Mountaintop Mining Valley Fills and Aquatic Ecosystems:
A Scientific Primer on Impacts and Mitigation Approaches

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To protect your rivers, protect your mountains. --Emperor Yu of China, 1600 B.C.E.

EXECUTIVE SUMMARY

Mountaintop mining and valley fill (MTVF) operations have both local and regional effects on aquatic ecosystems. The effects are described in brief here along with key points (bullets) from scientific studies published in peer-reviewed journals.

I. Watershed and Stream Alteration by Mountain Top Mining

The topography and the hydrology of mountain top mined watersheds are radically altered – valley contours are flattened and precipitation is routed through rock lined ditches on the surface or percolates through fill material. Even after reclamation, the vegetation is dramatically different. The alteration in topography persists forever and it will take centuries to reestablish the soils and forests that were historically present. The impacts of mountain top mining are more severe than other land use changes within these watersheds (e.g. clear cutting, residential development) because they are immense in scale and lead to irreversible alterations of watersheds. In fact, a 1999 study singles out mountaintop mining and valley fills in West Virginia and adjacent states as the greatest contributor to earth moving activity in the United States[1].

- The Office of Surface Mining reports that as of 2004 more than 1.1 million acres of land in northern and central Appalachia were undergoing active mining operations.[2] In 2009, the dominant driver of land cover land use change in this region remains surface mining and reclamation.[3]
- Numerous studies show that when impacts to watersheds exceed about 10% by area, biodiversity and water quality in their streams decline[4] yet some watersheds in West Virginia have more than 25% of their area covered by surface mine permits.

[1] Hooke 1999
[2] Loveland et al. 2003
[3] Townsend et al. 2009
[4] Yaun and Norton 2003; Allan 2004; Morgan and Cushman 2005

II. Structure and Function of Headwater Streams

Small streams like those buried by valley fills are biological hotspots: The Mountaintop Mining Environmental Impact Statement found that in 2002 more than 1200 miles of stream channels had already been buried by valley fills or directly harmed by mining. Later studies by the Office of Surface Mining found that from October of 2001 to June of 2005, mining permits impacted yet another 535 miles of streams nationwide and approximately 2/3 of those impacts were from valley fills. Some watersheds have been particularly hard hit by mining activities. For example, in the Laurel Creek of the Big Coal River in WV, 28% of the *total* stream length have been buried beneath valley fills or impacted by surface mines. Loss of this magnitude mean some downstream reaches may be permanently impaired. In addition to the localized destruction of individual stream reaches, many thousands of miles of downstream reaches have been impacted by the resulting sediment and chemical pollutants that are transmitted throughout the river network.

This represents not only a significant loss of a treasured natural resource but loss of ecosystems that are critical to the provision of water that is clean and abundant in supply to the larger downstream streams and rivers. The headwater streams of the southern Appalachians are also a biodiversity hotspot, supporting hundreds of species (some unique to these smallest of streams) that require stream habitat for all or part of their life cycle. The organisms living within headwater streams are well adapted to habitats with large fluctuations in flow and populations persist through occasional droughts and floods within stream sediments and isolated pool habitats. Despite their resilience to fluctuating flows, these organisms are not adapted to the dramatic changes in water chemistry that result from valley fills. In particular, the diverse historic assemblages of salamanders and mayflies are lost from polluted streams.

- Loss of headwater streams impacts hydrologic processes, chemistry, and stream biota in downstream waters.[5]
- Stream structure and function are both impacted by mountain top mining. Structural attributes include biodiversity, habitat, and channel properties while functional attributes include all those ecological and hydrogeomorphic processes that support healthy headwater streams.[6]
- Headwater streams support unique and ecologically important species including insects, fish, and salamanders.[7]
- Ephemeral and intermittent streams support diverse plants and animals and contribute to critical biogeochemical processes. Many ephemeral and stream organisms live in the streambed substrate and thus even when surface water is not running many species depend on these small streams.[8]

Ecosystem Functions within the River Continuum: In addition to serving as habitat or feeding-ground for a unique and diverse assemblage of organisms including salamanders, insects, fish and larger wildlife, the ephemeral and intermittent streams within the river network are conduits that transport water, sediments and dissolved materials from mountain tops to large river ecosystems. Shallow headwater streams have high contact between water and sediments and thus very high rates of nutrient and organic matter storage and processing. The biological communities in headwater streams import low-quality lignin and cellulose forest products (leaves and sticks) and convert that material into high-quality fats and proteins (insects and fish) that are exported to riparian and downstream food webs.

[5] Wipfli et al. 2007
[6] Hauer and Lamberti 2006; Fischenich 2006; Palmer and Richardson 2008
[7] Meyer et al. 2007
[8]Stout and Wallace 2003; Davic and Welsch 2004; Meyer et al. 2007

- Important ecosystem functions performed in ephemeral, intermittent, and perennial headwater streams include the purification of water, removal of excessive nutrients and sediments before they reach downstream waters, processing of organic material and primary and secondary productivity.[9]
- Surface waters on reclaimed mines or along valley fills have year round high light availability, altered thermal regimes and reduced organic matter inputs.

III. Water Quality Impacts of Valley Fills

Pollutants added to ephemeral and intermittent stream channels will be transported downstream to larger rivers. The more surface mining and valley fill activity within a large watershed, the greater the cumulative transport of alkaline mine drainage pollutants to major rivers will be. The streams and rivers below valley fills receive alkaline mine drainage that include highly elevated concentrations of sulfate, bicarbonate, calcium and magnesium ions and which often include elevated concentrations of multiple trace metals. The combined toxicity of multiple constituents results in significant increases in conductivity and total suspended solids below valley fills. This decline in water quality leads to a loss of sensitive aquatic organisms even when downstream habitats are intact. The resulting high conductivity and high sulfates can persist long after mining activities cease and scientists have found no empirical evidence documenting recovery of macroinvertebrate communities in the streams impacted by alkaline mine drainage. The water quality impacts of MTMVF activities are more severe and more persistent than other land use changes within the southern Appalachians.

- Streams impacted by MTVF often have 30-40 fold increases in sulfate concentrations and sulfate concentrations in receiving waters continue to increase after mining activities end.[10] High sulfate concentrations can lead to impacts on aquatic organisms and ecosystem functions.
- Ions of calcium, magnesium, and bicarbonate increase dramatically in the waters so that electrical conductivity levels and total suspended solids in receiving streams below fills can be extremely high ("alkaline drainage syndrome"). Trace elements of iron, aluminum, zinc, and selenium are often elevated as well.[11]
- The cumulative effect of elevated levels of all these ions is highly correlated to biological impairment in streams below MTVF. Functionally important aquatic biota are sensitive to ionic stress which disrupts water balance and can cause stress or death.[12]

Typical mitigation projects do nothing to reverse the severe ecological consequences of the water quality impacts downstream from large scale surface mining operations.

IV. The Potential for Mitigating Watershed Scale Destruction

Mitigation for the loss of streams from valley fills generally includes offsite enhancement of streams structurally or onsite attempts to 'create streams' on or near valley fills by digging ditches and sculpting rocks in an artificial channel. However, there is no evidence that structural approaches like these that focus only on channel form e.g. creating artificial channels in former drainage ditches or channel manipulations and placement of instream structures, will lead to the recovery of the ecological functions that are lost by the valley fills. In addition, mitigation projects not only fail to address stream function but also fail to use generally accepted scientific protocols when using structural measures.

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[9] Baron et al. 2002; Hauer & Lamberti 2006; Fischenich 2006, Palmer & Richardson 2008
[10] Sams and Beer 1999; Brooks et al. 2002; Pond et al. 2008
[11] WVDEP database (see figures 3.2 and 3.3.); Brooks et al. 2002
[12] Goetsch and Palmer 1997, Chadwick et al. 2002, Kennedy et al. 2003, Kefford et al. 2003, Hassell et al. 2006; Pond et al. 2008

While mining companies are attempting to construct new stream channels in reclaimed mine lands, there are no examples of successful creation of streams in any setting. Any claim that the structure and function of high gradient, forested headwater streams could be recreated in the flat grasslands of a reclaimed mine is thus highly suspect. Even if channels are constructed with high quality habitat, the routing and timing by which rainwater and groundwater are delivered to these channels will be highly altered. As a result the channels are likely to be filled with waters polluted by alkaline mine drainage (resulting from subsurface flows through mining fill) or to flow only during major precipitation events. In either case, there is little reason to expect that these constructed channels would support the diverse fauna of Appalachian headwater streams or that they would even approximate the energetic and nutrient transport processes of the streams they are meant to replace.

The efforts proposed to mitigate for the permanent loss of streams buried under valley fills by enhancing other streams cannot replace the ecological functions or unique biota lost. These projects typically target perennial streams while fills are usually in ephemeral and intermittent streams. While stream functions take place in perennial streams, they do so at different rates and in different ways than those occurring in ephemeral and intermittent streams and the smallest streams harbor some species that are not found in perennial reaches. Also mitigation projects like those proposed by mining companies may produce only short term benefits while the valley fills represent a permanent loss of habitat and function from the river network. This represents an important temporal mismatch between valley fills and attempts to mitigate for the streams that are buried.

- Mitigation plans associated with mountain top mining have not used available methods for directly measuring ecological functions yet these processes must be measured in order to determine how and whether they may be brought back to the right levels and direction through mitigation. There are abundant scientific studies outlining how to make and interpret such measurements and how they can be used to evaluate a restoration project.[13]
- Mitigation plans propose stream creation to offset loss of streams that are buried but stream creation is beyond the realm of current science. Out of over 38,000 projects in the most comprehensive database of restoration there is not a single example in which building streams de novo has been shown to be successful.[14]
- Most mitigation plans that include stream enhancement or restoration are based on a morphological approach to stream restoration that has been extensively criticized in the scientific literature because of its failure to promote ecological recovery.[15]
- Restoration or enhancement of existing perennial streams cannot replace or compensate for the habitat or the unique functional role of lost ephemeral and intermittent streams.
- Mitigation based on diverting flow to sediment ditches will not replace stream function. Successful restoration requires that key processes and linkages beyond the channel reach be considered.[16]
- Mitigation approaches fail to include any mechanisms that will reduce the export of ions and trace metals from mined sites yet these are known to be associated with impaired aquatic biota even after mining activities cease.[17]

END OF EXECUTIVE SUMMARY

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[13] e.g., Peterson et al. 2001; Gessner and Chauvet 2002; Hauer and Lamberti 2006; Buckveckas et al. 2007; Roberts et al. 2007

[14] Bernhardt et al. 2005, Palmer et al. 2005

[15] Gillilan 1996; Shields et al. 1999; Kondolf et al. 2001; Juracek & Fitzpatrick 2003; Niezgoda & Johnson 2005; Smith& Prestegaard 2005; Slate et al. 2007; Simon et al. 2007; Roper et al. 2008

[16] Sear 1994; Stanford et al. 1996; Graf 2001; Palmer et al. 2005

[17] Pond et al. 2008

I. Watershed and Stream Alteration by Mountain Top Mining

Mountain top mining and valley fill operations (MTVF) have both local and regional effects on aquatic ecosystems. The most obvious impact of MTVF operations are the local destruction of stream segments that are buried beneath valley fills and the loss of streams that are converted to waste treatment systems in the form of ponds at the base of fills. Streams which have been filled no longer exist – thus MTVF leads to a net loss of stream habitat and stream and riparian ecosystem functions in the watersheds in which it occurs. In addition, the impacts of MTVF operations have far reaching downstream impacts through the export of sediments and dissolved substances (solutes) from mined watersheds. Further the removal of vegetation from mined watersheds, and the flattening of valley contours on mined sites fundamentally alter the patterns of water flow through impacted valleys and changes the delivery of water to larger receiving streams.

Figure 1.1: Photos of MTVF

(A) A view of a mountain top operation rock face. (B) An aerial view of a completed mining

The total amount of land impacted by surface mining has been growing as the price of energy has continued to rise in the U.S. As of 2004, the Office of Surface Mining reported that more than 1.1 million hectares of land in northern and central Appalachia were undergoing active mining operations (Loveland et al. 2003). Indeed, the most significant changes in land use and land cover in the central Appalachian Plateau were related to surface mining of bituminous coal (Loveland et al., 2003) and today, the dominant driver of land cover land use change in this region remains surface mining and reclamation (Townsend et al. 2009).

Table 1.1 Examples of cumulative impacts in two West Virginia watersheds (12 digit HUC)

Watershed (area)	% by area covered by surface mine permits	% including pending permits	% of 1st order stream length intersecting permitted mines or valley fills
Cabin Creek (22, 518)	25.6%	29.1%	32.1%
Laurel Creek (31,519)	26.5%	28.6%	37.3%

Data from several watersheds (12 digit HUC) in West Virginia provide an example of the size of impact (Table 1.1). This level of watershed alteration (even when the land is reclaimed) has significant impacts on receiving stream ecosystems. In fact, the impacts of mountain top mining are more severe than other land use changes within these watersheds (e.g. clear cutting, residential development) because they are immense in scale and lead to irreversible alterations of impacted watersheds The process of mining includes removing all vegetation, blasting or digging soil and rocks to reach the coal seams and moving this 'overburden' into valleys to form fills. Once filled, streams are completely destroyed and those streams remaining below the fills are impacted significantly (fully described in Part III below). The reason that the mountain-top mining has impacts that extent well beyond the immediate blast and fill areas is that as low-lying points on the landscape, streams integrate the effects of all activities within the watershed above them. In fact, the single best predictor of stream water quality to date is what fraction of a watershed is impacted (Yuan and Norton 2003; Allan 2004). The most current and quantitatively intensive work by Bunn and colleagues (2009) reinforces previous findings. They studied 53 streams in 15 major catchments comparing over 50 approaches to find indicators of stream ecosystem health and show that watershed impacts explained 73% of the variability in native fish species diversity. These analyses show that the single most important predictor of stream biotic communities are watershed attributes rather than local habitat. Many studies to date have shown that when impacts to watersheds exceed about 10% of the watershed area, there can be dramatic declines in aquatic biodiversity and water quality (Allan 2004; Booth et al. 2004; Morgan and Cushman 2005; Moore and Palmer 2005).

The significance of this type of research for MTVF is that: 1) cumulative land impacts within a watershed are extremely important to the ecological health of streams; 2) small scale mitigation, restoration and enhancement efforts are insufficient to offset watershed scale degradation.

Mechanisms by which mining leads to cumulative impacts. Three fundamental scientific principles are critical to understanding why cumulative impacts of MTVF on downstream aquatic resources are so important. First, changes at the watershed scale influence stream hydrology throughout the catchment (Brooks 2003). The timing and magnitude of stream flows result from complex interactions between rainfall, plants, topographic relief, and soil properties of all land above a drainage point (Tong and Chen 2002). Once vegetation is lost as occurs on mined and even reclaimed mine land, hydrological changes that negatively impact stream biota and water quality ensue (Simmons et al. 2008; Ferrari et al. 2009). Second, stream water chemistry is shaped by processes that occur as rainwater infiltrates the ground and moves through pore spaces and soil on its way to streams (Allan and Castillo 2007). Microbial processes between the water, soil, and rooted vegetation lead to biochemical transformations that influence water quality. Not only are these processes fundamentally altered by the dramatic land disturbance at mined sites but water emerging from valley fills carries with it dissolved constituents that are toxic or damaging to biota (discussed extensively in section III below). Third, downhill movement of water and one-way flow in stream networks means that whatever happens on land or in 1st and 2nd order streams (headwaters) not only determines sediment and water flow in streams and rivers below but also determines ecological structure and functions of larger waterways (Allan and Castillo 2007).

In short, MTVF within a watershed can directly destroy local stream reaches through filling or can degrade downstream reaches by altering the magnitude, timing and composition of water flow.

II. Structure and Function of Headwater Streams

Ephemeral, intermittent or perennial streams that are buried beneath valley fills represent a significant natural resource loss. As *headwater* streams they represent the points "where rivers are born" (*sensu* Meyer et al. 2003) because their flow and associated biota, sediment, and dissolved constituents feed all downstream waters. Any major changes affecting headwater tributaries or any activity that isolates or cuts off these tributaries from the lower part of the watershed will have profound consequences for hydrologic processes, sediment delivery, channel morphology, biogeochemistry, and stream ecology further downstream in the watershed which is why their loss due to mountain top mining is of such concern (Wipfli et al. 2007).

What's the difference between ecological structure and function? Streams and impacts to them can be characterized in two ways: structurally and functionally. Because the concept of ecosystem structure and function is so central to assessing MTVF impacts and mitigation [(ENDNOTE)] we provide a brief overview here. *__Structural measures__* evaluate ecological state at a point in time (Table 2.1) while functional attributes describe how the system is performing over time (Table 2.2). Examples of ecological *structure* include channel form, habitat features, and number of species; these are typically evaluated at a point in time and are dimensionless (e.g., number of species at a site, ratio of channel width to depth, index of biotic integrity) or are expressed along one dimension (e.g., channel depth in cm, number riffle habitats/100 m).

TABLE 2.1 COMMON STRUCTURAL ATTRIBUTES OF STREAMS

Structural Attribute	Examples	Measurements required	Role
Biomass	Algal, Plant, Insect, Fish, etc.	Mass/area; Collect, dry and weigh.	Food for higher trophic levels; Important in photosynthesis and secondary production.
Biodiversity	Diatoms, Invertebrates, Fish, Amphibians, Riparian Vegetation	# Species per unit length or area of stream (species richness), Index of Biotic Integrity, EPT taxa, Shannon-Weiner Index etc.	Many species valued in themselves but loss of biodiversity may result in loss of function and eventually collapse of ecosystems (see text)
Habitat	Pools, Riffles, Substrate types, Riparian vegetation, Woody Debris	Presence/absence or # per unit length of stream	Structure for reproducing, feeding, escaping predation, may enhance flow complexity.
Geomorphic metrics	Ratios: Riffle:Pool, Width:Depth, Sinuosity, Slope, Particle size and heterogeneity, Depth of Hyporheic Zone, Bankfull bench	Measured during stream walks, Photographs, or Surveying equipment	Provides the template or "vessel" for water [flow], influences turbulence and other aspects of flow and sediment transport
Hydrologic metrics*	Water stage (depth), Wetted channel perimeter, Bankfull stage, Peak Discharge events,	Stage recorder or staff, rulers, survey equipment, visual estimate of bankfull bench	Delivers food and oxygen to biota, disperses young and adults, transports waste products; Reproduction often tied to annual flow

*hydrologic metrics can be considered functional metrics if there is a time series of measurements. E.g., an annual hydrograph is developed using gage or pressure transducer data.

__Functional attributes__ describe processes and rates and thus they are expressed per unit time (e.g., discharge in ft^3/sec, photosynthesis in $umoles/meter^2/sec$). Sometimes functional measures are expressed in a dimensionless fashion (e.g., ratio of photosynthesis to respiration) but the important point is that they still describe some process that characterizes 'how the system is performing' not just 'how the system is'. Measurements of ecological functioning evaluate dynamic properties of ecosystems that underlie an ecosystem's ability to provide vital goods and services (Gessner and Chauvet 2002). Functions reflect system performance and their measurement requires quantification of ecological processes over time such as primary production or nutrient uptake. The scientific literature on ecological functions is now quite extensive and while different words may be used by different people, there is broad agreement among the scientific community that the primary ecological functions of healthy streams include: the purification of water, the removal of excessive levels of nutrients and sediments before they reach downstream waters, the processing of organic material (decomposition or biological utilization), and primary and secondary productivity (growth of photosynthetic organisms and consumers) (Baron et al. 2002; Hauer and Lamberti 1996, 2006; Fischenich 2006, Allan and Castillo 2007; Palmer and Richardson 2008). These functions are supported by ecological processes (sometimes also called functions) including: the normal flux of water, the processing of nutrients at the same rate and form as unimpacted streams, the decomposition of organic matter at rates typical of nearby unimpacted streams, and, microbial, primary and secondary production the same as healthy streams (Palmer et al. 1997; Naiman et al. 2005).

TABLE 2.2 ECOLOGICAL FUNCTIONS OF HEADWATER STREAMS

Ecosystem function	Ecological Process that supports this	Measurements required	Without it what happens
Water Purification a) Nutrient Processing	Biological uptake and transformation of nitrogen, phosphorus	Direct measures of **rates** of transformation of nutrients; for example: microbial denitrification, conversion of nitrate to N_2	Excess nutrients can build up in the water making it unsuitable for drinking or to support life
Water Purification b) Processing of contaminants	Biological removal of materials such as excess sediments (e.g., removed by riparian plants) or toxins (taken up by plants or microbial processes that moving them from the water)	Direct measures of contaminant flux (e.g., the movement of sediment into and down streams). This is a **rate.**	Toxic contaminants kill biota; excess sediments smother invertebrates (kill them), foul the gills of fish (kill them), etc; water not potable
Decomposition of organic matter (organic matter processing)	The biological (mostly by microbes and fungi) degradation of organic matter (could be leaf material or other input such as sweater or organic wastes)	Decomposition is measured as a **rate**. Usually expressed as the slope of a line showing weight loss over time of organic matter heated to high temperatures to convert the particulate carbon to gas (CO2)	Without this, excess organic material builds up in streams, leading to low oxygen levels which leads to death of invertebrates and fish and the water is not something anyone would want to drink
Production (Primary = algae & aquatic plant; Secondary = growth of organisms like insects, fish, etc	Measured as a rate of new plant or animal tissue produced over time	Primary - measure the **rate** of photosynthesis in the stream; for secondary, you measure growth rate of organisms	Primary production supports the food web; secondary production (fish) we often eat or it (inverts) supports fish.
Temperature Regulation	Water temperature is "buffered" by sufficient infiltration in the watershed & riparian zone AND shading of the stream by riparian vegetation.	Measure the **rate** of change in water temperature as air temperature changes or as increases in discharge occur.	If water infiltration or shading reduced (e.g., via clearing of vegetation), water heats up beyond what biota are capable of tolerating
Flood Mediation/Control	Slowing of flow from land to streams so flood frequency and magnitude reduced; intact flood-plains buffer increases in flow; flow spreads out over floodplain & energy absorbed; also healthy riparian vegetation in the watershed increases infiltration into soils & uptake of water by plants before it reaches the stream	Measure the **rate** of infiltration of water into soils OR discharge in stream in response to rain events (discharge = **rate** of water flow measured in volume per time…m^3/sec)	Without the benefits of floodplains, healthy stream corridor and watershed vegetation you see increased flood frequency and flood magnitude
Biodiversity support	All of the processes above contribute to the maintenance of biodiversity. For example, primary production and the flux of organic materials into streams help support diverse living assemblages	Measure the number of species and how abundance varies among them; this function is not a rate per se but because it is critical to the support of all other functions, it is included in the table.	Headwater streams support extremely high biodiversity and many rare species that contribute food for higher trophic levels and help maintain functions such as organic matter processing

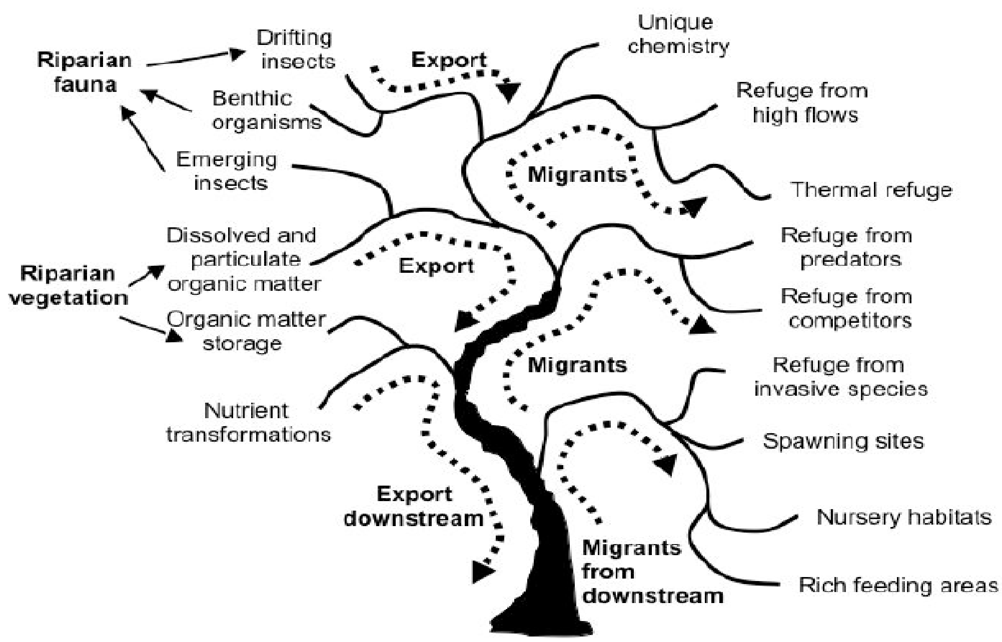
Headwater streams (ephemeral, intermittent, or perennial) that are buried or degraded by MTVF represent a major loss from a structural and functional perspective. The role of headwater streams in supporting high levels of biodiversity has been emphasized in a great deal of scientific research (Lowe and Likens 2005; Meyer et al. 2007). These small streams provide habitats for a rich array of species, which enhances the biological diversity of the entire river system. Some of the species are unique – i.e., the only place in a river network these species occur is in the headwaters (Erman and Erman 1995; Stout and Wallace 2003). They also provide a refuge from predators and changes in temperature for some species (Franssen et al. 2006) and are important spawning and nursery grounds for some species.

Meyer et al. (2007) provide the best review of biodiversity in headwater streams citing over 150 peer-reviewed papers (Fig. 2.1). They also provide a succinct summary of why headwater streams rich in biodiversity are important along with citations of the supporting scientific studies including:

- Headwaters Support Many Species That Occur Nowhere Else in the River System
- Headwaters Provide Unique and Highly Diverse Physico-chemical Habitats
- Headwaters Provide a Refuge from Predators
- Headwaters Provide a Refuge from Competitors
- Headwaters Provide a Refuge from Alien Species
- Headwaters Are Essential for Species Living in Larger Streams
- Species Migrate to Headwaters for Spawning and Nursery Habitats
- Headwaters Provide Rich Feeding Grounds
- Headwaters Provide Thermal Refuges
- Headwaters Provide a Source of Colonists and a Network of Movement Corridors
- Headwaters Supply Food to Neighboring Ecosystems
- Biological Activity in Headwaters affects Downstream Food for Higher Tropic Levels

Summary of Headwater Stream Biodiversity*:* The dominant group of algae in headwater streams are diatoms and it is common to find 30-60 species some of which are only found in headwaters (Sherwood et al. 2000).Thirty to forty species have been found in southern Appalachian headwaters (Greenwood, 2004; Greenwood and Rosemond 2005) and they are particularly common on bryophytes and rocks (Meyer et al. 2007). These bryophytes are important primary producers in headwater streams and four species dominate in high-gradient Appalachian streams (Glime, 1968). Among the most important decomposers in headwater streams, fungi can be quite diverse. Gulis and Subekropp (2004) reported finding over 51 taxa of hyphomycete fungi in two small southern Appalachian streams and they and others (Barlocher and Graca, 2002) have shown that when inputs of leaf litter declines, biodiversity also declines and that species composition of fungi is influenced by the diversity of litter inputs.

Invertebrate diversity is particularly high in headwater streams (Clark et al. 2008). Rather than providing an extensive list, we provide a few examples for Appalachian region. McCabe and Sykora (2000) found 18 species of caddisflies. Stout and Wallace (2003) sampled 23 intermittent streams and found over 86 insect genera from more than 47 families species. Small ephemeral and intermittent steams are often unmapped and appear unimportant to the untrained person yet mayflies, stoneflies, and caddisflies have been found right where the water emerged from the ground (a seep) and Stout and Wallace showed that just 150 m downstream the number of species doubled or tripled. Amphipods, isopods, copepods, cladocerans and ostracods are particularly common and the latter three may reach abundances of > 10,000/m^2 (Galassi et al. 2002).



The impacts of mountain top mining are more severe than other land use changes within these watersheds (e.g. clearcutting, residential development) because they are immense in scale and lead to irreversible alterations of impacted watersheds

Figure 2.1. Factors that contribute to the biological importance of headwater streams in river networks. Attributes on the right benefit species unique to headwaters and also make headwaters essential seasonal habitats for migrants from downstream. On the left are biological contributions of headwater ecosystems to riparian and downstream ecosystems. From J.L. Meyer, D.L. Strayer, J.B. Wallace, S.L. Eggert, G.S. Helfman, and N.E. Leonard. 2007. The contribution of headwater streams to biodiversity in river networks. Journal of the American Water Resources Association 43(1): 86-103.

Meyer et al. (2007) documented that many of the smaller interstitial taxa such as rotifers, gastrotrichs, oligochaetes are diverse and can reach incredibly high abundances in headwater streams (Table 2.3). Fish can also be abundant in headwaters and while their diversity generally increases with stream size, many of the headwater species are unique so headwaters may disproportionately contribute to network-wide diversity and play a critical role in the genetics of fish populations (Meyer et al. 2007, Burridge et al. 2008). Generally the species founds in these small streams are small in body size such as minnows, darters and

Table 2.3. Invertebrates other than Mollusks, Crustaceans, and Insects that are Common in Headwaters.
(from Meyer et al. 2007)

Group	Typical Species Richness in Headwaters	Typical Density in Headwaters (no./m^2)	Key References
Turbellaria	3–30	1,000–10,000	Kolasa (1983, 2002)
Gastrotricha	3–30 (?)	10,000–300,000 (?)	Strayer and Hummon (2001), Balsamo and Todaro (2002)
Rotifera	20–200	10,000–1,000,000	Schmid-Araya (1998), Wallace and Ricci (2002)
Nematoda	10–100	5,000–500,000	Traunsperger (2002)
Tardigrada	1–10	1,000–10,000 (?)	Nelson and McInnes (2002)
Oligochaeta	3–30	1,000–50,000	Schwank (1981a,b)
Acari	5–50	100–10,000	Di Sabatino *et al.* (2002, 2003)
Total	40–450	28,000–1,880,000	

sculpins but also may include salmonids such as those found in cold North Carolina headwaters (Moyle and Herbold 1987). Even when intermittent streams are not running, they may support fish in isolated pools – these pools are often maintained by local groundwater inputs. A surprising fraction of the trout population (almost 50%) have been found to spawn in some intermittent streams in California – such studies are rare so while we know of no studies with similar data for Appalachian headwaters, this may be common in that region as well. Trout and salmon typically spawn in the smallest of channels even when it means half of their body is out of water while the move up these channels.

Where fish are absent in Appalachian streams, amphibians are common and are typically the top aquatic predators. Their production in 1st and 2nd order streams is higher than that found in larger streams (Wallace et al. 1992) and salamanders are the most common vertebrate in headwaters (Davic and Welsh 2004). Frogs, toads, and reptiles can also be common in some headwater streams (Meyer et al. 2007). Ephemeral and intermittent streams provide vital habitat for amphibians, many of which are state and/or federally threatened and endangered (Reid and Ziemer 1994; Davic and Welsh 2004). Many amphibian species are most abundant in intermittent streams, perhaps because they offer freedom from predators (Reid and Ziemer 1994). In Appalachian streams, larvae of the Blue Ridge two-lined salamander *Eurycea wilderae* is abundant (Johnson et al. 2006). Many stream salamanders require headwater seeps and small streams in forested habitats to maintain viable populations (Petranka 1998). Plethodontid salamanders are extremely diverse in Appalachia, and their lungless condition appears to be an adaptation for small headwater streams, which are their principal larval habitat, where they spend from a few months to five years (Beachy and Bruce 1992). Yet, they are also very vulnerable. Ford et al. (2002) have shown that diversity and abundance of salamanders in the southern Appalachian mountains is reduced when forests are clear cut even after 75 years of re-growth is >75. Loss of salamander populations from headwater streams can have ecosystem-wide consequences since they influence insect population dynamics, regulate detritus food webs, and link stream and terrestrial food webs (Davic and Welsh 2004).

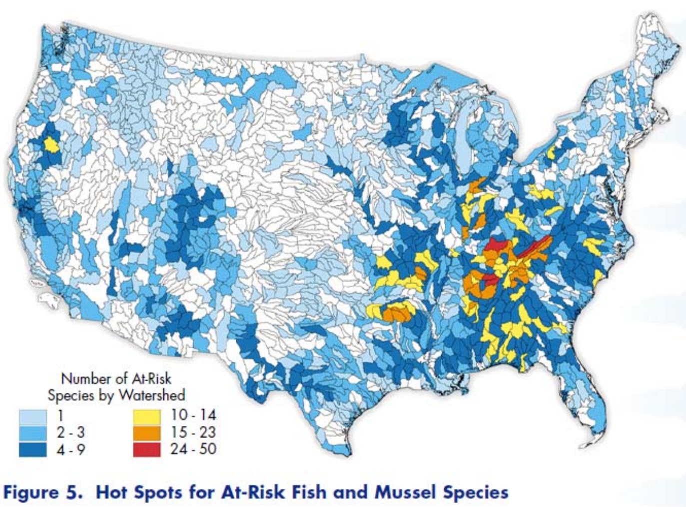


Figure 2.2. Hotspots for at-risk fish and mussel species. From Master et al. 1998

A Blue Ridge Salamander: common in Appalachian headwaters

The streams and rivers threatened by MTVF activities support among the highest levels of aquatic diversity in North America (Fig. 2.2, Master et al. 1998). Because the southern Appalachians escaped glaciation, these are among the oldest mountainous ecosystems on Earth. Nearly 10% of *global* salamander diversity and 10% of freshwater mussel diversity are found within streams of the Southern Appalachian Mountains. (Green & Pauley 1987; Master et al. 1998). Where mining activities destroy stream habitat and degrade stream water quality many of these taxa become locally extinct and for species with small geographic distributions mining activities will contribute to their global extinction.

Ecosystem Functions of Headwater Streams. There is abundant scientific evidence that headwater streams play disproportionate roles in many ecological processes. Sediment produced in headwater systems moves through channel networks and alters channel morphology (Benda and Dunne 1997a, 1997b). Headwater streams are also the streams that have the closest contact between water and soil – as a result they are the sites of high chemical and biological activity which influence the water quality throughout the downstream river network. Organic matter is delivered to headwater streams from the surrounding riparian vegetation and transported downstream to larger channels – trees drop leaves and contribute wood to streams that shape healthy channels and fuel aquatic food webs (Webster et al. 1999). After wood, leaves and other dead vegetation enter streams, they begin decaying to produce detritus – this mixture of organic matter supports the downstream food web by enhancing productivity, population density, and community structure of stream biota (Wipfli and Gregovich 2002).

The headwater channels are sometimes described as being analogous to the very small passageways in the human lung that accomplish most of the important work in exchanging gases between the respiratory and circulatory system. They do much of the processing of source materials for delivery to sustain the downstream ecosystem including water, organic matter, and even biota that disperse (Clark et al. 2008). Cut them off and the patient starts to suffer a condition like emphysema. The natural filtration system and timing of delivery of water and associated constituents from upstream tributaries to larger channels downstream are delicately adjusted among components of the system. There is a substantial body of science documenting their roles in watershed health (Clark et al. 2008). Because headwater systems make up a major portion (70 - 80%) of the total catchment area (Meyer and Wallace 2001), headwater streams are important sources of sediment, water, nutrients, and organic matter for downstream systems. Thus any major changes affecting headwater tributaries or any activity that isolates or cuts off these tributaries from the lower part of the watershed will propagate downstream, and will have consequences for hydrologic processes, sediment delivery and channel morphology, biogeochemistry, and stream ecology further downstream in the watershed.

MTVF activities fundamentally alter the energetics of streams directly impacted by mining and valley fills by changing the light environment and removing vegetation. Surface waters on reclaimed mines or along valley fills have year round high light availability, altered thermal regimes and reduced organic matter inputs. All of the streams which receive alkaline mine drainage may become more susceptible to nutrient pollution and less capable of performing the valuable ecosystem service of nitrogen removal (*discussed in section 3*).

ENDNOTE, SECTION II

The Clean Water Act and its implementing guidelines require that permits authorizing valley fills be issued only if those permits do not result in adverse effects on the aquatic environment. In order to determine whether those permits have such an effect, the guidelines require the Corps of Engineers to evaluate both the structure and the function of streams that would be filled pursuant to those permits. There has been considerable controversy since a 2007 ruling by a federal district court in West Virginia that called into question decisions by the US Army Corps to permit several mountaintop mining operations based in part on inadequate consideration of ecological functions. The 4th Circuit Court of Appeals[a] subsequently reversed the decision but not before the Huntington, West Virginia office of the Corps released a regulatory guidance document for making functional assessments on streams.[b] The plantiffs in the federal case filed for a re-hearing before the Court of Appeals which was denied in 2009. At the heart of the scientific issue is how natural resource *value* is assessed: are structural attributes such as channel shape, habitat types, and rapid biotic assessments adequate or must ecosystem functions be measured and used in evaluating impacts and mitigation requirements.

[a] The federal district court in West Virginia issued the order to remand the decisions and permits to the Corps for further consideration on 3/23/2007 (Ohio Valley Coalition vs. U.S. Army Corps of Engineers; Civil Action No. 3:05-0784). However, on 2/13/2009, the 4th Circuit Court of Appeals reversed this decision arguing that the Corps should be allowed deference in using 'best professional judgment' for methods to evaluate impacts and mitigation requirements.
[b] Interim Functional Assessment Approach for High Gradient Streams within the State of West Virginia, Public Notice no. LRH-2007-IFAA-01; dated July 16, 2007.

III. Water Quality Impacts of Mountain Top Mining and Valley Fills

Mountain top mining leads to:

- Higher annual water export from the watershed as a result of the removal of vegetation and a significant decrease in evapotranspiration
- Higher rates of rock weathering as a result of the fragmentation and exposure of mined rock to air and water
- Increased concentrations of solutes weathered from exposed rock in stream water – especially the high SO_4^{2-}, Mg^{2+}, Ca^{2+}, HCO_3^- associated with alkaline mine drainage
- Increased likelihood of elevated concentrations of trace elements and toxic metals derived from parent material in stream water.
- Decreased abundances or local extinction of sensitive aquatic organisms, with the potential for altered ecosystem function

It is important to note that mining results in increases in both the concentration of solutes and in the volume of water exported from the watershed. This means that the total mass of solutes delivered to downstream ecosystems is higher than concentration changes alone would suggest.

$$\text{Flux (lbs yr}^{-1}\text{)} = \text{Flow (m}^3\text{ yr}^{-1}\text{)} * \text{Concentration (lbs m}^{-3}\text{)}$$

Thus individual valley fills not only profoundly impact stream water quality, community structure and ecosystem functions immediately downstream of the fill, but multiple valley fills within larger watersheds have cumulative effects on larger downstream rivers through increasing loads of dissolved substances derived from alkaline mine drainage.

Increased concentrations of solutes weathered from exposed rock in stream water – especially the high SO_4^{2-}, Mg^{2+}, Ca^{2+}, HCO_3^- associated with alkaline mine drainage

Sulfate. Sulfate is an acid anion that has been well studied for decades as an important acid rain associated pollutant. Just as coal burning in power generation produces SO_x aerosols, the exposure of coal seams during coal mining provides many opportunities for the leaching of SO_4^{2-} into surface waters. Unlike SO_x emissions which distribute S aerosols regionally, mining activities lead to a localized point source of SO_4^{2-} to the drainage network. As a consequence of regional SO_x emissions ('acid rain'), freshwater systems throughout North American and Europe have had 10-fold or greater increases in SO_4^- concentrations. In contrast, mining impacted streams in WV often have 30-40 fold increases in SO_4^{2-} concentrations (Brooks et al. 2002; Pond et al. 2008) with 13 streams in the 2009 WVDEP database[18] having SO_4^- concentrations higher than found in seawater (>2717 mg L^{-1}). The relationship between mining activities and high sulfate concentrations is so well established that the 2008 WVDEP West Virginia Integrated Water Quality Monitoring and Assessment Report suggested that SO_4^{2-} concentrations >50 mg L^{-1} could be used as an indicator of mining activity (Fig. 3.1). Id. at 21.

[18] Upon request, Jeffrey Bailey of the WV Department of Environmental Protection provided a MS Access version of their water quality database to E.S.B. on March 27, 2009

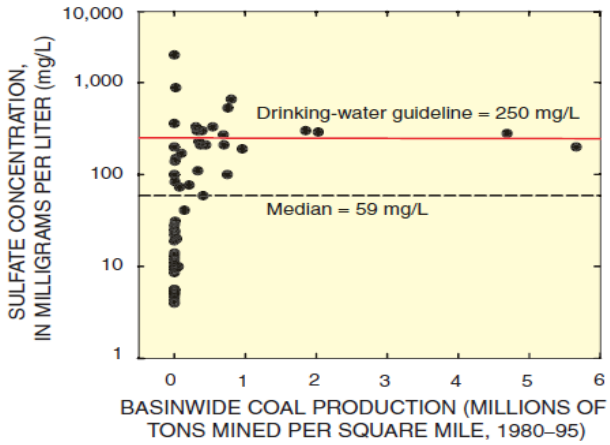


Figure 3.1. Sulfate concentrations in WV mountain streams relative to basinwide coal production. FROM Paybins, Messinger, Eychaner, Chambers and Kozar. Water Quality in the Kanawha–New River Basin West Virginia, Virginia, and North Carolina, 1996–98 U.S. Geological Survey Circular ; 1204 [*this report appears as an attachment to the 2001 EIS on Mountain top mining and valley fill operations*]

The headwater mountain streams of WV that are being impacted by mountain top mining were historically dilute with low nutrient levels. An earlier study in major watersheds of West Virginia directly linked increases in river sulfate load to increasing coal production in the watershed (Sams and Beer 1999) and through time-series analysis suggested that sulfate concentrations in streams continue to increase after mining activities end (Sams and Beer 1999). Likewise, a USGS NAWQA study found that, in the Kanawha–New River Basin, total Fe and Mn decreased in stream basins as a result of reduced coal production between 1991 and 1998, while sulfate concentrations continued to increase (Paybins et al. 1998). Both of these studies document an increase in SO_4^{2-} loading to major river systems that corresponds to increases in coal extraction within their watersheds.

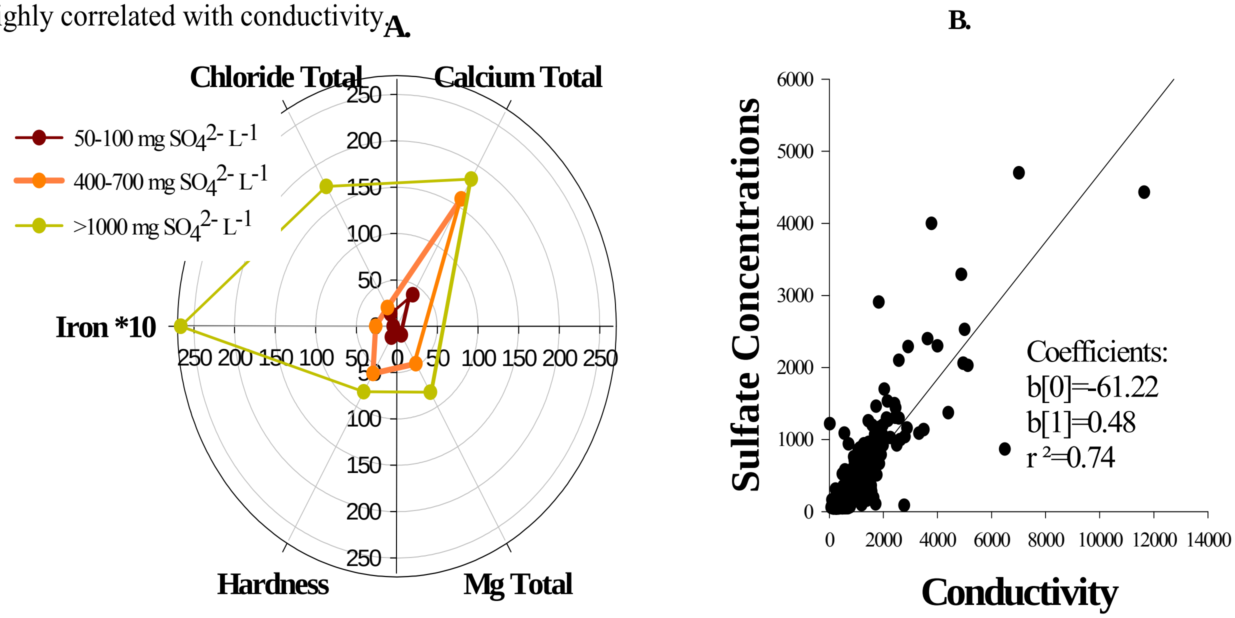
This fundamental change in the chemistry of headwater streams can have important local and watershed scale impacts on aquatic organisms and ecosystem functions. Elevated sulfate concentrations will stimulate microbial sulfate reduction in stream and wetland sediments. As sulfate concentrations increase, the production of sulfide also increases and this has important implications for the receiving ecosystems. Sulfide is directly phytotoxic to many aquatic plants (reviewed in Wang and Chapman 1999; Lamers et al. 2002; van der Welle et al. 2008).

Elevated sulfide also has important biogeochemical impacts. Sulfide binds strongly with iron (Fe) in sediments – converting it to pyrite minerals. While this has positive benefits in terms of reducing Fe concentrations in sulfate rich mine drainage, it also has implications for nutrient pollution. High sulfate loading can also make freshwater ecosystems more sensitive to nutrient pollution by preventing abiotic reactions that bind phosphorus (P) to Fe and sequestering P in inaccessible forms in the sediments. High sulfide can also inhibit nitrification (the process by which ammonium is converted to nitrate) in sediments and thereby dramatically reduce denitrification rates – again contributing to a reduced N removal efficiency within S polluted sediments and promoting or enhancing nitrogen eutrophication (Joye and Hollibaugh 1995).

Co-Occurring Contaminants. While an increase in sulfate loading is the most predictable consequence of mountain top mining in the Appalachians, many other substances are released to surface waters as a result of mining activity. In these valleys, the presence of significant carbonate and base cations in parent material neutralizes the acidity of sulfate leaching, but leads to dramatic increases in Ca^{2+}, Mg^{2+} and HCO_3^- ions. This natural acid buffering potential leads to an increase in the pH of receiving streams (rather than the more well understood acidification associated with acid mine drainage). The release of these ions contributes to dramatic increases in the electrical conductivity and total suspended solids within the water column of receiving streams. An analysis of all small streams (width <10m) from the WVDEP database for which there are no residences recorded in the watershed (residences = 0) and for which SO_4^{2-} concentrations are >50 mg L-1 captures streams with varying degrees of mining impacts. For this dataset, sulfate concentrations are highly correlated with conductivity (Fig. 3.2B R^2=0.74) and higher

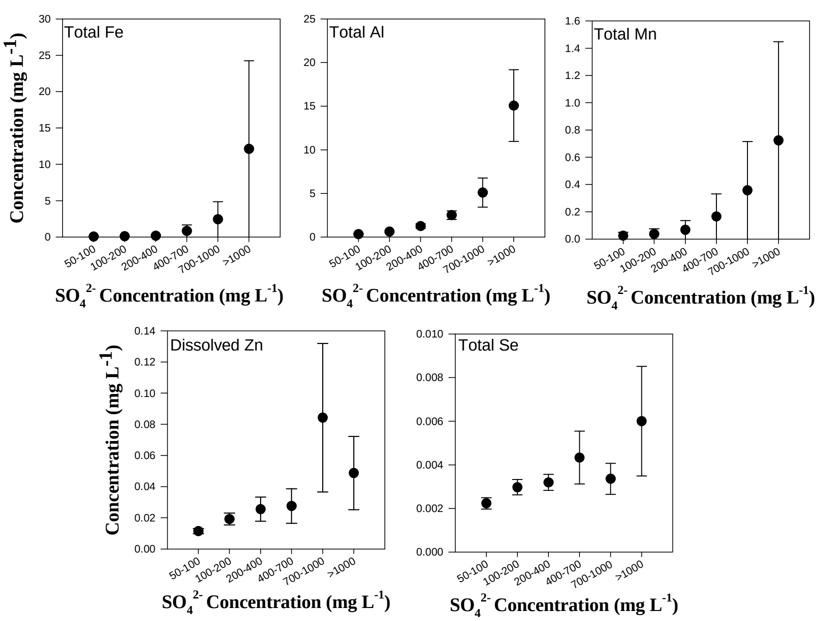
SO_4^{2-} concentrations are associated with higher Ca, Cl, Fe, Mg and Hardness values (Fig. 3.2A) – all of which contribute to heightened ionic stress in these impacted streams.

Figure 3.2. Panel A shows the concentrations of alkaline drainage associated constituents for streams from the WV DEP database that very in their [SO_4^{2-}] concentrations. Streams with higher [SO_4^{2-}] have higher mining activity and these streams have higher concentrations of Ca, Cl, Fe, Mg and total hardness than streams with low [SO_4^{2-}]. Panel B, this alkaline mine drainage "syndrome" associated with high [SO_4^{2-}] is highly correlated with conductivity.



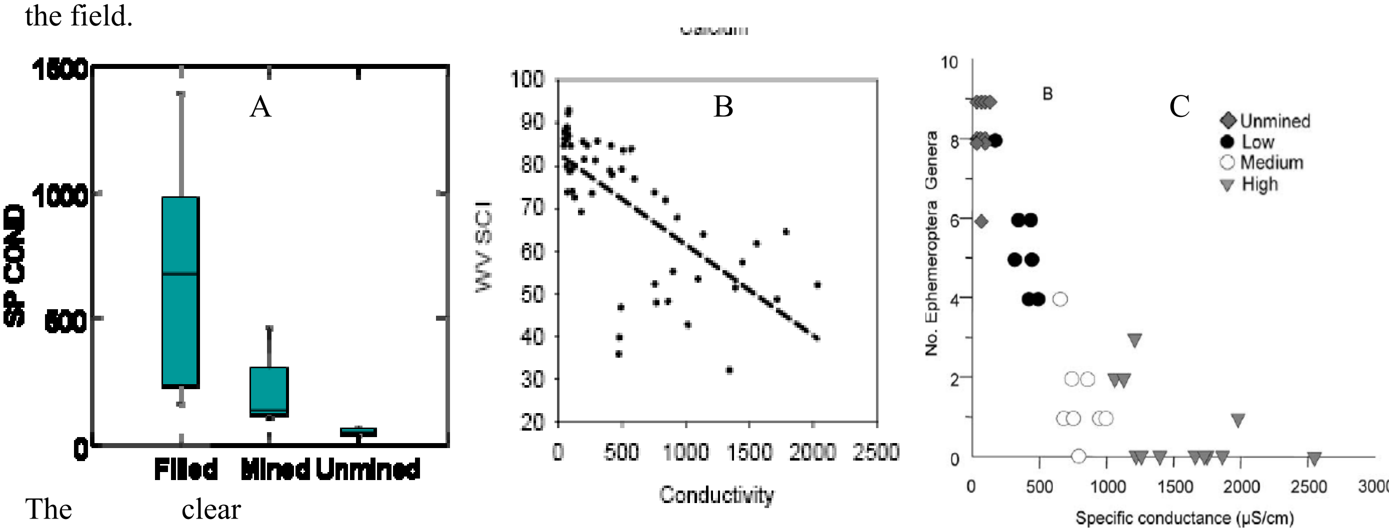
The abundance of each trace element (excepting Cu) also increases with SO_4^{2-} concentration (Fig. 3.3).

Figure 3.3. Concentrations of trace elements +/- one standard error within categories of SO42- loading for the WVDEP database (all streams <10m wide with no residences and [SO_4^{2-}] > 50 mg L-1



Elevated Conductivity. Recent studies by Hartman et al. (2005) and Pond et al. (2008) compared water quality between paired reference and valley fill impacted streams and found that specific conductivity in the filled sites was at least twice as high as in the reference streams (Figure 3.4A). Typical specific conductance levels in low order West Virginia streams measured in previous research ranged from 13 to 253 µS/cm (Angradi 1996; Pond et al. 2008, while valley fill streams exceed these values (502–2540 µS/cm) (Hartman et al. 2005 and Pond et al. 2008) (Fig. 3.4A).

For many streams it is the cumulative or additive impact of elevated concentrations of multiple stressors that leads to biological impairment – and this is undoubtedly a part of the reason that conductivity (a cumulative measure of ionic strength) is such an effective predictor of biological impairment (Figs. 3.4 B&C)[19]. The ionic stress associated with high conductivity can have direct toxicity as well as providing an indication of the additive impacts of a variety of solutes. High conductivity can be directly toxic to aquatic organisms by disrupting osmoregulation (Pond et al. 2008). This is particularly important for aquatic insects with high cuticular permeability. Mayflies in particular are highly sensitive to ionic stress as they regulate their ion uptake and release using specialized structures within their gills, integument and internally via Malphigian tubules (Komnick 1977, Gaino and Rebora 2000, Pond et al. 2008). For these sensitive taxa, large increases in certain ions can disrupt water balance and ion exchange processes and cause organism stress or death. Tests for conductivity toxicity for mayflies have often proved inconclusive (Goetsch and Palmer 1997, Chadwick et al. 2002, Kennedy et al. 2003, Kefford et al. 2003, Hassell et al. 2006), yet studies performed to date typically perform ecotoxicological tests on hardy organisms that are easy to rear in lab settings (i.e., Hexagenia, Centroptilum, Cloeon, Isonychia) and which are likely to be less sensitive than the mayfly genera that appear especially susceptible to ionic stress (e.g., ephemerellids, heptageniids) (*discussion in* Pond et al. 2008). Rather than being directly lethal, high conductivity may encourage sensitive taxa to drift out of the reach (Wood and Dykes 2002) – an effect that would not be measured in the closed vessels of laboratory trials, but which could strongly alter community structure in the field.



The clear

Figure 3.4. (A) The background conductivity of WV mountain streams in µS/cm "from an online presentation by USEPA Region 3 Scientists Greg Pond and Margaret Passmore "**Revisiting The Analysis of the Condition Of Streams In The Primary Region Of Mountaintop Mining/Valley Fill (MTM/VF) Coal Mining"** http://www.cpe.vt.edu/cmrs/presentations/GregPond.pdf). Accessed on 30 March 2009.; (B) data from Fulk et al. 2003 (which appeared as a supplement to Final Programmatic Environmental Impact Statement on Mountaintop Mining/Valley Fills in Appalachia – 2005); (B) Figure excepted from Pond et al. 2008.

[19] The WVSCI is the West Virginia Stream Condition Index. The metric summarizes family level identifications on benthic macroinvertebrate assemblages as a "bioassessment" tool for evaluating the condition of wadeable streams. The metric includes six biological metrics that represent the structure and function of the benthic macroinvertebrate community (Pond et al. 2008b).

patterns linking high conductivity to a loss of Ephemeroptera taxa (Fig. 3.4C) has ecosystem scale importance since these mayfly taxa often account for 25 to 50% of total macroinvertebrate abundance in the least disturbed Central Appalachian streams (Pond et al. 2008). The finding that entire orders of benthic organisms are nearly eliminated in MTM streams suggest that alkaline mine drainage is fundamentally changing the structure of aquatic macroinvertebrate communities (Pond et al. 2008).

It is widely recognized that individual contaminants rarely exist alone, and although many ecotoxicological studies examine the impacts of single contaminants on laboratory organisms – it is the actual combined toxicity of constituents in field settings that is of interest (Wang and Zin 1997). In cases where an association of contaminants is well characterized (e.g., the trace metals and cations associated with alkaline or acid mine drainage or the road runoff associated with high traffic volume corridors), a concentration-addition method should be applied which assesses their cumulative impact (Wang and Zin 1997). A lack of laboratory ecotoxicological effects of any isolated component of the complex mixture of solutes associated with alkaline mine drainage pollution should not be used to defer control of the obvious pollution problems caused by the combined toxicity of multiple constituents. The weight of evidence suggests that mining activities in watersheds often degrade downstream water quality and lead to dramatic alterations in macroinvertebrate community structure (Fig. 3.5). Mine sites may vary considerably in the extent to which they impact regulated solutes in downstream waters, yet the valley fill operations studied to date are clearly causing heightened conductivity and high SO_4^{2-} concentrations.

These increases in conductivity and sulfate are associated with a loss of sensitive macroinvertebrate taxa from affected stream reaches (Fig. 3.5[20]).

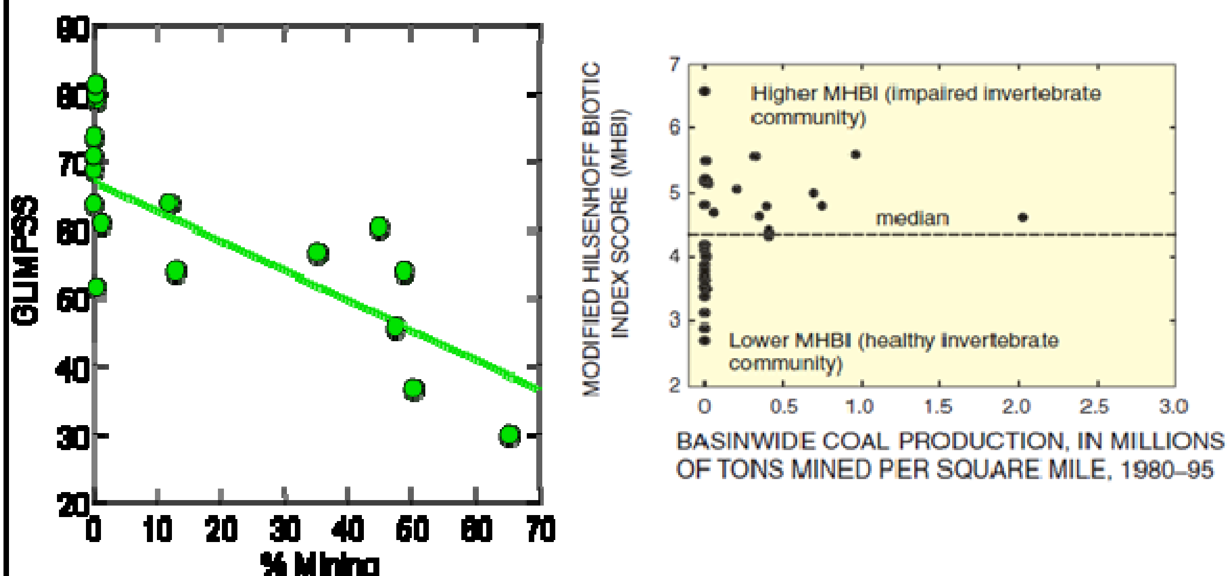


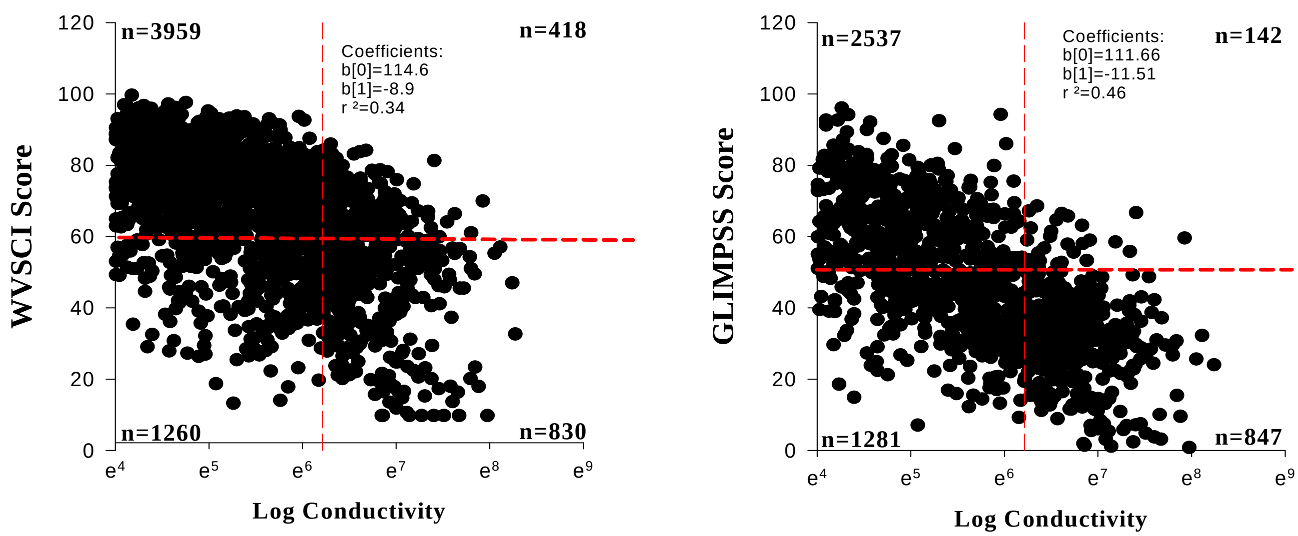
Figure 3.5. Panel A shows the relationship between the genera based macroinvertebrate metric for WV streams (GLIMPSS[3]) and mining activity [http://www.cpe.vt.edu/cmrs/presentations/GregPond.pdf]; Panel B shows a family level macroinvertebrate metric (the Hillsenhoff Biotic Index, MHBI) vs. basinwide coal production [figure from Paybins et al. 2003]

[20] The GLIMPSS index is a newly developed, genus based assessment of stream macroinvertebrate communities developed by US EPA Region 3 scientists which assesses stream condition based on the genera level taxonomic identification. This metric has proven much more sensitive to known environmental stressors.

There are strong correlative relationships within the WVDEP database which demonstrate that there are water quality thresholds beyond which there is little likelihood of protecting benthic communities from impairment. Figure 3.6 shows conductivity vs. WVSCI and GLIMPSS scores for all of the samples from small streams (<10m) taken during the summer in the mountains ecoregion of West Virginia. In this simple analysis a line is drawn at the divide between impaired and unimpaired scores (60 for WVSCI, 50 for GLIMPSS) and a second line is drawn through the data at the conductivity of 500 µS/cm –the conductivity level that appears to be a threshold for sensitive mayfly taxa according to Pond et al. 2008. Numbers within each quadrant represent the total number of unique samples in each situation.

A comparison of these graphs shows that it becomes increasingly unlikely to find an unimpaired aquatic benthic community as conductivity increases (as evidenced by the significant negative correlations between macroinvertebrate community integrity as measured by either WVSCI or GLIMPSS). Indeed, 86% of the West Virginia mountain streams in the WVDEP database with conductivity exceeding 500 µS/cm were scored as impaired using the genera based GLIMPSS index. Using the more lenient WVSCI index, 67% of all West Virginia mountain streams with conductivities greater than 500 µS/cm were classified as impaired. Similarly, 81% of all West Virginia small mountain streams with conductivity greater than 1000 µS/cm were scored as impaired using the WVSCI index, and 91% of those streams were scored as impaired using the GLIMPSS index.

Figure 3.6: WVSCI and GLIMPSS Scores vs. Conductivity - All Summer Mountains Data for streams <10m wide



Consequently, as conductivity (and the associated SO_4^{2-}, Ca^{2+}, Mg^{2+}, HCO_3^- and trace metals) increases in West Virginia mountain streams – the biological community is degraded. Sensitive species (especially Ephemerellidae and Heptageniidae mayflies) are lost from these systems. High conductivity and high sulfates can persist long after mining activities cease (Sams and Beer 1999, Paybins et al. 2003, Pond et al. 2008), and there is little empirical evidence documenting recovery of macroinvertebrate communities in the streams impacted by alkaline mine drainage.

In addition, the differences in sensitivity between WVSCI and GLIMPSS methodologies have important long term consequences when WVSCI is used to assess mitigation projects. The resulting data will likely mask important impacts to genera that belong to families of benthic organisms where there is a wide spectrum of sensitivity to increased conductivity. This means that significant harm to the biological integrity of stream ecosystems could be missed or understated when WVSCI is used for mitigation monitoring.

IV. The Potential for Mitigating Watershed Scale Destruction

The 404 guidelines mandate permit applicants to avoid, minimize and mitigate impacts on the waters of the United States to prevent significant degradation of waters of the United States. When impacts are unavoidable, stream habitat and functions lost through mining and filling are subject to amelioration through mitigation. Because mitigation actions must replace lost stream resources and ecological functions, the value of those natural resources and functions must be assessed prior to their loss. This value(s) is then used to determine how much mitigation is required.

Compensatory mitigation to replace lost stream habitat and functions may occur through a variety of actions but they generally fall into two categories:

- Stream enhancement/restoration - Restoration or enhancement of degraded streams in areas adjacent or contiguous to the mining site typically involves stabilizing a streambank, re-shaping a channel, or replanting riparian vegetation. Enhancement and restoration actions are typically applied to perennial streams even if the streams that are lost due to mining are ephemeral or intermittent.
- Stream creation (Fig. 4.1) – Attempts to create a stream by excavating a ditch and placing structures like boulders and rocks into the channel are often proposed to replace streams that are filled. These creation attempts are often undertaken on or near a valley fill and they usually rely on the fill or mined area for their water source.

Figure 4.1: Photos of natural intermittent and perennial streams (left) and a created channel (right) along a valley fill

A restoration or stream creation plan may attempt to build or fix individual components or channel segments but no existing channel restoration or mitigation procedures are yet designed to reintegrate the different parts of the drainage network back into a functioning whole after the network has been dismembered.

***Deficiencies of plans to mitigate for the loss of streams due to MTVFs fall into six major categories*:**

1. Mitigation plans fail to assess ecosystem functions. As described earlier in this document, healthy streams are living, functional systems which support a number of critical ecological processes (Table 2.2): the processing of nutrients, the decomposition of organic matter and, microbial, primary and secondary production (Palmer et al. 1997a; Naiman et al. 2005; Palmer and Richardson 2008). To date mitigation plans associated with mountain top mining have not used readily available methods for directly measuring ecological functions yet these processes must be measured in order to determine how and whether they may be brought back to the right levels and direction through mitigation. There are now abundant scientific studies outlining how to make and interpret such measurements (e.g., Peterson et al. 2001; Gessner and Chauvet 2002) and how such measurements can be used to evaluate the success of a restoration project (Buckveckas et al. 2007; Roberts et al. 2007).

Use of well-accepted methods for measuring ecological functions (e.g., see Hauer and Lamberti 1996, 2006) is important because ecological functions evaluate dynamic properties of ecosystems that underlie an ecosystem's ability to provide vital goods and services (Gessner and Chauvet 2002; Falk et al. 2006; Fischenich 2006, Palmer and Richardson 2008). Functions reflect system performance and their measurement requires quantification of ecological processes such as primary production or nutrient uptake (Hauer and Lamberti 1996, 2006). This should be reflected in the mitigation plan if the plan is to mitigate functions that are lost due to the mining through of streams. Functional measures have been used to compare degraded vs. restored vs. reference streams (Roberts et al. 2007; Buckveckas 2007; Kaushal et al. 2008). and have been shown to be quite sensitive to degradation and restoration (e.g., Fig. 4.2) but to date measurements of functions for created or restored MTVF streams have not been published thus there is no evidence the mitigation practices result in healthy, fully functional streams.

2. Mitigation plans fail to adequately assess ecosystem structure. Even the structural measures typically used in mitigation projects are inadequate and fail to comply with minimum scientific standards. For example, baseline measurements such as macroinvertebrate assessments are frequently one time measurements instead of measurements made on several dates across different seasons or years. Invertebrate diversity and composition change throughout the year and particularly following high flow events which can dramatically reduce diversity and abundance for short periods of time (days to a week typically). If samples are only collected once then findings can not be unambiguously interpreted – if abundances or diversity are low is this because the sampling happened to be done right after a rainstorm or following a drought? This is particularly problematic in mining and mitigation contexts because the streams are ungauged so there is no way to know what flow levels that immediately preceded the sampling.

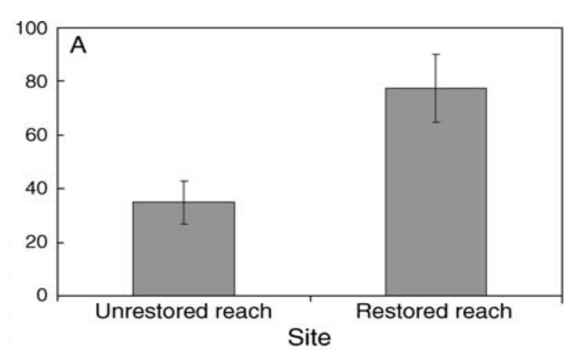


Figure 4.2: Denitrification rate - µg N/kg soil/day (from Kaushal et al. 2008)

Another problem is that invertebrate sampling methods described in mitigation plans rely on the use of nets or other devices to capture fauna in the water or on the streambed, yet many intermittent streams have diverse and abundant fauna in that live subsurface. As Collins et al. (2007) have shown, "streams with no visual evidence of surface flow may contain subsurface flowpaths with water chemistry and biota comparable to coupled perennial surface flow reaches". Indeed, assessments of ecosystem structure using most rapid bioassessment methods assume that the presence of water in the channel is a pre-requisite for stream health. Indeed, ephemeral and intermittent channels are *supposed* to have wet and dry periods and some important ecosystem functions are actually enhanced by alternating wet and dry periods (e.g., denitrification; Euliss et al. 2008).

Assessments of stream chemistry (another structural measure) for mitigation is also typically done using samples collected once or at best twice in the streams to be impacted or enhanced for credits. Yet snapshots of chemistry tell you little about many chemical parameters that can fluctuate dramatically depending on rainfall or inputs from upstream. Organisms are surrounded by stream water continuously for extended periods of time and spikes in contaminants or changes in temperature or dissolved oxygen that only last hours to days may be lethal to them. Thus one shot sampling efforts fail to pick up such 'threshold' events.

Most surprising in many mitigation documents are indications that streams are only visually assessed and often by a single person i.e., no direct measures are made. Even if photographs are taken, they do not provide sufficient information to arrive at a valid ecological assessment of a stream. Quantitative, direct measurements of plant diversity, faunal diversity and abundance, channel characteristics and other structural attributes should be made by several individuals after cross-calibrating methods. No where in the mitigation plans have we seen references to the repeatability of physical or biological assessments or when a calibration exercise was completed, if a all. Yet, the National Research Council has emphasized that many well-meaning but unsuccessful stream restoration projects have been caused by inadequate analysis of the physical characteristics and processes that govern stream form and function (NRC 1992).

Finally, it is inappropriate to use structural measures as surrogates for functional measures because there is no scientific peer reviewed study linking stream structure with stream function. In fact, most mitigation plans that include stream enhancement or restoration are based on a morphological approach to stream restoration that has been extensively criticized in the scientific literature because of its failure to promote ecological recovery (Gillilan 1996; Shields et al. 1999; Kondolf et al. 2001; Juracek & Fitzpatrick 2003; Niezgoda & Johnson 2005; Smith& Prestegaard 2005; Slate et al. 2007; Simon et al. 2007; Roper et al. 2008).

3. Stream creation is outside the scope of accepted science. MTVF projects destroy fully healthy streams which are often in pristine watersheds. Many mitigation plans propose to re-grade the land and then construct a channel that has similar dimensions (width, depth, slope, sinuosity, etc) to the one destroyed. Thus the goal is to create a stream yet all the natural flow paths and landscape topography have been destroyed. This is not even in the realm of anything that has been scientifically tested and is certainly not within the realm of what is considered ecological restoration. As 'evidence' that stream creation is a routine practice, mitigation plans often cite projects that are actually channel reconfigurations or projects that have spatially shifted a section or meander of a channel – these are *not* the same as stream creation because for the former, the natural flow-paths are still intact.

In practice, ecological stream restoration varies along a continuum from: removing on-going impacts to a stream (e.g., preventing toxic inputs) and letting the system recover on its own; to enhancing in-stream habitat or the surrounding riparian zone (e.g., adding coarse woody debris to streams and planting vegetation) in an otherwise healthy stream; to full scale restoration that involves manipulations of an *existing* stream channel (e.g., re-grading banks and planting trees along a stream with eroding banks) (Williams et al. 1997; FISRWG 1998; Karr and Chu 1999).

Some mitigation plans refer to channel creation projects as "restoration" or "reconstruction" but while the latitude and longitude of the streams may be similar to what they were before, everything else that defines an ecologically healthy stream will be gone or will have been dramatically altered at the end of the mining period (e.g., flow paths, riparian soil and streambed biogeochemistry, groundwater-surface water (hyporheic) exchange rates, mature riparian vegetation, etc). In fact, a 1999 study singles out mountaintop removal mining and valley fills in West Virginia and adjacent states as the greatest contributor to earth moving activity in the United States (Hooke, 1999). Further, there is no evidence provided that the groundwater-surface water exchange, the concentration of suspended sediments, or the water quality in the new channel will be similar to what is in the undisturbed streams presently.

Based on our work leading a national project that developed the first comprehensive database on stream and river restoration for the U.S. (38,000 projects in the database; Bernhardt et al. 2005, Palmer et al. 2005) and on extensive work with scientists and restoration practitioners, we do not know of a single case in which building streams in the manner outlined in mitigation plans have been shown to work, much less fully compensate for ecological functions lost when a stream is destroyed. Contrary to suggestions made in the mitigation plans, the very concept of creating streams with levels of ecological functioning comparable to natural channels on sites that have been mined-through remains untested and quite unlikely to succeed. There are no peer-reviewed scientific studies referenced in mitigation plans that demonstrate healthy streams can be created after this level of impact to the land has occurred. Even with far less damage to a site, stream restoration projects that involve channel modification have an extremely high failure rate (Smith and Prestegaard 2005; Tullos et al. 2009; Palmer et al. 2009).

4. Morphologically based channel designs are not ecologically based. Most mitigation plans that include stream enhancement or restoration are based on the "Natural Channel Design" (NCD or Rosgen approach) approach but the NCD approach to stream restoration is not an *ecological* restoration approach and it has never been shown to promote ecological recovery. In fact, results from recent studies point in the opposite direction (Tullos et al. 2009). Evidence to date suggests that extensive channel engineering which is typical of the NCD approach may in fact cause damage to streams in need of restoration i.e., species diversity may actually decrease following restoration and may decrease over time (Palmer et al. 2009).

The NCD approach is fundamentally focused on channel form (structure) not ecological function. This approach was designed by Rosgen (1994) to address channel stability based only on building a channel structure (shape, slope, etc) that is able to transport the sediment and water inputs that are expected to be delivered to the stream prior to completion. There is no scientific evidence supporting the assumption that restoration of channel form will lead to full restoration of function (Palmer et al. 1997b; Hilderbrand et al. 2005; Falk et al. 2006). How a stream looks (its *form)* is simply not the same as how it processes (its *function)* material and supports life (primary producers, invertebrates, etc).

Most MTVF stream mitigation plans assume that selection of a channel type from a channel classification scheme such as those proposed by Rosgen (1994) will necessarily result in full ecological restoration, but they also assume that use of the NCD or Rosgen approach guarantees successful creation of a channel from a geomorphic and hydrologic perspective. However, channel designs based on a classification system that has not been fully evaluated at the site can lead to serious failures (Smith and Prestegaard 2005). As indicated in Palmer et al. (2005): "Attempts to develop restoration designs based on application of a single classification system across many environments have led to many failures in North America (e.g., Kondolf et al. 2001), because the specific processes and history of the river under study were not adequately understood." If mitigation projects fail and channels are unstable, this could cause new environmental degradation. However, even if they are geomorphically stable, this does not address restoration of function. Indeed, the Rosgen scheme of classification does not deal with ecological functions at all.

While use of the Rosgen scheme for stream restoration has been very common in the past, current science (published in many peer-reviewed scientific journals) has documented numerous reasons that use of this scheme for restoration can be extremely problematic (Gillilan 1996; Shields et al. 1999; Kondolf et al. 2001; Juracek and Fitzpatrick 2003; Niezgoda and Johnson 2005; Smith and Prestegaard 2005; Slate et al. 2007; Simon et al. 2007; Roper et al. 2008). In fact, an analysis of > 75 channel reconfiguration projects overwhelmingly showed that restoration of biodiversity failed (Palmer et al. 2009).

The fundamental problem with classification based restoration approaches is that they assume fixed endpoints and rigid classification schemes in which the type of stream desired can be achieved by constructing a specific channel form. Yet, streams are living systems – far more than rock-lined ditches. Even from a practical point of view, restoration is far more than creating some design based on external appearance. The fundamental distinction between form and function of stream channels is not acknowledged by mitigation plans, which focus on structural aspects of channels and ignores functional aspects. The NCD method in no way takes into account a whole array of biophysical factors that determine the ability of the channel to support all of the living resources in pristine streams in the area. Such factors include: intensity and duration of sunlight reaching the stream, which is determined in part by the vegetative structure; inputs of organic matter upon which the food web depends; nitrogen and carbon levels in the soil and streambed; etc.

5. Restoration/enhancement of perennial streams do not mitigate for impacts to ephemeral and intermittent streams. Headwater streams contribute to the aquatic ecosystem in important ways that make them different from perennial streams. In particular, intermittent and some ephemeral streams provide unique habitat for a diverse population of insects and other animals, from macroinvertebrates to salamanders (Collins et al. 2007). The interaction of groundwater and surface water that takes place in these stream segments helps purify the stream and regulate the downstream water temperature, affecting both aquatic life and water quality below. As these intermittent and ephemeral streams characteristically are found in forested hollows, with considerable riparian vegetation, they play an elevated role in nutrient processing and the decomposition of organic matter. In turn, these processes directly affect the downstream water quality, aquatic life, and other values. Intermittent and ephemeral streams have unique characteristics that distinguish them from perennial streams. The most obvious difference is hydrological – surface water is only present part of the year and this attribute leads to the support of unique species and characteristic communities of organisms that would not exist if flow were perennial.

We elaborated on the importance of intermittent and headwater streams earlier but it is important to note their unique roles with respect to: evolution of diversity; support of unique species and assemblages of organisms; provision of refugia that are critical to the life history of many species; and contribution to ecosystem processes including biogeochemical cycling, water and sediment storage and transport.

The evolution of some amphibians (particularly salamanders) and the origins of their diversity are tied to the type of periodic inundation and drying "cycle"– it prevents year-round colonization of competitors and predators who otherwise may dominate these habits to the exclusion of amphibians (Davic and Welsh 2004). Because intermittent and ephemeral streams have a seasonal mosaic of habitat types they typically support fauna that may not be found in perennial reaches -- these fauna may be able to withstand dry periods but would not compete well with species common in perennial reaches (Bond and Cottingham 2007). Some species rely on intermittent or ephemeral reaches as refuges from predation or rely on them for spawning -- Erman and Hawthorne (1976) found that from 1972 to 1975, an estimated 39-47% of the adult rainbow trout (*Salmo gairdneri*) in a Sagehen Creek, California spawned in an intermittent stream while several permanently flowing tributaries attracted only 10-15% of the run.

Intermittent and ephemeral streams are also critical to biogeochemical processes that have watershed scale impacts (e.g., influence nutrients downstream) and streams that go through wet and dry cycles may support high rates of denitrification (Butturini et al. 2003). Further, intermittent and ephemeral streams supply water and sediments which are important to downstream perennial reaches (Bond and Cottingham 2007). Finally, these smallest of streams act as a link between terrestrial ecosystems and perennial reaches and when they are re-wet following dry periods, the inundation of dry organic matter (especially in forested region) may release large amounts of dissolved organic matter to downstream reaches (Bond and Cottingham 2007).

6. Constructed channels do not have the energetic base, thermal or flow regimes to support the native aquatic community. The energetic basis of the stream food web of mountainous Appalachian streams is leaf litter from the surrounding trees (Wallace et al. 1995). For most of the year, bacteria, fungi and aquatic insects consume the leaves and wood that fall or are washed into the stream from the surrounding forest (Wallace et al. 1982). There may be brief periods of the year (between snowmelt and leaf out and between autumn litterfall and first snow) when aquatic plants (algae) are important food resources. Constructed streams on or below valley fills are in high light environments, with early vegetation consisting primarily of short-stature grasses. With abundant light, algal production is likely to be high (Hill et al. 1995). Further, with the open canopy, temperatures may reach levels that native fauna can not acclimate to. Thus, while the forested stream ecosystem is fueled by leaf litter from the surrounding forest, the created streams will be fueled by algal production. Without a forest canopy, water temperatures in the constructed streams will be significantly hotter in summer and significantly colder in winter than in the forested streams.

Further, there is no evidence that diversion of water flow to ditches or low-lying points creates a stream. Sub-surface and surface flow paths to natural streams may be complex and the residence time of the water in the groundwater varies before it reaches streams (Gregory et al. 1991; Jones and Mulholland 2000). Without a thorough scientific study including a hydrological analysis of groundwater, surface water, and hyporheic interactions (rates of flow and flow paths), there is no evidence that the water resources left after the mining and mitigation will compensate for what was lost. Yet there is abundant scientific evidence that these hydrological interactions determine ecosystem functions including rates of whole stream metabolism, nutrient processing, organic matter decomposition, productivity and reproduction of invertebrates and fish (Allan and Castillo 2007; Baron et al. 2002). In one of the leading hydrologic journals, Wohl et al. (2005) recently reiterated this point: "successful restoration requires that key processes and linkages beyond the channel reach (upstream/downstream connectivity, hillslope, floodplain, without question; water, sediment and hyporheic/groundwater connectivity) be considered. The importance of these linkages is organic matter, nutrients and chemicals move from uplands, through tributaries, and across floodplains at varying rates and concentrations." In short, mitigation based on diverting flow to sediment ditches will not "replace" stream functions and showing this would require data and detailed studies. Certainly "removing interior barriers and reconstructing outlets [from drainage control structures]" combined with the placement of a few rock vanes and root wads, will not convert mining drainage ditches to streams that replace ecological functions that were permanently lost.

Successful restoration requires that key processes and linkages beyond the channel reach (upstream/downstream connectivity, hillslope, floodplain, and hyporheic/groundwater connectivity) also be considered (Sear 1994; Stanford et al. 1996; Graf 2001; Palmer et al. 2005). The importance of these linkages is without question; water, sediment, organic matter, nutrients and chemicals move from uplands, through tributaries, and across floodplains at varying rates and concentrations.

7. Existing mitigation approaches fail to include any mechanisms that will reduce the export of SO_4^{2-}, HCO_3^-, Ca^{2+}, Mg^{2+}, Fe and trace metals from mined sites, or that will remediate these impacts for the water columns of constructed channels. Most mitigation plans merely state that channels will be constructed using natural channel design approaches and that their success will be gauged based upon their structural similarity to reference sites. If the water flowing through these mitigated channels comes into contact with overburden it will contain the characteristic signature of alkaline mine drainage. Thus the capacity for even a channel that is "structurally and hydrologically" similar to reference streams to support a diverse aquatic fauna and an ecosystem functional capacity similar to those lost when unmined streams are buried will be very constrained. The severe water quality degradation associated with water flowing through mined landscapes will constrain mitigation success. The mitigation projects associated with MTVF operations are not designed to actually mitigate for the severe water quality impacts generated, and these long-term, long-distance impacts represent unmitigated stressors to the stream reaches below valley fills and to the full river network extending downstream.

8. Current monitoring requirements for mitigation projects will not assure ecological success. Mitigation projects are typically monitored for 5 to 10 years after completion. The required monitoring suffers from the same short falls that have been previously discussed, failure to measure stream functions and inadequate structural measures. In addition, while the burial of streams is permanent many stream enhancement projects will be of short duration (testimony says 20-25 years). Thus monitoring of 5-10 years will miss the temporal differences between impacts and the mitigation intended to offset them. Indeed, since the time frame for full forest re-growth that is required for full restoration of ecosystem functions and biodiversity is on the order of many decades, monitoring should continue for at least 30 years.

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