Appendix A
Case Studies

This appendix presents four cases studies illustrating land application at agricultural, forest, and reclamation sites. The case studies include:

- Madison Metropolitan Sewerage District (MMSD), Madison, Wisconsin. The MMSD applies approximately 20 dry tons of sewage sludge per day to private farmland. Reprinted from *Document Long-Term Experience of Biosolids Land Application Programs*, Water Environment Research Foundation, 1993.
- Metro Wastewater Reclamation District (MWRD), Denver, Colorado. The MWRD produces 70 dry tons of sewage sludge per day, which are either applied to agricultural land or composted and sold to the public. Reprinted from *Document Long-Term Experience of Biosolids Land Application Programs*, Water Environment Research Foundation, 1993.
- The Municipality of Metropolitan Seattle (Metro), Seattle, Washington. Metro has applied sewage sludge to private forest land, with 19,000 dry tons applied to date. Reprinted from *The Future Direction of Municipal Sludge (Biosolids) Management: Where We Are and Where We're Going*, Proceedings, Volume 1, Water Environment Research Foundation, 1992.
- Venango County, Pennsylvania, Abandoned Mine Land Reclamation. Sewage sludge was applied in a single application at a rate of 184 mg/ha.

These case studies provide valuable insights into design, operation, monitoring, public relations, and other aspects of programs representing a range of sizes and geographical locations. It should be noted that, in some cases, these programs will need to make minor operational changes to achieve compliance with the Part 503 regulation.

MADISON METROPOLITAN SEWERAGE DISTRICT, MADISON, WI

Contact Person: David S. Taylor
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Average flow:	37 mgd
Design capacity of WWTP:	50 mgd
Dry tons of biosolids/day:	20
Type of biosolids:	anaerobically digested
Biosolids management options:	land application
Application method:	injection
Started application:	1974

5.1 Program Overview

Wastewater treatment at the Nine Springs WWTP started in 1933. Until 1942, anaerobically digested biosolids was air dried and applied to farmland as a fertilizer/soil conditioner. Because of the manpower shortage during World War II, the system was abandoned in favor of a lagoon storage system. In 1974, after evaluating several alternatives, the Madison Metropolitan Sewerage District (MMSD) decided to begin land applying the biosolids to private farmland.

Currently all biosolids produced at the Nine Springs Wastewater Treatment Plant (WWTP) are land applied. The design capacity of this activated biosolids treatment plant is 50 mgd. Current flow is around 37 mgd. About 15% of the wastewater comes from industrial sources. The raw sludge is stabilized by anaerobic digestion, and the resulting biosolids are marketed to farmers

through the Metrogro™ Program. Current biosolids production is approximately 20 dry tons per day. The MMSD is also removing biosolids from the lagoons, resulting in a 50 percent increase in the quantity of biosolids land applied.

Biosolids are thickened by gravity belt thickeners to approximately 6% total solids. The thickened solids are transported directly to land application, to off-site storage lagoons, or to storage lagoons located adjacent to the treatment plant. Prior to off-site transport, the thickened or dredged biosolids are pumped to a 100,000 gallon holding basin at the truck loading station. The biosolids dredged from the lagoons have a total solids concentration between 4 and 5 percent. From the holding basin the biosolids are pumped to a 50,000-gallon elevated loading well from which biosolids can be pumped to the transport trucks. After a truck is loaded any spilt biosolids are washed off using the on-site washing facilities that are available at the loading site. The MMSD owns six transport trucks, three mobile storage tanks, and four application vehicles.

Liquid biosolids are transported to the land application site using 5,500-gallon vacuum trucks that are compatible with the weight limits on the local roads. The trucks discharge the biosolids into a 12,000-gallon mobile storage tank located at the application site. A 3,500-gallon application vehicle withdraws biosolids from the storage tank, and injects them 6 to 8 inches beneath the soil surface. Figure 5-1 shows a typical storage tank and application vehicle.

Two trucks normally supply one storage tank and application vehicle. The use of the storage tank has resulted in a 25% increase in productivity. Usually the storage tank stays in one place during the application to minimize the size of the staging area. After the application is complete, the staging area is tilled to counteract the compaction caused by the truck traffic. One application vehicle is capable of spreading biosolids over 8 to 10 acres during a 10-hour operating period. The biosolids injection vehicles have been modified by increasing the number of injection shanks to 6 per vehicle, and by adding a drag behind the injectors to smooth the disturbed soil as shown in Figure 5-2. During the application season the vehicles return to the treatment plant only for major repairs.

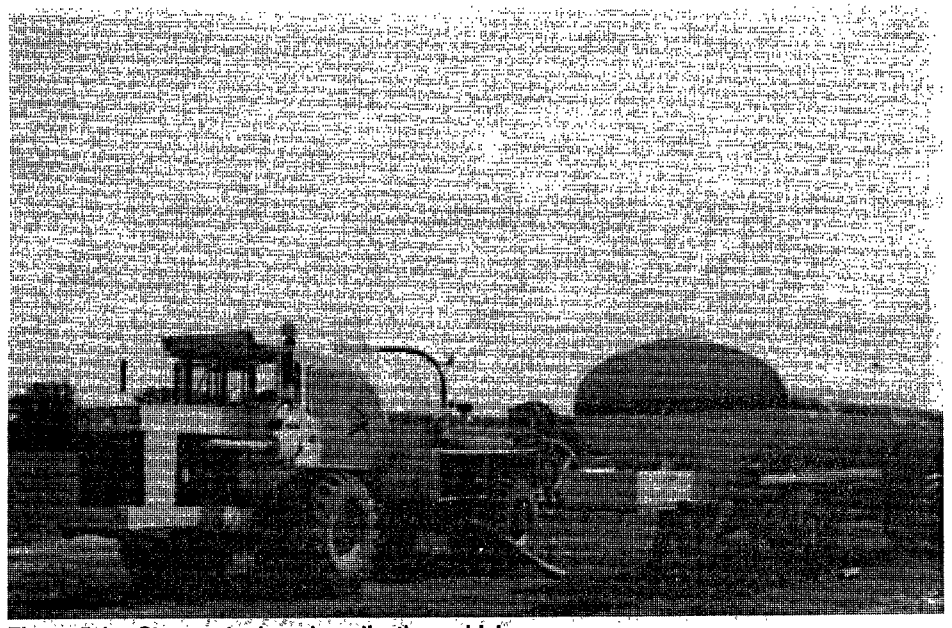

Figure 5-1. Storage tank and application vehicle.

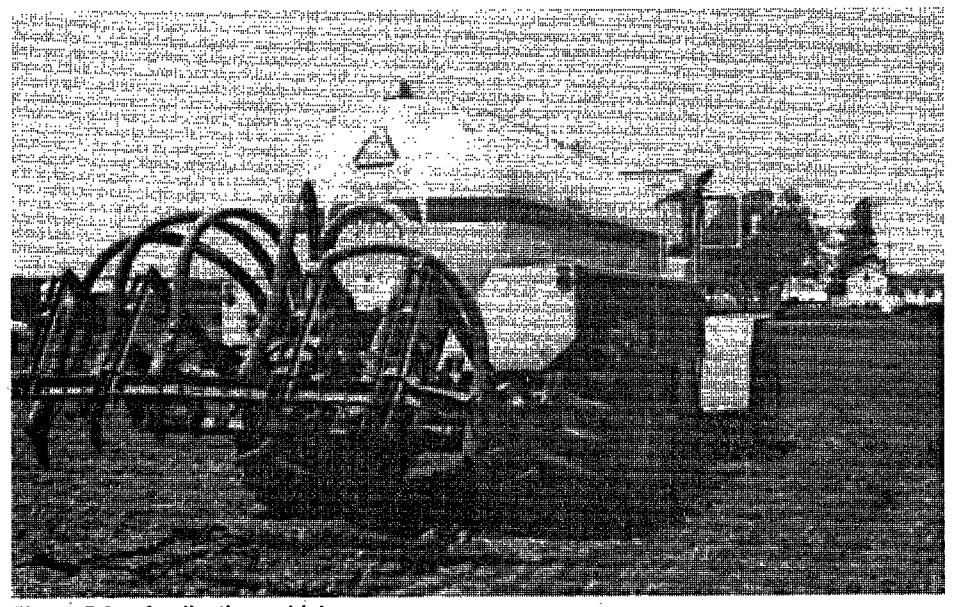

Figure 5-2. Application vehicle.

The MMSD has permits for 250 to 300 farms to apply biosolids or approximately 30,000 acres of permitted land with 3,000 to 4,000 acres used annually. Biosolids are applied at agronomic rates ranging from 3 to 5 dry tons per acre per year depending on the crop. The biosolids cumulative loading on the field included in this study (site 22, Field 2) is approximately 80 dry tons per acre. Field corn is the primary crop, but other crops include sweet corn, soybeans, and alfalfa (at seedbed preparation). No minimum size has been established for fields; however the MMSD prefers to use large fields to help reduce operating costs. The average transport distance is about 13 miles, while the maximum distance is 22 miles.

During peak application periods, i.e. spring and fall, biosolids are applied 10 to 12 hours per day, 6 days per week. Contract operators, under MMSD supervision, are employed to assist the MMSD, and truck traffic becomes heavy with as many as 100 truckloads hauled every day. This truck traffic can generate numerous complaints from the public. Participating farmers have expressed concern over the use of contractors during the peak application season. Most contractors use five-wheeled application vehicles, which the farmers feel cause more soil compaction than the MMSD's four-wheeled application vehicles.

The MMSD is closing both the on-site and off-site storage lagoons, except for a portion of the on-site lagoons which will be retained for emergency storage. Concurrently with the lagoon closure plan, the MMSD is constructing tank storage facilities for 18 million gallons of biosolids or for 180 days at maximum monthly design flow.

The MMSD uses a computerized recordkeeping and tracking system for all aspects of its Metrogro Program. The MMSD works closely with the Wisconsin Department of Natural Resources (WDNR) to ensure that reports are formatted to ensure a fast and efficient transfer of information to the regulating agency.

5.2 Monitoring

As shown in Table 5–1, the monitoring program includes sampling and analyses of biosolids, soil, crop/tissue/grain, and groundwater. Samples of biosolids are collected from each truck and combined into a daily composite sample. The daily composite is analyzed for total solids, total kjeldahl nitrogen and ammonia nitrogen. Weekly and monthly composite samples are made from the daily composites. The monthly samples are analyzed for the parameters in Table 5–1. A full priority pollutant analysis is conducted once each year.

Surface soil samples (0 to 6 inch depth) are collected from each field when the site is initially permitted with the WDNR. Active application sites are resampled every three years. The surface soil samples are used to determine crop nutrient requirements, as well as the soil cation exchange capacity (CEC) and soil pH. Where necessary, the MMSD requires that farmers lime fields to meet the minimum soil pH requirement of 6.5 that is specified by the WDNR.

Deep core (4 feet) soil samples and plant tissue samples are collected from representative soil types encountered in the Metrogro program. These samples are analyzed for the parameters listed in Table 5–1. Deep core samples are collected from these soil types prior to the initial biosolids application, and every three years thereafter. These samples are used to evaluate whether metals are moving from the zone of incorporation. Plant tissue samples are collected from these sites every three years, and the metal concentrations are compared to available risk–based criteria.

Groundwater samples are collected from private wells located near land application sites. Approximately 750 private wells are sampled each year. The samples are analyzed for nitrate, chloride, sulfate, coliform bacteria, and zinc. Results of the groundwater analyses are provided to the well owner.

Table 5–1
Parameters Monitored by Madison Metropolitan Sewerage District

Parameter	Biosolids	Soil	Crops	Groundwater
Total Solids	x			
Total Volatile Solids	x			
pH	x	x		
Cation Exchange Capacity (CEC)		x		
Total Kjeldahl Nitrogen (TKN)	x			
Ammonium–Nitrogen	x			
Nitrate–Nitrogen	x			
Phosphorus	x			x
Potassium	x	x		
Cadmium	x	x		
Chloride	x	x	x	
Chromium				x
Copper		x	x	x
Nickel	x	x	x	
Lead	x	x	x	
Zinc	x	x	x	
PCB (lagoon)	x	x	x	x
Arsenic	x			
Molybdenum (lagoon)	x			
Selenium (lagoon)	x			
Pesticides	x			
Phenol	x			
Tetrachloroethylene	x			
Trichloroethylene	x			
Vinyl Chloride	x			
Ascaris		x		
Coliform			x	
Salmonella		x		x

Table 5–2
Average Concentrations in MMSD Digested Biosolids

Parameter	1989	1990	1991	1992
pH	7.4	7.5	7.5	7.6
			%	
Total Solids	2.2	4.8	5.5	5.7
TKN	10.6	8.2	7.5	7.4
Ammonium–Nitrogen	5.5	3.2	2.1	2.0
Phosphorus	2.8	2.5	2.6	2.6
Potassium	1.0	0.7	0.6	0.7
			mg/kg	
Arsenic	4.1	6.9	4.7	3.7
Cadmium	15.0	13.1	11.2	13.7
Chromium	96.6	107	71.5	81.6
Copper	683	671	634	609
Lead	145	152	133	134
Mercury	6.7	8.1	5.9	4.8
Molybdenum	18.4	18.9	15.3	12.2
Nickel	46.2	46.7	45.4	42.9
Selenium	2.9	5.3	8.2	6.3
Zinc	1,200	1,250	1,060	1,040

The deep core soil, plant tissue, and groundwater monitoring programs are not required by the WDNR. They are conducted on a voluntary basis by the MMSD in an effort to increase both farmer and the general public's confidence in the Metrogro program. Soil and plant samples have also been collected from a number of test sites, with controlled, replicated biosolids applications.

5.3 Results

Table 5–2 lists the average digested biosolids quality. The values for the lagooned biosolids are similar. Of the organics tested, only bis–(2–ethylhexyl) phthalate was above the detection limit and measured 6.3 mg/kg. Although bis–(2–ethylhexyl) phthalate is a common laboratory contaminant and was found in some of the blanks, it is commonly found in biosolids. Parameter

concentrations in biosolids are currently below the Pollutant Concentration limits of 40 CFR Part 503.

Figures 5–3 through 5–5 show the soil concentrations for cadmium, nickel, and lead, at different soil depths on site 22, Field 2. The metal concentrations in the soil do not appear to be well correlated with the loading. Nickel concentrations in the soil are declining; cadmium concentrations stay fairly constant in the surface soil, but are declining in the subsoil; and lead concentrations in the surface soil increased much faster than would be expected from the loading but show little change in the lower soil layers.

The plant uptake of metals was investigated by the MMSD through a field experiment with three replications. Fertilizer, biosolids at agronomic rates, and biosolids at twice the agronomic rates were applied to the field. Table 5–3 shows the cumulative metals loadings for the three test fields and the soil concentrations at the conclusion of the study in 1987. Corn was grown, and samples were taken from ear leaf and grain tissues. Results from the ear leaf analyses are shown in Table 5–4. Significant increases in the zinc and cadmium and decreases in the copper concentrations could be detected in the ear leaf tissues. Grain tissue concentrations were always significantly lower than ear leaf concentrations.

The groundwater monitoring results have shown a trend for increasing nitrate and chloride concentrations over time. The lack of background data for coliform bacteria in many wells made it difficult to evaluate changes in water quality relative to this parameter. A long–term groundwater monitoring study was initiated by the MMSD in 1982 to compare groundwater quality trends at Metrogro application sites to sites where commercial fertilizers and animal manures were used. The study found no significant difference in groundwater quality trends between sites where Metrogro was used and sites where commercial fertilizers/animal manures were used. Thus, while the farming practices seem to impact the groundwater, the impact from Metrogro applications seems to be no different than the impact of traditional farming practices.

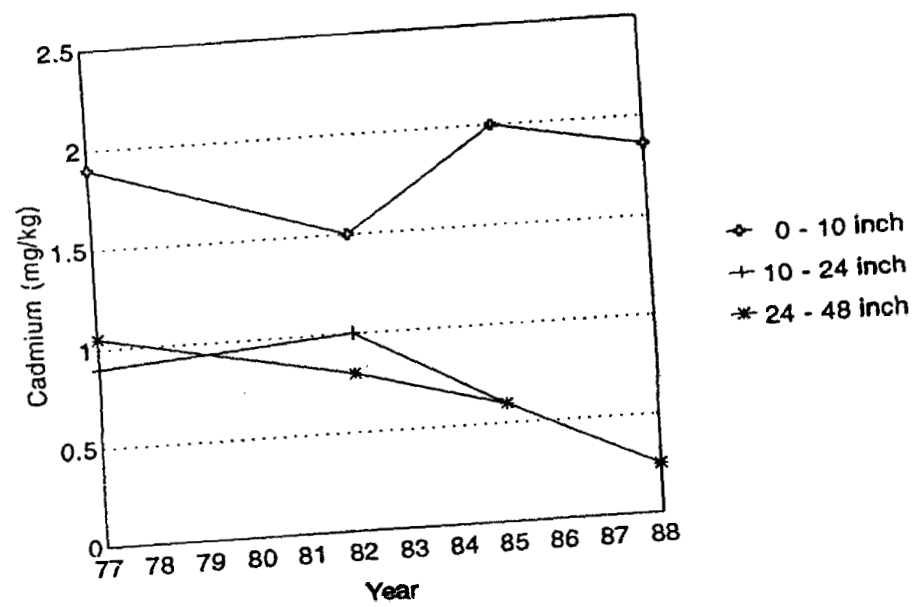

Figure 5-3. Cadmium concentrations in the soil on site 22, Field 2.

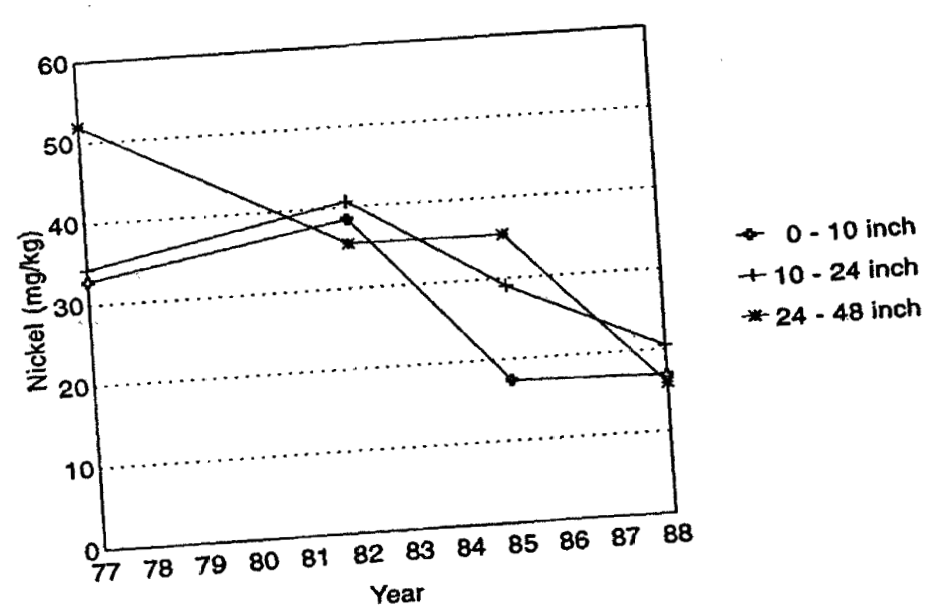

Figure 5-4. Nickel concentrations in the soil on site 22, Field 2.

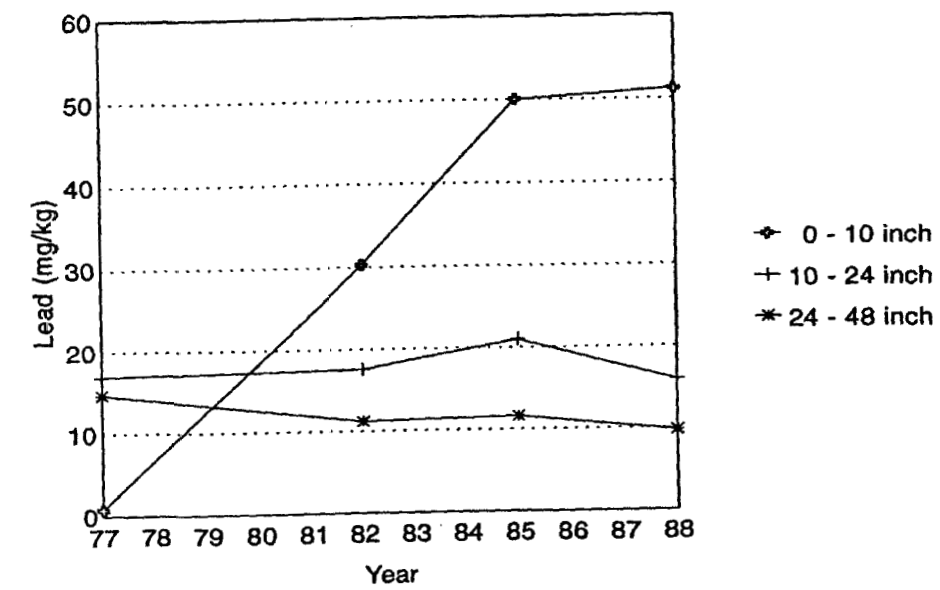

Figure 5-5. Lead concentrations in the soil on site 22, Field 2.

Table 5-3
Cumulative Metals Loadings and Soil Test Levels for Plant Uptake Study

Treatment	Cd	Cr	Cu	Ni	Pb	Zn
			Cumulative Loading (lb/acre)			
Fertilizer	0	N/A*	0	0	0	0
Biosolids	1.31	N/A	30.6	3.0	12.5	97.1
Biosolids 2X	2.62	N/A	61.2	6.0	23.9	194
			1987 Soil Test (mg/kg)			
Fertilizer	0.27	17.2	16.8	13.8	23.7	95
Biosolids	0.63	19.2	23.9	14.2	25.9	113
Biosolids 2X	0.81	24.1	29.4	15.7	28.1	134

* Data not available.

Table 5–4
Metal Concentrations in Corn Ear Leaf Tissue

Year	Cd	Cr	Cu	Ni	Pb	Zn
			mg/kg (dry weight)			
			Fertilizer			
78	0.13	0.51	13.8	0.87	0.86	67.5
79	0.22	0.63	12.4	1.00	0.93	79.5
80	0.14	0.39	14.7	0.75	0.63	80.0
81	0.15	0.44	13.0	1.08	0.82	88.8
82	0.22	0.51	16.8	1.31	1.74	125.5
83	0.18	6.48	10.2	5.27	0.78	66.0
84	0.18	3.60	12.4	3.24	0.66	50.0
85	0.10	2.03	10.8	1.75	0.53	54.0
86	0.19	1.72	11.0	1.13	0.20	47.0
87	0.06	1.02	7.6	0.93	0.24	39.8
			Biosolids			
78	0.17	0.62	13.1	0.64	0.94	68.7
79	0.28	0.68	11.8	0.85	1.06	79.0
80	0.41	0.41	14.0	0.67	0.76	79.5
81	0.31	0.56	12.3	0.97	0.79	132.
82	0.43	0.67	14.2	1.35	1.98	152
83	0.27	6.41	10.0	5.76	0.69	57.5
84	0.30	3.91	11.4	3.45	0.57	49.0
85	0.17	2.00	9.6	1.69	0.69	59.5
86	0.27	1.81	11.2	1.18	0.20	46.5
87	0.09	1.42	8.0	1.05	0.20	47.8
			Biosolids 2x			
78	0.20	0.54	13.8	0.57	0.91	65.5
79	0.48	0.51	12.5	0.72	0.91	91.0
80	0.70	0.44	14.7	0.68	0.62	105.5
81	0.41	0.52	12.3	0.88	0.77	172.5
82	0.52	0.66	14.6	1.36	1.94	167.0
83	0.36	4.78	9.3	4.45	0.50	66.0
84	0.33	6.33	11.5	5.27	0.50	47.5
85	0.23	2.00	10.2	1.68	0.59	65.8
86	0.31	1.86	11.8	1.27	0.22	57.5
87	0.14	2.13	8.2	1.55	0.23	60.3

5.4 Public Relations

Public relations and education are critical to the success of the MMSD's Metrogro program. The MMSD has sought to include the public in the planning and design of the Metrogro system. Questionnaires were distributed to farmers to determine their interests, concerns, and farming practices. Equipment demonstrations were held, and feedback was sought from farmers, local officials, and the public. Farmers were interested in having equipment that would incorporate residuals into the soil, and they preferred high flotation tires that would help reduce soil compaction. Local officials were concerned about road damage from heavy truck traffic. The cleanliness of the applications was of concern to both homeowners and farmers.

One of the first steps taken in the Metrogro public education effort was to avoid the use of the term "sewage sludge" because of its negative connotations. A contest was held to select an alternative term. The reus ogram became known as the "Metrogro Program" and the biosolids were referred to as "Metrogro". A logo was developed to help identify the "Metrogro Program".

The MMSD attends town meetings and sponsors farmer meetings to explain the benefits and limitations of the environmental monitoring program, the wastewater treatment processes, and the land application program. Tours of the treatment plant are given to interested parties. Public demonstration plots comparing Metrogro and commercial fertilizer treatments were established and maintained.

The local news media are kept informed about the project and its activities. The relationship with the media continues to be favorable. Articles in local newspapers and farm publications generally promote the Metrogro program.

The perception that Metrogro is a resource rather than a waste product was fostered by establishing a fee for the biosolids application. Over the years increases in the fees have been made. The fee is currently $7.50 per acre. The fertilizer $N–P_2O_5–K_2O$ value of the biosolids is

around $35 in fertilizer savings. This value was calculated for 64, 120, and 14 pounds of N, P_2O_5, and K_2O/ton using $0.20, $0.23, and $0.12 for N, P_2O_5, and K_2O respectively.

Other activities and publications the MMSD has developed to educate the public and farm community include the following:

- Informational brochures.
- Letters to farmers once or twice a year.
- A slide show for public meetings and school demonstrations.
- Periodic farmer meetings.

The private groundwater testing program has also become a part of the outreach program. A representative of the treatment plant contacts the landowners on a regular basis. Complaints and concerns about the program are likely to be discussed with the representative and can be dealt with in a constructive manner.

Farmer acceptance of the Metrogro program seems to rest on the following factors:

- Keeping the application equipment clean and neat to project a professional image.
- Trying to minimize the compaction of soil by keeping the staging area in the field as small as possible.
- Using a storage tank in the field to provide a buffer between the trucking and application of biosolids, increasing the efficiency of the operation.
- Employing experienced operators, who can minimize mistakes during the land application.
- Being willing to do a little extra work to leave the field in a condition that helps the farmer with his operation.
- Maintaining a constant presence in the community, so that the program is associated with the activities of the city, like garbage pickup or street cleaning.

5.5 Summary

The MMSD has been applying biosolids from its Nine Springs WWTP on privately owned farmland since 1974. The Nine Springs WWTP produces approximately 20 dry tons of biosolids per day. An existing lagoon storage system allows the MMSD to store biosolids during periods when inclement weather and agricultural practices prevent land application. New storage tanks are being constructed, and a portion of the existing lagoons is being closed. The new tank facilities should provide storage capacity for 180 days of biosolids production at maximum monthly flows.

Anaerobically digested biosolids are thickened to approximately 6 percent prior to land application. The MMSD uses its own equipment to transport and apply biosolids on a regular basis; however, contractors are used to supplement the MMSD's operations during peak periods. Biosolids are injected at agronomic rates that typically range from 3 to 5 dry tons per acre per year. Total cumulative biosolids loading on the site evaluated is approximately 80 dry tons per acre, equivalent to 16 to 27 years of consecutive agronomic applications.

One of the unique aspects of this program is the use of a storage tank in the field to decouple the transport and application of biosolids. Using storage tanks in the field has increased the MMSD's productivity by about 25%.

A comparison of soil metal loadings and soil metal test values show that the two parameters are not well correlated. For example, lead concentrations in the surface soil increased faster than would be expected from the loading.

Field experiments were conducted by the MMSD to evaluate plant uptake of metals. Under the controlled conditions, significant increases in zinc and cadmium concentrations could be detected in corn ear leaf tissue.

The MMSD's groundwater monitoring program has shown a trend for inc asing nitrate and chloride concentrations over time. However, a study comparing the groundwater quality at Metrogro sites to sites where commercial fertilizers and animal manures are used showed that the impacts from Metrogro applications appear to be no different than the impacts from traditional farming practices.

The MMSD credits its extensive public relations efforts and willingness to work with farmers for the success of the program. The public is not only regularly informed about the program's status through the news media and public meetings, but the MMSD also involves the public in the planning and design of the program. For example, the pu lic was actively involved in the selection o equipment and the Metrogro logo. The perception that biosolids are a resource rather than a waste is fostered by charging a fee for the biosolids application.

METRO WASTEWATER RECLAMATION DISTRICT, DEN CO

Contact Person: William J. Martin
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Phone Number: (303) 289-5941

Average flow	150 mgd
Design capacity	185 mgd
Dry tons of biosolids/day	70
Type of biosolids	anaerobically digested
Biosolids management options	land application and composting
Application method	injection/surface application followed by incorporation
Started application	1979

6.1 Program Overview

The Metro Wastewater Reclamation District (MWRD) began processing wastewater at the Central Plant in 1966. The agricultural land application program was established in 1979. The MWRD currently processes 150 mgd at its Central Plant, which has a design capacity of 185 mgd. The plant provides primary and secondary treatment using the activated sludge process to provide nitrification–denitrification. Primary and secondary sludges are combined and stabilized by anaerobic digestion. The treatment plant produces about 70 dry tons per day of digested biosolids. The digested biosolids are thickened or dewatered using centrifuges. The dewatered biosolids are either applied to agricultural land or composted and sold to the public under the name METROGRO™. The charges for the METROGRO™ products at the time of this study are:

- $1 $1.75 per 1.25 cubic foot bag of fine-screened compost.
- $1 $19.00 per ton for fine-screened compost.
- $1 $13.00 per ton for coarse-screened compost.
- $: $3.00 per acre for thickened or dewatered biosolids.

About 10% of the biosolids produced is currently composted, and the remaining 90% is applied to land. While composting is more expensive than land application, the MWRD maintains the composting facilities to enhance the flexibility and reliability of the program. During the preparation of this report, the MWRD purchased approximately 10,000 acres of land. Use of this site will reduce the need to obtain permits from local jurisdictions for privately-owned farmland and allow MWRD to manage the entire agricultural program.

The MWRD began applying biosolids to privately-owned farmland in 1979. The biosolids are thickened to approximately 8 to 9 percent total solids prior to being transported to the application site in 7,000-gallon tank trucks. The MWRD owns eight tank trucks like the one shown in Figure 6-1. The biosolids are injected 6 to 12 inches beneath the soil surface by one of three injection vehicles. Two of the injection units have a capacity of 7,200 gallons and the third one, 4,000 gallons.

Later, the MWRD began surface application of dewatered biosolids to improve the cost-effectiveness and flexibility of the program. Dewatered biosolids can be applied during the winter months when subsurface injection is impossible. The dewatered biosolids are transported to the application site in 45 cubic yard tractor/trailer trucks and discharged into a temporary holding area at the application site. The holding area is a three sided earthen pit (similar to a bunker silage pit), that will be restored when the application has been completed. A front-end-loader is used to load the biosolids into one of three 22-cubic yard, custom-built surface spreaders. The biosolids are usually not stockpiled overnight at the application site because of the odor potential. However, if they must remain in the loading pit overnight, soil is used to cover the biosolids.

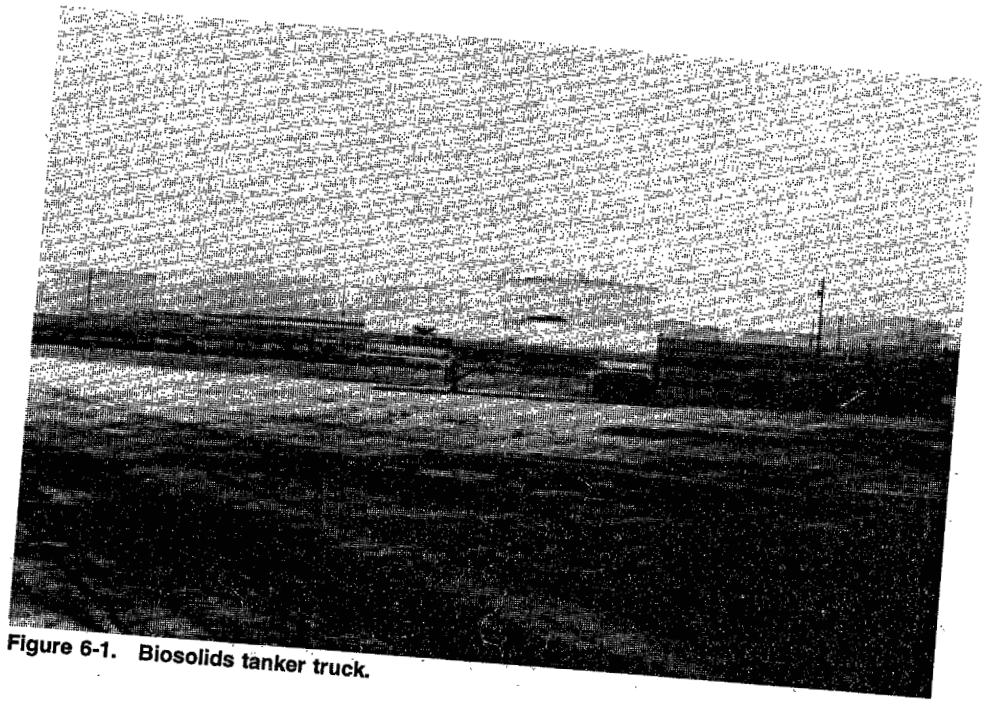

Figure 6-1. Biosolids tanker truck.

Spreaders were custom bu lt to provide a more even application of biosolids than commercially available spreaders. The M D's spreaders have a metering screw and gauge that allow the operator to obtain a more even application than could be obtained with commercial equipment and the MWRD's biosolids. In addition, the MWRD installed a heating system on the spreader box, which allows for spreading of biosolids during the winter months.

Following surface application, the solids are incorporated into the soil by disking and plowing, as shown in Figure 6–2. The MWRD supplies the labor and tillage equipment. In some cases, minimum tillage (para–tilling) is required by the U.S. Department of Agriculture Soil Conservation Service (SCS) to minimize erosion potential. The Agriculture Stabilization and Conservation Service (ASCS) and SCS are also beginning, through contingencies on farm subsidies, to encourage certain tillage practices. To facilitate application during the winter, sufficient land is prepared to allow application of 90 days' biosolids production. Construction plows pulled by a tracked tractor are used to incorporate the biosolids during the winter. Although the MWRD prefers to surface apply dewatered biosolids, it continues to use subsurface injection on sites in developed areas to avoid odor complaints.

Biosolids application rates are based on the recommended nitrogen loadings for the intended p, and the plant available metal concentration in the soil. The most common crops grown on biosolids–amended soils are dryland wheat and irrigated corn. In 1992, the MWRD had permits for approximately 18,000 acres of dryland wheat, and 5,000 acres of irrigated corn land. Average winter wheat yields have increased from 40 bushels per acre without biosolids to 65 bushels per acre after biosolids application. Corn is grown for both silage and grain. Annual application rates range from 1 to 3 dry tons per acre (50 to 75 pounds of nitrogen per acre) for dryland wheat, and from 5 to 10 dry tons per acre (about 300 pounds of nitrogen per acre) for corn. Based on these rates, biosolids are applied to 1,900 to 19,000 acres annually. The exact acreage depends on the mix between dryland and irrigated fields used. Other crops that have been grown on biosolids–amended so ls include milo, oats and barley.

Figure 6-2. A field after biosolids application and incorporation.

The MWRD had approximately 150 permitted sites at the time of this study. Transport distances vary widely from approximately 30 miles to as much as 150 miles one-way. Of the 150 sites, 24 are at least 90 miles away. One of the primary reasons for the long transport distances is the difficulty in obtaining permits from local jurisdictions.

In selecting application sites, the MWRD follows the criteria established by the Colorado Department of Health. In addition to the state permits, the MWRD is required to obtain county permits for sites in Adams and Wells Counties. More than 50 percent of the MWRD's permitted sites are located within Adams County. Approval of a site in Adams County is contingent on SCS approval. A number of sites used in the past have been denied renewed permits because the SCS had concerns about the suitability of sandy soils for application. The primary concern is that sandy soils could pose an increased risk for leaching of nitrate and other constituents.

Permitting fees are charged by the state and the county. The state currently charges $2.40 per dry ton of biosolids applied, while the County fees are approximately $0.50 per dry ton. In addition to the permit fees, local jurisdictions often require a 24 to 48-hour notice before biosolids can be applied to specific sites.

6.2 Monitoring

Soil samples are taken from each site prior to the application of biosolids and tested for nutrients using Colorado State University tests. Both total and extractable metal concentrations are determined. DTPA extraction is used to measure available metals in the soil. Soil samples are stored for one year. Crop samples are collected at harvest. Biosolids are sampled from the loading area during the land application. The District works with the U.S. Geological Survey (USGS) to monitor the groundwater at a selected site, which is assumed to be representative of all of the application sites. The parameters monitored are summarized in Table 6-1.

Table 6-1
Parameters Monitored by Metro Wastewater Reclamation District

Parameter	Soil	Biosolids	Crops	Groundwater
pH	x	x		x
Electrical Conductivity (EC)				x
Cation Exchange Capacity (CEC)	x			
Organic Matter (OM)	x	x		
Total Volatile Solids		x	x	x
Total Kjeldahl Nitrogen (TKN)		x	x	
Nitrate-Nitrogen (NO_3-N)	x	x		x
Ammonium-Nitrogen	x	x		x
Phosphorus	x	x		x
Available Phosphorus	x			
Potassium		x		
Available Potassium	x			
Aluminum		x		
Antimony		x		
Arsenic		x		
Beryllium				
Cadmium	x	x	x	x
Chromium		x		x
Copper	x	x	x	x
Iron	x	x	x	x
Lead	x	x	x	x
Mercury		x		
Manganese				x
Molybdenum		x		
Nickel	x	x	x	x
Selenium		x		
Silver		x		
Zinc	x	x	x	x x
Available Cadmium	x			
Available Copper	x			
Available Iron	x			
Available Lead	x			
Available Nickel	x			
Available Zinc	x			
Polychlorinated Biphenyls (PCB)		x		
Asbestos		x		
Fecal Coliforms				x

6.3 Results

Table 6–2 shows the composition of the thickened digested biosolids. The concentrations of most metals and nutrients have been fairly constant during the past 10 years. Lead concentrations show a downward trend over the last decade, while zinc, nickel, and cadmium remain unchanged as shown in Figure 6–3. The biosolids have concentrations less than the Pollutant Concentration limits of the 40 CFR Part 503 regulations for all elements except molybdenum; but the molybdenum concentration is well below the Ceiling Concentration of 75 mg/kg.

Table 6–3 and Table 6–4 show the soil analysis from two sandy loam fields. Field 88 had received 53 dry tons of biosolids per acre over an 8–year period, while Field 89 had received 42 dry tons per acre. Tables 6–5 and 6–6 show the amount of biosolids and the concurrent metal loadings applied to these two fields.

The usable site–life of these fields is going to be limited by zinc or copper. On the sites examined, the concentration of organic matter has doubled since the biosolids application began. This should enable farmers to reduce the application of water to amended fields, although no water use data are available to verify this. The increase in organic matter might account for the higher yields on the biosolids–amended soils.

The total and available phosphorus levels in the soils at Fields 88 and 89 increased significantly during the study period, as shown on Tables 6–3 and 6–4. For example, on Field 88 the total phosphorus level increased from 210 to 505 mg/kg, and the available phosphorus level increased from 19 to 100 mg/kg. This increase is in response to the application of about 2,900 pounds per acre phosphorus over a 10 year period. Only about one–fifth of the applied phosphorus can be detected in the soil, but a TKN digestion is used to determine total phosphorus content. This type of digestion does not solubilize all of the phosphorus in the system.

Table 6–2
Average Concentrations in the Metro Wastewater Reclamation District Digested Biosolids

Parameter	1983	1984	1985	1986	1987	1988	1989	1990	1991	1992
pH	7.4	7.3	7.7	8.0	7.8	7.4	7.8	7.8	7.8	7.9
EC (μmho/cm)	6,980	12,600	4,130	9,960	6,900	6,900	15,300	15,300	15,300	11,800
						%				
OM	N/A†	N/A	N/A	32	N/A	N/A	62.1	64.1	64.1	67.7
TKN	8.33	8.28	7.5	7.0	4.9	6.2	9.4	9.5	9.5	7.7
NH_4–N	2.83	4.48	2.24	3.00	1.08	2.38	2.87	2.87	2.87	3.13
NO_3–N	0.08	0.02	<0.01	0.01	<0.01	<0.01	<0.01	<0.01	<0.01	0.01
Phosphorus	2.35	3.13	2.7	2.12	3.4	2.35	2.23	2.23	2.23	2.32
Potassium	0.49	0.50	0.42	0.30	N/A	0.30	0.33	0.33	0.33	0.39
						mg/kg				
Aluminum	6,950	9,080	20,000	6,890	7,350	11,000	10,900	10,900	10,900	8,920
Arsenic	0.09	1.55	0.29	3.0	4.2	0.0	9.2	9.2	9.2	6.0
Cadmium	24.9	28.0	18.0	12.1	7.2	9.1	9.5	9.5	9.5	12.0
Chromium	276	N/A	212	123	86.9	137	165	165	165	114
Copper	675	826	670	535	1,130	566	829	829	829	622
Iron	30,400	18,000	19,900	14,900	18,200	18,200	31,000	31,000	31,000	26,600
Lead	344	445	270	203	189	180	210	210	210	165
Mercury	9.9	10.5	5.2	3.0	4.1	3.8	4.2	4.2	4.2	3.0
Molybdenum	18	67	36	8.5	10	19	28.3	28.3	28.3	30
Nickel	98	124	76	69	135	64	114	114	114	54
Selenium	<0.01	0.09	<0.08	3	5.1	10	3.3	3.3	3.3	7
Silver	110	N/A	92	53	57	115	86	86	86	95
Zinc	1,500	1,500	1,400	1,220	1,040	1,130	1,450	1,450	1,450	1,010
PCB	N/A	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0

† Data not available.

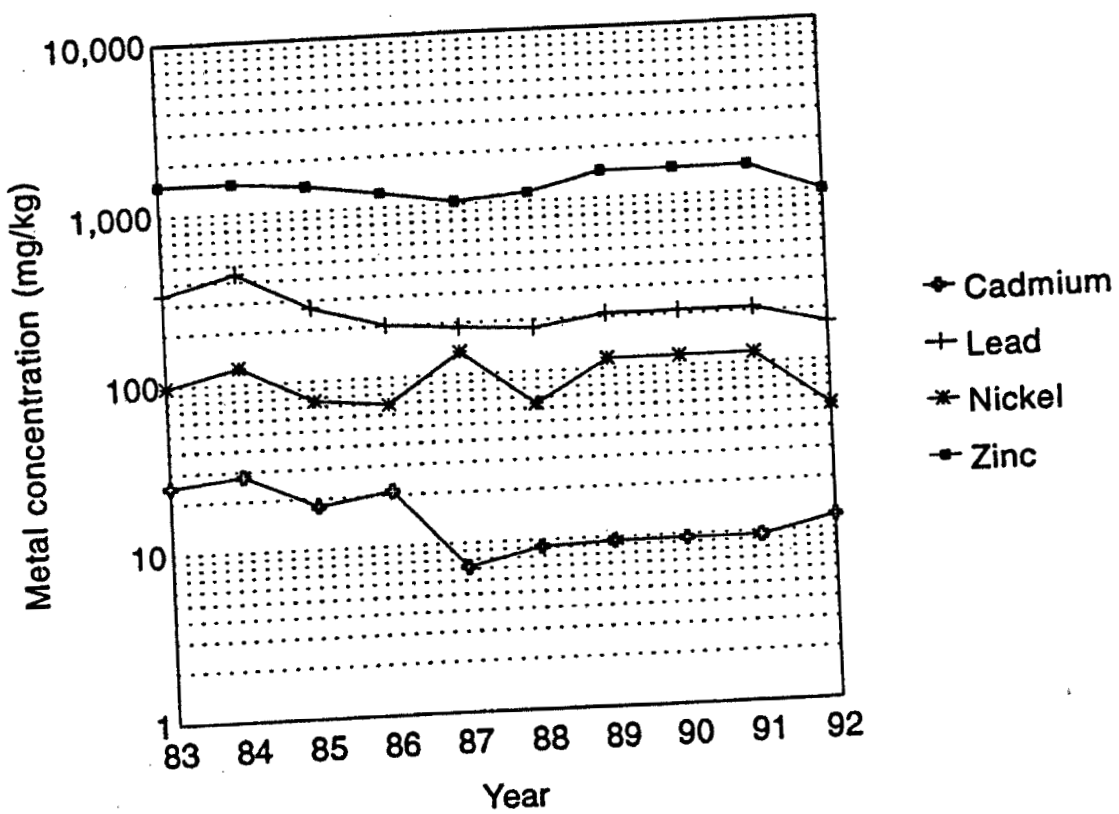

Figure 6-3. Pollutant concentration trends (1983-1992).

Table 6-3
Soil Analysis for Field 88

Parameter	1982	1983	1984	1985	1986	1987	1988	1989	1990	1992
pH	7.4	7.8	6.6	6.5	6.6	6.6	6.5	7.7	7.1	7.0
CEC (meq/100g)	6.5	6.1	8.7	9.4	7.0	7.0	6.0	14.6	12.9	13.8
OM (%)	0.60	0.60	0.80	0.83	0.80	1.01	0.62	1.28	1.60	1.24
EC (μmoh/cm)	380	329	420	295	368	568	426	520	468	516
				Total Concentrations (mg/kg)						
Phosphorus	210	210	290	325	446	490	610	560	580	505
Cadmium	N/A	0.08	0.20	1.32	1.40	0.80	0.30	0.20	0.20	0.49
Copper	5.0	3.5	8.5	4.8	9.4	9.0	6.7	9.0	10.0	7.0
Iron	N/A†	6,500	10,600	6,920	8,380		7,960	10,200	9,760	7,770
Lead	N/A	7.5	10.0	13.9	20.0	20.0	20.0	40.0	24.0	27.0
Nickel	N/A	4.0	8.0	4.4	6.8	5.9	5.3	7.8	6.1	4.2
Zinc	27	24	42	27	40	44	38	55	56	47
				Available Concentration (mg/kg)						
NO_3-N	7.4	14.2	8.9	4.0	3.8	23.0	6.3	19.5	20.0	9.6
NH_4-N	N/A	N/A	N/A	N/A	N/A	3.6	2.2	3.0	4.7	2.9
Phosphorus	19.0	28.2	57.2	50.8	59.8	81.0	67.0	108	101	52.4
Cadmium	0.05	0.08	0.12	0.15	0.16	0.17	0.74	N/A	N/A	N/A
Copper	0.52	0.86	2.78	2.77	3.49	4.92	4.02	N/A	N/A	N/A
Iron	N/A	16	24.8	30.6	30.2	35.8	37.2	N/A	N/A	N/A
Lead	0.94	0.94	1.6	1.18	1.32	1.31	1.4	N/A	N/A	N/A
Nickel	0.26	0.24	0.64	0.92	0.59	0.9	0.66	N/A	N/A	N/A
Zinc	1.2	1.5	3.98	4.34	5.39	6.91	5.18	N/A	N/A	N/A

† Data not available.

Table 6–4
Soil Analysis for Field 89

Parameter		1982	1983	1984	1986	1987	1988	1989	1990	1991
pH		6.5	7.4	7.0	6.5	6.9	6.5	7.4	7.4	6.5
CEC	meq/100g	12.6	8.3	7.4	6.7	6.3	5.0	14.3	6.1	10.1
O.M.	%	0.43	0.82	0.62	0.73	0.85	0.57	1.21	0.63	1.24
NO_3-N	mg/kg	10.4	1.2	11.6	4.6	11.6	2	10.6	2.4	7.4
NH_4-N	mg/kg	N/A*	N/A	N/A	N/A	28.6	2.2	1	1.38	2.10
EC	moh/cm	N/A	N/A	N/A	N/A	465	197	198	224	251
		Total Concentrations (mg/kg)								
P		230	330	310	567	400	620	490	340	486
Cd		N/A	0.2	0.2	1.93	0.5	0.6	1.5	0	0.5
Cu		7.6	6.5	12	6.7	7.0	6.2	12	3.0	15
Pb		N/A	6.2	12	20	20	17	27	10	22
Ni		N/A	5.8	6.5	5.8	5.3	4.8	9.3	2.0	4.7
Zn		42	34	42	33	31	31	56	20	47
Fe		N/A	8,000	9,250	6,970	6,320	6,790	10,915	7,030	8,760
		Available Concentrations (mg/kg)								
P		20	21	59	64	69	55	120	56	61
Cd		0.92	0.09	0.10	0.12	0.12	0.12	N/A	N/A	N/A
Cu		1.1	1.3	2.52	2.66	4.12	3.2	N/A	N/A	N/A
Pb		1.4	1.0	1.42	1.03	0.99	1.2	N/A	N/A	N/A
Ni		0.68	0.46	0.62	0.66	0.77	0.60	N/A	N/A	N/A
Zn		0.56	2.56	3.56	3.46	5.15	3.90	N/A	N/A	N/A
Fe		N/A	22	24	31	32	34	N/A	N/A	N/A

* Data not available.

Table 6–5
Annual Loading to Field 88

Year	Biosolids	Cd	Cu	Pb	Ni	Zn	P
	– dt/acre –	– – – – – – – – – – – – lb/acre – – – – – – – – – – – –					
1983	9.0	0.38	13.7	5.94	1.88	25.6	421
1984	6.4	0.26	8.02	3.65	1.16	18.2	401
1985	6.0	0.21	7.07	3.24	0.69	15.6	323
1986	8.4	0.21	9.86	3.59	1.13	19.9	356
1987	7.3	0.13	2.66	0.96	0.44	6.9	496
1988	11.5	0.23	12.7	4.13	1.65	24.6	551
1989	5.2	0.08	5.61	1.63	0.74	10.8	195
1990	4.6	0.08	4.4	1.43	0.39	8.7	181
Total	58.4	1.5	64.0	24.6	8.08	130	2924

Table 6–6
Annual Loading to Field 89

Year	Biosolids	Cd	Cu	Pb	Ni	Zn	P
	– dt/acre –	– – – – – – – – – – – – lb/acre – – – – – – – – – – – –					
1983	9	0.38	15.8	7.42	1.81	28	381
1984	5	0.24	5.32	2.56	0.85	11.7	275
1986	7	0.19	8.23	3.21	1.19	16.7	242
1988	18	0.43	17.3	6.05	2.27	36.5	201
1990	7	0.13	6.99	2.28	0.63	13.9	290
Total	46	1.37	53.6	[illegible]	[illegible]	[illegible]	389

With the exception of lead, only a relatively small portion of the added metals could be detected in the soil. For the two fields studied, an average of 25 percent of the cadmium, 8.7 percent of the copper, 8 percent of the lead, 2 percent of the nickel, and 11 percent of the zinc was found in the soil. Metal concentrations in the corn tissue on Field 88, as shown in Table 6-7, are variable. The concentrations are similar to those in diagnostic corn tissue grown on so s t treated with biosolids.

The MWRD, jointly with the USGS, recently completed a five year groundwater monitoring program. The site used in the study was selected because of its sandy soils and relatively shallow depth to groundwater. The program was to determine whether the land application practices resulted in contamination of the groundwater with nitrates. Elevated concentrations of nitrates and higher specific conductance were observed beneath the site; however, the source of the contamination could not be identified. The use of commercial fertilizers, animal manure, and biosolids were all considered to be potential sources. Because of the inconclusive results of the groundwater monitoring program, the MWRD is beginning a new groundwater monitoring program at a controlled site where the MWRD will control not only the application of biosolids, but also the agricultural management of the site.

Table 6-7

Metal Concentration in Corn Ear Leaf Tissue on Field 88

	Cu	Ni	Zn	Pb	Cd	TKN
Year				mg/kg		
1984	3.8	10.2	19	<0.2	< 0.1	13,000
1986	3.6	0.2	22	nd†	0.1	13,800
1987	nd	5.3	45	6.0	nd	16,300
1988	4	2	60	2	nd	13,000
1989	2.6	nd	31	nd	nd	12,000

† Parameter not detectable by the method of analysis.

6.4 Public Relations

The MWRD strives to maintain positive relationships not only with the farmers providing the land, but also with the general public. The MWRD works with the farmer to schedule biosolids application and tilling operations to meet the farmer's needs and to ensure that the tillage method complies with SCS requirements. Farmers are charged $3.00 per acre for the biosolids application. The MWRD has estimated that the total value of this service to the farmer, including the nutrients and tillage, is between $30 and $60 per acre. In addition, the MWRD maintains the roads during application at the farm site.

MWRD personnel participate in public hearings, respond to citizen complaints, and assist with the repair of roads damaged by the biosolids trucks. Some counties require a public hearing for each permitted site. MWRD personnel respond to odor complaints by going to the source of the complaint and taking scentometer readings. The readings are recorded, and any possible mitigation measures are implemented. The number of complaints in recent years has not exceeded four per year.

The METROGRO™ name was chosen for the biosolids and the composted biosolids to provide a name free of the negative connotations associated with "sludge".

6.5 Summary

The land application program, which has been in operation since 1979, is the primary method of biosolids utilization by the MWRD. While a portion of the biosolids produced are handled through a composting and distribution program, land application remains the primary method because of its cost-effectiveness. Recently, the MWRD has encountered difficulties in permitting sites in nearby townships and counties and has been forced to transport biosolids to sites as far as 150 miles away. The MWRD has recently purchased land for a biosolids application site because of these problems.

Biosolids are either injected or surface applied and incorporated in the soil. Typical application rates are between 3 and 8 dry tons per acre. Cumulative biosolids applications after eight years are currently between 30 and 60 dry tons per acre. Review of available biosolids quality data shows that most metal and nutrient concentrations over the last eight years have remained relatively constant. Cadmium, lead, and nickel concentrations have decreased, probably as a result of industrial pretreatment.

Concentrations of extractable metals in the soil remained constant through the last 10 years. One exception was lead, which showed a slightly increasing trend. Total and available phosphorus increased, and the organic matter content of the sandy loam soil doubled. The increase in organic matter could be expected to reduce the demand for irrigation water. Plant tissue data showed no increase in the plant uptake of metals.

The results of past groundwater monitoring at the District's test site were inconclusive because the District was unable to control the management of the privately-owned site. Although elevated nitrate levels were observed, commercial fertilizers, animal manures, and biosolids were all believed to have contributed to the contamination.

FERTILIZING FORESTS WITH BIOSOLIDS: HOW TO PLAN, OPERATE, AND MAINTAIN A LONG-TERM PROGRAM

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INTRODUCTION/PROGRAM HISTORY

The Municipality of Metropolitan Seattle (Metro) has a program of beneficial use of its biosolids in composting, agriculture and forest fertilization projects. Metro's land application program began in the early 1970s, with a proposal from the University of Washington to study the potential benefits of wastewater sludge as a fertilizer of commercial forests of the Puget Sound area. The first ten years of research by the University focused on application technology, environmental effects, and growth response. After determining that sludge greatly increased tree growth on nutrient-poor soils and could be applied safely with no detrimental public health or environmental effects, the University and Metro moved on to larger-scale demonstrations.

In 1985, Metro conducted operational-scale applications on some of its own forestland in the county. After that, two timber-growing companies and the state department of natural resources signed agreements with Metro for applications on their own lands. The most suitable sites for sludge application, both from a technical and public access standpoint, were found on one of the companies' lands. Metro staff concentrated their efforts on developing a project with that landowner, the Weyerhaeuser Company.

Metro is now in its sixth year of operations on Weyerhaeuser lands with over 19,000 dry tons of biosolids applied. The program has been successful for both biosolids generator and landowner, but, as with any ongoing program, has had its share of the unexpected. As Metro now begins working with farmers in agricultural uses of biosolids, we are using many of the "lessons learned" from forestry in how to work with the landowner and the public, and how to manage operations and maintain quality control.

In this paper, the authors will describe how Metro has developed its program with this landowner, how application sites are designed and operated, and the standards of performance that we feel are necessary for successful long-term operations.

WHY FOREST APPLICATION?

Technical Reasons

(1) The soils need nitrogen and organic matter.
The soils in the Puget Sound area are glacially derived, composed of deep layers of gravel and sand deposited by glaciers that moved into Washington from the north. They are young on a geological timescale, and so lack the reserves of organic matter and minerals found in older, more developed soils. Forest soils of the entire region are generally deficient in nitrogen.

(2) Forest fertilization with nitrogen is a well-known industrial practice.
Some of the large industrial landowners have established programs of fertilizing both natural stands and plantations with chemical nitrogen fertilizer in the form of urea. Thus, the concept of routine fertilizing to produce faster growth in trees is not new in the Northwest.

(3) The most important commercial tree species grows faster with biosolids.
Early research with a variety of Northwest tree species demonstrated that Douglas-fir trees had the best growth response to sludge. Douglas-fir is the most important commercial tree in the Pacific Northwest. Most private timberland owners in our region grow Douglas-fir on a cycle of 45 to 50 years, replanting and managing it in single-species plantations. Since the 1960s, Douglas-fir has been fertilized with nitrogen. But research showed that growth response to biosolids exceeded the response from urea.

(4) The climate and terrain near Seattle allow nearly year-round operations.
The maritime climate is characterized by mild, wet winters and cool, dry summers. In the lowland forests east of the city, precipitation averages about 60 inches per year, with average daily temperatures of 40 degrees in the winter and 60 degrees in the summer. Light snow may occur December through February, with accumulations averaging less than 6 inches. The gravelly forest soils are well-drained and can withstand the impact of ground equipment, even during the wet
rs.

Location and Land Use/Ownership Patterns
Other cities may find, like Seattle, that if large tracts of forestland are close to the city, they are a logical and feasible choice for biosolids management.

The population centers of western Washington are located along Puget Sound. East of the cities is the broad, rolling to level plain occupied by commercial forests and rural communities, but with encroaching suburban development. Further east, about 75 miles from Seattle, are the foothills and mountains of the Cascade Range. Most of the state's agricultural areas (grains and fruit) are located over the mountain passes on the eastern side of the Cascades, where the climate is much drier.

Several forest products companies have large timber holdings in the glacial plains immediately east and within 30 miles of the Puget Sound cities (Seattle, Tacoma, Olympia). Although these forests are open to the public for hunting, they are "working" forests with a great deal of harvesting activity and log truck traffic. These large contiguous tracts have a well developed network of gravel roads and access that is controlled through a few main gates. These characteristics, plus the remoteness from residences, make these areas well suited for use of biosolids.

Transportation Cost
The close-in location reduces the cost of hauling biosolids from the treatment plants. Metro's hauling costs are from $9 to $10 per wet ton (23% solids) for forest sites, while agricultural sites are generally about 200 miles from the treatment plants and average $25 per ton for hauling. As seen in Figure 1,

however, total haul and application costs for the two uses are comparable due to the ease of application in agricultural fields.

OPERATIONS ON THE SNOQUALMIE TREE FARM

In 1985, Metro and the Weyerhaeuser Company signed a 2-year agreement for the utilization of Metro's biosolids -- trademarked Silvigrow -- on the company's Snoqualmie Tree Farm, approximately 30 miles east of Seattle. The tree farm encompasses 170,000 acres, most of it in one large contiguous block. The application of Silvigrow to selected areas would supplement the company's urea fertilization program. The first Silvigrow project, 160 acres of 5-year-old trees, was begun and successfully completed in 1987. After two years of projects, the agreement was renewed for another two years and then in early 1991, a ten-year agreement was signed.

Metro has the responsibility for site selection, design, permitting, operation and monitoring. Site design and operating plans are subject to company approval, particularly with respect to haul and transfer routes within the private road system of the tree farm. Weyerhaeuser retains the responsibility for managing the timber to meet its corporate objectives. What follows is a discussion of how Metro plans and operates its fertilization projects on this tree farm.

Site Selection
Careful site selection is essential for producing the best growth response. Listed below are the most important factors that we consider when choosing candidate sites. Initial screening is done in Metro s office with topographic maps, soil maps, recent aerial photos and the landowner's inventory records. A careful walk-through of each potential site is necessary to confirm the suitability of the soils and terrain. See Figure 2 for the checklist that we develop for each site that is inspected in the field.

• Terrain - gentle
For ground application, equipment is limited to slopes of 30%, and ideally, slopes of 15% or less. Federal and state guidelines recommend rolling to level sites, with only short stretches of slopes at 30%. We've found that sites with a slight tilt or those with some variable topography are preferable to those "flat-as-a-pancake" sites, where drainage problems can develop.

Slope allowances for forestry sites are considerably higher than those allowed in agriculture. This is due to the excellent infiltration capacity of the forest floor and, in young stands, the amount of herbs and shrubs in the understory whose foliage intercepts the biosolids and aids in stabilizing and drying.

• Soils - well drained
We target soils that have a high content of gravel and sand and minimal amounts of clay. These soils work best for two reasons: (1) they can withstand the impact of the loaded applicator vehicles, even during wet winter weather. To apply a full prescription of biosolids usually requires many passes. If the soils are too fine-textured, the applicator vehicles can create deep ruts and mud. In our experience, trail rutting is one of the "hot buttons" for the timberland owner. The owner wishes to preserve and enhance the long-term productivity of his lands, and rutting destroys the fertile upper horizons of the soil. (2) coarse textured soils are low in nutrients and need extra nitrogen and organic matter. The best growth response to biosolids are on sites of this medium to poor quality.

• Vegetation - well stocked and the right height
Height of the trees is a critical factor. Early research by the University of Washington demonstrated that when biosolids is applied to very young plantations, there are several undesirable results: (1) if not controlled by herbicides, understory plants will respond rapidly and compete with the tree seedlings for water, nutrients, and light; (2) the heavy herbaceous growth leads to population growth

of small rodents who will chew on and girdle the tree seedlings; (3) the amount of damage to the seedlings from browsing deer increases, as the deer will preferentially browse on fertilized seedlings that are at or below their "browse height" of 4 to 5 feet. To avoid these problems, we apply only to plantations that are at least five feet tall and that have a minimum of brushy, unstocked "holes" in the plantation.

• Surface waters - as few as possible
Sites with many draws, streams and wetlands may require a large proportion of the area in setbacks or buffers, thus reducing the net usable area for application. Generally, sites with well drained soils will have 30% or less of the area lost to buffers.

• Road system - suitable width and grade
Although the tree farm includes plateau, foothills, and mountainous areas from 700 to over 3500 feet in elevation, our operations are limited to the lower elevations by the inability of the biosolids delivery trucks to haul steep grades on gravel roads. Grades cannot exceed 10% for long distances and the roads must have frequent turnouts or be wide enough to allow two trucks to pass each other.

• Seasonal restrictions - no slurry on the foliage in dry season
Liquid or rewatered Silvigrow at 7 to 15% solids cannot be applied over the foliage of trees during the growing season, since the summers in the Pacific Northwest are relatively dry. There is no rain to wash the foliage, and the biosolids become cemented onto the foliage. (Metro is currently testing equipment that applies biosolids as dewatered cake. This type of application may minimize the amount of biosolids clinging to the foliage and so may be suitable for summer use. More on this later in the paper.)

• Project size
The minimum parcel size that allows continuous operations is dependent upon the time required for a layer or lift of Silvigrow to stabilize. A typical rate of 10 DT/ac is applied in three separate lifts with drying time after each application. During the wet season, a lift requires three to four weeks to stabilize. If Silvigrow can be applied at the rate of 40 acres per week, then 160 acres of working area is required to keep operations continuous for 4 weeks. By that time the first areas to be applied would be stabilized and ready for the second lift. The entire 160 acres would be completed in 12 weeks.

Design Factors

The first steps in confirming the initial assessment of a site are a soil evaluation and an assessment of the ground water conditions. These tasks are performed by University soil scientists and hydrogeology consultants, respectively. See Figure 3 for the sequence of steps in designing and permitting a site.

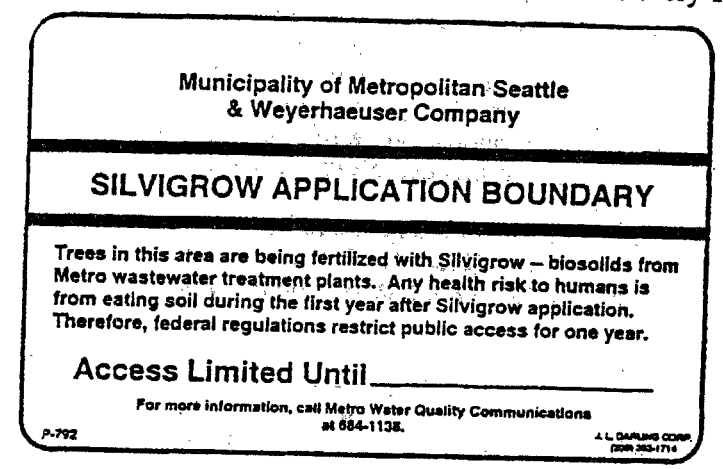
To design each project, Metro employs contract foresters who are knowledgeable in the best management practices of biosolids application. During a thorough examination of each proposed unit, they eliminate areas that are too steep, too wet or that might be pathways for water movement during rainstorms. Boundaries of the usable area are marked in the field with fluorescent pink flagging. Then they design a trail system of parallel, looping or dead ended trails which will allow the applicator vehicle to completely reach all the usable areas. We achieve slightly overlapping, even coverage by applying into a compartment from trails on either side. The spacing between trails varies from 185 to 200 feet, depending on the height and density of the trees. See Figure 4 for an example of a trail system that covers a 98-acre site.

Streams in or adjacent to the application area are buffered by non-application strips of varying widths. We use the following guidelines: 200 feet from large, continuously flowing streams, 100 feet from small tributary streams, and 50 feet from ephemeral drainage ways. The purpose of the buffer is to

provide a safety margin if an operator were to overshoot the boundaries or if Silvigrow were to move during a rainstorm. The width of these buffers is far greater than actually needed. Since beginning operations on this tree farm, we have had no significant movement of Silvigrow away from an application area, primarily for two reasons: sites are heavily covered with vegetation, and the practice of applying in thin layers works well to stabilize the Silvigrow.

The development of an appropriate application rate is an essential part of the design process. Researchers from the University of Washington inspect all proposed forest sites and recommend an agronomic rate. The variables in this calculation are: estimated annual uptake of nitrogen for tree and understory species, mineralization rate for the organic nitrogen in the biosolids, soil storage capacity, and estimates for volatilization and denitrification. With the total nitrogen in our biosolids averaging about 5%, a typical application rate for a 10-year-old plantation is around 9 dry tons per acre. Our current plans are for a 4 to 5-year cycle of reapplication.

Because Metro's biosolids are treated by a PSRP (Process to Significantly Reduce Pathogens) rather than a PFRP (Process to Further Reduce Pathogens), site access is restricted for 12 months after application. Yellow plastic signs are posted around the site boundaries every 100 to 200 feet:



Permitting Process

In the state of Washington, the state Department of Ecology has delegated permitting authority for biosolids to local health districts. For this particular project, the Seattle-King County Department of Public Health is the regulator and permitting authority. We are fortunate to have local regulators who are knowledgeable about biosolids practices and research as well as the draft federal regulations. Permitting of new areas on the tree farm has gone smoothly because of the projects' remoteness, low public profile, and good monitoring results.

Following the submission of the permit application package (which includes description of soil profiles, analyses of soils for metals and nutrients, chemical analyses of biosolids, topographic maps of application areas, hydrogeology study, monitoring plan, calculation of application rates, and proposed trail layout), the regulator makes a field visit with the project manager and field designer for the project. Representatives from the state Department of Ecology attend whenever possible. The field inspection usually focuses on the buffering and protection of water bodies and other sensitive areas as well as any downstream water users. The entire permitting process can usually be completed in 45 days, the minimum review period required by county regulations.

Operations Tracking

Metro's current forest operations involve the addition of water to dewatered cake biosolids to produce a slurry of 7 to 15% solids which is then sprayed onto the trees. The mixing/delivery station at the tree farm is located in a large gravel pit. Here the haul trucks unload biosolids (at 18 to 27% solids) into an in-ground mixing tank to which dilution water is added. The diluted biosolids, called Silvigrow, are then pumped into adjacent storage tanks for the day's application. Usually 4 to 5 truckloads of 30 wet tons each can be processed and applied in a day.

The application units are usually located in a 3-mile radius from the mix station, so transfer tanker trucks are used to shuttle Silvigrow from the mix station out to the working applicator vehicles. The applicator vehicle is a rubber-tired, articulated, four-wheel drive chassis with a 2200-gallon tank mounted over the rear axle. The tanks contain an internal pumping system driven by the power take-off connected to a one-inch diameter nozzle mounted on top of the vehicle. The loaded applicator vehicles travel into the forest on the trail system; they are stationary as the operator applies the material, controlling the direction and trajectory of the spray from a joystick inside the vehicle cab.

Each operator has a clipboard with a map of the application unit and a logbook (see Figure 5). Each application unit is divided into compartments of 1 to 6 acres which are used to keep track of the actual amount of Silvigrow applied. For example the application rate for Unit 24-08-02 is 8.5 DT/acre. Compartment 22 in this unit is 1.1 acres, which would require 1.1 X 8.5 = 9.3 DT to complete. Each applicator applies 1 DT per load, so 9 loads total would be needed for this compartment. Applying this amount in three separate lifts means that 1 complete lift consists of 3 loads. The logbook is marked to show when each lift is completed.

At the end of each day, the site supervisor checks the condition of trails and the buffers for all the compartments that were applied that day. Records of these checks (see Figure 6) are kept at the field trailer at the mixing station for the Metro site manager's inspection.

Contingency Plans

Metro and the application contractor have developed a set of procedures for responding to any incidents on the site. An "incident" may be a spill, surface runoff, traffic accident, work site accident, misapplication of biosolids or any other site problem. The operations plan includes a contingency plan, which outlines the individuals to be contacted in case of a large-scale incident. The plan also includes a list of local contractors and their equipment (dump trucks, loaders, vacuum trucks, tow trucks, and cranes) that could be called for assistance. Small spills or misapplications are corrected immediately, and an Incident Report form (developed by Metro) is filed. We have had some trucking incidents but no large spills in the 6 years of operation.

Monitoring

Water Quality - To evaluate the water quality of streams near Silvigrow sites, Metro establishes *test* sampling stations downstream from project areas and *control* stations upstream. Two types of monitoring are conducted: (1) Routine or ambient - conducted on a quarterly basis before, during, and for three years following applications; and (2) Storm - occurs during two to three rainstorms in the wet season following application. Storm sampling is conducted to ensure that Silvigrow is not being carried offsite by surface runoff. All samples are grab samples, collected by water quality specialists with Metro's Environmental Laboratories. Samples are analyzed for ammonia nitrogen, nitrate-nitrite nitrogen, fecal coliforms, and enterococcus. Six years of sampling have shown little to no significant changes in the excellent water quality in these streams.

There are no drinking water wells within a mile of any site, and most of the sites do not overlie aquifers of any significant size. For these reasons, we do not use ground water wells in our monitoring program. Two of our sites, however, have installations of tube lysimeters. Nitrate data

collected from the lysimeters is used by the University of Washington to fine-tune their model and assumptions of nitrogen uptake in Douglas-fir stands.

Tree Growth - Many of the application areas at the tree farm contain growth plots. To maintain consistency in data collection, all growth plots are installed and measured by field crews from the Stand Management Cooperative (SMC). (The SMC is a cooperative of universities and landowners that sponsors integrated research in forest nutrition, silviculture, and wood quality.) Not all areas have these plots; we install them whenever there is an opportunity to gather data from different soil types or age classes of timber. The standard installation consists of three tenth-acre square plots treated with biosolids and three control (no biosolids) plots in the same stand. All trees are numbered and tagged; height and diameter are measured annually. Results from the first three years of operations in young stands indicate increases in annual height increment can range from 20 to 75% over controls.

Partnership with the University

Metro has continued its contract relationship with the University of Washington College of Forest Resources since 1973, not only for research but for design assistance on operational sites. As described in previous sections of this paper, researchers from the U.W. are an essential part of site design. They make a field visit to each proposed application area to evaluate the suitability of the soil to receive biosolids and to sustain traffic. They estimate the nutrient needs of the site and prescribe the appropriate application rate. They propose research to fill in the knowledge gaps, monitor the growth response, and assist us when something goes wrong. We know that their role is one of the critical factors in the long term success of this project.

Other municipalities have developed this kind of partnership with research institutions. Some examples are Greater Vancouver Regional District with the University of British Columbia, City of Spokane with Washington State University, Massachusetts Water Resources Authority with the University of Massachusetts, and Vail, Colorado with Colorado State University.

Performance Standards

Many of the operating practices that have been developed over the past six years of operations at the Snoqualmie Tree Farm have been formalized and incorporated into a set of standards that is now applied to all other kinds of biosolids projects. In any given month, Metro may deliver biosolids to two or three kinds of projects. Each site may be operated by a different contractor, and even permitted by different counties. Last year when one of the contractor-managed soil improvement sites came under public scrutiny for failing to closely follow the operations plan, the sludge program staff developed common performance standards to which all projects would conform. These standards would ensure that all projects receiving Metro biosolids would operate with the same attention to detail, regardless of the local requirements. The new standards gave Metro a visible and active role during the permitting and operating of the project. Listed below are some of the key requirements that have worked well on forestry sites and are now required of all other projects as well:

- Operations plan with detailed site maps;
- Haul route approved by Metro;
- Agronomic application rates reviewed by university or other independent specialists;
- Buffers and boundaries clearly marked in the field;
- Good housekeeping measures at the site with daily inspections of boundaries and buffers;
- Pre- and post-application monitoring of soils, surface water, and, if appropriate, ground water and crops.
- Public information plan with early and ongoing public involvement opportunities;
- Contingency plan for any incidents;
- Quarterly and annual reports to be produced and available for any interested parties.

WHEN SOMETHING GOES WRONG

Despite careful planning and site management, Murphy sometimes visits our projects. For the first two years the Metro/Weyerhaeuser projects went smoothly; a total of 1200 acres had been permitted and completed. Then scattered trees began to yellow and droop on one of the fertilized areas. Scientists from the University of Washington College of Forest Resources began an investigation into the source of the problem, which was obviously related to the biosolids application as adjacent unfertilized areas were unaffected. Over the next few months, the clumps of dying trees totaled about 40 acres.

The research team concluded that the trees weakened because of inadequate soil aeration. This lack of oxygen was caused by a combination of site conditions and the slow drying characteristics of secondary biosolids under these conditions. The very flat terrain and shallow soils restricted winter drainage, while the dense tree canopy kept the ground cool and shaded so that the biosolids did not dry. Under these conditions, the biosolids sealed the soil surface, reducing the movement of oxygen into the soil.

Weyerhaeuser forest scientists were consulted and involved in the investigation at every step, so there was consensus among Metro, the University and the landowner that we had a developed a problem that could be easily avoided in the future by focusing on young, open stands. The affected areas were harvested prematurely and Metro paid Weyerhaeuser for the value of the lost growth. Applications resumed the next year and are continuing.

CRITERIA FOR SUCCESS

• Find your niche in the landowner's overall management plan.
Niche, from the science of plant ecology, is defined as "the ultimate unit of the habitat, i.e. the specific spot occupied by an individual; the more or less specialized relationship existing between an individual and its environment." Forest landowners in Washington state have a multitude of laws, restrictions and regulatory agencies to deal with. We want the use of biosolids to be an easy practice to implement on their tree farm and one that requires minimal investment of staff time for them. Metro staff handle all the site development and permitting for Silvigrow projects and work hard to minimize any "hassle factor" for the landowner.

We also have found a place in the landowner's current management regime. Weyerhaeuser presently begins urea fertilization around age 17 and continues on 7 year intervals through the entire rotation of 45 to 50 years. Silvigrow fertilization begins around age 5 and is reapplied on 5 year intervals. This provides a real boost to developing plantations and allows the trees on these poorer-quality sites to grow at a rate typical of much more productive sites.

• Hold your projects to the highest standards. There are many obvious reasons to run a clean, well-managed operation. But it's essential if you're counting on a long-term relationship with a particular land owner and his community.

• Be actively involved and visible to the public and the landowner. As the biosolids generator, you will find it to your benefit to be visible, accountable, and responsive to your "customers". It eliminates confusion about who is responsible for the quality of the application and any perceived liability. Other types of projects with Metro's biosolids have been permitted and managed by private vendors/contractors. Whenever issues or problems arise, the public usually looks beyond the vendor to the generator for explanations or satisfaction of their complaint.

• Make projects a team effort with the landowner, contractor, scientists and community. There is no substitute for the support of your local research institution and the local newspaper editor/writer. The researchers will provide a check and balance for your operation plans, keep your projects on sound technical footing, and help with the problems that will surface. We found that working with and establishing an open relationship with the local editor from the very outset of the Snoqualmie project ensured that we had more reasonable and informed coverage when problems did arise.

• Monitor and publish results, both water quality and crop response.
Let the world know what a good job you're doing -- talk, talk to community groups and professional organizations. Presentations to the local SAF (Society of American Foresters) chapter or other industry group will go a long way toward informing the forestry community in your locale about the opportunities with biosolids.

PLANNING FOR THE NEXT DECADE

New Products, New Equipment

1992 is a year of transition and testing for Metro's forestry program. In addition to the current rewatered applications, this year we will be testing the feasibility of dewatered cake applications. In April and May we pilot-tested a side-cast spreader unit that flings dewatered material 200 feet out into the plantation. This type of application could extend operations into the summer and allow us to access areas of the tree farm that are only operable during the dry season. Such an operation would also reduce costs by eliminating the need for dilution water and reducing crew size from five to two.

Later this year Metro's first dried biosolids product will become available through a contract for biosolids drying with PCL/SMI. Metro will be testing some of this material in its existing forestry and irrigated agriculture projects.

More Efficient Planning and Permitting

During the first two years of operations on the Snoqualmie Tree Farm, we concentrated on choosing suitable sites for the upcoming year, doing a good job with operations, and following up carefully and accurately with monitoring results and reports. Now with a new ten-year contract, plus two new forms of biosolids product becoming available to us this year, we face the challenge of a more long-term planning approach.

Our goals are to:
• predict number of acres and locations that will be available each year over the next decade;
• reduce amount and redundancy of staff and consultant work.

To accomplish the first goal, Metro staff are currently working on a screening process for the entire tree farm. We are making field visits to all areas that have the potential to use liquid, cake, or dried biosolids. Using the information gathered with the checklist in Figure 2, we will be developing a database of stands that can be sorted by a number of variables: location, tree age, soil type, season of application, and type of fertilizer product.

Permitting and environmental reviews to date have been somewhat piecemeal. Each project area of 160-200 acres has been evaluated and permitted separately, with separate operations plans and individual reports of soils and ground water. To bring some continuity to the program and to streamline our permitting efforts, this year we are developing two documents (in three-ring binders) that can be used for all projects: (1) an operations plan for the entire tree farm, with site maps and specific permit conditions located in appendices; and (2) a hydrogeology study for the tree farm, again with site-specific studies added as needed.

Research Needs

For the next couple of years, Metro and the University of Washington will be focusing on further fine-tuning of application rates, including the effects of residual nitrogen and multiple applications; expansion of operations to other forest types such as hybrid cottonwood plantations and mixed conifers in eastern Washington; and research on the fate of nutrients other than nitrogen.

One of the most exciting developments of the 1990s is the startup of similar forestry programs in other parts of the US and the world. We're watching with great interest what's happening in Vancouver, British Columbia; Christchurch, New Zealand; eastern Massachusetts, eastern Australia and elsewhere.

For the biosolids generator, forest application can provide a type of reuse that has a reasonable cost, is non food-chain, remote from homes, and provides economic benefits for the user. For the land-owner, the use of biosolids can result in faster-growing trees, greater timber volumes, and long-term improvements in productivity. With the information and operational experience gained by Metro and other forest fertilization programs, more POTWs may find that forest fertilization is the right option for their biosolids.

Acknowledgements

Although there have been many people who have helped shape the Silvigrow program, the authors want to recognize three who "made it happen": Steve Anderson, area forester for the Weyerhaeuser Snoqualmie Tree Farm; Charles Nichols, who designed the Silvigrow application/transfer equipment and is now with the Sanitary District of Orange County, California; and Suzanne Schweitzer, who developed the framework for designing and managing these projects and is now with East Bay Municipal Utility District.

Any correspondence or questions can be addressed to: Peggy Leonard, Municipality of Metropolitan Seattle, 821 Second Avenue, Mail Stop 81, Seattle, WA 98104-1598.

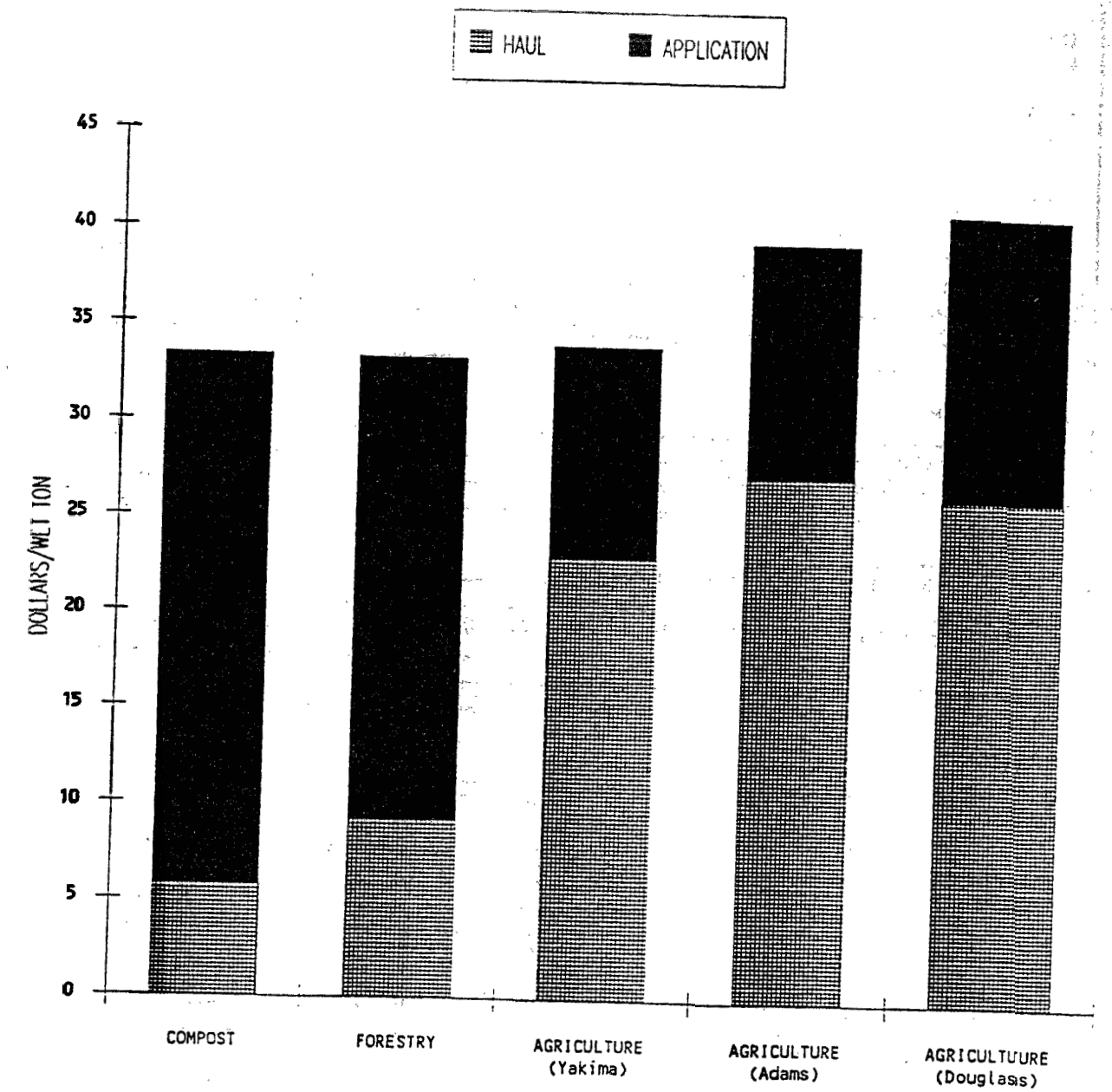


Figure 1. Approximate haul and application costs for compost, forest, and agriculture projects (by wet tons a giving 23% solids).

FIELD CHECKLIST

DATE OF FIELD CHECK: _____
FIELD EXAMINER: _____

LOCATION: (Section, Township, Range)
Attach map with boundaries marked.
_____
_____

PROPERTY OWNER: _____
ELEVATION: _____
NUMBER OF ACRES: _____
NEARBY SITES: _____

SOILS
Information Source: _____
Soil Series: _____
Parent Material: _____
Approx. Depth: _____ Does soil appear suitable? _____
_____

TOPOGRAPHY
Slope: _____
Presence of draws (mark on map): _____
Areas where slope may be critical factor (mark on map): _____
_____

SURFACE WATERS
Water body type and location (mark on map): _____
_____
Areas of poor drainage (standing water, wet-site indicators): _____
_____
Buffers required (mark on map): _____
_____

VEGETATION
Tree species: _____
Stocking levels: _____ Average stand height: _____
Understory:

Species	Average Height	Average Cover (nearest 10%)

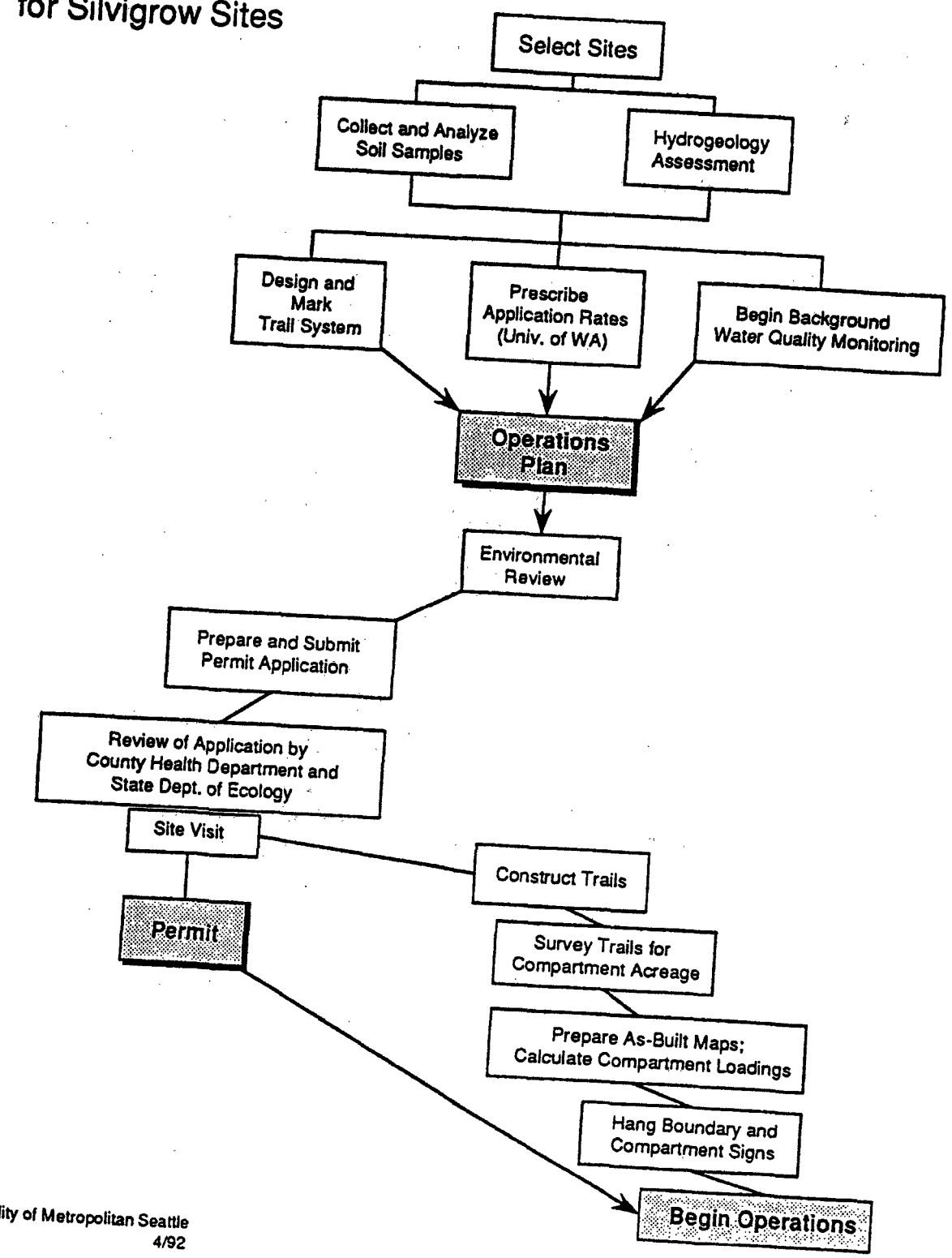
ACCESS
Main Roads: Grade: _____ Overall Condition: _____
Width: _____ _____
Any Limitations for Application Trails: _____
_____

COMMENTS/RECOMMENDATIONS: _____
_____
_____

ESTIMATE OF USABLE ACRES: _____
RECOMMENDED SEASON OF APPLICATION: _____

Figure 2. Field checklist for evaluation of potential Silvigrow sites.

Site Design and Permitting for Silvigrow Sites



Municipaility of Metropolitan Seattle
4/92

Figure 3. Steps in the design and permitting - st application sites.

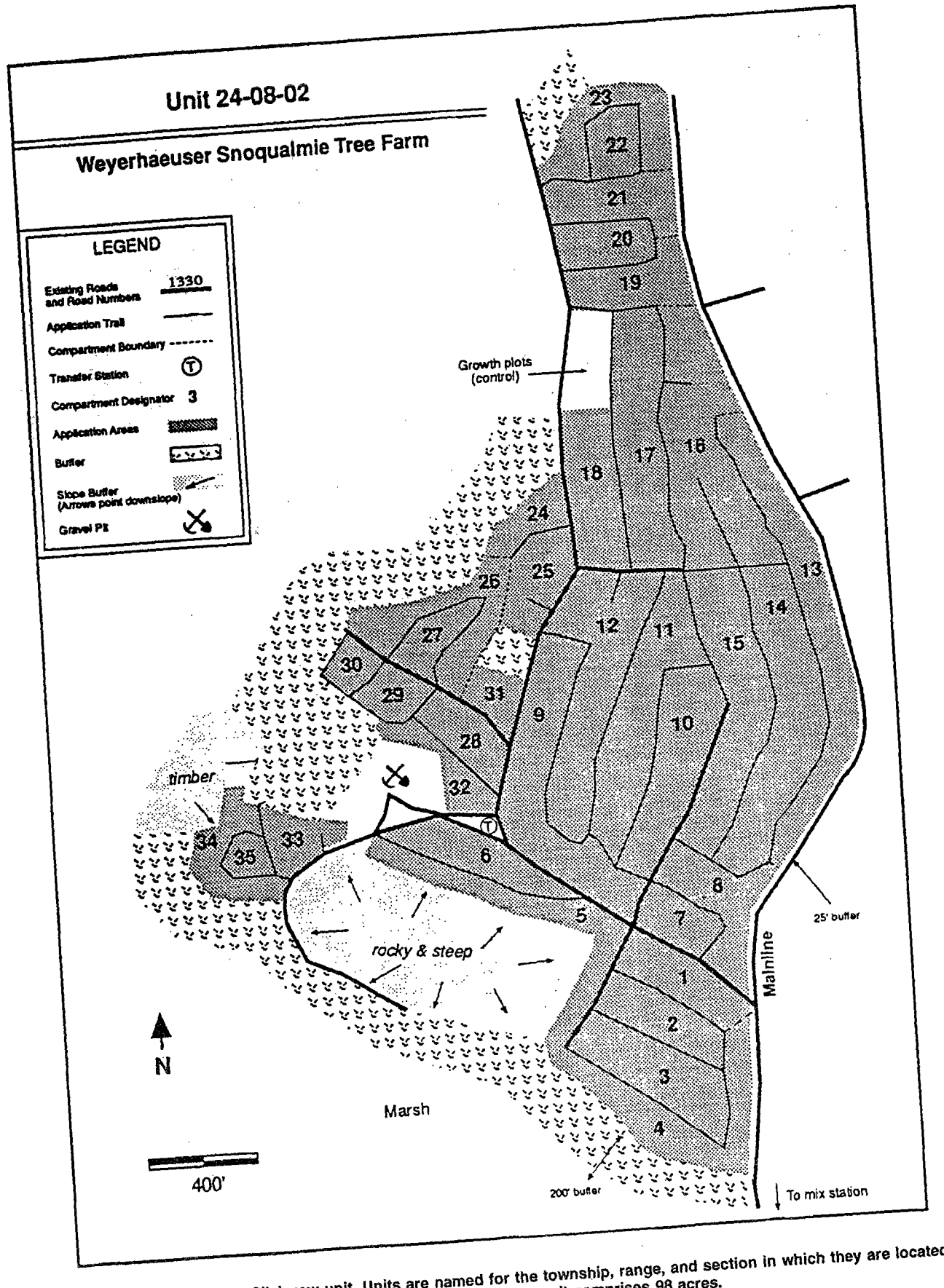


Figure 4. Trail map of typical Silvigrow unit. Units are named for the township, range, and section in which they are located—Unit 24-08-02 is located in T24N R8E, Section 2. This particular unit comprises 98 acres.

METRO

Application Log

I = IME
A = Ag Chem
~~~ = End Lift

Load	Date	Time	Applicator 1	Applicator 2
1	4/24	1:05	I	
2	4/26	11:45	I	
3	4/26	1:30	I	4/26
4				
5				
6				
7				
8				
9				
10	END			
11				
12				
13				
14				
15				
16				
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35				
36				
37				
38				
39				
40				

Load	Date	Time	Applicator 1	Applicator 2
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42				
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Load	Date	Time	Applicator 1	Applicator 2
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117				
118				
119				
120				

Area Size 1.1 acre
Loads per lift 3
Page 1 of 1

Project SECTION 2
Unit 24-08-02
Compartment 22

1432 (Rev. 3/88)

Figure 5. Application log for tracking loadings to each compartment.
~~~

DAILY BOUNDARY AND BUFFER CHECK

Inspector _____ Date _____

UNITS WORKED TODAY

Unit/ Compartment	# Passes per Day	Tire Depressions 0-6"	6-12"	12-18"	Stuck	Standing Water

	Trails (General conditions, incl. any Silvigrow on trails)
	Buffers (Note any oversprays, spills, etc.)
	Compartments (Application uniformity)

Figure 6. Field sheet for daily boundary and buffer checks by the site supervisor.

LONG-TERM EFFECTS OF A SINGLE APPLICATION OF MUNICIPAL SLUDGE ON ABANDONED MINE LAND[1]

BY

William E. Sopper and Eileen M. Seaker[2]

Abstract. In 1977, digested and dewatered municipal sludge was applied and incorporated in spoil material at a rate of 184 Mg/ha on a 0.4 ha experimental plot on an abandoned strip mine site in Pennsylvania. Data were collected for a five-year period (1977-1981) to determine the effects of the sludge application on the quality and growth of the herbaceous vegetation, the chemical properties of the soil, and the chemical quality of groundwater. In 1989, 12 years after sludge application, the site was again resampled to determine the long-term residual effects of the sludge application. Results of the re-evaluation indicated that the single high application of sludge facilitated the rapid development of a vegetative cover which has persisted over the 12 years with no apparent adverse effects on vegetation, soil, or groundwater.

Additional key words: Reclamation, trace metals, sludge utilization, revegetation, groundwater quality.

Introduction

It is estimated that more than 7.7 million dry metric tons of municipal sludge are currently produced each year by the 15,300 public-owned treatment works in the United States. Approximately 25% of this is being land-applied for its fertilizer and organic matter value (Federal Register 1989). One of the most efficient uses for sludge is the reclamation of disturbed lands, such as those abandoned after coal mining which are acidic, droughty, and devoid of organic matter. Sludge has been shown to improve spoil structure, water holding capacity, and bulk density in addition to adding N, P, K, and other plant nutrients (Sopper et al. 1982; Sopper and Seaker 1983).

Approximately 121,000 hectares of land in Pennsylvania, strip mined prior to the federal Surface Mining Control and Reclamation Act of 1977, were abandoned after the coal was removed, leaving vast areas of barren spoil (USDA 1980). These sites have remained barren for years due to the difficulty of establishing and maintaining vegetation on the highly acidic material.

In 1977, a project was initiated in Pennsylvania that introduced the concept of using municipal sludge for revegetation of mined land to the general public in order to gain public acceptance and support. The specific objective of the project was to demonstrate that municipal sludge could be used to reclaim strip mined land and return it to potential agricultural use or to a wildlife habitat in an environmentally acceptable manner, without adverse effects on the quality of the vegetation, soil, or water. Vegetation, soil, and groundwater samples were collected over a five-year period (1977-1981) and results of these studies have been reported by Seaker and Sopper (1984).

[1]Paper presented at the 1990 Mining and Reclamation Conference and Exhibition, Charleston, West Virginia, April 23-26, 1990. The research described in this article has been partially funded by the U.S. Environmental Protection Agency through Grant No. S-804511-020 and CR807408010.

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The issue of the long-term effect of applying single, large amounts of sludge in order to revegetate mine land often arises. What happens after all the sludge has been mineralized and all the nutrients and trace metals have been released to the soil and are potentially available for plant uptake and leaching? Will the vegetative cover persist or deteriorate?

One of the sites used in the 1977 project was an abandoned strip mine bank located in Venango County that had been backfilled and recontoured after mining without top soil replacement. Several revegetation attempts were unsuccessful. Dewatered digested sludge was applied in May 1977 to a 0.2-ha plot. In August, 1989, 12 years after sludge application, the site was revisited and samples of vegetation, soils, and groundwater were collected to evaluate the long-term effects. The project was originally designed as a demonstration to the public, rather than an experiment. Subsampling was employed, but statistical analyses could not be performed on the data. Instead, general trends are discussed.

Materials and Methods

Sludge Application

The surface soil was compacted, stony, and extremely acid (pH 3.8). The 0.2 ha plot was scarified with a chisel plow to loosen the surface spoil material and agricultural lime was applied at 12.3 Mg/ha to raise the spoil pH to 7.0. Sludge for the project was obtained from three local wastewater treatment plants. The sludge was applied at 184 Mg/ha with a manure spreader. The average concentrations of nutrients and trace metals and amounts applied in the sludge are given in Table 1. The amounts of nutrients applied were equivalent to applying an 11 (N) -9 (P_2O_5) -0 (K_2O) chemical fertilizer at 22,400 kg/ha.

Table 1. Chemical analysis of dewatered sludge applied and amounts of elements applied at 184 Mg/ha rate (Dwt Basis)

Constituent	Average Concentration	Amount Applied
	mg/kg	kg/ha
Total P	4624	918
Total N	12188	2388
K	93	18
Ca	9970	1834
Mg	2082	383
Zn	811	147
Cu	661	129
Pb	349	55
Ni	69	12
Cd	3.2	0.6
pH	7.9	

The amounts of trace metals applied are given in Table 2 along with the U.S. Environmental Protection Agency (EPA) and Pennsylvania Department of Environmental Resources (PDER) interim guideline recommendations (United States Environmental Protection Agency 1977; Pennsylvania Department of Environmental Resources 1977). It is quite obvious that the amounts of trace metals applied were well below the recommended lifetime limits except for copper, which slightly exceeded the Pennsylvania guidelines.

Immediately after sludge application and incorporation, the site was broadcast seeded with a mixture of two grasses (Kentucky-31 tall fescue, Festuca arundinacea Schreb., 22 kg/ha, Pennlate orchardgrass, Dactylis glomerata L., 22 kg/ha) and two legumes (Penngift crownvetch, Coronilla varia L., 11 kg/ha, and Empire birdsfoot trefoil, Lotus corniculatus L., 11 kg/ha). Then the site was mulched with straw and hay at the rate of 3.8 Mg/ha.

Sampling and Analyses

A complete monitoring system was installed on the plot to evaluate the effects of the sludge applications on water quality, vegetation, and soil. Two groundwater wells were drilled (up-gradient and down-gradient) to sample the effects of the sludge application on groundwater quality. After sludge application, groundwater samples were collected bi-weekly for the first two months and monthly thereafter. Samples were analyzed for pH, nitrate-N by ion-selective electrode (Ellis 1976), dissolved Cu, Zn, Cr, Pb, Co, Cd, and Ni by atomic absorption spectrophotometry (EPA Methods of Chemical Analysis 1974).

Minesoil samples were collected at the 0 to 15, and 15 to 30 cm depth, passed through a 2 mm sieve, and analyzed for pH, Kjeldahl-N, Bray-P, exchangeable K, Ca, and Mg by ammonium acetate extraction, and dilute hydrochloric acid extractable Cu, Zn, Cr, Pb, Cd, and Ni (Jackson, 1958). Exchangeable cation and extractable metal concentrations were determined by atomic absorption.

At the end of each growing season vegetation growth responses were determined by measurements of percentage areal cover, and dry matter production. No crops were harvested over the 12-year period. Individual samples of tall fescue, orchardgrass, crownvetch, and birdsfoot trefoil from each plot were collected for foliar analyses. Plant samples were analyzed for Kjeldahl-N; P, K, Ca, Mg, by plasma emission spectrometry (Baker et al. 1964), and Cu, Zn, Cr, Pb, Co, Cd, and Ni by atomic absorption (Jackson 1958), after dry ashing and digestion.

Results and Discussion

Vegetation

The site was completely vegetated by August 1977, three months after sludge application, which has persisted throughout the 12-year period. Average annual dry matter production for the first five years and in 1989 was as follows:

Year	Yield
	Mg/ha
1977	6.0
1978	9.3
1979	11.3
1980	31.2
1981	22.6
1989	15.5
AHY	4.0

Table 2. Trace metal loadings of the sludge application and lifetime loadings recommended by the EPA and PDER.

Constituent	Sludge Application 184 Mg/ha	EPA[1] (CEC 5-15)	PDER
	kg/ha		
Cu	129	280	112
Zn	147	560	224
Cr	74	NR[2]	112
Pb	55	800	112
Ni	12	280	22
Cd	0.6	11	3
Hg	0.09	NR[2]	0.6

[1] Average CEC of site ranged from 11.6 to 15.2 meq/100g

[2] No recommendation given by EPA

Dry matter production increased during the first four years, leveling off in 1981. In 1989 it was slightly lower but still well above the average hay yield (AHY) for undisturbed farmland soils in the county. During the first two years the two grass species dominated the site, but by the third growing season, the two legume species predominated and persisted through the fifth year (1981). However, by 1989 the birdsfoot trefoil had almost disappeared and now the dominating vegetative cover consists mostly of crownvetch and orchardgrass.

For brevity, only the foliar analyses for crownvetch and orchardgrass will be discussed. Foliar concentrations of macronutrients are given in Table 3. Nutrients (N and P) were all generally higher in the sludge-grown plants. Potassium and Ca were higher in the sludge-grown orchardgrass than in control plants. Potassium and Ca were only slightly lower in the sludge-grown birdsfoot trefoil plants than in the control plants. Foliar Mg concentrations were similar in both sludge-grown and control plants. Nutrient levels in the sludge-grown plants in 1989 were about the same level as the first year when sludge was applied. There appears to be little depletion of nutrients from the site over the 12-year period. Birdsfoot trefoil data are given in Table 3 because no crownvetch plants were present on the control plot for comparison. Macronutrient concentrations in crownvetch on the sludge-amended plot are given in Table 4. Concentrations were quite similar to those of birdsfoot trefoil.

Foliar concentrations of Zn, Cu, Pb, Ni, and Cd in orchardgrass and crownvetch are shown in Figures 1 to 5. Concentrations of Zn (Fig. 1), and Ni (Fig. 4) tended to be higher in crownvetch than in orchardgrass; whereas, concentrations of Cu (Fig. 2) tended to be higher in orchardgrass. Concentration of Pb (Fig. 3) and Cd (Fig. 5) were variable and showed no distinct trends. In general, trace metal foliar concentrations tended to be highest the first year and then decrease over time. Except for Ni, foliar concentrations of trace metals in the sludge-grown orchardgrass plants were higher than in control plants. The 1989 values for Cu (Fig. 2) and Cd (Fig. 5) were quite similar to those of 1981. Foliar concentrations of Zn, Ni, and Pb showed a slight increase from 1981 to 1989. Although sludge application appeared to increase some trace metal concentrations in the foliage, these increases were minimal and well below the suggested tolerance levels for agronomic crops (Melsted 1973). No phytotoxicity symptoms were observed during the study. The suggested tolerance levels are not phytotoxic levels but suggest foliar concentration levels at which decreases in growth may be expected.

Spoil Chemical Status

Changes in spoil pH over time are shown in Table 5. Spoil pH tended to increase from 1977 to 1979 and declined thereafter. This may explain why some of the foliar trace metal concentrations showed an increase in 1989. The nutrient status of the spoil seemed to show a general increase in concentrations of Kjeldahl-N up to 1981 and up to 1984 for Bray-phosphorus, K and Ca (Table 6). The application of lime and sludge initially resulted in a decrease in the concentration of Mg; however, since 1978 there has been a steady increase. The 1989 values are lower but still quite adequate to support plant growth.

Concentrations of extractable trace metals in the 0 to 15 cm spoil depth are given in Table 7 and for the 15 to 30 cm spoil depth in Table 8. Concentrations of Cu, Zn, Cr, Pb, Cd, and Ni all show a steady increase for the first five years (1977-81). By this time, most of the sludge organic matter was probably mineralized and most of the trace metals released to the surface spoil. Results of spoil analyses in 1984 and 1989 showed a gradual decrease in concentrations of all trace metals. Although the sludge application seemed to increase the concentrations of extractable trace metals in the 0 to 15 cm spoil depth, these higher concentrations are still within the normal ranges for these elements in U. S. soils (Allaway 1968).

It appears that there is some leaching of trace metals through the spoil profile. Concentrations of trace metals in the 15 to 30 cm spoil depth show a general increasing trend from 1977 to 1989.

Groundwater Quality

Results of the analyses of groundwater well samples are given in Table 9. The values for Well

Table 3. Mean foliar concentrations of macronutrient elements in orchardgrass and birdsfoot trefoil collected from the control and sludge-amended plots.

Sludge application	Year	Orchardgrass N	Orchardgrass P	Orchardgrass K	Orchardgrass Ca	Orchardgrass Mg	Birdsfoot trefoil N	Birdsfoot trefoil P	Birdsfoot trefoil K	Birdsfoot trefoil Ca	Birdsfoot trefoil Mg
Mg/ha		----------%----------					----------%----------				
0	1977	1					1				
	1978	0.92	0.18	1.51	0.36	0.23	1.03	0.24	1.93	0.61	0.26
	1979	1.17	0.22	2.41	0.30	0.22	2.59	0.14	1.74	1.82	0.40
	1980	1.11	0.24	1.86	0.32	0.20	2.11	0.17	1.92	1.02	0.23
	1981	1.22	0.18	1.62	0.68	0.22	3.32	0.17	1.89	1.52	0.29
	1989	1.67	0.17	1.82	0.42	0.30	2.31	0.17	1.71	0.92	0.22
184	1977	2.62	0.40	2.84	0.84	0.31	3.64	0.27	1.46	1.99	0.28
	1978	1.26	0.37	2.01	0.49	0.28	1.27	0.36	2.30	0.59	0.25
	1979	1.33	0.51	2.53	0.47	0.23	3.57	0.25	1.56	0.54	0.20
	1980	1.70	0.42	2.65	0.45	0.23	2.93	0.25	1.62	1.27	0.18
	1981	2.57	0.37	2.38	0.53	0.26	4.03	0.26	1.69	1.14	0.23
	1989	2.36	0.37	2.24	0.45	0.22	2.38	0.16	1.01	0.65	0.23

[1]No plants available for sampling

Table 4. Mean foliar concentrations of macronutrient elements in crownvetch on the sludge-amended plot.

Year	Crownvetch N	Crownvetch P	Crownvetch K	Crownvetch Ca	Crownvetch Mg
	----------%----------				
1977	3.36	0.34	1.64	2.63	0.42
1978	2.35	0.37	3.14	0.96	0.45
1979	3.35	0.22	1.29	1.68	0.25
1980	3.00	0.27	1.89	1.72	0.29
1981	3.78	0.31	1.89	1.25	0.23
1989	2.62	0.21	2.20	0.91	0.26

Table 5. Changes in Spoil pH over the thirteen year period

Depth	Soil pH May 1977[1]	Sept 1977	Nov 1978	Oct 1979	May 1981	Aug 1989
cm						
0-15	3.8	6.2	6.7	7.3	5.8	5.4
15-30	3.8	4.2	4.6	5.1	3.4	5.6

[1]Pre-treatment samples

1 (control) reflect quality of groundwater for the disturbed mine site. Well 2 reflects the effects of the sludge application on water quality. Depth to the water table was 4.9 m in Well 1 and 3.0 in Well 2 in 1989. During the first five years (1977 to 1981) the water table fluctuated between 4.4 to 5.3 m in Well 1 and between 2.5 and 3.4 m in Well 2. Results indicate that the sludge application did not appear to have any significant effect on groundwater concentrations of nitrate-N. Average monthly concentrations of NO_3-N were below 10 mg/l (maximum concentration for potable water) for all months sampled during the five-year period (1977-81). The highest monthly values were 3.0 mg/l for the control well and 2.4 mg/l for Well 2.

Application of lime and sludge and subsequent revegetation appears to have had a positive effect on groundwater pH (Table 9). Groundwater pH increased from 4.6 (1977) to 6.0 by 1981. Results of the 1989 sampling indicated a pH of 6.6. There has also been a gradual increase in pH in the

Table 6. Changes in concentrations of Kjeldahl-nitrogen, Bray-phosphorus and exchangeable cations in the spoil collected at the 0-15 cm depth

Year	Kjeldahl Nitrogen	Bray Phosphorus	K	Ca	Mg
	%	---------- mg/kg ----------			
May 1977[1]	0.04	2	12	541	452
Sept 1977	0.05	11	19	1222	32
1978	0.09	9	23	2600	40
1979	0.16	38	46	3873	53
1981	0.34	79	45	1298	99
1984	---	91	74	1440	108
1989	0.12	83	30	733	84

[1] Pre-sludge samples

Table 7. Changes in concentrations of extractable trace metals from spoil collected at the 0-15 cm depth following sludge application.

Sampling Date	Cu	Zn	Cr[2]	Pb	Cd	Ni
	---------- mg/kg ----------					
May 1977[1]	2.5	2.9	0.2	0.5	0.02	1.1
Sept 1977	10.8	7.7	0.4	3.5	0.04	0.9
1978	8.8	7.7	0.2	2.3	0.02	1.2
1979	58.7	56.9	1.7	13.0	0.27	1.5
1981	87.3	74.6	3.5	22.7	0.95	2.8
1984	57.6	59.6	---	14.8	0.56	2.8
1989	51.9	37.8	---	13.5	0.42	2.0
Normal Range for U.S. Soils	2-100	10-300	5-3000	2-200	0.01 7.00	5-500

[1] May 1977 values represent pretreatment conditions
[2] Values for Cr are total concentrations.

control well from pH 4.4 to pH 5.8. Since 1980, attempts have been made to reclaim the control area by conventional methods using lime and fertilizer. The amounts of lime and fertilizer applied and frequency of application are not known as the coal company is no longer in business. However, these applications and vegetation growth probably contributed to the increase in groundwater pH in the control well.

There appears to be no significant increase in any of the trace metal concentrations over the initial five-year period (1977-1981) in the groundwater samples from Well 2 compared to the control well (Table 9). From 1977 to 1981 most of the monthly concentrations were within the U.S. Environmental Protection Agency drinking water standards. The only exception was Pb which exceeded the limit of 0.05 mg/l for both the control well and Well 2, probably resulting from solubilization upon weathering after mining. The highest monthly Pb values were 0.28 mg/l in the control well and 0.33 mg/l in Well 2 in 1978, and the mean annual Pb concentrations were 0.19 and 0.20 mg/l for control well and Well 2, respectively. By 1981, however, the mean annual Pb concentrations had decreased to 0.04 and 0.05 mg/l for the two wells. Results of analyses of the groundwater samples collected in 1989 had extremely low concentrations of all trace metals in both wells in comparison to values for the initial five years (1977-81).

Conclusions

Re-evaluation of an abandoned strip mine spoil bank 12 years after being amended with 184 Mg/ha of

Table 8. Changes in concentrations of extractable trace metals from spoil collected at the 15-30 cm depth following sludge application.

Sampling Date	Cu	Zn	Cr	Pb	Cd	Ni
	mg/kg					
May 1977[1]	3.0	2.4	0.10	0.6	0.020	1.0
Sept 1977	4.0	2.0	0.10	1.3	0.010	0.4
1978	2.5	1.7	<0.01	1.3	0.007	0.7
1979	9.2	8.7	0.28	2.4	0.026	0.2
1981	2.4	2.8	0.05	0.5	0.014	0.4
1989	13.8	10.2	0.43	3.8	0.122	1.9

[1]May 1977 values represent pretreatment conditions
[2]Values for Cr are total concentrations

Table 9. Mean annual concentrations of nitrate - N and trace metals in groundwater

Site	Year[1]	pH	NO_3-N	Cu	Zn	Cr	Pb	Cd	Ni
			mg/l						
Well 1 (control)	1977	4.4	1.4	0.22	4.13	0.02	0.14	0.006	3.67
	1978	4.3	<0.5	0.23	2.02	0.01	0.19	0.002	0.98
	1979	4.6	<0.5	0.17	1.48	0.03	0.13	0.001	0.50
	1980	5.5	0.6	0.05	0.89	0.05	0.09	0.001	0.50
	1981	5.7	0.7	0.06	0.83	0.03	0.04	0.003	0.31
	1989[2]	5.8	0.02	0.01	0.09	<0.001	0.01	0.001	0.06
Well 2 (sludge)	1977	4.6	1.1	0.10	3.39	0.03	0.09	0.001	2.67
	1978	4.5	<0.5	0.14	3.29	0.01	0.20	0.002	1.26
	1979	4.4	<0.5	0.18	1.49	0.03	0.13	0.001	0.97
	1980	5.7	0.6	0.05	1.05	0.04	0.11	0.001	0.76
	1981	6.0	0.6	0.05	0.57	0.02	0.05	0.001	0.31
	1989[2]	6.6	0.06	0.01	0.07	<0.001	0.01	0.001	0.04
EPA drinking water standard			10	1	5	0.05	0.05	0.010	---

[1]Values are annual means of monthly samples.

[2]Average of three samples collected in August 1989.

municipal sludge indicates that a single large application of sludge can be used successfully to revegetate mine lands with no apparent adverse effects on vegetation, spoil, or groundwater quality.

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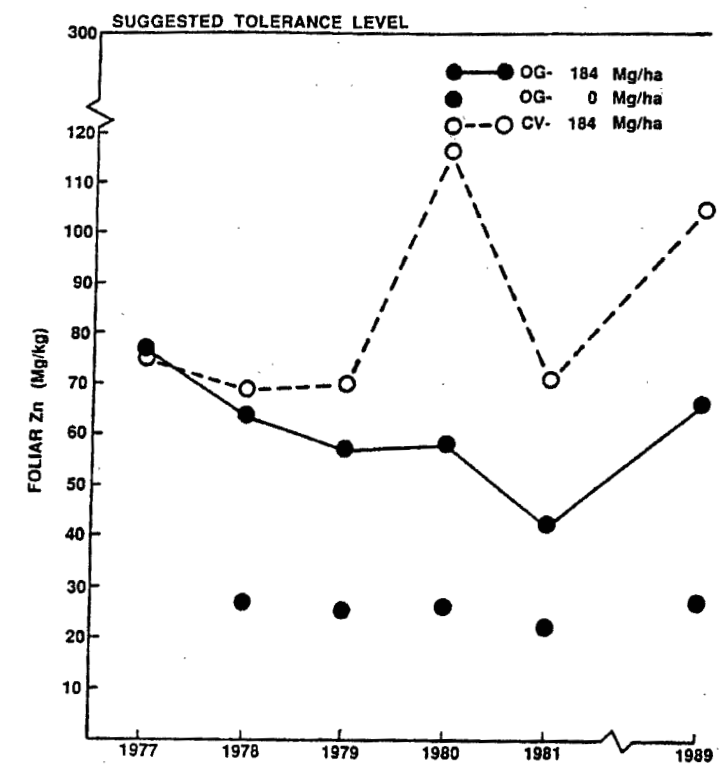

Figure 1. Mean foliar concentration of Zn in orchardgrass and crownvetch collected from the control and sludge-amended plots.

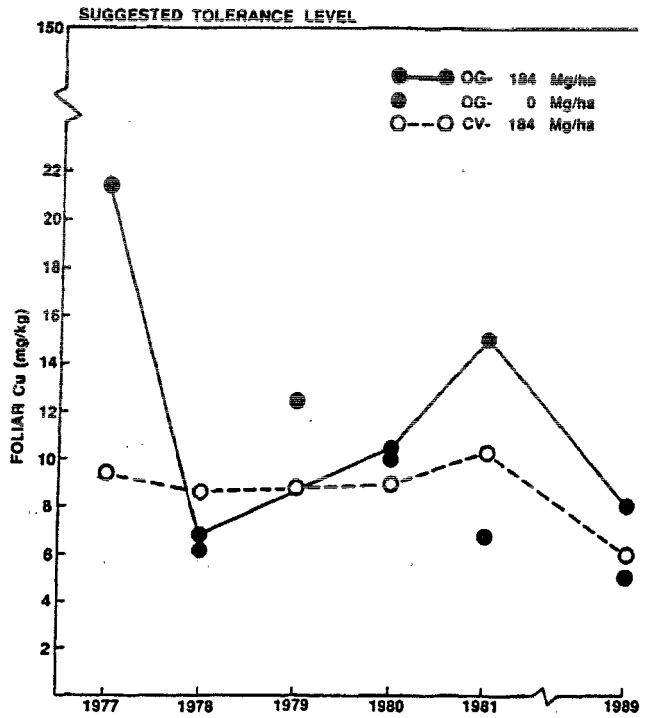

Figure 2 Mean foliar concentration of Cu in orchardgrass and crownvetch collected from the control and sludge-amended plots.

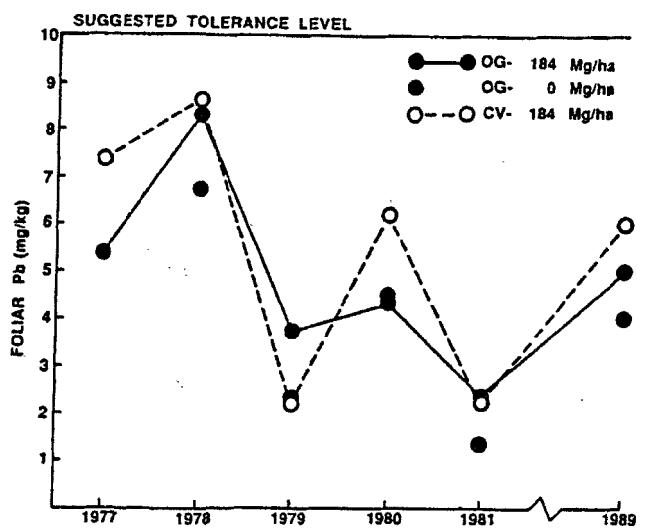

Figure 3. Mean foliar concentration of Pb in orchardgrass and crownvetch collected from the control and sludge-amended plots.

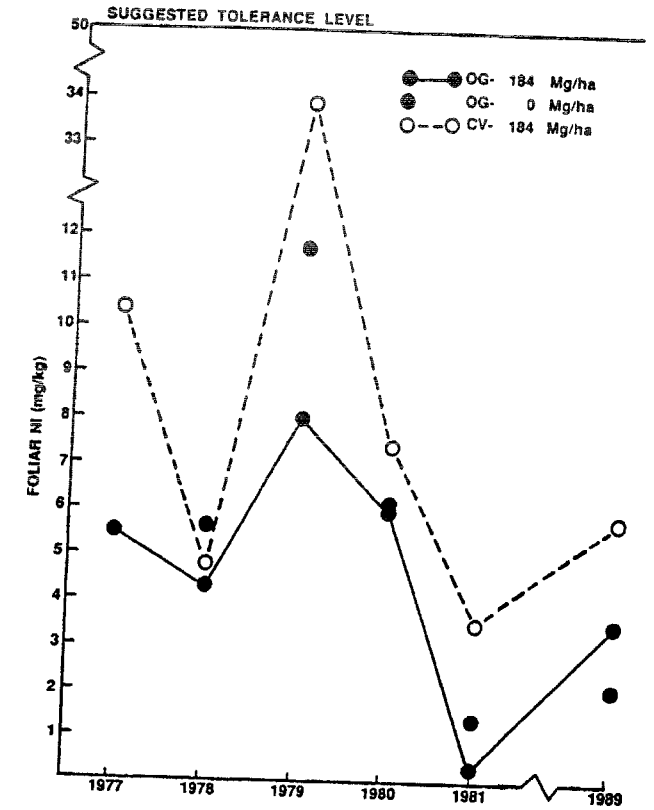

Figure 4. Mean foliar concentration of Ni in orchardgrass and crownvetch collected from the control and sludge-amended plots.

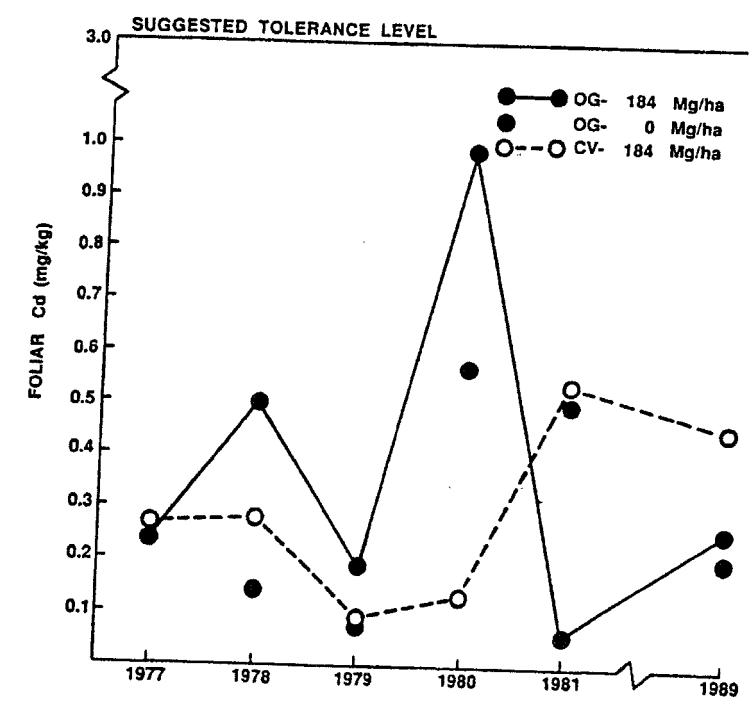

Figure 5. Mean foliar concentration of Cd in orchardgrass and crownvetch collected from the control and sludge-amended plots.

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Appendix B
Federal Sewage Sludge Contacts

Table B-1. EPA Regional Sewage Sludge Contacts

REGION 1
Thelma Hamilton (WMT-ZIN)
JFK Federal Bldg.
One Congress St.
Boston, MA 02203
(617) 565-3569
Fax (617) 565-4940

REGION 2
Alia Roufaeal
Water Management Division
26 Federal Plaza
New York, NY 10278
(212) 264-8663
Fax (212) 264-9597

REGION 3
Ann Carkhuff (3WM55)
841 Chesnut St.
Philadelphia, PA 19107
(215) 597-9406
Fax (215) 597-3359

REGION 4
Vince Miller
Water Division
345 Courtland St., NE.
Atlanta, GA 30365
(404) 347-3012 (ext. 2953)
Fax (404) 347-1739

REGION 5
Ash Sajjad (5WQP-16J)
Water Division
77 W. Jackson Blvd.
Chicago, IL 60604-3590
(312) 886-6112
Fax (312) 886-7804

REGION 6
Stephanie Kordzi (6-WPM)
Water Management Division
1445 Ross Ave., #1200
Dallas, TX 75202-2733
(214) 665-7520
Fax (214) 655-6490

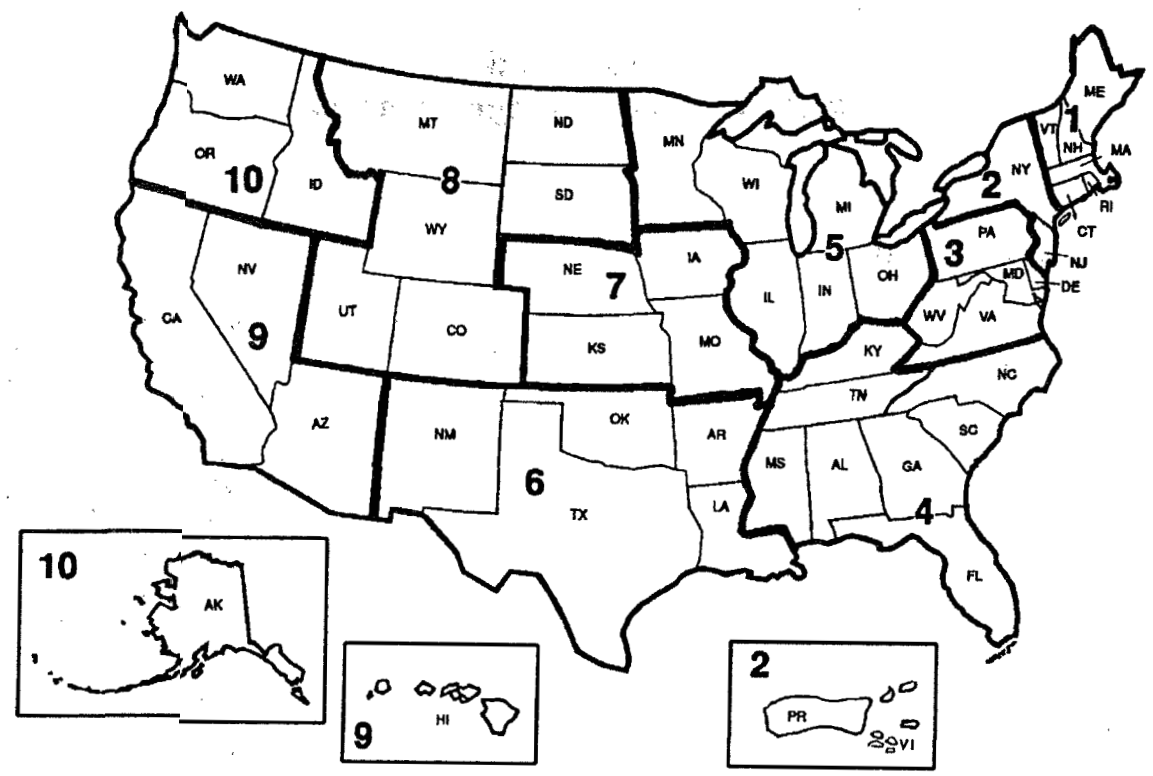
REGION 7
John Dunn
Water Management Division
726 Minnesota Ave.
Kansas City, KS 66101
(913) 551-7594
Fax (913) 551-7765

REGION 8
Bob Brobst (8WM-C)
Water Management Division
999 18th St., Suite 500
Denver, CO 80202-2405
(303) 293-1627
Fax (303) 294-1386

REGION 9
Lauren Fondahl
Permits Section
75 Hawthorne St. (W-5-2)
San Francisco, CA 94105
(415) 744-1909
Fax (415) 744-1235

REGION 10
Dick Hetherington (WD-184)
Water Management Division
1200 Sixth Ave.
Seattle, WA 98101
(206) 553-1941
Fax (206) 553-1775

U.S. EPA Regions



Region—State	Region—State	Region—State
4—Alabama	1—Maine	3—Pennsylvania
10—Alaska	3—Maryland	1—Rhode Island
9—Arizona	1—Massachusetts	4—South Carolina
6—Arkansas	5—Michigan	8—South Dakota
9—California	5—Minnesota	4—Tennessee
8—Colorado	4—Mississippi	6—Texas
1—Connecticut	7—Missouri	8—Utah
3—Delaware	8—Montana	1—Vermont
3—Washington, DC	7—Nebraska	3—Virginia
4—Florida	9—Nevada	10—Washington
4—Georgia	1—New Hampshire	3—West Virginia
9—Hawaii	2—New Jersey	5—Wisconsin
10—Idaho	6—New Mexico	8—Wyoming
5—Illinois	2—New York	9—American Samoa
5—Indiana	4—North Carolina	9—Guam
7—Iowa	8—North Dakota	2—Puerto Rico
7—Kansas	5—Ohio	2—Virgin Islands
4—Kentucky	6—Oklahoma	
6—Louisiana	10—Oregon	

Figure B-1. Map of U.S. EPA regions.

Appendix C
Permit Application Requirements

Permits that are issued to publicly owned treatment works (POTWs) must include standards for sewage sludge use or disposal. In addition, EPA may issue sewage sludge permits to other "treatment works treating domestic sewage" (TWTDS) (i.e., treatment works that generate, change the quality of, or dispose of sewage sludge).

The EPA's sewage sludge permit program regulations establish a framework for permitting sewage sludge use or disposal. The regulations require submission of a permit application that provides the permitting authority with sufficient information to issue an appropriate permit. A permit application must include information on the treatment work's identity, location, and regulatory status, as well as information on the quality, quantity, and ultimate use or disposal of the sewage sludge managed at the treatment works.

Because the sewage sludge permitting regulations were promulgated several years before the Part 503 standards, they describe the required application information in broad, almost generic terms. Currently, EPA is developing application forms and the Agency is planning to revise the permit application regulations to reflect specifically the Part 503 standards and to enable permit writers to tailor permit requirements to facilities' specific use or disposal practices.

The deadlines for submitting permit applications were revised in 1993 and are as follows:

- Applicants requiring site-specific pollutant limits in their permits (e.g., sewage sludge incinerators) and facilities requesting site-specific limits (e.g., some surface disposal sites) were required to submit applications by August 18, 1993.
- All other applicants with National Pollutant Discharge Elimination System (NPDES) permits are required to submit sewage sludge permit applications at the time of their next NPDES permit renewals.
- So-called sewage sludge-only (non-NPDES) treatment works that are not applying for site-specific limits, and are not otherwise required to submit a full permit application, only need to submit limited screening information and must have done so by February 19, 1994.

The permit application information that must be submitted depends upon the type of treatment works and which sewage sludge management practices the treatment works employs. Questions on permit applications should be directed to the appropriate State and EPA Regional Sewage Sludge Coordinators listed in Appendix B.

Sludge-Only Treatment Works

The limited screening information submitted by a sewage sludge-only treatment works typically will include the following:

- Name of treatment works, contact person, mailing address, phone number, and location.
- Name and address of owner and/or operator.
- An indication of whether the treatment works is a POTW, privately owned treatment works, federally owned treatment works, blending or treatment operation, surface disposal site, or sewage sludge incinerator.
- The amount of sewage sludge generated (and/or received from another treatment works), treated, and used or disposed.
- Available data on pollutant concentrations in the sewage sludge.
- Treatment to reduce pathogens and vector attraction properties of the sewage sludge.
- Identification of other facilities receiving the sewage sludge for further processing or for use or disposal.
- Information on sites where the sewage sludge is used or disposed.

Facilities Submitting Full Permit Applications

A full permit application is much more comprehensive than the limited screening information described above for sewage sludge-only facilities. A full permit application typically will include the following information:

General Information

- Name of treatment works, contact person, mailing address, phone number, and location.
- Name and address of owner and/or operator.
- An indication of whether the treatment works is a POTW, privately owned treatment works, federally owned treatment works, blending or treatment operation, surface disposal site, or sewage sludge incinerator.
- Whether the treatment works is a Class I sludge management facility (i.e., a pretreatment POTW or another facility designated Class I by the permitting authority).
- The NPDES permit number (if any) and the number and type of any relevant Federal, State, or local environmental permits or construction approvals applied for or received.
- Whether any sewage sludge management occurs on Native American lands.
- A topographic map showing sewage sludge management facilities and water bodies 1 mile beyond the property boundary and drinking water wells 1/4 mile beyond the property boundary.
- Results of hazardous waste testing for the sewage sludge, if any.
- Data on pollutant concentrations in the sewage sludge.

Information on Generation of Sewage Sludge or Preparation of a Material From Sewage Sludge

- The amount of sewage sludge generated.
- If sewage sludge is received from off site, the amount received, the name and address of the offsite facility, and any treatment the sewage sludge has received.
- Description of any treatment at the applicant's facility to reduce pathogens and vector attraction properties of the sewage sludge.
- Description of any bagging and distribution activities for the sewage sludge.
- If sewage sludge is provided to another facility for further treatment, the amount provided, the name and address of the receiving facility, and any treatment occurring at the receiving facility.

Information on Land Application of Sewage Sludge

- The amount of bulk sewage sludge applied to the land.
- The nitrogen content of bulk sewage sludge applied to the land.
- The name and location of land application sites, and a copy of the land application plan if all sites have not been identified.
- The name and address of the owner and the person who applies bulk sewage sludge to each site.
- The site type and the type of crop or other vegetation grown.
- Description of any processes at each land application site to reduce vector attraction properties of the sewage sludge.
- Ground-water monitoring data, if available.
- If bulk sewage sludge is subject to cumulative pollutant loading rates, information on how the necessary tracking and notification requirements will be met.
- If bulk sewage sludge is applied to the land in a different state, information on how the permitting authority in the receiving state will be notified.

All permit applications must be signed and certified. The permitting authority may request additional information to assess sewage sludge use or disposal practices, determine whether to issue a permit, or identify appropriate permit requirements.

Appendix D
Conversion Factors

Table D-1. Conversion Factors (Metric to U.S. Customary)

Metric			U.S. Customary Unit	
Name	**Abbreviation**	**Multiplier**	**Abbreviation**	**Name**
Centimeter(s)	cm	0.3937	in	inches
Cubic Meter	m^3	8.1071×10^{-4}	acre-ft	acre-foot
		35.3147	ft^3	cubic foot
		264.25	Mgal	million gallons
Cubic Meters Per Day	m^3/d	2.6417×10^{-4}	Mgal/d or MGD	million gallons per day
Cubic Meters Per Hectare	m^3/ha	1.069×10^{-4}	Mgal/acre	million gallons per acre
Degrees Celsius	°C	1.8 (°C) + 32	°F	degrees Fahrenheit
Gram(s)	g	0.0022	lb	pound(s)
Hectare	ha	0.24711	acre	acre
		0.004	mi^2	square miles
Kilogram(s)	kg	2.205	lb	pound(s)
Kilograms Per Hectare	kg/ha	0.0004	T/ac	tons per acre
Kilograms Per Hectare Per Day	kg/ha/d	0.893	lb/ac/d	pounds per acre per day
Kilograms Per Square Centimeter	kg/cm^2	14.49	lb/in^2	pounds per square inch
Kilometer	km	0.6214	mi	mile
Kilowatt	kW	1.34	hp	horsepower
Liter	L	0.0353	ft^3	cubic foot
		0.264	gal	gallons
Liters Per Second	L/s	0.035	ft^3/s	cubic feet per second
		22.826	gal/d	gallons per day
		15.85	gal/min	gallons per minute
		0.023	Mgal/d	million gallons per day
Metric Tonne	t	1.10	T	ton (short)
Metric Tonnes Per Hectare	t/ha	0.446	T/ac	tons per acre
Meter(s)	m	3.2808	ft	foot (feet)
Meters Per Second	m/s	2.237	mi/h	miles per hour
Micrograms Per Liter	µg/L	1.0	ppb	parts per billion
Milligrams Per Liter	mg/L	1.0	ppm	parts per million
Square Centimeter	cm^2	0.155	in^2	square inch
Square Kilometer	km^2	0.386	mi^2	square mile

BIOSOLIDS FACT SHEET

EPA REGION VIII—*NPDES Branch—Permits Program*
999 18th Street, Suite 500, Denver, Colorado 80202
Mr. Robert Brobst

EPA REGION X—*NPDES Branch—Permits Program*
1200 6th Avenue, Seattle, Washington 98101
Mr. Richard Heatherington

3.3 DRY WEIGHT BASIS (FS/793/03/1)

Laboratory results for sludge are typically reported in one of two forms, wet weight (i.e., mg/L) or a dry weight (i.e., mg/kg). You should request your laboratory to provide the results on a dry weight basis. In the event that the laboratory results are reported on a wet weight basis (i.e., in mg/L), the results for each pollutant in each sample must be recalculated to determine the dry weight concentration. To accomplish this conversion, the percent total solids in the sludge sample must be known.

The following equation can be used to determine the dry weight concentration because the equation uses the assumption that the specific gravity of water and sewage sludge are both equal to one. However, this assumption holds true only when the solids concentration in the sludge is low. The calculated dry weight concentration may vary slightly from the actual concentration as the solids content increases because the density of the sewage sludge may no longer be equal to that of water. Typically, this concern is unrealized as the solids content of sludge is usually low. EPA is aware of this potential problem and may make a determination regarding this matter at a later date.

Determine the pollutant concentration on a dry weight basis using the following abbreviated conversion:[1]

$$\text{ry,mg/kg)} = \left(\frac{\text{PC(wet, mg/L)}}{\text{\% total solids}}\right)$$

where **PC = Pollutant Concentration**

A unit conversion is incorporated into the equation

[1] *Analytical Methods Used in the National Sewage Sludge Survey.* August 1988. U.S. EPA Office of Water Regulations and Standards (WH-552), Industrial Technology Division, Washington, DC.

FS/793/03/1

Dry Weight Basis

Determine the pollutant concentration on a dry weight basis using the following conversion:

$$\text{PC(dry,mg/kg)} = \left(\frac{\text{PC(wet, mg/L)}}{\text{\% total solids}}\right)$$

Example #1: Determine the dry weight concentrations of the pollutants.

- The laboratory analysis of your sludge yielded the following results:

As - 6.6 mg/L Cd - 5.5 mg/L Cr - 192.5 mg/L Cu - 374 mg/L
Pb - 44 mg/L Hg - 0.22 mg/L Mo - 0.88 mg/L Ni - 44 mg/L
Se - 2.2 mg/L Zn - 330 mg/L

- The percent solids was determined to be 22%.

Therefore, using the given equation, the dry weight concentration of As can be determined as follows:

$$\frac{\text{6.6 mg/L (As,wet)}}{\text{22 \%}} = \frac{\text{6.6 mg/L}}{\text{0.22}} = \text{30 mg/kg As, dry weight}$$

Remember to convert the percent total solids to a decimal by multiplying by 100.

The remainder of the converted results are:

Cd=25mg/kg, Cr=875mg/kg, Cu=1,700mg/kg, Pb=200mg/kg, Hg=1mg/kg, Mo=4mg/kg, Ni=200mg/kg, Se=10mg/kg, Zn=1,500mg/kg

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$$\frac{(\quad)\text{mg/L}}{(\quad)\ \%} = \frac{(\quad)\text{mg/L}}{0.} = (\quad)\text{mg/kg dry weight}$$

Table D-3. Conversion of Sludge Volume to Dry Metric Tons.

EQUATIONS FOR CONVERTING SLUDGE VOLUME TO DRY METRIC TONS[a]

Applicability:

The amount of sewage sludge used or disposed must be reported as metric tons, dry weight.

Procedure:

Step 1: Convert the common measure (e.g., cubic yards or gallons) to the English System or short tons, dry weight.

$$\textit{Dry short tons} = \textit{gallons of sewage sludge} \times \frac{8.34\ lb}{gallon} \times \frac{ton}{2000\ lb} \times \textit{Percent Solids}$$

8.34 lb/gal is the density of water. This equation is therefore applicable to liquid sludges (less than 5 percent solids). Site-specific densities may be determined and substituted in this equation for a more accurate result.

$$\textit{Dry short tons} = \textit{cubic yards (wet) of sewage sludge} \times \frac{Y\ lb}{cubic\ yard} \times \frac{ton}{2000\ lb} \times \textit{Percent Solids}$$

Y lb/cubic yard is the site-specific bulk density of the sewage sludge. It must be determined for each type of sludge prepared and substituted in the equation for accurate results.

Step 2: If you are starting with the English System or short tons, convert them to dry weight.

$$\textit{Dry tons} = \textit{Wet tons} \times \textit{Percent Solids}$$

Step 3: Convert the English System or short tons to metric tons.

$$\textit{Dry metric tons} = \textit{Dry short tons} \times .907$$

[a] Source: U.S. EPA. 1993. Preparing sewage sludge for land application or surface disposal. EPA/831/B-93/002a. Washington, DC.

*U.S. Government Printing Office: 1996 — 750-001/41037