Municipal Sludge Application in Forests of Northern Michigan: A Case Study

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ABSTRACT A large-scale operational demonstration and research project was cooperatively established by the US. Environmental Protection Agency, Michigan Department of Natural Resources, and Michigan State University to evaluate the practice of forest land application as an option for sludge utilization. Project objectives included completing (1) a logistic and economic assessment and demonstration of the technology available for conducting sludge applications in forest stands, and (2) several research studies that would augment knowledge in the areas of public involvement and acceptance, wildlife populations, food-chain transmission of potential toxicants, groundwater quality, nutrient cycling, and vegetation growth. Field trials in four forest types (aspen, oak, pine, northern hardwoods) were of a completely random design covering 54 ha, of which 18 ha were treated with nearly 4 million liters of anaerobically digested sludge. Average solids loading ranged from 8 to 10 Mg/ha, resulting in total nitrogen levels of 400 to 800 kg/ha. Differences in loading levels of nutrients, heavy metals, and trace elements were generally not significant among treated plots. Sludge was transported by truck a distance of 80 km to the study sites and sprayed by an all-terrain tanker on the forest floor at a cost of $48,576. The resulting unit cost of 1.3 cents per liter was comparable to typical operational costs for sludge application to farmland, considering the greater transport distance in this study. Preliminary findings indicate an enhanced nutritive quality of forage on fertilized plots and a resulting increase in use by both deer and elk. Increases in plant growth were related to elevated levels of soil nitrogen, phosphorus, calcium, and magnesium. Slight increases of nitrate-N were observed in soil percolate within one year of application, but these rapidly returned to near background concentrations. Analysis of sociological data provided new insights into public concerns and attitudes and outlined a process for constructive citizen involvement in program planning.

Implementation of secondary treatment standards for wastewater discharges in the Great Lakes Region has resulted in increased volumes of wastewater sludge requiring removal from treatment facilities. In Michigan, combined residential and industrial water use and mandatory effluent phosphorus removal have resulted in the annual generation of 202,500 dry Mg (223,218 tons) of sludge by municipal wastewater treatment plants (MDNR 1983). While traditional strategies for dealing with this residual waste have emphasized options for disposal such as incineration and use as landfill, sludge management programs developed since 1978 have increasingly turned to nutrient and organic matter utilization through the practice of land application.

Numerous concerns have been raised about the hazards of land application of sludge. The concerns of state residents center on public health and environmental quality (Peyton et al. 1983). The potential presence of pathogens, heavy metals, and toxic organic compounds in sludge is a leading health concern. Nutrient enrichment of groundwater and contamination of wildlife, soil, and groundwater by toxic metals and organics are the major environmental quality concerns of land application programs.

BACKGROUND

In Michigan during the last decade, fertilization of farmland has become the most frequently selected option for the land application of wastewater sludge. Literature devoted to agricultural application research is far more voluminous than that dealing with studies of silvicultural use. However, numerous municipalities in the northern two-thirds of the state do not have cropland available for sludge recycling. In this locale are millions of hectares of forest land that could serve as sites where the constituents in sludge would be assimilated in a manner that could stimulate forest productivity while posing minimal danger to environmental quality or public health.

Forest crops (wood products) are generally nonedible, thereby diminishing the risk of human exposure to hazardous elements in the food chain. The long-term accumulation of biomass on a forest site provides substantial storage capacity for elements applied in sludge over the length of a crop rotation. The harvest of tree boles and whole trees offers a means of removing sludge-applied elements from the treated forest site. Forest soils are generally porous, resulting in minimal surface runoff of applied nutrients, and usually nutritionally impoverished, providing opportunity to increase soil organic matter and nutrient levels substantially through sludge additions. Native forest plants, though adapted to low ambient nutrient levels in forest soils, have demonstrated their ability to respond with nutrient and biomass increases following fertilization with sludge (Brockway 1983). Forest sites are usually remote from large population centers and are used for recreational activities of a dispersed nature, minimizing the opportunity for human contact with recently applied sludge.

PROJECT AND OBJECTIVES

Early USDA Forest Service research provided evidence that forest ecosystems could accommodate sludge constituents in a manner that would enhance nutrient cycling and biological productivity while ensuring protection of groundwater in the phreatic aquifer (Urie et al. 1978, Brockway 1979, Brockway and Urie 1983). In building on these small-plot studies, a demonstration and research project was cooperatively established by the U.S. Environmental Protection Agency, Michigan Department of Natural Resources, and Michigan State University to evaluate the practice of forest land application as a viable option for sludge utilization. Project objectives included completing (1) a logistic and economic assessment and demonstration of the technology available for conducting sludge applications in forest stands and (2) several research studies that would augment the base of knowledge in the areas of public involvement and acceptance, wildlife populations, food-chain transmission of potential toxicants, nutrient availability and groundwater quality, nutrient cycling, and vegetation growth and nutrition.

This project was seen as a means of bridging the gap between small-plot research and eventual large-scale program operation by municipalities and industries. The anticipated products are to include (1) numerous summaries of scientific findings, (2) operational guidelines based on project and previous research and management experience, (3) materials for a public education program, and (4) a model for encouraging constructive public involvement in future program planning decisions. Each of these will address the information needs of the public, municipal and industrial planners and managers, government agency officials, and the scientific community. These documents will aid state agency specialists in providing sludge generators with information to assist them in establishing properly planned and managed forest land application programs in accord with the statewide strategy for land recycling of wastewater sludge.

MATERIALS AND METHODS

Demonstration Sites

Wastewater sludge fertilization trials were conducted in Montmorency County on the Atlanta Forest Area (Figure 1) of the Mackinac State Forest in northeastern lower Michigan (45°N, 84” 10′W). Vegetation on each site was representative of the upland forest types of major commercial importance in the northern portion of the state. Permeable glacial drift materials formed the parent material for the soils, which are low in native fertility and allow rapid infiltration of excess precipitation falling on all four of the forest sites (Hart et al. 1983). Annual precipitation averages 735 mm (29 inches) in this area

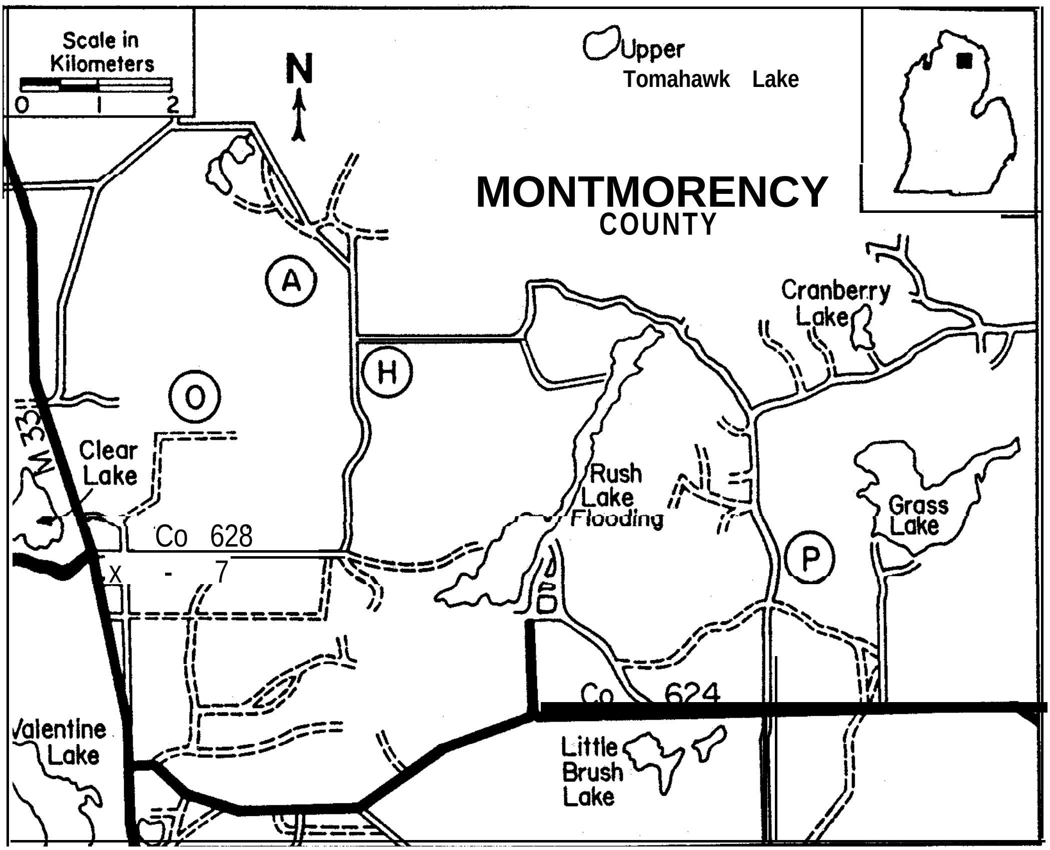

Figure 1. Sludge fertilization sites in northern Michigan. A = aspen; 0 = oak; P = pine; H = northern hardwoods.

(Strommen 1967). The sites are underlain by a phreatic aquifer which is contiguous with the regional groundwater system (Urie et al. 1983).

Aspen Site. The aspen site was occupied by a lo-year-old stand of regeneration which is predominantly bigtooth aspen (*Populus grandidentata* Michx.) containing a secondary component of quaking aspen (*Populus tremuloides* Michx.), northern pin oak (*Quercus ellipsoidallis* L.), cherry (*Prunus* spp. L.), and other species. Soils on this site generally belong to the Grayling series (Spodic Udipsamment) and the Rubicon series (Entic Haplorthod). Grayling soils are excessively drained and developed on deep glacial outwash sands. Rubicon soils are deep, excessively drained and formed in sandy giacio-fluvial deposits. Depth to groundwater was 5 to 8 m (16 to 26 ft).

Oak Site. The oak site was occupied by a '/O-year-old stand that was a mixture of red oak (*Quercus rubra* L.) and white oak (Q. *alba* L.) with scattered pines (*Pinus* spp. L.) and aspen. The stand contained 388 trees/ha (157/acre) and an average combined basal area of more than 20 m^2/ha (87 $ft^2/acre$). Soils were predominantly of the Graycalm series (Alfic Udipsamment) with smaller areas of the Rubicon series. Graycalm soils are somewhat excessively drained and formed in deep glacio-fluvial sands. Depth to groundwater was in excess of 25 m as determined from on-site drilling.

Pine Site. The pine site was occupied by a 50-year-old plantation that was a mixture of jack pine (*Pinus banksiana* Lamb.) and red pine (*P. resinosa* Ait.). The stand contained 557 trees/ha with a combined basal area of 17.3 m^2/ha. Soils on the site were of the Grayling series with a smaller area of the Montcalm series (Eutric Glossoboralf). Montcalm soils are deep, well drained, and formed in sandy and loamy glacio-fluvial deposits. Depth to groundwater was 6 to 7 m.

Northern Hardwoods Site. The northern hardwoods site was occupied by a 50-year-old stand that was predominantly red maple (*Acer rubrum* L.) and sugar maple (*A. saccharum* Marsh.) with remnants of American beech (*Fagus grandifolia* Ehrh.), yellow birch (*Betula alleghaniensis* Britton), and white birch (B. *papyrifera* Marsh.) and a minor number of red oak, American basswood (*Tilia americana* L.), white ash (*Fraxinus americana* L.), and eastern hemlock (*Tsuga canadensis* [L.] Carr.). The stand contained 288 trees/ha and an average combined basal area of 14 m^2/ha. Soils were primarily of the Mancelona series, Melita series, and Menominee series (Alfic Haplorthods) with minor areas of the Kawkawlin series (Aquic Eutroboralf) and Sims series (Mollic Haplaquept). Mancelona soils are deep, excessively drained, and formed in sandy and gravelly glacio-fluvial upland deposits. Melita soils are deep, somewhat excessively drained, and formed in sandy materials overlying loamy deposits. Menominee soils are moderately well to well drained and formed in sandy material overlying loamy deposits at 50 to 100 cm. Kawkawlin soils are deep, somewhat poorly drained, and formed in moderately fine-textured glacial tills and ground moraines. Sims soils are deep, poorly to somewhat poorly drained, and formed in fine-textured glacial tills and ground moraines. Depth to groundwater ranged from 1 to 15 m.

Experimental Design

Three replications of three experimental treatments were assigned to completely randomized plots within each study site. The treatments consisted of (1) a control group of plots left undisturbed, (2) a group that underwent access trail development but received no sludge application, and (3) a group that underwent access trail development and received a single application of liquid sludge. Experimental plots were each 1.5 ha (3.7

acres) in area and of a rectangular shape approximately 100 by 150 m. The study plots covered a total of 54 ha, of which 18 ha were treated with nearly 4 million liters (1 million gallons) of wastewater sludge. The sludge application rate averaged 9 Mg of dry solids per ha (4 tons/acre). This design was sufficient to evaluate large-scale operational procedures, costs, and limitations, while affording adequate area for the conduct of a diverse array of research studies.

Site Preparation and Sludge Application

Prior to sludge application, a grid of parallel trails at 20 m (66 ft) intervals was prepared to facilitate application vehicle access and more uniform sludge distribution. Trees harvested from the oak, pine, and northern hardwood sites were felled and removed as whole trees from the stand using a rubber-tired skidder. Because of their small unmerchantable size, trees on the aspen site were removed at the groundline with a bulldozer blade.

Anaerobically digested sludges from the municipal wastewater treatment facilities in Alpena and Rogers City, Michigan, were transported by tank truck to the demonstration sites, where single applications of liquid were sprayed on the forest floor. Applications were conducted in October and November 1981 on the oak and aspen sites and in June and July 1982 on the pine and northern hardwood sites. An all-terrain vehicle, equipped with high flotation tires, a standard pressure-vacuum pump, and a modified three-nozzle spray system, was used for sludge applications on each site (Figure 2).

SLUDGE LOADING AND DISTRIBUTION

Because of the variation in site characteristics, such as microtopography and vegetation structure, and that encountered in operation of application equipment, such as vehicle speed, discharge rate, and tank pressure, a substantial amount of variation in solids, nutrient, and trace element loading can be anticipated on any sludge-treated forest site. An overall assessment indicated that this variation in loading and distribution of sludge constituents was less than expected. However, certain factors did influence the uniformity of sludge applications both among and within treated plots.

Loading Rate Variation Among Plots

Review of past studies of sludge application to forest land revealed that precise estimates of solids, nutrient, and trace element loading rates could not be reported because of the extreme variation in composition of sludge materials. Although only ranges of nutrient and trace element loadings are generally documented, relatively precise measures of these loadings can be obtained from analysis of samples collected from each truckload of sludge and from records of application, which include source of sludge, plot where applied, and number of liters delivered to each plot. Such data were recorded for the aspen and oak sites, while on the pine and hardwood sites more precise loading rates were computed because records of sludge source and volume applied to each strip within a treated plot were included in the loading calculation.

Aspen Site. The aspen site was treated with 1,112,878 liters (294,412 gal) of Alpena wastewater sludge. Variation in the distribution of this liquid is shown in Figure 3. The average dry solids content of the material was 3.2%, resulting in a mean sludge loading rate of approximately 10 Mg/ha (Table 1). The loading rates of nutrients and trace ele-

Figure 2. Sludge application on aspen (above) and oak sites.

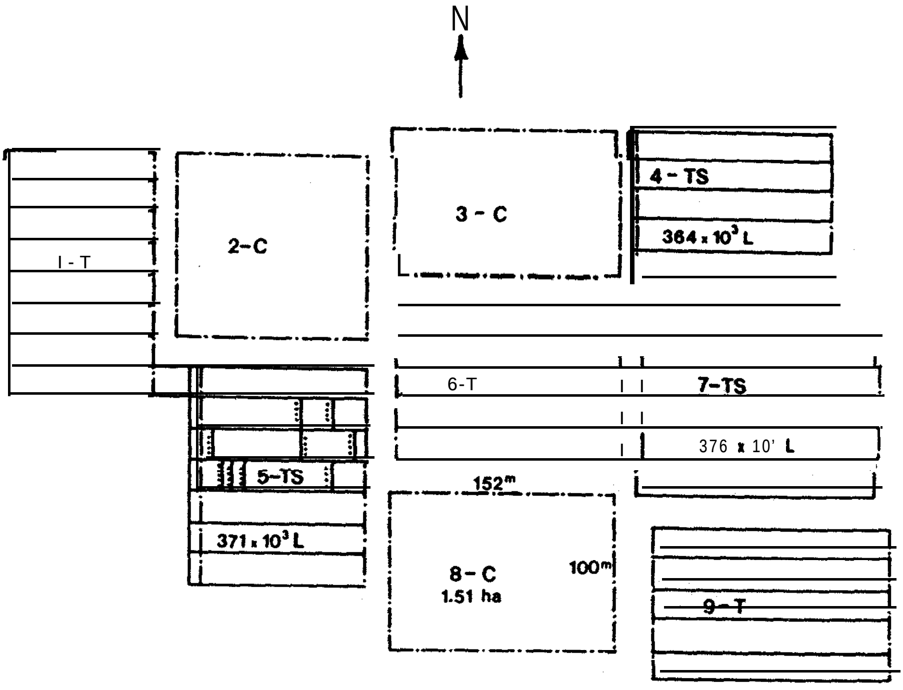

Figure 3. Sludge loading and distribution, aspen site. C = control; T = trails only; TS = trails and sludge; ▬▬ = access trail; —— · —— = plot boundary; ⋯⋯ = sampling transect.

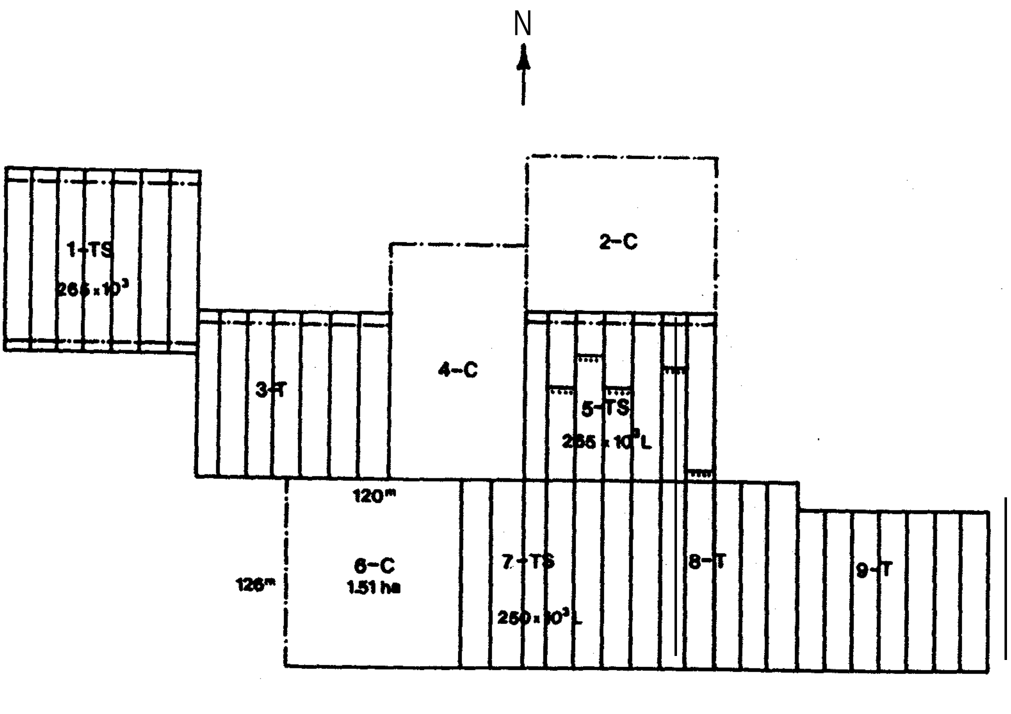

Figure 4. Sludge loading and distribution, oak site. C = control; T = trails only, TS = trails and sludge; ▬▬ = access trail; —— · —— = plot boundary; ⋯⋯ = sampling transect.

ments were computed from data on area of application, volume of sludge applied, and chemical analysis of sludge samples collected during the application period. Loading rates for nitrogen and phosphorus averaged 561 and 291 kg/ha (500 and 260 lb/acre), respectively. Differences in concentrations and loading rates for most major elements were generally not statistically significant between plots.

TABLE 1. Solids, nutrient. and trace element loading, aspen site.

Component	Plot 4 (1.13 ha)	Plot 5 (1.20 ha)	Plot 7 (1.24 ha)	Mean (1.19 ha)
		(kilograms/hectare)		
Solids	8,586a	11,190b	10,165b	9,980
Nitrogen	514.5a	587.3b	580.0b	560.6
Phosphorus	257.2a	309.1b	305.2b	290.5
Potassium	24.82a	27.07b	26.73ab	26.21
Magnesium	39.92a	47.57b	46.58b	44.36
Calcium	402.4a	419.8a	431.7a	418.0
Sodium	30.51a	31.30a	32.53a	31.45
Aluminum	257.2a	343.3b	311.6b	304.0
Iron	470.5a	612.5b	588.6b	557.2
Manganese	6.27a	7.79b	7.06ab	7.04
Copper	4.52a	6.02b	6.49b	5.68
Zinc	9.92a	13.75b	13.20b	12.29
Cadmium	0.54a	0.22b	0.08b	0.28
Boron	0.47a	0.51a	0.34a	0.44
Nickel	0.39a	0.39a	0.49a	0.42
Chromium	1.54a	2.00b	1.88ab	1.81

Plot means followed by the same letter are not significantly different at the 0.05 level (Duncan's multiple range test).

TABLE 2. Solids, nutrient, and trace element loading, oak site.

Component	Plot 1 (1.11 ha)	Plot 5 (1.17 ha)	Plot 7 (1.10 ha)	Mean (1.13 ha)
		(kilograms/hectare)		
Solids	13,964a	4,461b	5,632b	8,019
Nitrogen	453.5a	430.3a	317.9b	400.6
Phosphorus	453.5a	181.2b	181.7b	272.1
Potassium	33.35a	14.33b	16.37b	21.35
Magnesium	80.44a	36.66b	35.56b	50.89
Calcium	1,205.0a	300.3b	351.6b	619.0
Sodium	32.58a	21.58b	21.48b	25.21
Aluminum	275.5a	59.6b	103.8c	146.3
Iron	787.0a	338.84	349.3b	491.7
Manganese	14.97a	1.16b	3.19b	6.44
Copper	6.06a	6.78a	5.54a	6.13
Zinc	15.62a	5.70b	6.44b	9.25
Cadmium	0.11a	0.47b	0.69b	0.42
Boron	0.06a	0.66b	0.57b	0.43
Nickel	0.58a	0.15b	0.21b	0.31
Chromium	1.53a	0.38b	0.65c	0.85

Plot means followed by the same letter are not significantly different at the 0.05 level (Duncan's multiple range test).

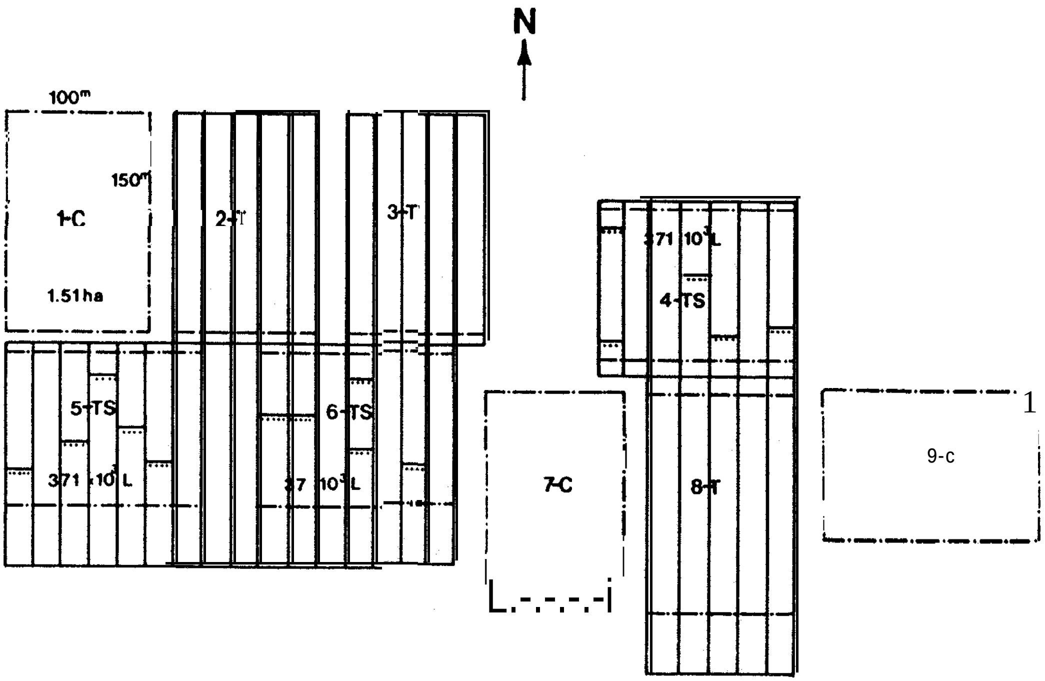

Figure 5. Sludge loading and distribution, pine site. C = control; T = trails only; TS = trails and sludge; —— = access trail; —— · —— = plot boundary; ······ = sampling transect.

Oak Site. The oak site was treated with 264,971 liters of wastewater sludge from Alpena (plot 1) and 514,801 liters of wastewater sludge from Rogers City (plots 5 and 7). Variation in the distribution of these liquids is shown in Figure 4. The average dry solids content of these materials was 3.4%, resulting in a mean sludge loading rate of approximately 8 Mg/ha (Table 2). Plot 1 received the highest application rate (14 Mg/ha). Over the entire site, the nitrogen loading rate averaged 401 kg/ha, while that for phosphorus was 272 kg/ha. Nutrient loadings for plot 1 were much higher than those of other plots. Because of the different chemical characteristics of the two sludges, significant differences were found between plot 1 and plots 5 and 7 for most major elements, except nitrogen, copper, and boron.

Pine *Site.* The pine site was treated with 1,112,878 liters of Alpena wastewater sludge. Variation in the distribution of this liquid is shown in Figure 5. The average dry solids content was 2.6%, resulting in a mean sludge loading rate of approximately 8 Mg/ha (Table 3). The nitrogen loading rate averaged 379 kg/ha and that of phosphorus 253 kg/ha. Differences in the loading rates of most elements were generally not statistically significant between plots.

Northern *Hardwoods Site.* The northern hardwoods site was treated with 673,783 liters of Rogers City wastewater sludge. Variation in the distribution of this liquid is shown in Figure 6. The average dry solids content was 5.196, resulting in a mean sludge loading rate of approximately 9 Mg/ha (Table 4). Because of the higher solids content of this sludge, nutrient additions to these plots were higher than those on other sites. The nitrogen loading rate averaged 783 kg/ha and that of phosphorus 384 kg/ha. Trace element additions were lower on this site than on the other sites. Differences in the loading rates of nutrients and trace elements were not statistically significant between plots.

TABLE 3. Solids, nutrient, and trace element loading, pine site.

Component	Plot 4 (1.25 ha)	Plot 5 (1.13 ha)	Plot 6 (1.15 ha)	Mean (1.18 ha)
		(kilograms/hectare)		
Solids	10,119a	7,058a	7,419a	8,119
Nitrogen	356.1a	459.6a	322.6a	379.4
Phosphorus	237.4a	295.4a	225.8a	252.9
Potassium	23.24a	22.13a	21.00a	22.12
Magnesium	37.09a	31.81a	27.84a	32.25
Calcium	451.9a	355.5ba	313.2b	373.5
Sodium	28.64a	31.61a	30.29a	30.18
Aluminum	176.3a	123.2ba	113.9b	137.8
Iron	592.6a	468.8a	441.3a	500.9
Manganese	5.19a	3.46a	2.76a	3.80
Copper	5.40a	3.66ba	3.61b	4.22
Zinc	10.36a	6.50b	5.97b	7.61
Cadmium	0.14a	0.42a	0.51a	0.36
Boron	0.68a	0.76a	0.69a	0.71
Nickel	0.39a	0.26a	0.40a	0.35
Chromium	1.11a	0.77ba	0.71b	0.86

Plot means followed by the same letter are not significantly different at the 0.05 level (Duncan's multiple range test).

TABLE 4. Solids, nutrient, and trace element loading, northern hardwoods site.

Component	Plot 4 (1.24 ha)	Plot 5 (1.25 ha)	Plot 9 (1.19 ha)	Mean (1.23 ha)
		(kilograms/hectare)		
Solids	8,851a	8,895a	9,885a	9,210
Nitrogen	659.3a	697.7a	992.4a	783.1
Phosphorus	362.6a	387.6a	400.8a	383.7
Potassium	12.46a	12.11a	11.09a	11.89
Magnesium	55.38a	53.68a	40.46a	49.84
Calcium	574.1a	487.0a	447.9a	503.0
Sodium	20.08a	18.33a	17.31a	18.57
Aluminum	90.0a	78.3a	71.0a	79.8
Iron	507.0a	487.4a	403.4a	456.9
Manganese	1.95a	1.63a	1.40a	1.66
Copper	12.05a	11.36a	9.06a	10.82
Zinc	10.12a	8.55a	7.14a	8.60
Cadmium	0.08a	0.08a	0.07a	0.08
Boron	0.30a	0.30a	0.22a	0.27
Nickel	0.26a	0.20a	0.17a	0.21
Chromium	0.68a	0.57a	0.50a	0.58

Plot means followed by the same letter are not significantly different at the 0.05 level (Duncan's multiple range test).

Loading Rate Variation Within Plots

Since variation was apparent in the terrain and vegetation density and structure within treated plots of such large size, it was anticipated that significant variation in sludge loading rates might result. Such variability in nutrient and trace element application rates could result in a differential response of the ecological components to treatment. Therefore, 280 catchment samplers were set out in a series of 28 transects covering all treated plots to quantify the variation in sludge loading rates within plot application areas.

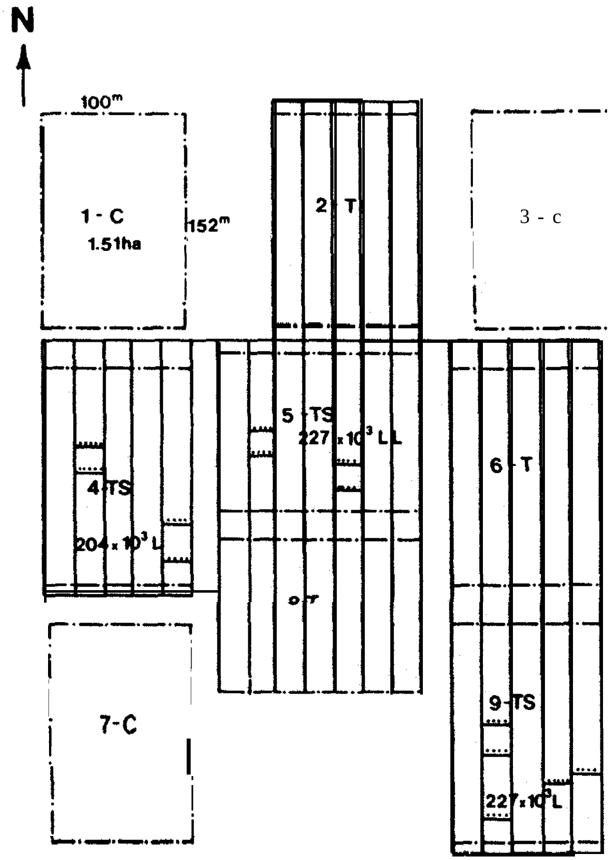

Figure 6. Sludge loading and distribution, northern hardwoods site. C = control; T = trails only; TS = trails and sludge; ▬▬ = access trail; —— . —— = plot boundary; .... = sampling transect.

Data from sludge samples collected were compared with factors that could affect the uniformity of sludge application. Sludge loading rates along and across application strips were affected by variation in application vehicle speed and tank pressure, pit and mound microtopography (including tree stumps), vegetation structure and density, wind speed, and distance from application vehicle. Among these, distance from the application vehicle and vegetation density and structure appeared to produce the most prominent effects.

Distance Effects. The variation of sludge loading rate with distance from application vehicle is shown in Figures 7, 8, 9, and 10 for the aspen, oak, pine, and northern hardwoods sites, respectively. Generally, there were nonsignificant variations in sludge application on the sites. However, a trend of decreasing solids loading with increasing distance from the point of discharge was noted on the aspen site (Figure 7). This measurable but nonsignificant trend resulted from mechanical difficulties with the application vehicle that were encountered while treating this site,

Basal Area Effects. The variation of sludge loading rate with stand basal area is shown in Figures 11 and 12 for northern hardwoods and pine, respectively. No significant variations in sludge applications attributable to basal area were found on the aspen, oak, or northern hardwoods sites. However, a trend of decreasing solids loading with increasing basal area was measured on the pine site. This trend was believed to be the result of

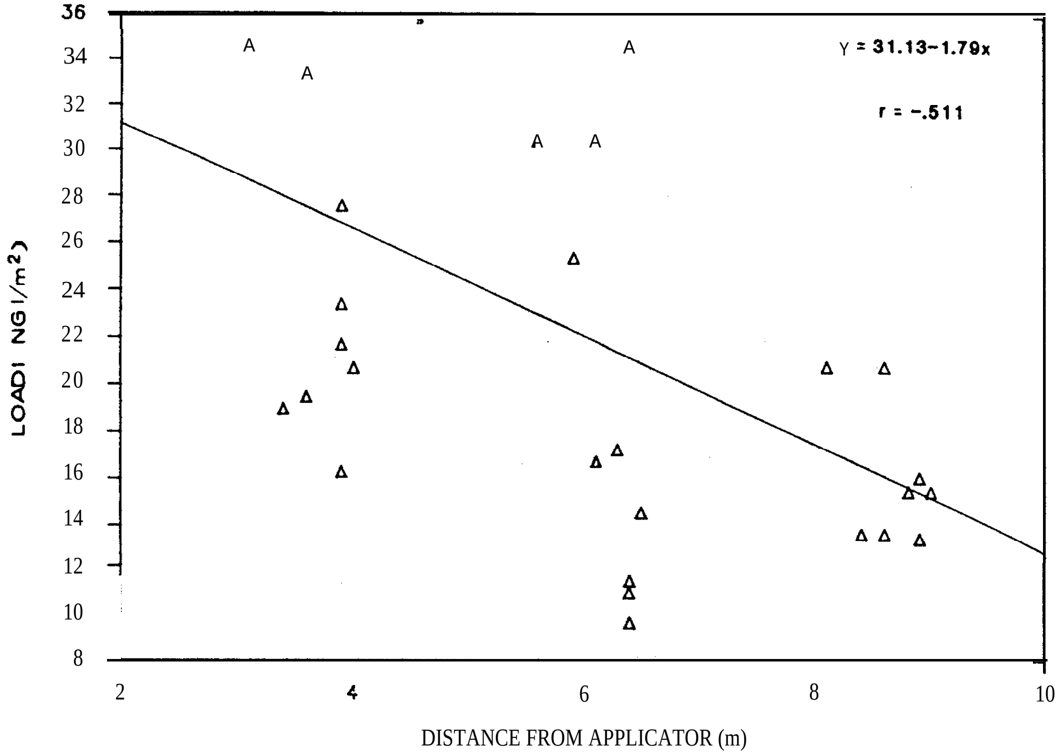

Figure 7. Sludge loading rate versus discharge distance, aspen site.

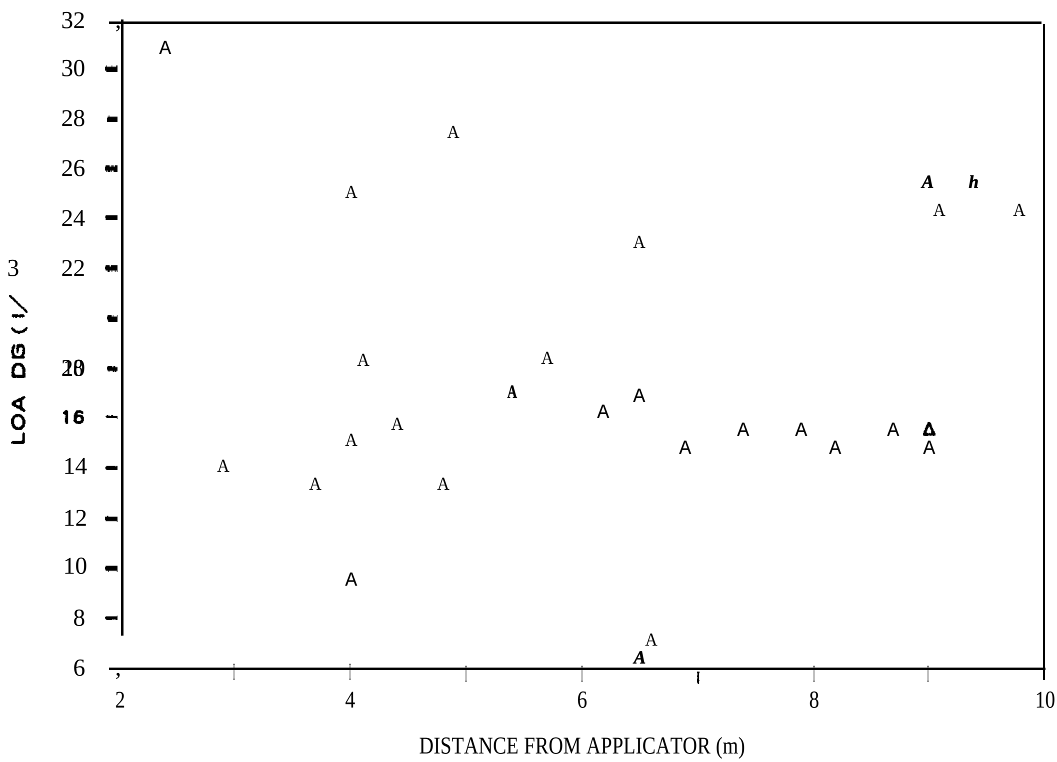

Figure 8. Sludge loading rate versus discharge distance, oak site.

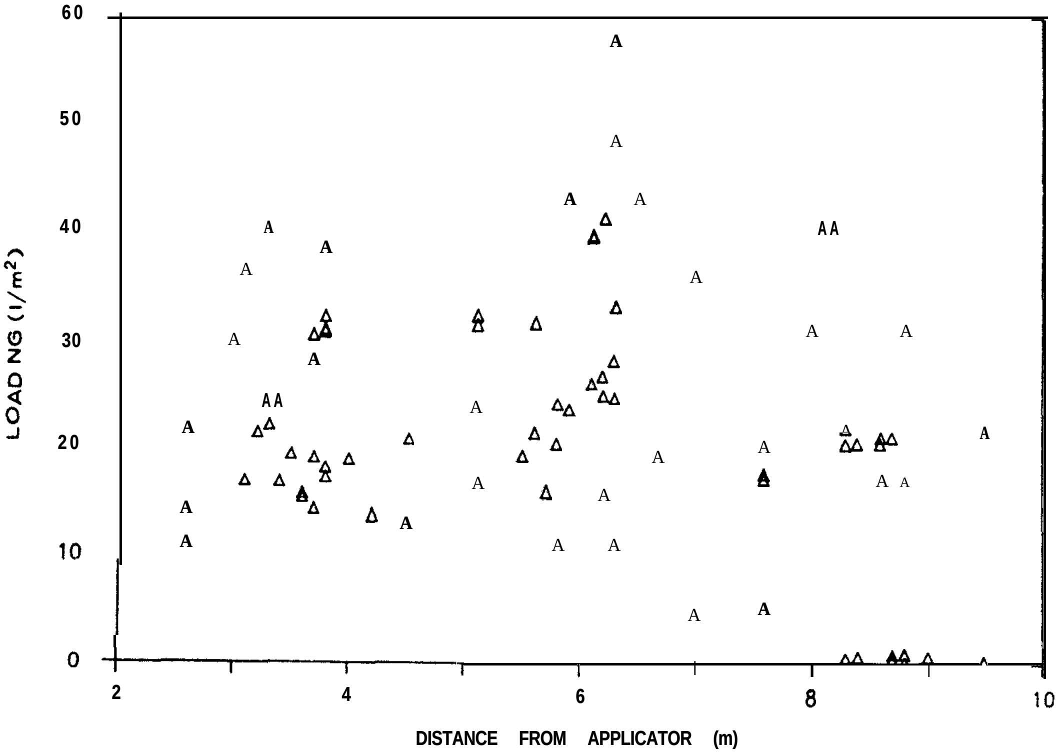

Figure 9. Sludge loading rate versus discharge distance, pine site.

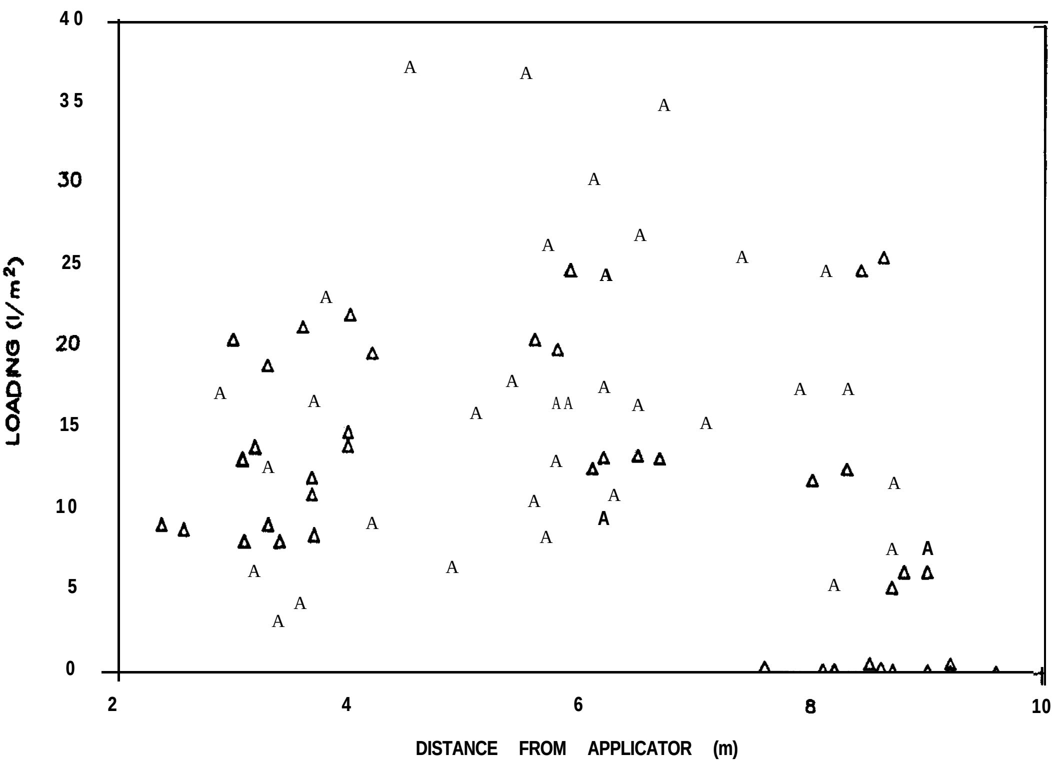

Figure 10. Sludge loading rate versus discharge distance, northern hardwoods site.

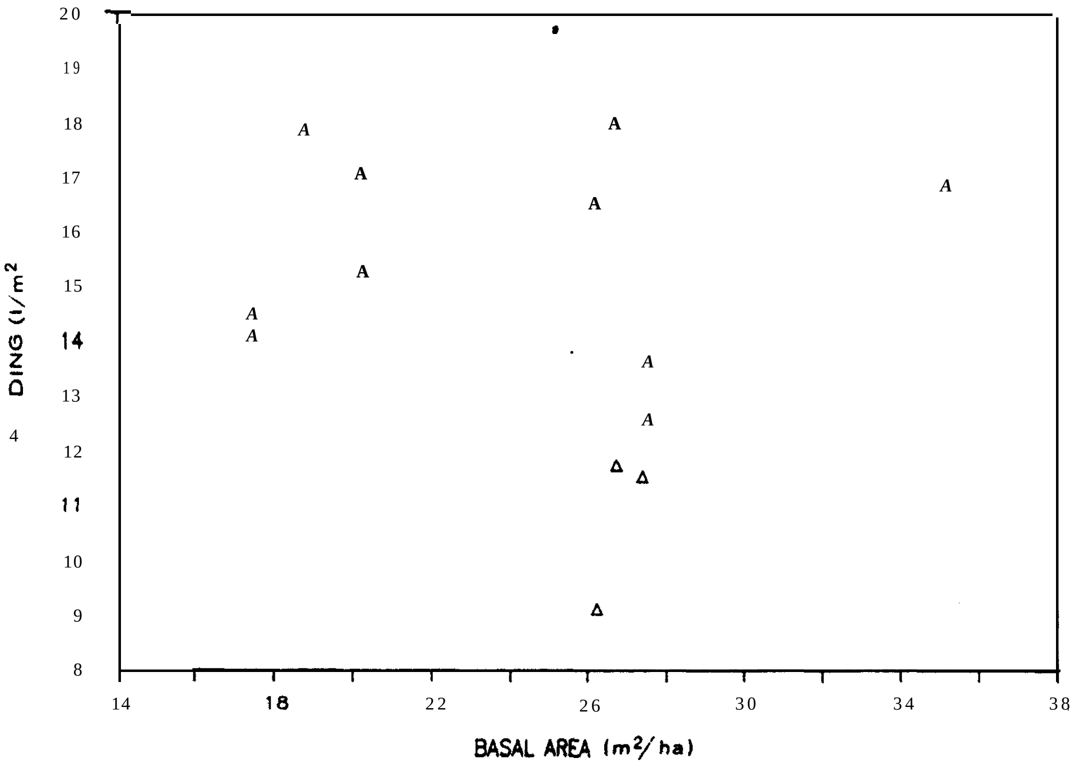

Figure 11. Sludge loading rate versus stand basal area, northern hardwoods site.

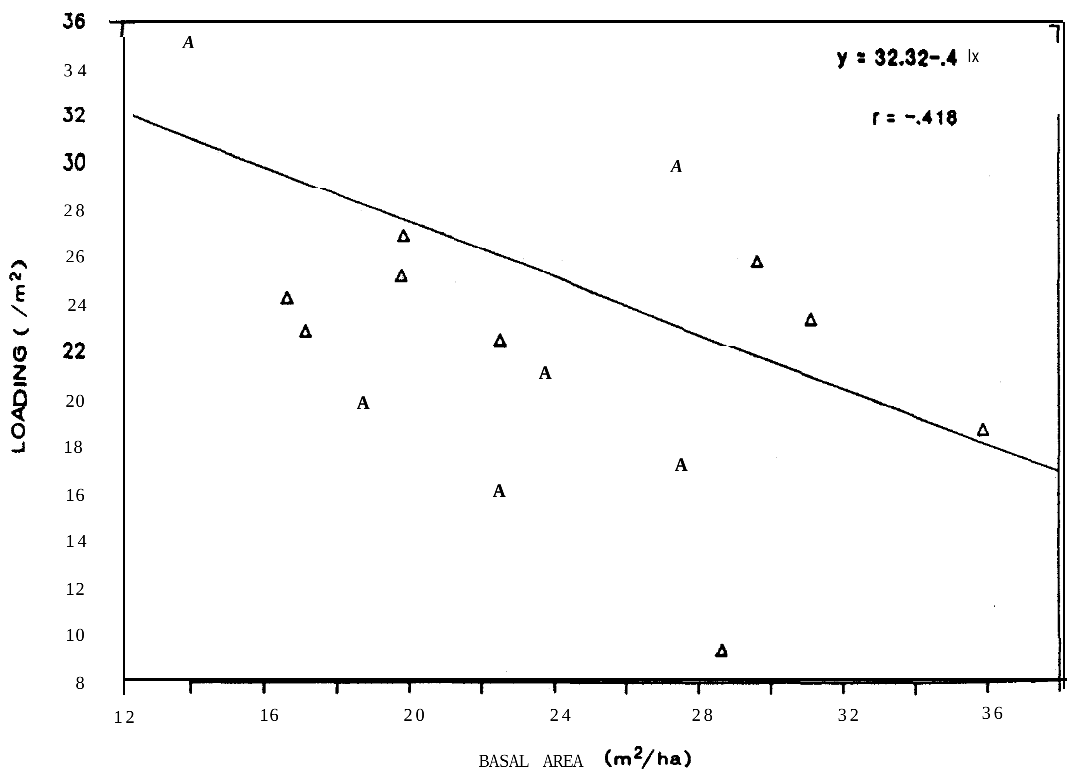

Figure 12. Sludge loading rate versus stand basal area, pine site.

uniform size and distribution of trees in the pole-sized plantation, providing a greater barrier to the movement of sludge discharged from the application vehicle. The more irregular distribution of trees in the naturally regenerating stands provided a lesser degree of physical impedence in this regard.

LOGISTICS AND COSTS

Site preparation to provide vehicle access in the stand is a major initial consideration in planning a forest land application program for wastewater sludge. If stands consist of young, unmerchantable age classes, site access may need be developed at a net cost to the manager. Such was the case with the aspen stand, in which trails were cleared at a cost of $1,485 ($163.91/ha) using a bulldozer. In contrast, a net income may be generated by harvest of timber growing in proposed access trails when trees are of sufficient size and quality. Following development of access trails on the pine, oak, and northern hardwoods sites, net respective returns from sale of timber were $340 ($37.53/ha), $158 ($17.44/ha), and $140 ($15.45/ha). Where the services of consulting foresters were required in site preparation, a rate of $21 per hour resulted in a total fee of $3,973 ($109.631 ha) for the project.

Using one 32,000 liter and two 23,000 liter tank trucks, sludge was transported from the municipal wastewater treatment plants at Rogers City and Alpena, a distance of 80 km (50 miles) to each of the forest sites. Loading time at each treatment plant varied from 45 to 60 minutes for each truck, and one-way transport time on the highway was approximately one hour. On-site unloading for each truck ranged from 30 to 40 minutes, resulting in a total delivery cycle of three to four hours per load. During a working day without mishap, each truck could complete three to four deliveries. More typically, because of operational delays, daily sludge delivery rates averaged 147,615 liters, requiring a travel distance of 950 km and 18 man-hours during the 26 days on which sludge was transported.

Sludge application was conducted using an Ag-Gator 2004, manufactured by Ag Chem Equipment Company of Minneapolis, Minnesota. Thii application vehicle was equipped with a standard pressure-vacuum pump that was used to fill and empty its 8,300 liter tank. Liquid sludge could be laterally discharged distances up to 10 m from one side of the vehicle through a modified spray system of three nozzles arranged to evenly cover near, intermediate, and distant bands of the forest floor.

Contractual costs for transport and application of 3,679,311 liters (972,074 gal) of liquid sludge totaled $48,576. This amount was equally apportioned by the contractor for transportation, application, and administration (Table 5). Had this procedure been a sludge reapplication to a previously used site, the contractor estimated a reapportionment of costs to 40% for transportation and 30% each for application and administration. The resultant lower total cost would be a product of less time needed in planning and greater efficiency in reapplication based on previous on-site experience.

While trafficability was satisfactory on most forest sites, pit and mound microtopography and high stumps remaining in trails at the completion of whole-tree skidding on the northern hardwoods site complicated application vehicle operation. Stumps caused the puncture of one high flotation tire on the application vehicle, and the generally rough terrain contributed to the eventual rupture of the hydraulic unit on its articulated steering mechanism. Repair costs for these breakdowns totaled $4,070.

TABLE 5. Contractor cost breakdown for transport and application.

	Initial Application	Subsequent Application
Transportation	$16,515.84 (342)	$16,515.84 (40%)
Labor	1,651.58 (10%)	1,651.58 (10%)
Equipment	11,561.09 (70%)	11,561.09 (70%)
Fuel	3,303.17 (20%)	3,303.17 (20%)
Application	16,030.08 (33%)	12,144.00 (30%)
Labor	1,603.01 (10%)	1,214.40 (10%)
Equipment	12,824.06 (802)	9,715.20 (80%)
Fuel	1,603.01 (10%)	1,214.40 (10%)
Administration	16,030.08 (33%)	12,144.00 (30%)
Totals	$48,576.00	$40,803.84

The cost of initial sludge transport and application to the four forest sites averaged 1.3 cents per liter (4.8 cents per gallon). If the expenditures for equipment repair are added, the total unit cost increases to 1.4 cents per liter. When care in site selection, stand preparation, and equipment operation are exercised, this cost increment for repairs can be minimized. If the expenditures for site preparation and retaining consulting foresters are also added, the total unit cost increases to 1.5 cents per liter of sludge applied. When care is taken to select sites containing merchantable timber that will be harvested and sold in the course of developing access trails, this cost increase can also be abated. Had the procedure been a sludge reapplication to forest sites receiving periodic operational use, the transport and application contractor cost estimate would have approximated 1.1 cents per liter.

These costs are comparable to those for sludge transport and application to farmland. Because the expenditures reported are for a demonstration and research project established to meet precise scientific criteria, the forest sites were located 80 km from the sludge source. Typical haul distances for operational sludge fertilization programs would more likely approximate 16 to 32 km, proportionally reducing transportation costs. This further decrease in program costs below those quoted above would make sludge application to forest land a highly attractive recycling alternative.

Finally, the costs related to creating stand access trails and those for repairing equipment subject to travel over residual stumps could be eliminated by careful planning during the establishment of a plantation scheduled to receive fertilizer applications of sludge at some future time. This could be accomplished by leaving one pair of unplanted seedling rows at 20 m intervals when a forest site is planted. The resultant system of parallel access trails would enable the stand to easily accommodate sludge application vehicles in the future and facilitate entry for intermediate silvicultural operations throughout the rotation.

SOCIAL CONSIDERATIONS

During the initial phases of project planning, numerous hours were devoted to evaluation of the logistic, physical, and biological characteristics of several candidate forest sites for land application of sludge. Of equal importance was assessment of the social climate for conduct of sludge application on publicly owned lands in each locale. Recognizing that forest land application of sludge is a relatively unfamiliar practice to a large segment of the population, it was essential to approach local elected officials in an open atmosphere where available information and concerns could be discussed.

Meetings held early in the course of program planning with representatives of the Huron Pines Resource Conservation and Development Council, the Northeastern Michigan Council of Governments, the Montmorency County Planning and Zoning Commission, and Montmorency Township were vital to the success of the project. Subsequent annual field tours have been conducted to update federal and state agency specialists, municipal officials, local groups, and individuals on progress of the project. During late summer of 1985 an information sharing conference and field workshop was held in the locale to summarize project findings and afford discussion opportunity for those groups and individuals who have an interest in land application of sludge on northern forest sites. This meeting also initiated a program of public education, wherein state agency specialists will disseminate information that objectively discusses the benefits and risks of wastewater sludge application on forest land.

PRELIMINARY FINDINGS

As indicated earlier, several research studies were conducted during the five years of the project to enhance the base of knowledge concerning the physical, chemical, biological, and social aspects of forest land application of sludge. Without offering the degree of detail provided in individual papers appearing elsewhere in this volume, the major highlights of initial findings are summarized.

Sociological

In northern Michigan, a survey of public opinion revealed that residents were generally undecided about the practice of sludge applications on forest land (Peyton et al. 1983). A lack of available information concerning this practice largely accounted for the absence of strongly held opinions. Forest application was perceived as being of benefit to forest growth and long-term environmental quality; however, short-term public health and environmental quality concerns were also noted. While university and state agency specialists generally enjoyed highest credibility as accurate information sources, local residents who mistrust state agency intentions were most likely to hold negative opinions about forest land sludge applications.

The low level of available information concerning forest application of sludge represents an important opportunity for public agencies to provide information that will allow state residents to develop accurate opinions about sludge utilization options. The basic aim of a public education program should be to provide local citizens with correct information, which would allow them to reach decisions that simultaneously evaluate the various options for sludge use and select the alternative that maximizes benefits and minimizes risks. In this effort there exists an opportunity to improve relations between the state agency and numerous groups and individuals.

Wildlife

Browse utilization by white-tailed deer (*Odocoileus virginianus* Zimmermann) and elk (*Cervus canadensis* Erxleben) was found to increase significantly on plots that had been provided with trails or with trails and sludge (Haufler and Campa 1983). Trails appeared' to encourage intermediate levels of ungulate use, and sludge addition resulted in the highest levels. These results are thought to be population responses to the greater ease of access provided by trails and higher nutritional value of browse plants growing on sludge-fertilized plots. Although no changes in digestibility or the content of crude fat and fiber were detected, increases in crude protein and hemicellulose were measured in wildlife food plants (Haufler et al. 1983). Heavy metal concentrations in forage plants growing on sludge-fertilized plots did not significantly differ from those in species found on control areas.

Small mammals were observed in greater numbers on the sludge-fertilized plots of the aspen, pine, and northern hardwoods sites one and two years following treatment (Haufler et al. 1983). A slight, but nonsignificant, decrease was measured on the fertilized plots of the oak site. Herbaceous and woody plant species composition and structure on the aspen, oak, and pine sites varied little as a result of sludge application. Sludge addition appears to have decreased herbaceous and woody plant cover on the northern hardwoods site, a result of applications conducted during the growing season. Sludge fertilization increased the annual production of primary wildlife food plants substantially on the aspen and oak sites and slightly on the northern hardwoods site, but resulted in no change on the pine site. While sludge addition and access trail development generally stimulated annual production, applications conducted during the growing season were less effective, because the understory species were smothered by the loading of sludge solids.

Nutrient Availability and Water Quality

Analyses for major nutrients and heavy metals in soil leachate and groundwater have established that concentration fluctuations occurred in a manner generally unrelated to sludge treatment (Urie et al. 1983). Slight elevations in nitrate-N and sodium levels were observed in water samples collected on the oak site during the 1982 growing season. These concentrations soon thereafter declined to near background. It was apparent from the data that adequate protection for the phreatic aquifer existed in these forest ecosystems when sludge was applied at recommended rates.

Vegetation and Soils

On the aspen site no changes in understory cover or diversity were observed one year following sludge application (Hart et al. 1983). The number of tree seedlings present also could not be related to treatment. Aspen mortality was increased to a significant degree by fungal infections caused by *Cytospora chrysosperma*, *Fusarium* spp., and *Armillaria mellea*. The increased activity of these pathogens was related to the method of access trail preparation and the increased browsing activity of ungulates on sludge-fertilized plots.

Exchangeable bases applied with the sludge were largely retained in the forest floor and the upper 45 cm of mineral soil (Hart et al. 1983). Phosphorus and trace element levels significantly increased in the forest floor following sludge application. One year after treatment, forest floor weight had decreased 14% as a result of microbial activity stimulated by nitrogen and phosphorus addition. While subsoil was minimally affected by sludge application, surface soil nitrogen, phosphorus, calcium, magnesium, and aluminum levels were increased. The retention of nutrients in the forest floor was approximately 45% of the total applied.

SUMMARY

Nearly 4 million liters of anaerobically digested wastewater sludge were applied to the forest floor of four forest types of major commercial importance. The large areas receiving the treatment of approximately 9 Mg of dry solids per hectare represented an important intermediate step between earlier small-plot research and eventual full-scale operation of municipal and industrial programs. The technology currently available to conduct liquid sludge application on forest land was demonstrated to be efficient in providing uniform distribution and loading of nutrients and trace elements on each site. Costs of transportation and application compared quite favorably with those of farmland applications, making forest land application a truly viable sludge recycling alternative. In addition, the opportunity to conduct a diverse array of land application research studies was provided. Preliminary findings of this research offer encouraging evidence of improved plant growth, enhanced wildlife habitat, and adequate protection for groundwater quality and the public health. Findings have also provided new insights into public concerns and attitudes and outlined a process for constructive citizen involvement in program planning. It is hoped that this demonstration project will serve as a model for future land application programs developed in the forests of northern Michigan and similar environments.

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REFERENCES

Brockway, D. G. 1979. Evaluation of northern pine plantations as disposal sites for municipal and industrial sludge. Ph.D. diss., Michigan State University, East Lansing. University Microfilms, Ann Arbor, Mich. (Diss. Abstr. 40-2919B).

———. 1983. Forest floor, soil, and vegetation responses to sludge fertilization in red and white pine plantations. Soil Sci. Soc. Am. J. 47:776–784.

Brockway, D. G., and D. H. Urie. 1983. Determining sludge fertilization rates for forests from nitrate-N in leachate and groundwater. J. Environ. Qual. 12:487–492.

Hart, J. B., P. V. Nguyen, J. H. Hart, C. W. Ramm, D. M. Merkel, and C. Thomas. 1983. Ecological monitoring of sludge fertilization on state forest lands in northern lower Michigan. Annual progress report. Department of Forestry, Michigan State University, East Lansing. 101 p.

Haufler, J. B., and H. Campa. 1983. Deer and elk use of forages treated with municipal sewage sludge. Annual progress report. Department of Fisheries and Wildlife, Michigan State University, East Lansing. 35 p.

Haufler, J. B., E. Seon, and D. Woodyard. 1983. Influences on wildlife populations of the application of sewage sludge to upland forest types. Annual progress report. Department of Fisheries and Wildlife, Michigan State University, East Lansing. 136 p.

Michigan Department of Natural Resources. 1983. A summary of current municipal sludge production and use in Michigan. In-house Paper, Groundwater Quality Division, Lansing. 9 p.

Peyton, R. B., L. Gigliotti, and T. Lagerstrom. 1983. A survey of public perception and acceptance of sludge application to state forest lands in

Michigan. Phase I summary report. Department of Fisheries and Wildlife, Michigan State University, East Lansing. 134 p.

Strommen, N. D. 1967. Monthly precipitation probabilities for climatic divisions in Michigan. ESSA-Weather Bureau, Michigan Weather Service in Cooperation with Michigan Department of Agriculture. 22 p.

Urie, D. H., A. R. Harris, and J. H. Cooley. 1978. Municipal and industrial sludge fertilization of forests and wildlife openings. p. 467–480. *In* Proceedings of First Annual Conference of Applied Research and Practice of Industrial and Municipal Waste, Department of Engineering and Applied Science, University of Wisconsin, Madison.

Urie, D. H., J. B. Hart, P. V. Nguyen, and A. Burton. 1983. Hydrologic and water quality effects from sludge application to forests in northern lower Michigan. Annual progress report, Department of Forestry, Michigan State University, East Lansing. 35 p.

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