Diptera	Tipulidae	*Megistocera sp.*						x				
	Chironomidae	Chironominae (subfamily)		320	11	x	640	x	920	x	1600	334
		Orthocladiinae (subfamily)						x				
		Tanypodiinae (subfamily)		40		x	480	x	240	x		
	Chaoboridae	*Chaoborus sp.*				x	40			x		
	Culicidae	*Aedes sp.*										11
	Simuliidae	*Simulium sp.*		40			40	x				

Total Density				1000	206		6920		1680		2800	786
Total Taxa			12			14		20		14		

September 2012 Sampling			Little Galum Creek (Unmined)		Galum Creek		
			LGA	LGD	GLA	GLC2	GLC3
Oligochaeta(Annelida)	Lumbriculidae						
	Naididae	*Chaetogaster sp.*					x
		Stylaria sp.					
	Tubificidae	*Branchiura sowerbyi*					x
Hirudinea (Annelida)	Glossiphoniidae	*Helobdella unk sp.*					x
		Placobdella sp.					x
Pelecypoda (Mollusca)	Corbiculidae	*Corbicula fluminea*				x	x
	Sphaeriidae	*Musculium sp.*		x			x
		Sphaerium sp.					x
Gastropoda (Mollusca)	Physidae	*Physella sp. (uk1)*	x	x	x		x
Cladocera (Crustacea)	Bosminidae	*Bosmina sp.*			x		x
	Daphinidae	*Daphia sp.*					x
Amphipoda (Crustacea)	Hyalellidae	*Hyalella azteca*	x	x	x		
	Crangonyctidae	*Crangonyx sp.*		x			
Decapoda	Cambaridae	*Cambarus sp.*		x			
Arthropoda	Araneidae	*Tetragnatha sp.*	x				
Ephemeroptera	Baetidae	*Baetis sp.*					
		Neocleon sp.		x	x	x	x
	Caenidae	*Caenis sp.*		x	x	x	
	Heptageniidae	*Stenonema sp.*		x			
Odonata	Aeshnidae	*Anax sp.*					x
		Boyeria sp.		x			
	Gomphidae	*Progomphus obscurus*		x			
	Libellulidae	*Libellula sp.*			x		
		Erythodiplax					

		Sympetrum sp.		x	x	x	
	Coenagrionidae	*Argia sp.*		x			x
		Enallagma sp.		x			
		Ischnura sp.		x	x		
Hemiptera	Corixidae	*Hesperocorixa sp.*				x	
		Trichocorixa sp.	x			x	
	Gerridae	*Trepobates sp.*		x			
	Saldidae	*Salda sp.*		x	x		
	Aphididae	*terrestrial unk*					
	Fulgoridae	*terrestrial unk*	x				
Coleoptera	Chrysomelidae	*terrestrial unk*	x				
	Dysticidae	*Coptotomus sp.*			x		
		Hydrotrupes sp.	x				
		Hydrovatus sp.	x				
		Laccophilus sp. 1	x				x
		Laccophilus sp. 2	x				x
	Haliplidae	*Peltodytes sp.*		x		x	
	Gyrinidae	*Dineutus sp.*			x		
		Gyrinus sp.			x	x	
	Elmidae	*Microcoellepus sp.*			x		
		Stenelmis sp. 1					
		Stenelmis sp. 2			x	x	
	Hydrophilidae	*Berosus sp.*			x	x	
		Cymbiodyta sp.	x				
		Helocharus	x				
		Tropisternus sp.					
		Sphaerinae subfamily	x				
	Scirtidae	*Elodes sp.*		x			
		Scirtes sp.	x			x	
	Staphylinidae	*unk sp. 1*	x				
Megaloptera	Corydalidae	*Chauliodes sp.*					
Trichoptera	Hydropsychidae	*Cheumatopsyche sp.*	x	x			

	Philopotamidae	*Chimarra sp.*					
	Lepidoptera	*terrestrial unk*					x
Diptera	Tabanidae	*Tabanus sp.*		x		x	x
	Tipulidae	*Tipula sp.*		x			
	Chironomidae	Chironominae (subfamily)	x	x	x	x	x
		Orthocladiinae (subfamily)	x	x			x
		Tanypodiinae (subfamily)			x		x
	Chaoboridae	*Chaoborus sp.*					x
	Culicidae	*Aedes sp.*				x	
		unk sp.					x
	Simuliidae	*Simulium sp.*					
		Prosimulium sp.					
	Strattiomyidae	*Odontomyia sp.*					
		Total Taxa	18	23	17	14	22

September 2012 Sampling			Bonnie Creek		
			BCA	BCB3	BCB4
Oligochaeta(Annelida)	Naididae	*Stylaria sp.*		x	
Pelecypoda (Mollusca)	Sphaeriidae	*Sphaerium sp.*	x		
Gastropoda (Mollusca)	Physidae	*Physella sp. (uk1)*	x	x	x
Amphipoda (Crustacea)	Hyalellidae	*Hyalella azteca*	x	x	x
Ephemeroptera	Baetidae	*Baetis sp.*			x
		Neocleon sp.		x	x
	Caenidae	*Caenis sp.*	x	x	x
	Heptageniidae	*Stenonema sp.*	x		
Odonata	Libellulidae	*Libellula sp.*			x
		Erythodiplax			x
		Sympetrum sp.			x
	Coenagrionidae	*Argia sp.*	x		
		Enallagma sp.	x		x
		Ischnura sp.	x		
Hemiptera	Corixidae	*Hesperocorixa sp.*			
		Trichocorixa sp.		x	x
	Aphididae	*terrestrial unk*	x		
Coleoptera	Haliplidae	*Peltodytes sp.*	x	x	x
		Gyrinus sp.	x		
	Elmidae	*Stenelmis sp. 1*	x		x
	Hydrophilidae	*Berosus sp.*		x	x
		Cymbiodyta sp.			x
		Tropisternus sp.			x
Megaloptera	Corydalidae	*Chauliodes sp.*	x		
Trichoptera	Hydropsychidae	*Cheumatopsyche sp.*			
	Philopotamidae	*Chimarra sp.*		x	
Diptera	Tabanidae	*Tabanus sp.*	x		
	Chironomidae	Chironominae (subfamily)	x	x	x
		Orthocladiinae (subfamily)	x	x	x

		Tanypodiinae (subfamily)	x		
	Simuliidae	*Simulium sp.*		x	x
		Prosimulium sp.		x	
	Strattiomyidae	*Odontomyia sp.*			x
		Total Taxa	17	13	19

September 2012 Sampling		Pipestone Creek									
Family	Genus-Species	L-3 Qual	L-3 PONAR	L-3 Surber	R-1 Qual	R-1 PONAR	R-2 Qual	R-2 PONAR	R-3 Qual	R-3 PONAR	R-3 Surber
Naididae	*Chaetogaster sp.*		720	43		40		360		360	53.8
	unk sp.	x	40	10.8						40	
	Gordian worm								x		
Araneidae	*Tetragnatha sp.*						x				
Corbiculidae	*Corbicula fluminea*	x						40			
Sphaeriidae	*Musculium sp.*									120	
	Sphaerium sp.			118.4						40	10.8
Physidae	*Physella sp. (uk1)*				x		x		x		64.6
Planorbidae	*Gyraulus sp.*						x				
Rhabditidae	*Rhabditis sp*							80		40	
Unknown sp.										40	
Hyallelidae	*Hyalella azteca*	x			x	40	x	x		560	398
Omniscoidea	*terrestrial unk*				x						
Asellidae	*Asellus sp.*				x						
Baetidae	*Baetis sp.*				x						
	Neocleon sp.			40	x		x		x		
Caenidae	*Caenis sp.*	x	80		x		x		x	600	
unk sp. and family											
Libellulidae	*Libellula sp.*				x						
	Sympetrum sp.								x		
Calopterygidae	*Hetaerina sp.*								x		
Coenagrionidae	*Argia sp.*				x				x		
	Enallagma sp.				x	200	x		x		10.8
	Ischnura sp.								x		
Corixidae	*Trichocorixa*	x			x		x		x		11

	sp.										
Geriidae	*Trepobates sp.*						x				
Ranatridae	*Ranatra sp.*				x						
Dytiscidae	*Laccophilus sp*				x						
Elmidae	*Dupiraphia sp*	x	120	86		40	x	40	x	280	21.5
	Microcylloepus								x		
	Stenelmis sp. 1		40	107	x				x		21.5
	Stenelmis sp. 2				x						
Gyrinidae	*Dineutes sp.*	x									
	Gyrinus sp	x									
Haliplidae	*Peltodytes sp.*								x		
Hydrophilidae	*Berosus sp.*				x	160	x		x	360	903.8
Psephnidae	*Ectopria sp.*				x						
Scirtidae	*Elodes sp.*	x									
Isotomidae	*unk sp.*								x		
Sialidae	*Sialis sp.*	x		10.8							
Philopotamidae	*Chimarra sp.*								x		
Tabanidae	*Tabanus sp.*				x						
Chironomidae	Chironominae (subfamily)	x		258	x	280	x	280		400	53.8
	Diamesinae						x				
	Orthocladiinae (subfamily)			10.8		80		80	x		
	Tanypodiinae (subfamily)	x	160	10.8			x	40	40		
Chaoboridae	*Chaoborus sp.*	x									
	Density		1160	695.6		840		920		2840	1495.8
	Total Taxa	18			21		18		27		

Appendix B. Fish sampling locations for Galum, Little Galum, Bonnie, and Pipestone Creeks.

Fish Sampling Point	Latitude	Longitude
Galum (upper)	38 05.214 N	89 33.263 W
Galum (lower)	38 04.777 N	89 32.792 W
Little Galum (upper)	38 02.439 N	89 25.746 W
Little Galum (lower)	38 01.044 N	89 26.254 W
Bonnie (upper)	38 04.536 N	89 31.059 W
Bonnie (lower)	38 03.923 N	89 31.207 W
Pipestone (upper)	37 59.681 N	89 32.061 W
Pipestone (lower)	37 59.577 N	89.31.827 W

Appendix C. Microhabitat variables measured at restored and unmined stream sites in Perry County, Illinois, July-September 2012. Little Galum Creek was the unmined control site.

	Galum Creek	Bonnie Creek	Pipestone Creek	Little Galum Creek
	x SD	x SD	x SD	x SD
Bank cover grass	0.22 ± 0.42	0.24 ± 0.44	0.23 ± 0.43	0.08 ± 0.28
Bank cover bare	0.35 ± 0.49	---[a]	0.18 ± 0.39	0.48 ± 0.51
Bank cover herb	0.17 ± 0.39	0.41 ± 0.51	0.09 ± 0.29	0.36 ± 0.49
Bank cover litter	---	---	---	0.08 ± 0.28
Bank cover phragmites	---	0.24 ± 0.44	0.50 ± 0.51	---
Bank cover rock	0.22 ± 0.42	0.12 ± 0.33	---	---
Bank cover shrub	0.04 ± 0.21	---	---	---
Low vertical cover	0.14 ± 0.22	0.23 ± 0.30	0.28 ± 0.21	0.49 ± 0.19
Mid vertical cover	0.46 ± 0.29	0.56 ± 0.33	0.63 ± 0.23	0.75 ± 0.19
High vertical cover	0.76 ± 0.28	0.77 ± 0.26	0.77 ± 0.20	0.79 ± 0.19
All vertical cover	0.45 ± 0.21	0.52 ± 0.26	0.56 ± 0.19	0.68 ± 0.16
Understory stem density	0.05 ± 0.09	0.03 ± 0.05	0.05 ± 0.05	0.08 ± 0.05
Overstory stem density	0.02 ± 0.03	0.02 ± 0.05	0.05 ± 0.06	0.05 ± 0.03
Understory soft mast	0.05 ± 0.09	0.01 ± 0.02	0.04 ± 0.04	0.06 ± 0.03
Understory hard mast	0.004 ± 0.01	0.02 ± 0.04	0.02 ± 0.04	0.02 ± 0.02
Overstory soft mast	0.01 ± 0.02	0.004 ± 0.01	0.03 ± 0.04	0.04 ± 0.03
<7.5cm log, decay class 1	0.22 ± 0.67	0.06 ± 0.24	0.04 ± 0.20	0.11 ± 0.39

<7.5cm log, decay class 2	0.22 ± 0.70	---	0.13 ± 0.49	0.71 ± 1.66
<7.5cm log, decay class 3	0.78 ± 2.59	0.11 ± 0.32	0.36 ± 0.82	0.96 ± 1.17
<7.5cm log, decay class 4	---	0.03 ± 0.17	0.19 ± 0.61	0.66 ± 1.35
<7.5cm log, decay class 5	---	0.03 ± 0.17	---	0.10 ± 0.34
>7.5cm log, decay class 1	---	0.03 ± 0.17	0.02 ± 0.15	0.14 ± 0.45
>7.5cm log, decay class 2	0.04 ± 0.21	0.06 ± 0.24	0.02 ± 0.15	0.59 ± 1.03
>7.5cm log, decay class 3	0.47 ± 1.53	0.17 ± 0.57	0.19 ± 0.58	1.11 ± 1.60
>7.5cm log, decay class 4	0.18 ± 0.44	0.26 ± 0.78	0.13 ± 0.40	1.45 ± 1.41
>7.5cm log, decay class 5	---	0.03 ± 0.17	0.02 ± 0.15	0.60 ± 1.11
Cavities	0.29 ± 0.73	0.29 ± 0.06	0.26 ± 0.07	1.93 ± 2.45
Fissures	0.04 ± 0.21	---	---	0.12 ± 0.33
Snags	0.18 ± 0.44	0.40 ± 1.06	0.17 ± 0.43	1.32 ± 1.04
Trees with top out	0.04 ± 0.21	0.03 ± 0.17	---	0.12 ± 0.33
Loose bark on trees	0.02 ± 0.15	---	0.06 ± 0.25	0.29 ± 0.54
Rock ground cover	0.01 ± 0.02	0.01 ± 0.03	0.005 ± 0.02	0.0002 ± 0.002
Log-wood ground cover	0.04 ± 0.05	0.01 ± 0.02	0.02 ± 0.04	0.12 ± 0.07
Grass ground cover	0.56 ± 0.25	0.34 ± 0.23	0.57 ± 0.21	0.14 ± 0.10
Shrub ground cover	0.01 ± 0.01	0.01 ± 0.05	0.01 ± 0.01	0.01 ± 0.01
Phragmites ground cover	0.08 ± 0.18	0.10 ± 0.21	0.08 ± 0.13	---
Litter ground cover	0.15 ± 0.18	0.18 ± 0.20	0.10 ± 0.18	0.48 ± 0.18

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[a] No data.

Appendix D. High level helicopter aerials of Bonnie Creek 2005.

Images from an aerial video taken from a helicopter in 2005 by the Illinois Environmental Protection Agency and the Illinois Department of Agriculture (all photos taken looking upstream).

Agricultural ditch upstream of Rte 154

Restored reach downstream of Rte 154

Restored reach downstream of Rte 154

Restored reach downstream of Rte 154

Restored reach downstream of Rte 154

Restored reach downstream of Rte 154 and incline pit

Restored reach downstream of incline pit

Restored reach downstream of incline pit

Restored reach downstream of incline pit and including road crossing

Restored reach downstream of incline pit

Restored reach downstream of incline pit

Restored reach downstream of incline pit

Restored reach downstream of incline pit

Confluence of Bonnie Creek (top) and Galum Creek (left)

Confluence of Bonnie Creek (top) and Galum Creek (left)

Appendix E. Low level helicopter aerials of Bonnie Creek 2005.

Images from an aerial video taken from a helicopter in 2005 by the Illinois Environmental Protection Agency and the Illinois Department of Agriculture (all photos taken looking downstream).

First bank downstream of Rte 154

Second bank below Rte 154

Third bank below Rte 154

Fourth bank below Rte 154

Fifth bank below Rte 154

Sixth bank below Rte 154

Seventh bank below Rte 154

Eigth bank below Rte 154

Ninth bank below Rte 154

Tenth bank below Rte 154

Eleventh bank below Rte 154

Twelfth bank below Rte 154

Thirteenth bank below Rte 154

Fourteenth bank below Rte 154

Fifteenth bank below Rte 154

Sixteenth bank below Rte 154

Sixteenth bank below Rte 154

Seventeenth bank below Rte 154

Eighteenth bank below Rte 154

Nineteenth bank below Rte 154

Twentieth bank below Rte 154 and directly upstream of the incline pit inlet

Incline pit (inlet at bottom of photo and outlet at top)

Incline pit and outlet

First meander bend downstream of incline pit

Second meander bend downstream of incline pit

Third meander bend downstream of incline pit

Fourth meander bend downstream of incline pit

Fifth meander bend downstream of incline pit

Sixth meander bend downstream of incline pit

Seventh meander bend downstream of incline pit

Eighth meander bend downstream of incline pit

Ninth meander bend downstream of incline pit

Tenth meander bend downstream of incline pit

Eleventh meander bend downstream of incline pit

Straight reach with riffles

Twelfth meander bend downstream of incline pit with riffles

Thirteenth meander bend downstream of incline pit

Fourteenth meander bend downstream of incline pit

Fifteenth meander bend downstream of incline pit

Sixteenth meander bend downstream of incline pit

Seventeenth meander bend downstream of incline pit

Eighteenth meander bend downstream of incline pit

Rock structure

Nineteenth and twentieth meander bend downstream of incline pit

Bonnie (bottom of photo) and Galum (right) confluence

Bonnie (bottom of photo) and Galum (right) confluence

Bonnie (bottom of photo) and Galum (right) confluence