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Project Summary

Revegetating Strip-Mined Land with Municipal Sewage Sludge

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The use of municipal sludge to revegetate mined land in an environmentally acceptable manner was demonstrated on several 4-ha plots in the anthracite and bituminous coal mining regions of Pennsylvania.

Three sites representative of abandoned, barren bituminous and anthracite mines were treated with various types of municipal sludge at high and low application rates and broadcast seeded with a mixture of grasses and legumes. A monitoring system was installed at each demonstration site to determine the effects of the sludge application on the chemical and bacteriological quality of groundwater and soil percolate water, chemical properties of the soil, and quality and growth of vegetative cover.

Data collected during the 3-year period indicate that the sludge applications ameliorated the harsh site conditions and resulted in a quick vegetative cover that completely stabilized the demonstration site. Moreover, each site's vegetative cover has persisted and improved each year since its establishment. No deterioration in yield or quality of vegetation has been observed. Although sludge applications increased some trace metal concentrations in the vegetation, all concentrations were below plant tolerance levels and no phytotoxicity was observed. Sludge applications have had no significant adverse effect on the chemical or bacteriological quality of soil percolate or groundwater.

The results from these demonstration projects indicate that stabilized municipal sludges, if applied properly, can be used to revegetate mined lands in an environmentally safe manner with no adverse effects on the vegetation, soil, or groundwater quality.

This Project Summary was developed by EPA's Municipal Environmental Research Laboratory, Cincinnati, OH, to announce key findings of the research project that is fully documented in a separate report of the same title (see Project Report ordering information at back).

Introduction

Much of our Nation's need for energy is currently being supplied and will probably continue to be supplied from our coal reserves. With the increasing price of oil, the demand for coal is expected to more than double by 1985. Though the production of anthracite coal from deep mining has been decreasing, the production of bituminous coal by strip mining has been steadily increasing. Estimates show that strip mining will account for 67 percent of the anticipated increased production.

The strip-mining industry has already disturbed approximately 1.6 million ha of land in the United States, of which, slightly less than 607,500 ha has been properly reclaimed. Strip mining of bituminous coal has affected 31 states.

The U.S. Geological Survey has estimated that approximately 2,590 km^2 of land is disturbed annually by strip mining. In Appalachia alone, more than 400,000 ha of land has been disturbed by strip mining, with more than 25 percent of it in Pennsylvania. Only half of this land has been adequately revegetated. In Pennsylvania, strip and surface mining of coal has adversely affected an estimated 4,800 km of streams and 810 ha of impoundments as a result of erosion and acid mine drainage. In addition, it has caused the loss of productive cropland and forestland, wildlife habitat, recreational, and hunting areas. Though current mining laws require proper back-filling and restoration of the land, much of the mining was done before such laws existed. Many of the old strip mine sites are a constant source of silt in streams from soil erosion. The rain that falls on these sites erodes the mine spoil and carries it to natural water courses, where it causes pollution of surface streams or rapidly percolates through the porous spoil material and adds to the acid drainage problems of the mining areas. The lack of a vegetative cover on old sites thus contributes to pollution from both soil erosion and acid drainage.

Strip mine spoils are notoriously difficult to revegetate. Most provide a harsh environment for seed germination and subsequent plant growth. Major problems are usually a lack of nutrients and organic matter, low pH, low water-holding capacity, toxic levels of trace metals, and poor physical characteristics. To alleviate these conditions, large applications of lime and fertilizer are often required. In some instances, organic soil amendments and mulches are necessary to obtain satisfactory vegetation establishment.

Cities and towns throughout Appalachia have benefited from Federal and State sewage treatment plant construction grants. The construction of treatment plants has done much to reduce health hazards, abate water pollution, and upgrade water quality. The cost of operating such plants places a burden on municipalities, and one of the most costly items in treatment plant budgets is sludge disposal. Higher degrees of sewage treatment result in larger quantities of sludge that must be handled in an environmentally satisfactory manner.

Sewage sludge incinerators were used to dispose of sludge for many years. The ash produced was landfilled and presented no particularly difficult disposal problems. Incinerators are now being phased out of service throughout Pennsylvania as air quality standards become more restrictive. The high cost and limited availability of fuel to fire conventionally designed incinerators have contributed to the rapid decline in sludge incineration in Pennsylvania. This changing situation presents a problem and an opportunity. More sludge that could be applied constructively to land renovation will now be available.

During the past decade, a considerable amount of research has been conducted that has shown that stabilized municipal sludge from secondary wastewater treatment plants is an excellent soil amendment and chemical fertilizer substitute. It is estimated that more than 4.5 million dry metric tons (mt) of municipal sludge is currently being produced annually in the United States. By the time secondary treatment is achieved by all wastewater treatment facilities across the country, this volume of sludge may reach 8 million dry mt per year. Current methods for sewage sludge disposal are land filling (40%), incineration (25%), ocean dumping (15%), and land application (20%). Of these, only land application provides an opportunity for disposal and beneficial use at the same time.

Farmers have used animal wastes as soil conditioners for centuries. Sewage sludges have been used for this purpose in many parts of the world. The availability of inexpensive chemical fertilizers in the United States probably has resulted in limited instances of sewage sludge being used as a soil builder and conditioner. Recent increases in the cost of chemical fertilizer should make the nutrient content of sewage sludge more attractive to farmers.

Though the benefits of using sewage sludge seem obvious, there is some reluctance on the part of farmers and local government officials to undertake such projects. It was quite obvious that we had to bridge the gap between available technical information and public understanding. To accomplish this, a cooperative project was initiated in 1977 with funding from the U.S. Environmental Protection Agency (EPA) to establish 4-ha (10 acre) demonstration plots in both the anthracite and bituminous coal mining regions of Pennsylvania. Cooperating in this effort were the Pennsylvania Bureau of Solid Waste Management, the Pennsylvania office of the USDA Agricultural Stabilization and Conservation Service, and the Appalachian Regional Commission. This effort was expanded in 1978 in cooperation with the City of Philadelphia Water Department and Modern-Earthline Companies.

Projects were conducted using several types of sludges on a variety of site conditions. Types of sludges used were (1) liquid digested, (2) dewatered by centrifuge, vacuum filter, and sand bed drying, and (3) compost—sludge-cake mix. Site conditions evaluated were bituminous strip mine banks and an anthracite refuse bank that were recontoured without soil replacement.

Bituminous Strip Mine Banks

This site, located in Venango County, is representative of bituminous strip mine banks, that have been backfilled and recontoured after mining without soil replacement. Several attempts had been made to revegetate the area using lime, commercial fertilizer, and seed but without success. The surface spoil was compacted, extremely acid (pH 3.8), and devoid of vegetation. A 4-ha demonstration plot was established. The plot was scarified with a chisel plow to loosen the surface spoil material and then treated with agricultural lime (4.5 to 12.3 mt/ha) to raise the spoil pH to 6.5.

Sludge for the project was obtained from three local waste treatment plants. Liquid digested sludge, obtained from the cities of Farrell and Oil City, was transported to the site in tank trucks. Dewatered sludge was obtained from Franklin where the sludge is dewatered by centrifuging, and from Oil City where the sludge is dewatered by spreading on sand drying beds. The dewatered sludge was brought to the site in coal trucks. The 4-ha plot was subdivided into four 1-ha subplots for application of liquid digested sludge at two rates and dewatered sludge at two rates (Figure 1). Liquid digested sludge was applied with a vacuum tank liquid manure spreader at 103 m^3/ha (equivalent to 7 mt/ha) and 155 m^3/ha (equivalent to 11 mt/ha). Dewatered sludge was applied at 90 and 184 mt/ha.

Immediately after sludge application and incorporation, the site was broadcast seeded with a mixture of two grasses and two legumes. The seeding mixture was Kentucky-31 tall fescue (22 kg/ha), Pennlate orchardgrass (22

Figure 1. *Spreading composted sludge on a bituminous strip mine after liming.*

kg/ha), Penngift crownvetch (11 kg/ha), and Empire Birdsfoot trefoil (11 kg/ha). The site was mulched with straw and hay at the rate of 3.8 mt/ha.

The amounts of trace metals applied at the highest liquid and dewatered sludge application rates are given in Table 1 along with the EPA and Pennsylvania Department of Environmental Resources (PDER) interim guideline recommendations. It is quite obvious that the amounts of trace metals applied even at the highest sludge application rate were well below the recommended lifetime limits except for copper, which slightly exceeded the Pennsylvania guidelines.

The amounts of nutrients applied by each of the sludge application rates are given in Table 2. Potassium is the only plant nutrient deficient in all sludge application rates. The commercial fertilizer equivalents are also given in Table 2. The highest sludge application rate (184 mt/ha) was equivalent to applying an 11-9-0 commercial chemical fertilizer at 22 mt/ha. One of the principal advantages of using sludge is that it is a slow-release fertilizer and will supply plant nutrients for 3 to 5 years. Most of the nitrogen is in the organic form and therefore not immediately available for plant use until it is mineralized and converted to available plant forms. Only approximately 20 percent of the organic nitrogen is mineralized in the first year and 5 to 10 percent of the remaining organic nitrogen is released the second year. Decreasing amounts of organic nitrogen are subsequently released each year. After this period, the natural process of nutrient recycling should be well established for sustaining the vegetation.

All sludge treated areas had a compete vegetative cover established within several weeks after sludge was applied (Figure 2). Vegetation growth and dry matter production were measured at the end of each growing season (1977 to 1979) (Table 3). Both vegetation height growth and dry matter production increased during the 3-year period.

Samples of the individual grass and legume species were collected at the end of each growing season for foliar analyses. Results for tall fescue and birdsfoot trefoil for the highest sludge application rate are given in Table 4.

Table 1. *Trace Metal Loadings (kg/ha) of the Highest Liquid and Dewatered Sludge Applications at the Venango County Demonstration Compared with EPA and PDER Recommendations.*

Constituent	kg/ha Loading at Sludge Application Rates (mt/ha)		kg/ha Recommendations	
	11	184	EPA[1] (CEC 5-15)	PDER
Cu	21	129	280	112
Zn	21	147	560	224
Cd	0.1	0.6	11	3
Pb	10	55	1,120	112
Ni	1	12	280	22
Cr	16	74	NR[2]	112
Hg	0.01	0.09	NR[2]	0.6

[1]Average CEC of site ranged from 11.6-15.2 meq/100g.
[2]No recommendations given by EPA.

Table 2. *Commercial Fertilizer Equivalents of the Sludge Application at the Venango County Demonstration Site.*

Sludge Application Rate, mt/ha	Amount, kg/ha	Fertilizer Equivalent (Fertilizer Formula)[1] N, kg/ha (%)	P_2O_5, kg/ha (%)	K_2O, kg/ha(%)
184[1]	22,400	2,388 (11)	2,103 (9)	21 (0)
90	11,200	1,165 (10)	1,026 (9)	11 (0)
11	2,240	284 (13)	143 (6)	6 (0)
7	2,240	187 (8)	95 (4)	2 (0)

[1]For example, 184 mt sludge/ha is equivalent to 11-9-0 fertilizer at 22,400/ha.

Figure 2. *Vegetation growth on same area as Figure 1 three months after sludge application.*

Table 3. *Vegetation Height Growth (cm) and Dry Matter Production (kg/ha) at the Venango County Demonstration Site for the Highest Liquid and Dewatered Sludge Applications.*

Sludge Application, mt/ha	1977	1978	1979
		Height, cm	
11	32	30	43
184	35	52	44
		Dry Matter Production, kg/ha	
11	7,731	8,654	17,141
184	6,013	9,336	11,322

Table 4. *Average Concentration (μg/g) of Trace Metals in the Foliar Samples Collected from the 184 mt/ha plot at the Venango County Demonstration Site.*

Species	Year	Cu	Zn	Cd
Tall Fescue	1977	9.4	44.4	0.20
	1978	8.6	44.4	0.41
	1979	9.2	72.5	0.08
Birdsfoot Trefoil	1977	13.9	95.9	0.43
	1978	7.7	30.4	0.07
	1979	9.2	41.5	0.04
Suggested Tolerance Level		150	300	3

Foliar trace metal concentrations generally decreased over the 3-year period. Overall, the trace metal concentrations were well below the suggested tolerance levels and no phytotoxicity symptoms were observed.

In general, the vegetation cover has improved over the three growing seasons following sludge application (Figure 3). No deterioration in vegetation quality or yield has been measured or observed. In comparison, the remainder of the site, not treated with sludge, remained barren.

Spoil samples were collected at the end of each growing season to evaluate the effect of the lime and sludge applications on spoil pH. Results indicate that, for the highest sludge application (184 mt/ha), after lime and sludge was applied the spoil pH at the 0- to 15-cm depth increased from 3.8 to 6.2 at the end of the first growing season.

Surface spoil pH continually increased over the 2.5-year period following sludge application. Results indicate that the lime and sludge applications did raise the spoil pH significantly and that the higher pH was maintained. After the 3-year period, surface spoil pH was 7.3.

Spoil samples were also analyzed for trace metals. A comparison of trace metal concentrations before and after sludge was applied indicate that even at the highest sludge application rate (184 mt/ha) the trace metal concentrations in the surface spoil (0 to 15 cm) were only slightly increased. In general, the trace metal concentrations in the spoil were all extremely low in comparison with normal ranges for soils.

Groundwater samples were collected every two weeks from monitoring wells to evaluate the effect of the sludge applications on water quality (Table 5).

Well No. 1 was drilled as a control outside the area of influence of the sludge applications. Groundwater flow under the dewatered sludge-treated area is toward Well No. 2 located approximately 11 m downslope from the plot. Results indicate that the high application of dewatered sludge did not significantly increase the concentration of NO_3-N in groundwater. Concentrations of NO_3-N were below the EPA limit for potable water (10 mg/l) for all months sampled. It also should be noted that the average depth to groundwater in Well No. 2 was only 3 m. There appears to be no significant increase in any of the trace metal concentrations in Well No. 2, which was influenced by the

Figure 3. *During the second year following sludge application the grass species are slowly replaced by legume species (birdsfoot trefoil in photo).*

Table 5. *Groundwater Analyses for Trace Metals and Nitrate-Nitrogen (mg/l) Following Sludge Application (184 mt/ha) at the Venango County Demonstration Site.*

Well No.	Year[1]	Cu	Zn	Cd	NO_3-N
Well 1 (Control)	1977	0.22	4.13	0.006	1.4
	1978	0.23	2.02	0.002	<0.5
	1979	0.17	1.48	0.002	<0.5
Well 2 (Dewatered Sludge, 184 mt/ha)	1977	0.10	3.39	0.001	1.1
	1978	0.14	3.29	0.002	<0.5
	1979	0.18	1.83	0.001	<0.5
EPA Drinking Water Standard		1.00	5.00	0.010	10.0

[1]*Values represent the mean of all samples collected from each well for the year.*

sludge applications. Average annual concentrations were below the EPA drinking water standards.

All groundwater samples collected during the period July 1977 to September 1980 were also analyzed for coliforms. No fecal coliform colonies were observed for any sample.

To maximize the value of the demonstration project, a second site was chosen on abandoned bituminous spoil for a fall sludge application. This would allow the evaluation of a fall seeding to establish a vegetative cover and the efficacy of that cover to control the environmental effects of the sludge application. During the spring of 1979, a site was located in the bituminous coal region of Southwestern Pennsylvania in Derry Township, Westmoreland County. The area had been mined approximately 10 years ago and is typical of bituminous spoil banks that had been recontoured without topsoil replacement. Four hectares of the approximate six hectare area was selected for sludge application.

Sludge for the project was obtained from the City of Philadelphia Water Pollution Control Plant, which is located approximately 450 km from the site. The plant produces a dewatered centrifuged sludge that is composted with wood chips. The composted sludge is then mixed with equal parts of centrifuged sludge-cake to increase the nutrient value of the final product. The total nitrogen content of the composted sludge is approximately 0.6 percent; whereas, the centrifuged sludge cake total nitrogen content is approximately 2.0 percent.

Results of the analyses of the compost-cake mix were used to calculate the amounts of selected nutrients and trace metals applied. The results indicated that at the selected application rate of 134 mt/ha, the compost-cake mix supplied 968 kg nitrogen/ha, 1,816 kg phosphate/ha, and 215 kg potash/ha to the area. This would be equivalent to applying a 10-18-1 commercial fertilizer at 10 mt/ha. The value of sludge as a substitute for commercial fertilizer is obvious.

A comparison of the application rate with the EPA and PDER recommendations for maximum trace metal loadings on the land indicates that the recommended limits were essentially met with the slude application rate of 134 mt/ha (Table 6). At an application rate of 134 mt/ha, the trace metal content of the sludge is well below the limits recommended by the EPA and, with the exception of zinc, meets all PDER guidelines.

Pretreatment surface soil samples were collected and analyzed for pH and buffer pH to determine the liming requirements. Results indicated that the average soil pH was 4.3. In September, 13 mt agricultural lime/ha were applied to adjust the soil pH to 6.0. Monitoring instruments were installed, including suction lysimeters at the 90-cm depth and groundwater wells.

In September, coal trucks brought the compost-cake mix from Philadelphia to the site on a return trip after delivering coal. The sludge was loaded into manure spreaders and spread on the site. Immediately after the spreading, the area was chisel plowed to incorporate the sludge into the surface 10 cm of spoil material.

After incorporating the sludge, the area was broadcast seeded with a mixture of Kentucky 31 Tall Fescue (11 kg/ha), Birdsfoot trefoil (6 kg/ha), and winter rye (63 kg/ha). Completion of seeding by October 1, 1979, allowed

Table 6. *Trace Metal Loadings (kg/ha) at the Westmoreland County Demonstration Project Compared with EPA and PDER Recommendations.*

Constituent	kg/ha Loading at Sludge Application of 134 mt/ha	kg/ha Recommendations EPA (CEC 5-15)[1]	PDER
Cd	0.2	22	3
Cu	76	560	112
Cr	42	NR[2]	112
Pb	59	2,240	112
Hg	0.06	NR[2]	0.6
Ni	13	560	22
Zn	245	1,120	224

[1]*Average CEC of site ranged from 16.7 to 19.0 meq/100g.*
[2]*No recommendation given by EPA.*

approximately 6 to 8 weeks for vegetation growth to become winter hardy.

A site inspection in November, approximately 8 weeks after seeding, indicated that a protective cover of winter rye had been established. Vegetation was approximately 5 cm in height. There was no evidence of any erosion on the sludge treatment area. It appeared that sufficient vegetation was established to protect the site from erosion and runoff over the winter season. This was confirmed by a site inspection in March 1980. The entire sludge-treated area developed a vegetative cover ranging from 5 to 10 cm in height. From 80 to 90 percent of the area appeared to be covered and there was no evidence of surface runoff or erosion from the sludge-treated area. As soon as the site was dry enough, the remaining portion of the seeding mixture was broadcast. The spring seeding mixture was Orchardgrass (11 kg/ha) and Birdsfoot trefoil (6 kg/ha). By early summer, there was a complete lush vegetative cover on the entire site. At the end of the first growing season (1980), average vegetation height was 68 cm and average dry matter product was 11,036 kg/ha. This would indicate that sludge can successfully be applied in the fall as well as the spring.

Results of the analyses of groundwater well samples indicated that sludge application did not have any apparent effect on the concentration of any constituents. The concentration of NO_3-N in the groundwater was 7.1 mg/l during the first month following sludge application and remained at a low level during the period of sampling. Concentrations of all trace metals except lead were below the maximum allowable limits for potable water. Lead concentrations exceeded the EPA standards on both the control and sludge-treated area.

Anthracite Refuse Bank

A 24-ha anthracite refuse bank, devoid of vegetation, in Scranton, Pennsylvania, was subject to severe erosion and was a constant eyesore. To demonstrate that the sludge can be used in an environmentally acceptable manner in the cities as well as in the rural areas, 4-ha of this area was selected for reclamation with sludge.

In April 1978, the 4-ha area was recontoured. A chisel plow was used to loosen the surface refuse material because of the compaction caused by the leveling process. Analyses of surface refuse samples indicated a pH of 3.6; therefore 11 mt lime/ha was applied to the area. Monitoring instrumentation was installed to collect soil percolate water at the 90-cm depth; groundwater wells were drilled to monitor the effect of the sludge on the groundwater leaving the site. Dewatered, vacuum-filtered, sludge was obtained from the Scranton waste water treatment plant. The sludge was applied at 80 and 108 mt/ha rates with manure spreaders and incorporated. The area was broadcast seeded with the same mixture of grasses and legumes as in the Venango County demonstration. The area was then mulched with hay and straw at the rate of 3.4 mt/ha.

The amounts of trace metals applied by the two sludge application rates are given in Table 7 along with the EPA and PDER guideline recommendations. Both sludge application rates were well below all recommendations for maximum trace metal loadings. The highest sludge application rate applied 1,691 kg nitrogen, 456 kg phosphorus, and 141 kg potassium/ha.

By August 1978, 2 months after the sludge application, a complete vegetative cover was established. There was no significant difference in vegetation growth between the two sludge application rates. At the end of the first growing season (1978), average vegetation height was 41 cm and average dry matter production was 3,655 kg/ha (Figure 4). By the end of the second growing season (1979), these values more than doubled.

After sludge was applied, samples from the groundwater monitoring wells were collected every 2 weeks. Results indicate that the sludge applications had little effect on the groundwater quality, with all sample concentrations of nitrate-nitrogen remaining well below EPA limits for potable water. Zinc was the only trace metal that increased

Table 7. *Trace Metal Loadings (kg/ha) on the Unburned Anthracite Refuse Site in Lackawanna County Compared with EPA and PDER Recommendations.*

Constituent	kg/ha Loading at Sludge Application Rate (mt/ha) 80	108	kg/ha Recommendations EPA (CEC 5-15)[1]	PDER
Cu	67	92	280	112
Zn	64	86	560	224
Cd	1.2	1.7	11	3
Pb	49	67	1,120	112
Ni	4.4	5.9	280	22
Cr	16	21	NR[2]	112
Hg	0.1	0.2	NR[2]	0.6

[1]*Average CEC of site ranged from 11.1 to 11.6 meq/100g.*
[2]*No recommendations given by EPA.*

Figure 4. *Dense vegetative cover established on an anthracite refuse bank following an application of dewatered sludge at 108 mt/ha in Scranton, PA.*

in concentration in the groundwater; however, the highest Zn concentration recorded (1.35 mg/l) was still well below the 5 mg/l drinking water standard for Zn. Separate samples were collected for bacterial analyses. No fecal coliforms were found in any sample to date.

Conclusions

The results from these demonstration projects indicate that stabilized municipal sludges can be used to revegetate bituminous strip-mined land and anthracite refuse banks in an environmentally safe manner with no adverse effects on vegetation, soil, or groundwater quality and with little risk to animal or human health. Specific conclusions are as follows:

1. Application of sludge in the spring produced a complete vegetative cover of grasses and legumes within 2 months.
2. Application of sludge in the fall produced a complete vegetative cover by the following summer.
3. Vegetation height and dry matter production increased each year following sludge application with no deterioration of productivity observed.
4. All foliar trace metal concentrations were below plant tolerance levels, and no phytotoxicity symptoms were observed.
5. Trace metal concentrations in the soil increased slightly because of the sludge application. These concentrations, however, were extremely low and were below the normal range for untreated soils.
6. Sludge application and liming significantly increased soil pH, and these increased pH levels were maintained throughout the study period.
7. No significant increases in concentrations of nitrate-nitrogen or trace metals occurred in the groundwater due to the sludge applications.
8. No fecal coliform colonies were observed in any groundwater samples collected during the study period.

All projects were highly successful. Project results should be useful throughout the Appalachian coal mining region. Both sludge production and strip mining of coal are increasing, and there is an urgent need to solve the environmental problems associated with both activities. Results indicate that the use of these small local demonstration projects is one of the best methods of obtaining public acceptance and support for the revegetation of strip-mined land using municipal sewage sludge.

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The complete report, entitled "Revegetating Strip-Mined Land with Municipal Sewage Sludge," (Order No. PB 82-102 484; Cost: $14.00, subject to change) will be available only from:
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