United States
Environmental Protection
Agency

Municipal Environmental
Research Laboratory
Cincinnati, OH 45268

Research and Development

EPA-600/S2-84-035 Mar 1984

EPA

Project Summary

Strip Mine Reclamation with Municipal Sludge

William E. Sopper and Eileen M. Seaker

Treated municipal sludge was used to revegetate three 4-ha demonstration plots in the anthracite and bituminous coal mining regions of Pennsylvania. The three sites selected represented more than 100,000 ha of abandoned, barren bituminous strip mine spoil banks and anthracite refuse banks present in the state.

Various types of sludges (liquid digested, dewatered, and composted) were applied at different application rates to supply the necessary nutrient pool for establishing vegetation and to adhere to state guidelines regarding lifetime applications of trace metals on the land. Following sludge application and incorporation, all sites were seeded with a mixture of grasses and legumes. A monitoring system was installed at each demonstration plot to determine the effects of the sludge applications on (1) the bacteriological and chemical qualities of soil percolate and groundwater, (2) soil chemical properties, and (3) the growth and quality of the vegetative cover.

Data collected over a 5-year period indicate that the sludge applications ameliorated the adverse site conditions and resulted in a quick, complete vegetative cover that has persisted and improved each year. No deterioration in vegetation yield or quality has been observed on any site. Although sludge applications increased some trace metal concentrations in the vegetation, all concentrations were below plant tolerance levels, and no phytotoxicity symptoms were ever observed. Before vegetation was established, the sludge applications caused some sporadic, short-lived increases in nitrate-nitrogen concentrations in soil percolate water. However, in general, the sludge applications had no significant adverse effects on the chemical or bacteriological quality of groundwater.

Study results indicate that stabilized municipal sludges can be used to revegetate mined lands in an environmentally safe manner with no adverse effects on the vegetation, soil, or groundwater quality. The study also shows that at the proper rates, single applications of sludge on a mined site can successfully establish vegetation and sustain it for the 5-year period mandated under the Federal Surface Mining Control and Reclamation Act of 1977.

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

Millions of acres of barren land disturbed by mining activities exist throughout the United States. Much of this land is a source of acid mine drainage, surface runoff, erosion, and sedimentation, all of which have created serious water pollution and land degradation problems. In the United States, surface mining alone has disturbed 1.76 x 10^6 ha (6,700 miles^2); half of that land was disturbed specifically by coal mining (Schaller and Sutton, 1978). Each year, coal mining will disturb an additional 40,470 ha, much of which will be in the populated eastern half of the United States. Paone et al. (1978) have projected that the amount of land that will be used by the surface coal mining industry will increase from 25,000 ha in 1977 to 47,000 ha in 1990.

Drastically disturbed lands generally provide a harsh environment for establishing vegetation. Major deterrents to vegetation establishment are usually a lack of nutrients and organic matter, low pH, low water-holding capacity, toxic levels of trace metals, compaction, and poor physical condition of the spoil.

The new Federal Surface Mining Control and Reclamation Act of 1977 established strict regulations for the revegetation of currently mined land (Federal Register, 1982). In general, the law requires establishment of a diverse, effective, and permanent vegetative cover of the seasonal variety native to the affected area of land. Furthermore, the cover must be capable of self-regeneration and plant succession at least equal in extent of cover to the natural vegetation of the area. The Office of Surface Mining Reclamation and Enforcement (OSM), which was established under the law, has recommended performance standards for meeting the revegetation requirements. These recommendations are as follows:

1. The permanent vegetative cover of the area must be at least equal in extent of cover to the natural vegetation of the area and must achieve productivity levels compatible with the approved postmining land use. Both native and introduced vegetation species may be used.
2. The period of responsibility begins after the last year of augmented seeding, fertilizing, irrigation or other work that ensures revegetation success.
3. In areas of more than 66 cm of annual precipitation, the period of extended responsibility will continue for not less than 5 years. In areas with 66 cm of precipitation or less, the period of responsibility will continue for not less than 10 years.
4. Normal husbandry practices essential for plant establishment will be permitted during the period of responsibility so long as they can reasonably be expected to continue after bond release.
5. In areas of more than 66 cm of precipitation, the vegetative cover must be equal to the success standard only during the growing season of the last year of the responsibility period (or during the last 2 years if required by the regulatory authority). In areas with less than 66 cm, the vegetative cover must be equal to the success standard for the last 2 years of the responsibility period.
6. The ground cover, productivity, or tree stocking of the revegetated area shall be considered equal to the success standard approved by the regulatory authority when the parameters are fully equivalent with 90 percent statistical confidence.

In addition to these Federal requirements, individual states will be developing their own regulations defining revegetation performance standards as they are granted primacy by OSM.

Also to be followed are the already existing state and Federal guidelines and regulations related to the land application of sludge (U.S. Environmental Protection Agency, 1977, and Pennsylvania Department of Environmental Resources, 1977). Most of these guidelines limit sludge application rates based on nitrogen and other plant nutrient requirements of the vegetation as well as trace metal loadings.

Bastian et al. (1982) have reported that more than 4.2 million dry tons of treated and processed sludge are produced annually. About 42 percent is applied to the land as a soil amendment or fertilizer, and the remainder is incinerated (27%), landfilled (15%), stored in lagoons (12%), or diposed of in the ocean (4%) (Feliciano, 1982).

Considerable research has been conducted during the past decade showing that stabilized municipal sludge from secondary wastewater treatment plants is an excellent soil amendent and fertilizer. But even though a sound technical base exists to support the use of sludge for land reclamation, the public has been reluctant to accept the concept.

To bridge this gap between available technical information and public understanding, a cooperative project was initiated in 1977 to establish several 4-ha plots in the anthracite and bituminous coal mining regions of Pennsylvania and to demonstrate that sludge can be used for revegetating mined land in an environmentally acceptable manner.

The present study continues the 1977 project. The initial grant from the U.S. Environmental Protection Agency (EPA) was used to establish three 4-ha demonstration plots in the anthracite and bituminous coal mining regions of Pennsylvania. The three stites were representative of abandoned, barren bituminous and anthracite mines. All were treated with various types of municipal sludges at various 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 (1) the chemical and bacteriological quality of groundwater and soil percolate water, (2) the chemical properties of the soil, and (3) the quality and growth of the vegetative cover. Data collected during the first 3-year period were reported in the final report of the initial grant. These results, as well as detailed information on each demonstration site, are available in the complete report (NTIS Order No. PB 82-102484) entitled "Revegetating Strip-Mined Land with Municipal Sewage Sludge" (Sopper and Kerr, 1980, 1981).

The purpose of the present project was to continue to collect samples from the existing monitoring system at each demonstration site. The broad objectives were threefold: (1) to demonstrate that municipal sludge could be used in an environmentally acceptable manner to revegetate lands disturbed by mining activities, (2) to reduce erosion and stream siltation, and (3) to reclaim land damaged by mining activities so that it could be returned to agricultural uses.

The Pennsylvania Department of Environmental Resources (PDER) currently requires monitoring for 2 years after land application of sludge. The revegetation regulations developed by the Federal Office of Surface Mining Reclamation and Enforcement require a 5-year period of responsibility for vegetation establishment and regeneration in areas with more than 66 cm of precipitation. The first demonstration plot in Venango County was established in May 1977. This project monitored the plot through five growing seasons (1977-1981). The other two demonstration plots in Westmoreland and Lackawanna Counties were monitored for 2 and 4 years, respectively.

Venango County

This site represented bituminous strip mine banks that were backfilled and recontoured after mining without top soil replacement. Several unsuccessful attempts had been made earlier to revegetate the area using lime, commercial fertilizer, and seed. 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 7.0.

Sludge for the project was obtained from three local waste treatment plants. Liquid digested sludge from the cities of Farrell and Oil City was transported to the site in tank trucks. Dewatered sludge came 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. Liquid digested sludge was applied with a vacuum tank liquid manure spreader at 7 mt/ha (103 m^3/ha) and at 11 mt/ha (155 m^3/ha). Dewatered sludge was applied at 90 and 184 mt/ha.

Procedures

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 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 levels of trace metals delivered even at the highest sludge application rate were well below the recommended Federal and state lifetime limits, except for copper, which slightly exceeded the Pennsylvania guidelines (Table 1).

The nutrients supplied at each of the sludge application rates are listed in Table 2. Potassium is the only nutrient deficient at all sludge application rates. 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 about 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 released with each subsequent year. After the first 3 to 5 years, the natural process of nutrient recycling should be well established for sustaining the vegetation.

Results

All sludge-treated areas had a complete vegetative cover within 3 months after application. Vegetation height and dry matter production were measured at the end of each growing season during the period 1977-81. Both measurements tended to increase over the first 4 years and then stabilize. Dry matter production includes all above-ground organic matter (green crop and organic litter accumulation). No crops were harvested over the 5-year period.

During the first 2 years, the two grass species were the dominant vegetation type on all sludge-treated plots. By the third growing season (1979), the two legume species were well developed and had become the predominant vegetative cover (Figure 1).

Table 1. Comparison of State and Federal Recommendations with Venango County Trace Metal Loadings at the Highest Application Rates of Liquid and Dewatered Sludge

Constituent	Trace Metal Loadings (kg/ha) at Two Sludge Application Rates: 11 mt/ha	184 mt/ha	Recommended Maximum Loadings (kg/ha): EPA* (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‡	112
Hg	0.01	0.09	NR‡	0.6

* Average CEC of site ranged from 11.6 to 15.2 meq/100 g.
† Pennsylvania Department of Environmental Resources Interim Guidelines.
‡ No recommendations given by EPA.

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

Sludge Application Rate (mt/ha)	Fertilizer Equivalent (Fertilizer Formula)*: Amount (kg/ha)	N kg/ha	N %	P_2O_5 kg/ha	P_2O_5 %	K_2O kg/ha	K_2O %
184	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)

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

Figure 1. *Venango County site 5 years after sludge application. Note that the two legume species have replaced the grass species as the predominant permanent cover.*

Samples of the individual grass and legume species were collected at the end of each growing season for foliar analyses. Results for tall fescue grown at the highest sludge application rate and with no sludge (the control plot) appear in Table 3. Many trace metal concentrations were higher in the tall fescue growing on the control portion of the site. This result was probably due to spoil pH at the 0- to 15-cm depth, which averaged 3.8 on the control area and ranged from 5.7 to 7.8 on the sludge-treated areas. Foliar trace metal concentrations generally decreased over the 5-year period, and overall, they were well below the suggested plant tolerance levels. No phytotoxicity symptoms were observed.

Spoil samples were collected annually to evaluate the effects of the lime and sludge on spoil pH. After 4 months, spoil pH (at the 0- to 15-cm depth) increased from an average of 3.8 and 6.9. Spoil pH remained at a high level and still averaged 7.0 (6.1 to 8.0) on the sludge-treated plots at the end of 5 years.

Spoil samples were also analyzed for trace metals. Extractable trace metal concentrations at the 0- to 15-cm depth generally increased over the 5-year period. However, the increases were minimal, and all fall within the normal range for soils in the United States.

Groundwater samples were collected monthly from monitoring wells to evaluate the effects of the sludge application on water quality (Table 4). Well No. 2 is within the zone of influence of the sludge treatments. The water table fluctuated between 2.6 and 3.4 m. Results indicate that the highest sludge application (184 mt/ha) did not significantly increase the concentrations of NO_3-N in groundwater, which were well below the EPA maximum limits for potable water for all months sampled during the 5-year period. In addition, the sludge treatments caused no significant increases in any trace metal concentrations in groundwater. Concentrations of Cu, Zn, Co, Cd, and Ni were within the EPA drinking water standards. Only Pb and Cr periodically exceeded the limits for potable water on both control and sludge-treated areas. No fecal coliform samples were observed in any samples over the 5-year period.

Westmoreland County

This site was also an abandoned bituminous spoil bank and was selected to test a fall application of sludge (all other demonstration sites received early summer sludge application). This demonstration would evaluate a fall seeding to establish a vegetative cover and the efficiency of the cover for controlling the environmental effects of the sludge application. The site had been recontoured without topsoil replacement and had been abandoned for approximately 10 years.

Procedures

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 is approximately 0.6 percent for the composted sludge and 2.0 percent for the centrifuged sludge cake).

Results of the compost/cake mix analyses were used to calculate the amounts of selected nutrients and trace metals applied. 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. The 134 mt/ha application rate would thus supply nutrients at a rate equal to that of a 10-18-1 commercial fertilizer applied at 10 mt/ha. The value of substituting sludge for commercial fertilizer is clear.

At the 134-mt/ha rate, the EPA and PDER recommended limits were essentially met. The trace metal loadings were well below the limits recommended by EPA, and except for zinc, they meet all PDER guidelines.

Surface soil samples were collected before treatment 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/ha of agricultural lime was therefore applied to adjust the soil pH to 7.0.

Table 3. *Trace Metals in Tall Fescue Samples Collected from the Control and Highest-Sludge-Application Plots at the Venango County Demonstration Project*

Sludge Application (mt/ha)	Year	Mean Foliar Concentrations (µg/g)						
		Cu	Zn	Cr	Pb	Co	Ni	Cd
0	1977	10.2	23.2	0.9	10.9	1.5	3.1	0.52
	1978	5.7	24.9	0.7	8.8	1.8	4.8	0.27
	1979	3.3	9.4	11.2	1.8	0.6	18.3	0.06
	1980	3.5	17.2	0.7	7.6	1.6	4.6	0.32
	1981	6.6	10.0	<0.1	3.2	<0.1	<0.1	0.27
184-Lime	1977	9.4	48.4	0.8	4.5	1.5	9.8	0.20
	1978	8.6	44.4	0.8	4.5	1.6	3.7	0.41
	1979	9.2	72.5	0.5	1.8	0.6	2.5	0.08
	1980	3.5	41.9	1.1	3.8	1.8	7.3	0.73
	1981	12.7	34.8	<0.1	1.9	1.0	0.7	0.50
Suggested Tolerance Levels		150	300	2	10	5	50	3

Table 4. *Groundwater Analyses for Selected Trace Metals and Nitrate-Nitrogen Following Maximum Sludge Application* at the Venango County Demonstration Site*

Well No.	Year †	Concentration (mg/L)			
		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
	1980	0.05	0.89	0.001	0.6
	1981	0.06	0.83	0.003	0.7
•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
	1980	0.04	1.05	0.001	0.6
	1981	0.05	0.57	0.001	0.6
EPA drinking water standards		1.00	5.00	0.010	10.0

* 184 mt/ha.
† Values represent the mean of all samples collected from each well for the year.

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 afterward, the area was chisel-plowed to incorporate the sludge into the surface 10 cm of spoil material.

After the sludge was incorporated, 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 approximately 6 to 8 weeks for vegetation to grow and become winter hardy. The following spring, the remaining portion of the seeding mixture was broadcast. The spring seeding mixture was orchardgrass (11 kg/ha) and birdsfoot trefoil (6 kg/ha).

Results

A site inspection on November 29, 1979 (approximately 8 weeks after sludge application and seeding) indicated that a protective cover of winter rye had been established. Vegetation was approximately 5 cm high. No evidence existed of any erosion on the sludge-treated area, and sufficient vegetation appeared to be established to protect the site from erosion and runoff over the winter season. This conclusion was confirmed by a site inspection on March 28, 1980. The entire sludge-treated area was covered by vegetation ranging from 5 to 10 cm high. Based on simple visual estimates, the cover extended over 80 to 90 percent of the area. No surface runoff or erosion was evident from the sludge-treated area, but some erosion did occur from barren areas upslope of the sludge-treated area. The sediment-laden surface runoff from these areas was dispersed as soon as it encountered the sludge-treated plot, which had been roughened by contour chisel plowing to incorporate the sludge.

By June 1980, the winter rye seed stalks were well over 1.5 m tall (Figure 2), and the entire sludge-treated area had developed a 100-percent vegetative cover. The rye was not harvested; rather the straw was allowed to collapse to provide an additional protective organic mulch on the site until the birdsfoot trefoil was well established. By September 1981 (2 years after sludge application), the entire site was predominantly occupied by a cover of birdsfoot trefoil.

Vegetative growth responses were evaluated each year. Average vegetation heights were 68 and 64 cm, an average dry matter production was 11 and 31 mt/ha in 1980 and 1981, respectively.

Figure 2. General view of the winter rye vegetative cover the spring after a fall application of sludge on the Westmoreland County demonstration plot.

Results of the analyses for soils, vegetation, soil percolate, and groundwater samples were similar to those reported for the Venango County demonstration project. The fall sludge application caused no significant adverse environmental effects and facilitated the establishment of a complete vegetative cover.

Lackawanna County

The Scranton, Pennsylvania, site consisted of a 24-ha anthracite refuse bank devoid of vegetation. The site was severely eroded and a constant eyesore. In April 1978, a 4-ha area was recontoured for the demonstration plot.

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. Thus 11 mt/ha of lime was applied to the area.

Dewatered, vacuum-filtered sludge was obtained from the Scranton wastewater treatment plant. The sludge was first applied with manure spreaders at rates of 80 and 108 mt/ha and then incorporated. The area was broadcast-seeded with the same mixture of grasses and legumes as in the Venango County demonstration, and a hay and straw mulch was applied at the rate of 3.4 mt/ha.

The amounts of trace metals applied by the two sludge application rates are given in Table 5 along with the EPA and PDER guidelines. Both rates yielded trace metal loadings well below all recommendations. The highest sludge application rate provided 1,691 kg nitrogen/ha, 456 kg phosphorus/ha, and 141 kg potassium/ha.

Table 5. Comparison of State and Federal Recommendations with Trace Metal Loadings (kg/ha) on the Unburned Anthracite Refuse Site in Lackawanna County

Constituent	Trace Metal Loadings (kg/ha) at Two Sludge Application Rates: 80 mt/ha	108 mt/ha	Recommended Maximum Loadings (kg/ha): EPA (CEC 5-15)*	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†	112
Hg	0.1	0.2	NR†	0.6

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

By August 1978 (2 months after the sludge application), a complete ground cover was established. No significant difference existed 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 3.6 mt/ha. Average height was almost double the second year, but it stabilized at 37 cm after 4 years (1981). Average dry matter production increased to 18.7 mt/ha during the first 3 years and then stabilized at 16 mt/ha in the fourth year (1981). Analyses of foliar and soil samples yielded similar results to those reported for the Venango County demonstration project. Sludge applications had no significant effects on the chemical or bacteriological quality of soil percolate water or groundwater.

Production and Quality of Forage Vegetation

The results of this project were combined with those of several other projects to evaluate the effects of sludge applications to mined land on the production and quality of forage. Sludge application rates ranged from 11 to 202 mt/ha, and the vegetation was analyzed over periods of 2 to 5 years. Vegetation species evaluated were orchardgrass, K-31 tall fescue, and birdsfoot trefoil.

Dry matter production (expressed as hay yield in mt/ha) was consistently higher on the sludge-amended strip mine sites than on undisturbed farmland in the same counties, even for as many as 5 years after sludge application. Crude protein equaled or exceeded the minimum for dairy rations. Concentrations of K, Ca, Mg, Fe and Co (essential in animal diets) were near or above the minimum suggested for total dairy rations. Phosphorus, Cu, and Zn were below these minimum levels but would routinely be subsidized in supplementary feed concentrates. Concentrations of trace metals not required in animal diets (Pb, Ni, Cd, and Al) were always below suggested food-chain tolerance levels. Concentrations of the essential plant nutrients N, P, and K were always higher in sludge-grown plants than in control plants that received conventional lime and fertilizer applications.

Conclusions

These demonstration projects indicate that single applications of stabilized municipal sludges applied at the proper rate can facilitate revegetation of mined land and maintain it for a minimum of 5 years 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. Springtime applications of various types of sludges (liquid digested, dewatered, and composted) at rates ranging from 7 to 184 mt/ha facilitated the establishment of a complete vegetative cover of grasses and legumes within 2 months.
2. Application of a mixture of dewatered sludge cake and composted sludge in the fall at 134 mt/ha produced an adequate vegetative cover to stabilize the site over winter and facilitated the development of a complete vegetative cover the following summer.
3. Vegetation growth responses (height increases and dry matter production) generally increased for several years after sludge applications and then stabilized. All vegetative covers have persisted for periods up to 5 years without any signs of deterioration in vegetation yield or quality.
4. Trace metal concentrations in foliage were generally below suggested food-chain tolerance levels, and no phytotoxicity or nutrient deficiency symptoms were observed on any sludge-amended site.
5. Sludge applications produced slight increases in trace metal concentrations in the 0- to 15-cm soil depth. These increases were minimal and generally within the normal range for soils in the United States (soils that have not been amended with sludge).
6. Sludge applications and liming generally increased soil pH significantly. These increased pH levels were maintained for as long as 5 years.
7. Sludge applications did not produce any significant increases in the concentrations of NO_3-N or trace metals in the groundwater.
8. Sludge applications did not affect the bacteriological quality of groundwater. No groundwater sample collected during the 5-year period contained fecal coliform colonies that could be attributed to the sludge application.

These findings should be useful throughout the Appalachian coal mining region. Demonstration projects such as those described in this report can be used effectively to educate the public and gain public acceptance and support for the concept of using sludge to revegetate land disturbed by mining activities.

The full report was submitted in fulfillment of Cooperative Agreement No. CR 807408 by the Pennsylvania State University for the Pennsylvania Department of Environmental Resources under the sponsorship of the U.S. Environmental Protection Agency.

William E. Sopper and Eileen M. Seaker are with Pennsylvania State University, University Park, PA 16802.
***G. K. Dotson** is the EPA Project Officer (see below).*
The complete report, entitled "Strip Mine Reclamation with Municipal Sludge," (Order No. PB 84-152 842; Cost: $17.50, subject to change) will be available only from:
National Technical Information Service
5285 Port Royal Road
Springfield, VA 22161
Telephone: 703-487-4650
The EPA Project Officer can be contacted at:
Municipal Environmental Research Laboratory
U.S. Environmental Protection Agency
Cincinnati, OH 45268

United States
Environmental Protection
Agency

Center for Environmental Research
Information
Cincinnati OH 45268

US OFFICIAL MAIL
CINCINNATI APR 18'84 OHIO
U.S.POSTAGE
.29

Official Business
Penalty for Private Use $300

PS 0000329
U S ENVIR PROTECTION AGENCY
REGION 5 LIBRARY
230 S DEARBORN STREET
CHICAGO IL 60604

☆ U.S. GOVERNMENT PRINTING OFFICE: 1984-759-102/0888