

# Mountaintop Mining Consequences

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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 ( $\text{SO}_4$ ), calcium, magnesium, and bicarbonate ions (13). The ions are released as coal-generated sulfuric acid weathers carbonate rocks. Stream water  $\text{SO}_4$  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  $\text{SO}_4$  in streams below mined sites (see the chart on page 149). Recovery of biodiversity in mining waste-impacted streams has not been documented, and  $\text{SO}_4$  pollution is known to persist long after mining ceases (14).

Conductivity, and concentrations of  $\text{SO}_4$  and other pollutants associated with mine runoff, can directly cause environmental degradation, including disruption of water and ion balance in aquatic biota (12). Elevated  $\text{SO}_4$  can exacerbate nutrient pollution of downstream rivers and reservoirs by increasing

nitrogen and phosphorus availability through internal eutrophication (15, 16). Elevated  $\text{SO}_4$  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

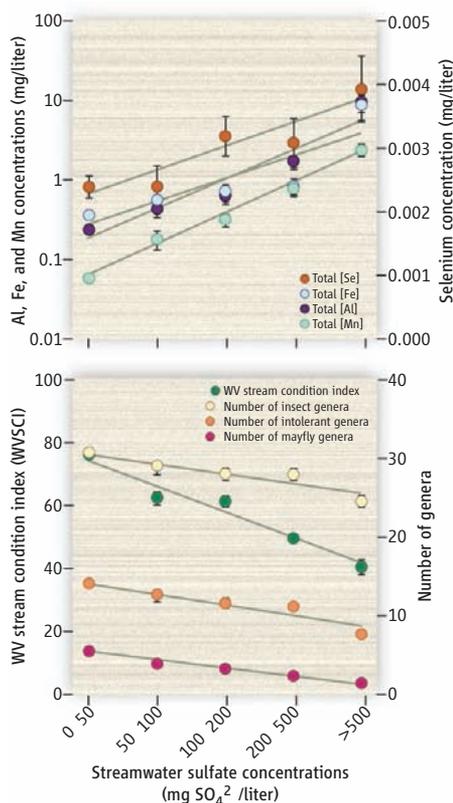
Even after mine-site reclamation (attempts to return a site to premined conditions), groundwater samples from domestic supply wells have higher levels of mine-derived chemical constituents than well water from unmined areas (22). Human health impacts may come from contact with streams or exposure to 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

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**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).

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- 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.
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- 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](http://www.sciencemag.org/cgi/content/full/327/5962/148/DC1)

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**Figure S1.** (Left) Aerial view of a southern West Virginia (WV) mountaintop mining site with valley fills. [photo by Paul Corbit Brown] (Right) Perennial streams below a Kentucky valley fill (top) [photo by Ken Fritz] and a WV valley fill (middle) [photo by Jack Webster] show visible pollution from trace metals. Unimpacted perennial streams such as this one in WV have generally clear water and are without metal deposits on the streambed such as those in the two photos above (bottom) [photo by Jack Webster].



**Table S1.** Percent of watershed covered by past, present, and pending mining permits based on ACOE permit Decision Documents for all new Clean Water Act 404 dredge and fill individual permits issued in 2008 in West Virginia. 2008 Permits were those reflected in online notification bulletins. Percentages are based on permitted areas and thus may not reflect actual disturbance. Permitting Decision Documents are part of the public record although not always easy to obtain; those used to generate the table and referenced below are available at [www.palmerlab.umd.edu](http://www.palmerlab.umd.edu)

Mine	West Virginia watershed	Watershed acreage	Percent of watershed covered by mining permits	Decision document (page)
Coal Mac, Phoenix No. 5	Island Creek	67,342	21.90%	
	Pigeon Creek	91,037	19.00%	S8. (p. 37)
Keystone Industries, Rush Creek	Rush Creek	2,934	25.80%	S9. (p. 44)
Independence, Twilight	West Fk-Pond Fk	27,389	24.40%	S10. (pp. 100, 105)
Loadout, Nellis Mine	Fork Creek	8,861	17.15%	S11. (p. 66)
Hobet Mine No. 22	Upper Mud River	22,457	31.86%	S12. (pp. 103, 104)
Appalachian Fuels	Smithers Creek	19,000	33.70%	S13. (pp. 45, 46)
Alex Energy / South	Whitman Creek	8,040	51%	S14. (p. 72)

**Table S2. Water Quality and Insect data by SO<sub>4</sub> category for Figure S1.** We received a MS Access version of the WV Department of Environmental Protection (WVDEP) water quality database from Jeff Bailey (Division of Water and Waste Management, WVDEP) on March 27, 2009 that included extensive data for WVDEP sampled streams in the WV Mountain bioregion. We queried the database for all water quality and aquatic insect sampling data for all streams that were identified in the “mountain” bioregion where the record contained a measure of SO<sub>4</sub> concentration. Stream water SO<sub>4</sub> concentrations increase with basin-wide coal production; streams with >50 mg SO<sub>4</sub> per liter are assumed to have some level of mining activity within their watershed (S1, S2). Other watershed impacts including urban development and forestry operations do not affect SO<sub>4</sub> loads to streams.

The query returned 2567 records; some streams were sampled multiple times while some were sampled only once. We queried the database to return only the maximum recorded value for water quality parameters and the minimum recorded value for insect analyses from each stream – representing the worst case scenario for each repeatedly sampled stream. This reduced the dataset to a total of 1058 independent records. Not all data fields were complete for all 1058 records; the number of records available for each metric within each category of SO<sub>4</sub> concentration are shown in the below table. For example, there were 666 records (a record = a set of water sample analyses from one collection date and site) in which SO<sub>4</sub> was <50 mg/liter. Of those 666 records, 652 had data for Al, 653 for Fe, 650 for Mn, and only 358 had data on Se. We removed one record for Se concentration where the value listed was more than 400 standard deviations above the dataset average; otherwise the dataset was unaltered from that provided by the WVDEP.

West Virginia stream condition index (WVSCI) scores were calculated using family level identification of macroinvertebrates, which is why there are more records for WVSCI scores than there are for genus level counts within each category. Determinations of tolerance were made by staff of the WVDEP according to WV stream condition index (S3) guidelines. Excerpted from that document (p. A-5): “Tolerance of a taxon is based on its ability to survive short- and long-term exposure to organic pollution. The Hilsenhoff Biotic Index (HBI) weights each taxon in a sample by its proportion of individuals and the taxon’s tolerance value. Following the basic framework established by Hilsenhoff (S4), tolerance values were assigned to individual taxa on a scale of 0-10, with 0 identifying those taxa least tolerant (most sensitive) to stressors, and 10 identifying those taxa most tolerant (least sensitive) to stressors. Tolerance values compiled by USEPA (S5) and Merritt and Cummins (S6) were used for this analysis.”

	Total number of records by SO <sub>4</sub> <sup>2-</sup> concentration (mg/liter)				
	0-50	50-100	100-200	200-500	>500
<b>Chemical constituents</b>					
Sulfate concentrations	666	92	100	134	66
Total Aluminum	652	90	100	133	66
Total Iron	653	90	99	134	66
Total Manganese	650	90	100	133	65
Total Selenium	358*	37	41	53	42
<b>Benthic invertebrates</b>					
# of Insect Genera	600	84	90	119	55
# of Intolerant Genera	600	84	90	119	55
# of Mayfly Genera	586	70	77	98	53
WVSCI Score	666	92	100	134	66

\*One outlier removed

**Table S3. Statistical results for regressions** between stream SO<sub>4</sub> concentrations and Al, Fe, Mn, Se, and biotic metrics presented in Figure 1 and described in S2.

<u>Regression with SO<sub>4</sub></u>	<u>Adjusted R<sup>2</sup></u>	<u>P value</u>
Aluminum	0.95	0.003
Iron	0.89	0.010
Manganese	0.998	<0.001
Selenium	0.78	0.03
Total taxa richness	0.89	0.010
# of Intolerant genera	0.94	0.004
# of Mayfly genera	0.67	0.056
WVSCI Score	0.76	0.034

**Figure S2. Impacts of selenium** emanating from MTM/VF impacted streams of the Mud River ecosystem, West Virginia has bioaccumulated in food webs up to 4x the toxic level; it causes teratogenic deformities in larval fish such as those shown here. Below: two eyes on one side of the head; right: spinal curvature (S7).



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