Carbon County, Pennsylvania
Reclamation of Palmerton Zinc Superfund Site

History

What once was a biological wasteland is now green and teeming with wildlife thanks to a unique mixture of biosolids, fly ash, potash, and lime called Ecoloam. The site, a thousand-acre plot of forest in Carbon County, Pennsylvania, is the largest revegetation project ever undertaken by the U.S. Environmental Protection Agency's Superfund program and serves as a model of innovative environmental technology. Wildlife that vanished from the area long ago has returned in abundance. Birds of prey such as kestrels and red-tailed hawks feed on groundhogs and other small mammals. Wild turkey, coyote and fox also have been observed. This bountiful mountainside, however, hides a toxic history.

Since 1898, two smelters flanking the town of Palmerton, Pennsylvania, have produced zinc for machinery, pharmaceuticals, pigments and other products. As a result of the zinc manufacturing, 33 million tons of residue were dumped, creating a cinder bank 2.5 miles (4 km) long, 200 ft (60 m) high, and 1,000 ft (300 m) wide. The smelters border Palmerton, which is located at the confluence of the Lehigh River and Aquashicola Creek. Smelting operations were conducted in the West Plant from 1898 to 1980, and in the East Plant from 1911 to 1980. The site had three operators, including its current owner, Zinc Corporation of America (ZCA).

Primary smelting of concentrated zinc sulfide ores occurred from 1898 until December 1980, resulting in the emission of large quantities of zinc, lead, cadmium, and sulfur dioxide. The emissions caused the defoliation of more than 2,000 acres (400 ha) of vegetation around the East Plant. Environmental damage first was identified in a 1951 aerial photograph as isolated patches on the steep, north face of Blue Mountain located adjacent to the East Plant. By 1980, vegetation damage had left a wide, continuous area of Blue Mountain barren and eroded (Figure 1). By the time the original forest was killed by the sulfur dioxide, concentrations of cadmium, lead, and zinc in the soil were

Figure 1. Typical condition on Blue Mountain, Palmerton, PA, after 82 years of zinc smelting.

so high as to prevent regeneration. In fact, metals levels stopped all microbial activity, creating a biological desert where trees that had been dead for 20 or more years could not decompose. After the death of the forest, severe soil erosion caused an estimated 12 to 24 in. (30 to 60 cm) of topsoil to be washed away from the site. As the soil eroded, rock layers emerged, slowing further movement. Metals levels in the upper 8 in. (20 cm) of soil, however, remained high.

At Palmerton Zinc's worst, between 1918 and 1962, sulfur dioxide emission rates were estimated to be between 3,300 and 3,600 pounds (1,500 and 1,630 kg) per hour.

Particulates of cadmium, lead, and zinc also were emitted and accumulated in the soil at toxic levels. Total emissions of cadmium from Palmerton have been estimated at 3,740 tons or 47 tons per year; of lead, 7,560 tons or 95 tons per year; and of zinc, 286,000 tons or 3,575 tons per year. Heavy metals concentrations have been measured at more than 100 times the typical soil concentrations for the area (Table 1).

Table 1. Heavy metal ambient soil concentrations vs. Blue Mountain soil concentrations

	Typical Ambient Soil Concentration (ppm)	Soil Concentration Measured on Blue Mountain (ppm)
Zinc	10-300	26,000 - 80,000
Cadmium	0.1-7.0	900 - 1500
Lead	<50	up to 6400

In 1982, the U.S. Environmental Protection Agency (U.S. EPA) placed the Palmerton site on the National Priorities List (Superfund) for remediation. A number of clean-up alternatives were evaluated, including removal of the top 12 in. (30 cm) of soil from the entire area. U.S. EPA estimated the cost of soil removal, without revegetation, at $1.3 billion. In addition to the contaminated soil on Blue Mountain, approximately 33 million tons of metal-laden smelting residues remain in a 2.5-mile-long (4 km) bank at the base of the mountain. Removal of the cinder bank would cost up to $2.8 billion and would take between 29 and 45 years to complete, assuming there would be a place to dispose of it. Because of the unreasonably high environmental and economic costs associated with removal, USEPA decided to attempt to stabilize the metals on-site through proper pH management and revegetation.

Strategy

In 1988, Zinc Corporation of America signed an agreement with U.S. EPA to develop the Blue Mountain Restoration Project as an interim remedy. The goal of the project was to reestablish grasses first and then trees to the approximately 1,000 treeless acres (400 ha) of Blue Mountain owned by ZCA.

Previous attempts to revegetate Blue Mountain using conventional reclamation methods were unsuccessful. The difficulty in reclaiming a site such as Blue Mountain lies in the combination of physical extremes (steep slopes, eroded soil, and high winds) and chemical and biological factors (heavy metal toxicity, micro- and macronutrient deficiencies, and absence of microbial activity).

Palmerton's newfound Superfund status site made new and innovative treatments available that might otherwise have been outside the permitted operations of state or local environmental regulatory agencies. Prior to this time, most research on sites similar to Palmerton focused on correcting the toxic effects of heavy metals in the soil. Such studies neglected the substantial impact of physical factors, such as lack of soil substrate (from erosion) and steep slopes, limiting remediation attempts. Consequently, the goal at Palmerton was to address the physical obstacles to remediation while selecting metals-tolerant ecotypes of desired species.

Zinc Corporation of America contracted Horsehead Resource Development Company (HRD) to perform the work of restoring Blue Mountain. HRD tested several soil additives to determine which would best stabilize hazardous metals in the soil while enhancing vegetative growth. The company also tested diverse grasses and trees to identify those that would thrive on Blue Mountain.

HRD proposed to use a combination of limestone, potash, municipal wastewater biosolids and power plant fly ash as a soil amendment (the combination was later termed "Ecoloam"), and then to hydroseed and hydromulch appropriate metals-tolerant species of vegetation. HRD would blow the amendments onto the soil surface because the near-vertical slopes, rocky surface, and tree-littered landscape of Blue Mountain, precluded incorporation of the amendments into the soil.

Without active soil incorporation, either biosolids or fly ash alone would not have remediated Blue Mountain. Left on the surface, the black biosolids would have dried and crusted on the slope's surface. Rainwater would have entered the cracks, moved below the biosolids, and carried the material off the slope and off-site. Fly ash, without incorporation, would have either dried and blown off the site or eroded from the slopes during rainfall.

On the other hand, a biosolids/fly ash mixture addressed most of the major problems associated with reclaiming Blue Mountain. First, the handling characteristics of the mixture were improved. Biosolids at 15 percent to 20 percent solids can be quite sloppy when used alone, while fly ash is prone to dust generation. Second, the light color of the fly ash lightened the dark-colored biosolids, helping to prevent excessive temperatures from developing at or near the soil surface. Finally, HRD believed that the fly ash, being composed of soil-sized particles, would help keep the biosolids from crusting on the surface, thereby increasing the porosity, infiltration, and percolation rates of the mixture.

Greenhouse and Field Plot Trials

First, greenhouse and field studies were undertaken to determine the technical feasibility of revegetating Blue Mountain using Ecoloam as a soil amendment. The greenhouse study was conducted from February 1986 to June 1986 at the USDA Soil Conservation Service Plant Materials Center in Corning, New York. The design called for applying 2,000 pounds per acre (2,200 kg/ha) of organic nitrogen from the biosolids, so the biosolids amount remained constant in various blends. The volumes of fly ash in the mixture varied from equal parts biosolids and fly ash on a volume basis to three parts biosolids and one part fly ash. The equivalent of 10 tons per acre of limestone and 132 pounds per acre (148 kg/ha) of potash also were mixed into the soil amendment.A group of 12 plants known or suspected of having tolerance to heavy metals was tested in HRD's study. The plants were placed in pots filled with soil from

Blue Mountain and the biosolids/fly ash mixes were spread on top to simulate unincorporated conditions.

Following completion of the 100-day study, the roots of 11 plant species had penetrated the Blue Mountain soils and escaped the bottom of the pots. The best-performing plants were switchgrass, tall fescue, intermediate wheatgrass, big bluestem, flatpea, perennial ryegrass, and birdsfoot trefoil. These species were used in the field plots established on Blue Mountain.

Based on the positive results in the greenhouse study, U.S. EPA approved large-scale field plot trials on Blue Mountain. The intent of the field plots was not only to test the soil amendments and herbaceous species, but also to test field-scale equipment. If the field work could not be completed in a cost-efficient manner using large equipment, the entire project would have to wait until appropriate equipment could be designed.

Researchers arranged 10 one-acre (0.4 ha) plots along an access road on the mid-slope portion of Blue Mountain. Three plots were located on the downslope side of the road, and the remaining seven plots were located on the uphill side of the road. The uphill plots were designed to test the throwing range on the spreading equipment. Each one-acre plot extended 150 ft (46 m) perpendicular to the road, and 290 ft (88 m) along the road. One plot was used as a control and received the same amounts of lime, potash, seed and mulch as the others, but no biosolids/fly ash. The field plots were subdivided into five 0.2-acre (800 sq m) subplots for seeding prior to application of the amendments. The seed mixtures applied on each subplot are shown in Table 2.

Table 2. Species and seeding rates used on five Blue Mountain PA subplots

Subplot #	Species	Rate, lb/acre, kg/ha
1[a]	'Blackwell' switchgrass	15[c] (16.8)
1[b]	'Cave-in-Rock' switchgrass	15[c] (16.8)
2	'Niagara' big bluestem	30[c] (33.6)
3	'Empire' birdsfoot trefoil +	20 (22.4)
	'Ky-31' tall fescue	40 (44.8)

4	'Pennfine' perennial ryegrass	+ 20 (22.4)
	'Lathco' flatpea	60 (67.2)
5	'Oahe' intermediate wheatgrass	30 (33.6)

[a] Seeded on field plots 2, 4, 6, 8, and 10; [b] on field plots 1, 3, 5, 7, and 9; [c] Pure live seed

Agricultural limestone [10 tons/acre (25 tons/ha)] and potash [132 lbs/acre (148 kg/ha) or 80 lb/acre (90 kg/ha) actual K] were applied using a spreader truck. The amount of limestone applied was double the amount required to raise the soil pH to 7.0, in order to help immobilize heavy metals in the soil. The two calcium sources, fly ash and limestone, worked well to precipitate heavy metals in the soil, with the fly ash-supplied $Ca(OH)_2$ entering the solution rapidly, and the limestone-supplied $CaCO_3$ entering the solution more slowly. Next, the biosolids and fly ash mix was applied (Figure 2). To

Figure 2. Biosolids and fly ash were thrown from the rear of the spreader by a fan

spinning at 800 to 1200 rpm.

supply approximately one ton per acre of organic nitrogen, an application rate of 21 dry tons per acre of biosolids or 105 product tons per acre (about 20 percent solids) was used.

The biosolids and fly ash were loaded into a dump truck in alternating layers to achieve the desired ratio. Mixing occurred during transport to the work site, dumping, and loading into the spreader truck. The material was then thrown from the rear of the spreader by a fan spinning at 800 rpm to 1,200 rpm.

Data for 1986 were collected in mid-November of that year. All the plant species germinated and grew, but the legumes (birdsfoot trefoil and flatpea) apparently could not compete with the grasses. In general, after one growing season, the 1:1 biosolids to fly ash ratio had the best grass growth, and the 3:1 ratio had the least grass. Planted trees performed in just the opposite manner, with greatest tree growth in the 3:1 mix and worst growth in the 1:1 mix.

Researchers examined root development of the vegetation at each sampling point, and in all cases development was normal unless inhibited by a rock or restricting layer. Foliar samples were analyzed for N, P, K, Ca, Mg, Mn, Fe, Cu, B, Al, Zn, Pb, Cd, Ni, Cr, and Co. In general, N, P, K, Ca, and Mg were within tolerable limits. Heavy metals concentrations in the plants were lower in the 1:1 ratio and greatest in the 3:1 ratio. The only difference in the mixes was the amount of fly ash. $Ca(OH)_2$ in the fly ash (avg. pH 10.5) dissolved easily, and mixes with greater amounts of fly ash had more available $Ca(OH)_2$ to precipitate heavy metals in the soil, thereby making them biologically unavailable.

Legal Negotiations

In September 1987, after evaluating the results of two growing seasons on Blue Mountain, U.S. EPA Region III promulgated a Record of Decision (ROD) for the site. The ROD stated that *in situ* stabilization of the heavy metals in the soil coupled with revegetation using the biosolids/fly ash technique was the preferred alternative for remediation at the site.

Obtaining fly ash and biosolids for remediation proved a major obstacle. Initially, power plants and wastewater treatment facilities refused to transport fly ash or biosolids to the site for fear of liability. The site's Superfund designation is due to zinc, lead, and cadmium in the soil, and most fly ash and biosolids contain small amounts of zinc, lead, and cadmium. The residuals generators requested that U.S. EPA absolve them from any liability resulting from the use of their products (fly ash and biosolids). U.S. EPA was reluctant to establish such a precedent. This disagreement caused an impasse that lasted for nearly two years.

A breakthrough finally occurred when U.S. EPA agreed to grant Response Action Contractor (RAC) status to all suppliers of remedial material, including fly ash and biosolids. In effect, RAC status relieved fly ash and biosolids generators from all federal liability except for "gross negligence" or "willful misconduct" when participating in environmental remediation projects. This comfort from U.S. EPA was short-lived, as generators decided that they also needed protection at the state level. At the time, the Pennsylvania Department of Environmental Resources (DER) had no legal authority to grant such relief. Finally, Pennsylvania passed its own Superfund Act granting DER authority to issue state RAC status. DER exercised this right to procure fly ash and biosolids for Blue Mountain.

Full Scale Implementation

In May 1991, U.S. EPA approved ZCA's remedial design to begin restoring Blue Mountain using the Ecoloam soil mix. Construction began on a mixing plant to blend the limestone, potash, biosolids, and fly ash at one time rather than in two separate operations.

Simultaneously, remediation activities began on the mountain, with a front-end loader mixing residual materials on a pad. Fly ash and biosolids from several suppliers were evaluated, but most materials were unacceptable for the project due to poor physical characteristics. The biosolids were particularly problematic. Most biosolids were too wet (< 20 percent solids) for successful handling and spreading using the Aero-Spreader. The biosolids eventually selected originated in Allentown, PA, Warminster, PA, and New York City. Fly ash was obtained from the Pennsylvania Power & Light's Montour facility.

Based on earlier trials, the biosolids/fly ash ratio selected for the full-scale work was two parts biosolids to one part fly ash, which was intermediate in grass and tree performance. This ratio would provide initial grass cover to stabilize the site while allowing trees eventually to dominate. The grass seed mix included 'Oahe' intermediate wheatgrass, 'Reubens' Canada bluegrass, 'Pennfine' perennial ryegrass, 'Streeker' redtop and 'Empire' birdsfoot trefoil. As many as 12 species of native trees also were seeded each year, depending on market availability. Grass and tree seed were mixed with Ecoloam and applied.

Figure 3. Typical conditions on Blue Mountain after application of biosolids, limestone, potash and fly ash.

The Blue Mountain restoration project was concluded in 1995. In March of that year, restoration experts from the U.S. Army Corps of Engineers reported that Ecoloam appeared to stabilize soil in treated areas, reduce soil erosion, and reduce the amount of metals dissolving into runoff (Table 3).

Today it is clear that Ecoloam offers the potential not only to reclaim similar sites throughout the world but also to provide a viable and useful method of recycling municipal biosolids and power plant fly ash.

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Table 3. Concentrations of Selected Heavy Metals in Ambient Soil and Blue Mountain Soil.