

Mountaintop Mining Consequences

M. A. Palmer,^{1,2} E. S. Bernhardt,³ W. H. Schlesinger,⁴ K. N. Eshleman,¹ E. Foufloula-Georgiou,⁵ M. S. Hendryx,⁶ A. D. Lemly,⁷ G. E. Likens,⁴ O. L. Loucks,⁸ M. E. Power,⁹ P. S. White,¹⁰ P. R. Wilcock¹¹

Damage to ecosystems and threats to human health and the lack of effective mitigation require new approaches to mining regulation.

There has been a global, 30-year increase in surface mining (1), which is now the dominant driver of land-use change in the central Appalachian ecoregion of the United States (2). One major form of such mining, mountaintop mining with valley fills (MTM/VF) (3), is widespread throughout eastern Kentucky, West Virginia (WV), and southwestern Virginia. Upper elevation forests are cleared and stripped of topsoil, and explosives are used to break up rocks to access buried coal (fig. S1). Excess rock (mine “spoil”) is pushed into adjacent valleys, where it buries existing streams.

Despite much debate in the United States (4), surprisingly little attention has been given to the growing scientific evidence of the negative impacts of MTM/VF. Our analyses of current peer-reviewed studies and of new water-quality data from WV streams revealed serious environmental impacts that mitigation practices cannot successfully address. Published studies also show a high potential for human health impacts.

Ecological Losses, Downstream Impacts

The extensive tracts of deciduous forests destroyed by MTM/VF support some of the highest biodiversity in North America, including several endangered species. Burial of headwater streams by valley fills causes permanent loss of ecosystems that play critical roles in ecological processes such as nutrient cycling and production of organic matter for downstream food webs; these small Appalachian streams also support abundant aquatic organisms, including many endemic species (5). Many studies show that when more than 5 to 10% of a watershed's area is affected by anthropogenic activities, stream biodiversity and water quality suffer (6, 7). Multiple watersheds in WV



already have more than 10% of their total area disturbed by surface mining (table S1).

Hydrologic flow paths in Appalachian forests are predominantly through permeable soil layers. However, in mined sites, removal of vegetation, alterations in topography, loss of topsoil, and soil compaction from use of heavy machinery reduce infiltration capacity and promote runoff by overland flow (8). This leads to greater storm runoff and increased frequency and magnitude of downstream flooding (9, 10).

Water emerges from the base of valley fills containing a variety of solutes toxic or damaging to biota (11). Declines in stream biodiversity have been linked to the level of mining disturbance in WV watersheds (12). Below valley fills in the central Appalachians, streams are characterized by increases in pH, electrical conductivity, and total dissolved solids due to elevated concentrations of sulfate (SO_4), calcium, magnesium, and bicarbonate ions (13). The ions are released as coal-generated sulfuric acid weathers carbonate rocks. Stream water SO_4 concentrations are closely linked to the extent of mining in these watersheds (11, 14). We found that significant linear increases in the concentrations of metals, as well as decreases in multiple measures of biological health, were associated with increases in stream water SO_4 in streams below mined sites (see the chart on page 149). Recovery of biodiversity in mining waste-impacted streams has not been documented, and SO_4 pollution is known to persist long after mining ceases (14).

Conductivity, and concentrations of SO_4 and other pollutants associated with mine runoff, can directly cause environmental degradation, including disruption of water and ion balance in aquatic biota (12). Elevated SO_4 can exacerbate nutrient pollution of downstream rivers and reservoirs by increasing

nitrogen and phosphorus availability through internal eutrophication (15, 16). Elevated SO_4 can also increase microbial production of hydrogen sulfide, a toxin for many aquatic plants and organisms (17). Mn, Fe, Al, and Se can become further concentrated in stream sediments, and Se bioaccumulates in organisms (11) (figs. S1 and S2).

A survey of 78 MTM/VF streams found that 73 had Se water concentrations greater than the 2.0 $\mu\text{g}/\text{liter}$ threshold for toxic bioaccumulation (18). Se levels exceed this in many WV streams (see the chart on page 149). In some freshwater food webs, Se has bioaccumulated to four times the toxic level; this can cause teratogenic deformities in larval fish (fig. S2) (19), leave fish with Se concentrations above the threshold for reproductive failure (4 ppm), and expose birds to reproductive failure when they eat fish with Se >7 ppm (19, 20). Biota may be exposed to concentrations higher than in the water since many feed on streambed algae that can bioconcentrate Se as much as 800 to 2000 times that in water concentrations (21).

Potential for Human Health Impacts

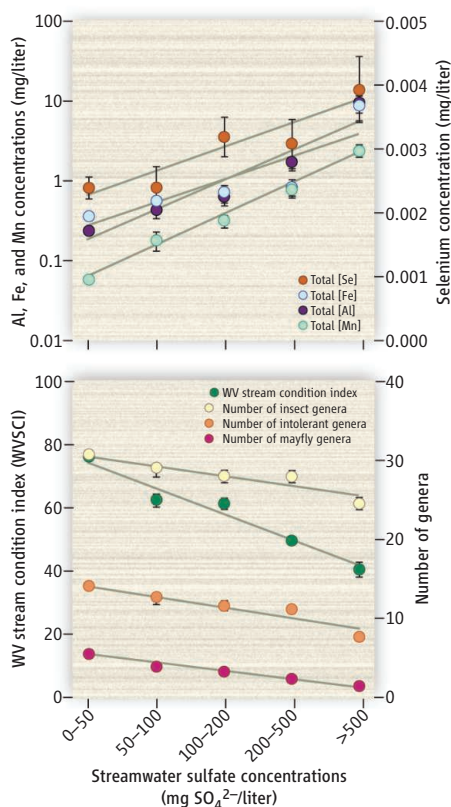
Even after mine-site reclamation (attempts to return a site to premined conditions), groundwater samples from domestic supply wells have higher levels of mine-derived chemical constituents than well water from unmined areas (22). Human health impacts may come from contact with streams or exposure to airborne toxins and dust. State advisories are in effect for excessive human consumption of Se in fish from MTM/VF affected waters. Elevated levels of airborne, hazardous dust have been documented around surface mining operations (23). Adult hospitalizations for chronic pulmonary disorders and hypertension are elevated as a function of county-level coal production, as are rates of mortality; lung cancer; and chronic heart, lung, and kidney disease (24). Health problems are for women and men, so effects are not simply a result of direct occupational exposure of predominantly male coal miners (24).

Mitigation Effects

Reclamation of MTM/VF sites historically has involved planting a few grass and herb species (20, 25). Compared with unmined

¹University of Maryland Center for Environmental Science, Cambridge, MD 21613, USA. ²University of Maryland, College Park, MD 20742, USA. ³Duke University, Durham, NC 27708, USA. ⁴Cary Institute of Ecosystem Studies, Millbrook, NY 12545, USA. ⁵University of Minnesota, Minneapolis, MN 55414, USA. ⁶West Virginia University, Morgantown, WV 26506, USA. ⁷Wake Forest University, Winston-Salem, NC 27109, USA. ⁸Miami University, Oxford, OH 45056, USA. ⁹University of California at Berkeley, Berkeley, CA 94720, USA. ¹⁰University of North Carolina at Chapel Hill, Chapel Hill, NC 27599, USA. ¹¹Johns Hopkins University, Baltimore, MD 21218, USA.

*Author for correspondence. E-mail: mpalmer@umd.edu



Mining effects on stream chemistry and biota.

Sulfate concentrations reflect amount of mining in watershed. (Top) Average concentrations of manganese, iron, aluminum, and selenium. (Bottom) Stream invertebrate community metrics in relation to sulfate concentrations for 1058 WV streams (methods in table S2). Regressions all statistically significant (table S3).

sites, reclaimed soils characteristically have higher bulk density, lower organic content, low water-infiltration rates, and low nutrient content (8, 25). Many reclaimed areas show little or no regrowth of woody vegetation and minimal carbon (C) storage even after 15 years (26). Decreased forest productivity may be related to the type of surface material (e.g., brown versus gray sandstone) used in the reclamation (27). In reclaimed forests, projected C sequestration after 60 years is only about 77% of that in undisturbed vegetation in the same region (28). Mined areas planted to grassland sequester much less. Since reclamation areas encompass >15% of the land surface in some regions (29) (table S1), significant potential for terrestrial C storage is lost.

Mitigation plans generally propose creation of intermittently flowing streams on mining sites and enhancement of streams off-site. Stream creation typically involves building channels with morphologies similar to unaffected streams; however, because they are on or near valley fills, the surrounding topography, vegetation, soils, hydrology, and

water chemistry are fundamentally altered from the premining state. U.S. rules have considered stream creation a valid form of mitigation while acknowledging the lack of science documenting its efficacy (30). Senior officials of the U.S. Army Corps of Engineers (ACOE) have testified that they do not know of a successful stream creation project in conjunction with MTM/VF (31).

A Failure of Policy and Enforcement

The U.S. Clean Water Act and its implementing regulations state that burying streams with materials discharged from mining should be avoided. Mitigation must render nonsignificant the impacts that mining activities have on the structure and function of aquatic ecosystems. The Surface Mining Control and Reclamation Act imposes requirements to minimize impacts on the land and on natural channels, such as requiring that water discharged from mines will not degrade stream water quality below established standards.

Yet mine-related contaminants persist in streams well below valley fills, forests are destroyed, headwater streams are lost, and biodiversity is reduced; all of these demonstrate that MTM/VF causes significant environmental damage despite regulatory requirements to minimize impacts. Current mitigation strategies are meant to compensate for lost stream habitat and functions but do not; water-quality degradation caused by mining activities is neither prevented nor corrected during reclamation or mitigation.

Clearly, current attempts to regulate MTM/VF practices are inadequate. Mining permits are being issued despite the preponderance of scientific evidence that impacts are pervasive and irreversible and that mitigation cannot compensate for losses. Considering environmental impacts of MTM/VF, in combination with evidence that the health of people living in surface-mining regions of the central Appalachians is compromised by mining activities, we conclude that MTM/VF permits should not be granted unless new methods can be subjected to rigorous peer review and shown to remedy these problems. Regulators should no longer ignore rigorous science. The United States should take leadership on these issues, particularly since surface mining in many developing countries is expected to grow extensively (32).

References and Notes

- World Coal Institute, www.worldcoal.org.
- K. L. Saylor, *Land Cover Trends: Central Appalachians* [U.S. Department of the Interior, U.S. Geological Survey (USGS), Washington, DC, 2008]; <http://landcover.trends.usgs.gov/east/eco69Report.html>.
- MTM/VF refers to surface mining operations that remove coal seams running through a mountain, ridge, or hill; it may also refer more broadly to large-scale surface mining, including area or contour mining in steep terrain

that disposes of excess rock in heads of hollows or valleys with streams.

- Debates are conspicuous because of recent high-profile federal court cases [e.g., (33)], widely publicized exchanges between the U.S. Environmental Protection Agency (EPA) and the ACOE over permitting decisions, advocacy by non-governmental organizations, and protests by miners.
- J. L. Meyer *et al.*, *J. Am. Water Resour. Assoc.* **43**, 86 (2007).
- J. D. Allan, *Annu. Rev. Ecol. Evol. Syst.* **35**, 257 (2004).
- This 5 to 10% issue is based on studies done on many nonmining types of land-use change. Thus far, EPA has not done mining-specific studies on this "threshold" issue (percentage of watershed mined versus impacts on streams) despite many calls for such data.
- T. L. Negley, K. N. Eshleman, *Hydro. Process.* **20**, 3467 (2006).
- B. C. McCormick, K. N. Eshleman, J. L. Griffith, P. A. Townsend, *Water Resour. Res.* **45**, W08401 (2009).
- J. R. Ferrari, T. R. Lookingbill, B. McCormick, P. A. Townsend, K. N. Eshleman, *Water Resour. Res.* **45**, W04407 (2009).
- K. S. Paybins *et al.*, *USGS Circular 1204* (2000); <http://pubs.water.usgs.gov/circ1204/>.
- G. J. Pond, M. E. Passmore, F. A. Borsuk, L. Reynolds, C. J. Rose, *J. N. Am. Benthol. Soc.* **27**, 717 (2008).
- K. J. Hartman *et al.*, *Hydrobiologia* **532**, 91 (2005).
- J. I. Sams, K. M. Beer, *USGS Water Res. Report 99-4208* (2000); http://pa.water.usgs.gov/reports/wrir_99-4208.pdf.
- N. F. Caraco, J. J. Cole, G. E. Likens, *Nature* **341**, 316 (1989).
- S. B. Joye, J. T. Hollibaugh, *Science* **270**, 623 (1995).
- M. E. van der Welle, J. G. Roelofs, L. P. Lamers, *Sci. Total Environ.* **406**, 426 (2008).
- EPA, *Stream Chemistry Report*, part 2 (EPA Region 3, Philadelphia, PA, 2002); <http://www.epa.gov/region3/mtnop/pdf/appendices/d/stream-chemistry/MTMVFChemistryPart2.pdf>.
- A. D. Lemly, *Selenium Assessment in Aquatic Ecosystems: A Guide for Hazard Evaluation and Water Quality Criteria* (Springer, New York, 2002).
- EPA, *Mountaintop Mining/VF Final Programmatic Environmental Impact Statement* (EPA Region 3, Philadelphia, PA, 2005); <http://www.epa.gov/region3/mtnop/index.htm>.
- J. M. Conley, D. H. Funk, D. B. Buchwalter, *Environ. Sci. Technol.* **43**, 7952 (2009).
- S. McAuley, M. D. Kozar, *USGS Report 5059* (2006); <http://pubs.usgs.gov/sir/2006/5059/pdf/sir2006-5059.pdf>.
- M. K. Ghose, S. R. Majee, *Environ. Monit. Assess.* **130**, 17 (2007).
- M. Hendryx, M. M. Ahern, *Public Health Rep.* **124**, 541 (2009).
- Mining industry and government organizations recently signed a statement of intent to promote reforestation approaches that improve reclamation [see, e.g., (34)]; however, adoption of recommendations is voluntary. Reforestation of a mined site to premined conditions has not been demonstrated.
- J. A. Simmons *et al.*, *Ecol. Appl.* **18**, 104 (2008).
- P. Emerson, J. Skousen, P. Ziemkiewicz, *J. Environ. Qual.* **38**, 1821 (2009).
- B. Y. Amichev, A. J. Burger, J. A. Rodrigue, *For. Ecol. Manage.* **256**, 1949 (2008).
- P. A. Townsend *et al.*, *Remote Sens. Environ.* **113**, 62 (2009).
- EPA and ACOE, *Fed. Regist.* **73**, 10 (2008).
- U.S. District Court, Civil Action No. 3:05-0784, transcript, vol. 3, pp. 34-45; http://palmerlab.umd.edu/MTM_US_District_Court_Civil_Action_Official_transcript_Volume_III.pdf.
- A. P. Chikkatur, A. D. Sagar, T. L. Sankar, *Energy* **34**, 942 (2009).
- U.S. Court of Appeals for the 4th District, *Ohio Valley Environmental Coalition et al. vs. U.S. ACOE et al.*, case 07-1255.
- Appalachian Regional Reforestation Initiative, www.arri.osmre.gov/FRAApproach.shtm.
- This is contribution no. 4368 of the University of Maryland Center for Environmental Science.

Supporting Online Material

www.sciencemag.org/cgi/content/full/327/5962/148/DC1

10.1126/science.1180543