Sewage sludge land application program in West Virginia

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ABSTRACT: Municipal sewage sludge can be used as a fertilizer for crops but may also introduce undesirable metals into the food chain, especially when used on acid minesoils. In this study, sewage sludge from Morgantown, WV was surface applied to two acid minesoils and a neutral undisturbed soil to evaluate sludge application rates on forage production, nutrient loadings, and on heavy metal accumulation in soils and vegetation. On a reclaimed surface mine at Westover, 0, 15, 31, and 64 dry Mg ha' of sewage sludge were applied in March 1986 and monitored annually through 1989. These rates of sludge were three to 12 times greater than recommended N rates for pasture on this site. Grass biomass increased and legume biomass decreased with increased sludge application. Weed biomass was increased only during 1986. Minesoil pH was not significantly affected while soil organic carbon four years after treatment increased from 15 to 22 g kg['] with sludge. Minesoil DTPA-extractable Cu, Zn, and heavy metal concentrations also increased with sludge application. Sludge was also applied at up to 27.6 Mg ha' at Dellslow (reclaimed surface mine) and Pentress (undisturbed). Vegetative production was 1.5 to 2.8 times greater on sludge-treated versus control plots during 1989 and 1990 at both sites, but soil pH was unaffected by sludge treatment. No significant differences were found for DTPA-extractable Cu, Pb, and Zn in the upper 15 cm (6 in) of soil. Forage tissue analyses revealed greater crude protein, but no differences in Cu, Pb, and Zn concentrations in treated compared to control plants. Guidelines for land application of sludge in West Virginia have been refined accordingly, and from 1988 to 1990, land applied sludge doubled from 4,150 to 8,520 Mg (4,570 to 9,430 tons).

M UNICIPALITIES in the U.S. currently generate more than 7.6 million dry Mg (8.4 million tons) of wastewater sludge per year, or about 32 kg (70.5 lbs) per person per year (*36*). About one-half of the sludge is land applied. Cities in West Virginia annually generate 24,000 dry Mg (26,448 tons) of

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sludge with 35 percent being land applied. The remaining sludge in the state is landfilled, 24 percent; incinerated, 25 percent; or composted and marketed, 15 percent, according to public records from the West Virginia Department of Natural Resources.

Sludge application on land improves the nutrient status, organic matter content, and water-holding capacity of the soil (10, 22, 28). Much research has been conducted on application of sewage sludge to agricultural lands, and guidelines for correct application procedures are available (2, 4, 5, 13, 19, 34, 35).

Many studies have also been conducted on application of sewage sludge to disturbed lands to aid reclamation (6, 11, 29, 31, 32, 33), and guidelines for application have been written for the Northeastern U.S. (30). Loomis and Hood (16) suggest that sewage sludge may decrease the rate of pyrite oxidation and reduce the formation of acidity in minesoils. Stabilized municipal sludges have also been used to establish vegetation on mined lands (24, 26) and on coal refuse piles (11, 22).

The benefits of amending soils and minesoils with sewage sludge are well-

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known; however, land application presents some potential hazards. Heavy metals in sludge are normally complexed in the organic fraction of soils and minor amounts are adsorbed to cation exchange sites and may be slowly available for plant uptake (7, 14, 17, 18, 20, 23, 37). Application of sludge to acid-producing materials or acidic minesoils is a significant potential problem if heavy metals in the sludge are solubilized and move into ground and surface water supplies (9).

Large areas of surface mined and reclaimed land in the Appalachian coal region have acidic minesoils that retard revegetation and the development of a productive postmining land use. Many native soils in West Virginia are also acidic and are in need of amelioration with organic materials, lime, and fertilizer for improved forage production.

These studies were conducted to examine various rates of municipal sewage sludge application to two acid minesoils and one undisturbed soil in Northern West Virginia. Vegetation production, soil chemical properties, and forage tissue contents were used to evaluate effects of sludge application to these different soils. The research results were then used to develop technial standards and to refine guidelines for sludge application to lands in West Virginia. Amounts of sludge generated by WWTPs and methods of sludge disposal were also examined.

Materials and methods

Westover site. The Westover site was located 15 km (9 mi) southwest of Morgantown, WV. Surface mining of the Waynesburg seam of coal (Upper Pennsvlvania Period) had been ongoing in this area since the early 1970s, and the site where this study was established was mined in 1976. Overburden associated with the Waynesburg seam is comprised of almost 75 to 80 percent sandstone, with small amounts of siltstone, red and gray shales, and limestone (3). The haul-back method of contour mining was employed using bulldozers, front-end loaders, and trucks. Reclamation involved backfilling, topsoiling, liming (4.5 Mg ha⁻¹), fertilizing (672 kg ha⁻¹ of 10-20-20), and seeding for pasture and hay. The plant species seeded

were red clover (*Trifolium pratense L.*), tall fescue (*Festuca arundinacea Schreb.*), orchardgrass (*Dactylis glomerata L.*), and birdsfoot trefoil (*Lotus corniculatus L.*). The minesoil was classified as a loamy-skeletal, mixed, acid, mesic Typic Udorthent with a loam surface texture of the less than 2 mm (.08 in) fraction. Bulk density of the < 2 mm fraction ranged from 1.2 to 1.5 Mg m⁻³ and the minesoil had a waterholding capacity of .08 to .10 kg water per kg soil and cation exchange capacity of 10 cmol kg⁻¹(1).

Dellslow and Pentress sites. The Dellslow site was located 13 km (8 mi) southeast of Morgantown, WV. The Upper Freeport Coal was surface-mined at this site in 1985. Overburden associated with this seam was comprised of 80 percent sandstone with the remainder being gray shales (3). Haul-back mining was employed, and 5 to 10 cm (2 to 4 in) of topsoil were replaced after backfilling. Plant species used in revegetation were orchardgrass, tall fescue, and clovers. Minesoils on the site also were classified as loamy-skeletal, mixed, acid, mesic Typic Udorthents,

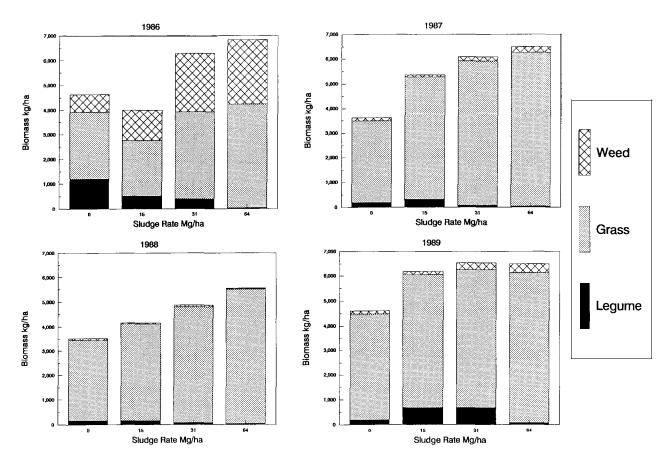


Figure 1. Grass, legume, and weed biomass from sludge-treated plots at Westover (minesoil) in September 1986 to 1989. Biomass values represented by bars for each vegetation type for each year with the same letter are not significantly different at the P<0.05 level.

The minesoil was somewhat compacted with a surface bulk density of 1.45 Mg m⁻³ and also had .10 kg water per kg soil water-holding capacity and 10 cmol kg⁻¹ cation exchange capacity.

The undisturbed Pentress site was located 21 km (13 mi) west of Morgantown, WV, on a farm primarily producing forages. The plant species growing on the site were fescue, orchardgrass, clovers, and miscellaneous weeds. The soil was classified as Monongahela silt loam (fine-loamy, mixed, mesic Typic Fragiudults) with .15 to .21 kg water per kg of soil waterholding capacity and 18 cmol kg⁻¹ cation exchange capacity. Soil pH was 5.8.

Sludge application. The Morgantown wastewater treatment plant uses an anaerobic, secondary sewage treatment process utilizing rotating biological contractors. The flood of November 1985 in West Virginia incapacitated the plant and necessitated the cleanout of the digestor tanks. The accumulated sludge was pumped from the digesters into tank trucks, mixed with lime, and hauled to the Westover site. Physical and chemical properties of the sludge before lime was added are shown in Table 1. The sludge application rate on the Westover site was calculated by using the following equation:

Mg ha⁻¹= Target N fertilizer rate (kg ha⁻¹) / Organic N in sludge (g kg⁻¹) x 20% available

The organic N content was 21 g kg⁻¹ (20 percent availability during the first year) and the target N fertilizer rate was 269 kg ha⁻¹ (240 lb ac⁻¹), the recommended N rate for corn (Table 1). The majority of inorganic N was assumed to be volatilized due to the addition of lime. The calculated rate equaled 64 Mg of dry sludge per ha. Two intermediate rates (15 and 31 dry Mg h⁻¹) were also chosen to make a comparison between control plots and those which received the high rate.

A nearly level 0.5 ha (1.2 ac) area was chosen on the Westover reclaimed and vegetated site and divided into twelve plots measuring 7.6 m wide by 30.4 m long (25 x 100 ft). One of the four sludge application rates (0, 15, 31, and 64 Mg ha⁻¹) with three replications per treatment was randomly assigned to each of the twelve plots. The sludge was surface-applied by a Terragator vehicle equipped with a splash plate in March 1986 and was not incorporated into the soil. The minesoil had a relatively porous surface allowing much of the 15 percent solid sludge to infiltrate the minesoil.

Morgantown wastewater sludge was also applied to the Dellslow and Pentress sites in 1989. However, the composition and solids content of the sludge were different than that used at Westover in 1986 (Table 1). Sludge application rates were based on the following equation which is a more conservative method of calculating N fertilizer rates from sewage sludge.

The calculation was based on 100 percent availability of the inorganic N content (5 g kg⁻¹), and 23 percent availability of the organic N content (25 g kg⁻¹), and the target N fertilizer rate was 148 kg ha⁻¹ (Table 1). The sludge rate was calculated to be 13.8 Mg ha⁻¹. The other rates used in these studies were either half or double the recommended rates.

Three 0.5 ha (1.2 ac) areas on the Dellslow site and four 0.5 ha areas on the Pentress site were selected for this part of the study, and sludge with 27 percent solids was applied with a commercial manure spreader.

Sampling Methods and analysis. In each experimental plot on all sites, five randomly placed quadrats measuring 50 cm by 50 cm (20 in x 20 in) were used for vegetation and soil sampling. Plant species in the quadrat were identified and their cover estimated. The above ground biomass in each quadrat was clipped at ground level; separated into grass, legume, and weed components; and placed in paper bags. The plant material was dried at 60° C (140°F) for 48 hours and weighed, and the weights converted to kg ha⁻¹.

Soil samples were taken to a depth of 15 cm in the center of each quadrat after clipping and composited into one sample for each plot. Our primary interest was to monitor the accumulation of metals in the root zone of the soils. Samples were analyzed for pH using a 1:1 soil:water suspension and organic carbon (OC) by the Walkley-Black Procedure (27). Potassium and calcium were extracted by 1M NH₄OAC (pH 7) and analyzed by atomic absorption spectrophotometry (AAS) (27). Iron, Cu, Pb, Zn, and Cd were extracted with diethylenetriaminepentaacetic acid (DTPA) and analyzed by AAS (15). Forage tissue was analyzed for crude protein by Kjeldahl N and multiplied by

Table 1. Some physical and chemical properties of the Morgantown, WV municipal wastewater sludge* applied in 1986 to Westover and 1989 to Dellslow/Pentress.

Property	Westover	Dellslow/Pentress		
	g kg ⁻¹ Dry Weight			
Solids	150	272		
Organic N	21	25		
NH₄-N	11	5		
Total N	32	30		
Р	16	15		
K	5	7		
Ca	26	34		
Mg	1	4		
	mg	mg kg ⁻¹ Dry weight		
Cd	9	12		
Cr	308	132		
Cu	349	550		
Ni	48	229		
Pb	58	333		
Zn	799	927		

* Analyzed by Ohio Agricultural Research and Development Center, Research-Extension Laboratory, Wooster, OH.

6.25 (8). Minerals in forage (Cu, Fe, and Zn) were determined by AAS after extraction with 3N HCl (8). Vegetation and minesoil samples were collected in September of 1986, 1987, 1988, and 1989 at Westover, and October of 1989 and 1990 at Dellslow and Pentress. Forage tissue analysis was not performed at Westover due to insufficient funding.

Vegetation production, tissue analysis, and soil data were analyzed by ANOVA to determine treatment differences within years for each site and were considered significant at the 0.05 level of probability. Treatment means found significantly different were separated by Duncan's multiple comparison test.

Results and discussion

Westover Site. Surface application of sewage sludge initially smothered the vegetation for several months. However by the end of the 1986 growing season, the vegetation had recovered and significant differences among sludge rates were found for aboveground biomass of grasses, legumes, and weeds (Figure 1). Legume biomass was generally decreased with higher sludge rates during the first three years of the study because increased nutrient levels in the minesoil caused increased grass growth and competition. Weed biomass increased with sludge in 1986, but was reduced to control levels after the first growing season. Weeds are common components of the vegetation after sludge application on both native and disturbed soils in West Virginia. Grass biomass increased with increasing

sludge rate across all years.

Soil analyses revealed that minesoil pH was not significantly different with sludge application (Table 2) although a trend of increasing pH with greater sludge application seemed evident. Pietz et al. (21) added 542 dry Mg ha⁻¹ of sewage sludge (pH 7.2) to acidic coal refuse and found an initial increase in pH, but a decline in pH to back-ground levels within three years. OC

content of our treated minesoils was significantly higher than OC in control plots. Most studies report an increase in OC content in soils immediately after treatment with an organic waste material (12).

Potassium and Ca showed no significant change with sludge application (data not shown). Iron, an element typically found at elevated concentrations in acid minesoils, showed only slight

Table 2. Soil characteristics at 0 to 15 cm depth in a sludge-amended, acid minesoil (Westover) in West Virginia from 1986-1989.

		Characteristic				
Rate	pН	0.C.	Fe	Cu	Pb	Zn
Mg ha ⁻¹		g kg 1		mg kg⁻¹		
		<u> </u>	September 1986			
0	5.0†*	1 0.0‡	54‡	1.1§	4.6†	1.6§
15	5.3†	12.7†	59†§	2.4§	4.4†	4.8‡
31	5.1†	12.7†	63†‡	2.4‡	5.1†	5.4‡
64	5.0†	11 .7†	70†	3.6†	5.6†	8.5†
		ç	September 1987			
0	4.8†	10.0‡	63‡	1.5§	4.3‡	1.3‡
15	5.1†	14.6 † ‡	74†‡	4.4 [±]	5.0†±	2.4‡
31	5.3†	16.0†	78†‡	4.4±	6.9†‡	4.2†
64	5.1†	15.5†	89†	5.3†	7.7†	5.7†
		S	September 1988			
0	5.4†	12.7‡	45†	0.9‡	6.4†	1.9‡
15	5.7†	15.2†‡	53†	3.1†‡	7.2†	4.3†‡
31	5.6†	19.0	55†	5.3†‡	8.9†	6.1†
64	5.9†	19.3†	52†	7.0†	8.7†	6.1†
		5	September 1989			
0	5.4†	14.6‡	41†	1.8§	7.9†	2.0‡
15	5.9†	21.4†	44†	5.5 ‡	7.7†	7.4†
31	5.9†	22.1†	37†	7.5†	9.1†	9.1†
64	6.3†	22.4†	35†	8.0†	8.6†	10.2†

* Values within columns for each year with the same symbol (\uparrow,\downarrow,\S) are not significantly different at p < 0.05.

Table 3. Soil characteristics at 0 to 15 cm depth in sludge-amended, minesoils (Dellslow) and native soils (Pentress) in West Virginia in 1989 and 1990.

	Characteristic					
Soil Type/Rate	pН	Fe	Cu	Zn	Cd	
Mg ha⁻¹.	mg kg ⁻¹					
	October 1989					
Minesoil						
0	5.8†*	33†	1.1†	0.8†	0.3†	
6.9	5.3†	33†	1.3†	1.0†	0.2†	
13.8	5.7†	42†	1.3†	1.0†	0.2†	
Native Soil						
0	6.0†	50†	1.0†	0.4†	0.4†	
6.9	5.8†	42†	0.8†	0.5†	0.1‡	
13.8	5.6†	33†	1.2†	0.5†	0.2‡	
27.6	5.6†	33†	1.0†	0.7†	0.1‡	
		October 1990				
Minesoil			000000 1000			
0	5.5†	32†	1.2†	1.2†	0.1†	
6.9	6.1†	28†	1.1†	0.9†	0.1†	
13.8	5.7†	29†	1.5†	1.4†	0.1†	
Native Soil						
0	5.8†	29†	0.9†‡	0.7†	0.1†	
6.9	5.9†	28†	0.7‡	0.5†	0.1†	
13.8	5.8†	34†	1.0†‡	0.5†	0.1 †	
27.6	5.9†	32†	1.4†	0.8†	0.2†	

* Values within columns for each year and for each soil type with the same symbol (\uparrow,\downarrow) are not significantly different at p < 0.05.

changes with sludge application (Table 2). Copper and Zn were significantly higher in treated versus control plots throughout the four years, while Pb was significantly higher only at the high rate during 1987.

The results of this four-year study clearly showed that sludge applied at 15 Mg ha⁻¹ or greater increased forage production and the DTPA-extractable Cu and Zn contents in the minesoil. OC content was also increased by sludge treatment. Minesoil pH, Fe, and Pb contents were not significantly different with sludge addition.

Dellslow and Pentress Sites. Forage production was higher with sludge treatment during 1989 and 1990 on both sites. In 1989, yields were increased by at least 1.5 times over control plots (Figure 2). Production was a little higher in 1990 because of greater precipitation during the 1990 growing season. Yields in 1990 were increased from two to three times with sludge treatment.

Soil pH was unaffected by sludge treatment on these sites (Table 3). At these low rates, soil Cu and Zn concentrations, metals whose concentrations increased with sludge treatment at Westover, were not significantly greater than those found in control plots (Table 3). The only exception was for Cu on the Pentress site in 1990. Iron and Cd were also not elevated in soils of sludge-treated plots.

Forage analysis confirmed the results of the soils analysis. Crude protein in plant tissues was higher at Pentress during both years due to increased N availability for plants at 14 and 28 Mg ha⁻¹ of sludge (Table 4). However, all other elements and metals did not follow specific trends and were not found at greater concentrations in treated plots. In fact, vegetation from control plots had the highest concentrations of these metals in some instances. From the results of these two studies, application of sludge at rates equivalent to the N requirement for a grass-legume pasture (approximately 150 kg ha⁻¹) showed no increase of metals in the soil or vegetation.

West Virginia sludge demonstration program. Initial work on land application of sludges began in 1975 with the West Virginia Department of Natural Resources (WVDNR) and the West Virginia University Cooperative Extension Service (WVU CES). At the time, many WWTPs were being upgraded to secondary and some to tertiary treatment

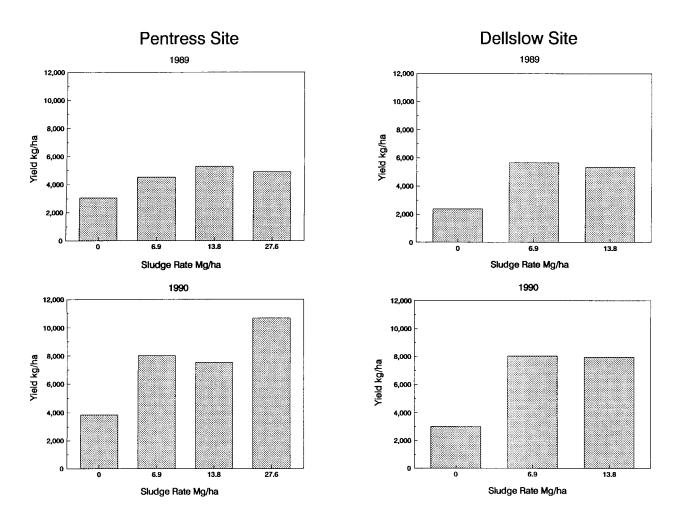


Figure 2. Total biomass from sludge-treated plots at Pentress (undisturbed soil) and Dellslow (minesoil) in October 1989 and 1990. Biomass values represented by bars for each year within a site with the same letter are not significantly different at the p<0.05 level.

resulting in greater amounts of solid residues or sludges. During the ensuing 10 years as WWTPs produced sludges with lower metal and higher solids concentrations, the agricultural community slowly became aware of the fertilizer and soil conditioning value of organic sludges. The use of pretreatment to reduce metal concentrations in the sludge convinced many farmers that sewage sludge was now a safe product.

Informal procedures for land application of sludges were developed gradually from 1975 to 1985 by cooperating agencies (WVDNR and WVU CES). Basically, sludge application rates were based on N content of the sludge and its ability to supply a required N amount to a crop or forage. Heavy metals such as Cd, Cr, Cu, Ni, Pb, and Zn were monitored so that these metals were not added to the soil in concentrations that would pose an environmental hazard. In 1984, the program gained some momentum and a number of WWTPs in the state began quarterly sampling and analysis of their sludges. The sludge analytical results were compiled and a data base of sludge analyses was developed for participating WWTPs across the state. In 1988, official records were kept and sludge data for all WWTPs in the state were compiled. With the data from soil and sludge analysis, proper application rates were calculated and landowners were more confident in the product that was being spread.

In 1990, WVU CES (38) produced a manual outlining procedures for applying sludges to land based on the sludge's N content and also gave precautions in "loading" the soil with heavy metals. Also in 1990, WVDNR, with technical assistance from WVU CES, published *Interim Technical Regulations for the Land Disposal of Sewage Sludge*. These guidelines used data

from chemical analyses of sludge and soils, site topography, geology, soil physical properties, and human proximity to determine site suitability and sludge loading rates. Data from both regional and in-state research institutions were used as a basis for these regulations.

WVDNR administers the state sludge land application program. WVDNR through the Water Resources Division, requires all WWTP operators to maintain records of the quantity of sludge that leaves the plant, detailed data on the destination of the sludge, and a signed agreement between the WWTP and any landowner accepting sludge for land application. The agreement states that the sludge will be applied to the prescribed field at the recommended rates in an acceptable manner. WVU CES provides technical assistance by assessing site suitability, examining soil properties including nutrient status

determined by soil testing, and assisting in determining sludge application rates based on sludge and soil analysis. Representatives of the county health department, the USDA SCS, and soil conservation districts are also invited to participate in developing sludge management plans.

Sludge application to lands has doubled in West Virginia from 4,150 Mg in 1988 (the earliest year for which complete records were kept) to 8,520 Mg in 1990 (Table 5). Preliminary data for 1992 show that several other plants are improving sludge quality and beginning to land apply.

The program is adding much needed

organic matter to soils and saving fertilizer expenses at the same time. With strict enforcement, this program may allow farmers to economically reclaim their soils to high productivity levels similar to that found in the Appalachian Mountains in the 18th and 19th centuries (25).

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Table 4. Tissue analysis of vegetation in sludge-amended minesoils (Dellslow) and native soils (Pentress) in West Virginia in October 1989 and 1990.

	Characteristic					
	Crude					
Soil Type/Rate	Protein	Fe	Cu	Zn		
<u>Mg ha</u>		mg kg ⁻¹				
	October 1989					
Dellslow						
0	97†*	175†	7†	42†		
6.9	127†	192†	10†	36†		
13.8	106†	226†	10†	30†		
Pentress						
0	106‡	870†	17†‡	47†		
6.9	91 <u>‡</u>	215‡	7‡	26†		
13.8	172†	894†	16†‡	42†		
27.6	192†	570†‡	23†	52†		
	October 1990					
Dellslow						
0	133†	277†	8†	28†		
6.9	157†	191†	10†	42†		
13.8	128†	361†	9†	39†		
Pentress						
0	121‡	972†	6†	38†		
6.9	148†‡	518†‡	7†	27†		
13.8	160†‡	319‡	7 †	30†		
27.6	213†	695†‡	12†	38†		

* Values within columns for each year and for each soil type with the same symbol (\uparrow,\downarrow) are not significantly different at p < 0.05.

Table 5. Summary of land application of sewage sludge in West Virginia.*

	1988	1990
Total wastewater facilities	47	66
Number of facilities which land apply sludge	32	36
Total sludge production (Mg)	11,733	24,197
Sludge land applied (Mg)	4,150	8,520
Percentage land applied	35.3%	35.2%
Sludge landfilled (Mg)	4,180	5,870
Percentage landfilled	35.6%	24.3%
Percentage incinerated or other	29.1%	40.5%

* Many facilities that had been land applying sludge in 1988 were not land applying in 1990 because their previous program was not in compliance with new WVDNR guidelines. During 1981, 17 additonal facilities came into compliance bringing the total facilities land applying sludge to more than 50.

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