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CONSIDERATIONS RELATING TO TOXIC SUBSTANCES IN THE APPLICATION OF MUNICIPAL SLUDGE TO CROPLAND AND PASTURELAND

A Background Summary

Prepared By

Office of Toxic Substances
Environmental Protection Agency
Washington, D.C. 20460

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INTRODUCTION

Background information is presented pertinent to an assessment of the potential health hazards from toxic substances when disposing/utilizing municipal sludge on agricultural lands, particularly croplands and pasturelands where the products enter the human food chain.

The report considers some of the toxic elements and synthetic organic chemical substances known to be present in municipal sludges. Only readily available information has been used. The report clearly does not represent an exhaustive review of the subject. Nevertheless, it is clear that applicable and available data on this subject are scarce adding to the uncertainties regarding the hazard potential associated with applying municipal sludge to cropland and pastureland. Potential difficulties which might be associated with bacterial and viral pathogens and radioactive substances present in municipal sludge are beyond the scope of the report.

I. Municipal Sludge

The volume of municipal sludge requiring disposal in the United States is estimated to be about 17,000 dry tons per day and is expected to increase over the next ten years, with the implementation of nation-wide secondary treatment, to be about 23,000 dry tons per day. Current disposal methodologies reported to the EPA Office of Water Programs Operations are presented in the Appendix. A review of that information has indicated that the quantity of sludge will increase by about 35% and that industrial users of municipal sewage treatment plants will increase by over 40% in the next 10 years. Industrial wastes are estimated to account for about 25% of municipal treatment plant influent nationally and may be near 100% in some localities. The toxic metal content of municipal sludge from various cities approaches the levels found in some industrial sludges.

At present, it is estimated that 20% of the total municipal sludge produced is applied to croplands (see Appendix). Estimates of the amount of agricultural land area that would be used if all sludges were disposed/utilized for landspreading have been made. One estimate is that with a "typical" application rate of 20 tons/acre/year about 570 square miles would be required (Dean, 1973). This amounts to less than 1% per year of the total agricultural land areas of the United States. Other estimates of typical application rates range from 10 to 20 tons/acre/year but these vary considerably due to site-specific conditions. Some guidelines exist which limit applications based on fertilizer rates of nitrogen.

The levels of trace elements and chemical substances found in municipal sludge can be highly variable even on a daily basis. The range of levels detected is quite wide, depending to a large degree on the type and quantity of industrial input to the municipal treatment plant (see p. 23). Considering purely domestic sludge to be free of trace element and chemical substance contaminants is not warranted. In sewer systems with no industrial connections there are inputs from hospitals, research laboratories, and dentist offices (mercury). Other sources of contaminants include motor oil additives; flow entrainment of lead, copper, cadmium, zinc, and antimony from water-carrying pipes; street runoff; detergents and laundry products; and consumer products, including pesticides and organics, flushed into the sewer.

II. Elements and Substances Found in Municipal Sludge

Table 1 lists some of the trace elements and chemical substances found in municipal sludge which may deserve attention from a health effects standpoint. The range of concentrations (dry weight) observed is indicated. The amount of sludge-analysis data is limited and the use of different analytical methodologies complicates the evaluation of the available data. The wide ranges observed have been attributed to the variable quantity and character of industrial input to different municipal treatment plants. References 1, 9, 13, 21, 25, 26, 27, 32, 47, 53, and 61 were used as sources in compiling table 1.

Commercial "bagged sludge" soil conditioners derived from municipal sludge, such as Milorganite, also deserve consideration. Milorganite has been analyzed and found to contain what were considered high cadmium and chromium levels. Recent analysis of a sample by EPA Region X found cadmium at 117 mg/kg and chromium at 6,042 mg/kg. Home and hobbyist use of municipal sludge such as Milorganite can result in intensive application to small plots of land. Use is not limited to ornamental plants, but it has been applied to vegetable gardens as well. Home-grown vegetables are not subject to FDA monitoring, nor are contaminants in them diluted in family use by the commercial food distribution system. In season, they can form a major portion of a family's diet.

As table 1 indicates, municipal sludges also may contain persistent organic chemical contaminants such as PCBs and chlorinated pesticides. Data are scarce on other organics present in municipal sludge largely due to lack of research in this area, although the range of contaminants (over 100) reported for drinking water is indicative of the compounds which could be present in municipal sludge. Typical drinking water contaminants which might be present in municipal sludges include halogenated (mostly chlorinated) hydrocarbons, long chain hydrocarbons, benzenes and polynuclear aromatics. Other classes of organic chemicals which appear to have a high potential for sludge contamination due to their persistence in environmental waters include chlorobenzenes, chlorophenols, chlorinated paraffins, and halogenated cyclodiene flame retardants (Braude et. al., 1975).

B - this size paper

Table 1. TRACE ELEMENTS AND SUBSTANCES FOUND IN MUNICIPAL SLUDGE

A)

Elements	Range of Concentration (ppm dry weight) In Municipal Sludge	Concentration Range (ppm) In Unamended Soil (dry)	Mean level (ppm) in dry Soil
Aluminum (Al)	8,100-51,200	10,000-300,000	71,000
Antimony (Sb)	2.6-44.4	2-10	6
Arsenic (As)	3.0-50	0.1-40	6
Boron (B)	4-1,430	2-100	10
Barium (Ba)	272-1066	100-3,000	500
Beryllium (Be)	<4-<15	0.1-40	6
Bismuth (Bi)	0.03-55.8	--	--
Bromine (Br)	13.7-165	1-10	5
Cadmium (Cd)	2-1,100	0.01-7	0.06
Calcium (Ca)	1760-116,400	7,000-500,000	13,700
Cerium (Ce)	12.4-272	--	50
Cesium (Cs)	0.45-2.9	0.3-25	6
Chlorine (Cl)	500-17,800	--	100
Chromium (Cr)	22-30,000	5-3,000	100
Cobalt (Co)	2-800	1-40	8
Copper (Cu)	84-17,000	2-100	20
Dysprosium (Dy)	0.7-19.8	--	--
Erbium (Er)	0.2-4.5	--	--
Europium (Eu)	0.7-12.2	30-300	200
Fluorine (F)	2.2-738	--	--
Gadolimium (Gd)	1.1-22.7	--	30
Gallium (Ga)	0.9-54	--	1
Germanium (Ge)	1.1-10.5	--	--
Gold (Au)	0.21-7.00	--	6
Hafnium (Hf)	1.3-10.7	--	--
Holmium (Ho)	0.07-0.67	--	--
Indium (In)	0.07-3.7	--	5
Iodine	1.0-17.1	--	--
Iridium (Ir)	0.04-0.46	--	38,000
Iron (Fe)	1,000-144,000	7,000-550,000	30
Lanthanum (La)	5.1-380	1-5,000	10
Lead (Pb)	80-26,000	2-200	--
Lutecium (Lu)	0.04-0.34	--	--
Magnesium (Mg)	2,000-14,035	600-6,000	5,000
Manganese (Mn)	32-8,800	100-4,000	850
Mercury (Hg)	0.1-89	0.01-0.3	0.03

TABLE 1. (CONT.)

	Elements	Range of Concentration (ppm dry weight) In Municipal Sludge	Concentration Range (ppm) In Unamended Soil (dry)	Mean level (ppm) in dry Soil
A)				
	Molybdenum (Mo)	1.2-1000	0.2-5	2
	Neodymium (Nd)	0.6-8.6	--	--
	Nickel (Ni)	12-8,000	10-1000	40
	Nitrogen (N)	16,000-66,000	200-2500	1000
	Osmium (Os)	0.06-3.18	--	--
	Palladium (Pd)	0.5-16.2	--	--
	Phosphorus (P)	8,000-40,000	--	650
	Platinum (Pt)	0.05-0.74	--	--
	Protractinium (Pr)	1.1-119	--	--
	Rhenium (Re)	0.03-0.98	--	--
	Rubidnium (Rb)	4.3-94.6	20-600	100
	Ruthenium (Ru)	0.21-7.05	--	--
	Samarium (Sm)	1.0-14.2	--	--
	Scandium (Sc)	0.5-7.1	10-25	7
	Selenium (Se)	1.7-8.7	0.01-2	0.2
	Silver (Ag)	ND-960	0.01-5	0.1
	Sodium (Na)	567-8,800	750-7,500	6,300
	Strontium (Sr)	ND-2,230	50-1,000	300
	Sulfur (S)	9,000-11,000	30-900	700
	Tantalum (Ta)	0.11-1.45	--	--
	Tellurium (Te)	0.07-1.52	--	--
	Terbium (Tb)	0.27-4.83	--	--
	Thorium (Th)	3.1-16.8	0.1-12	5
	Thullium (Tm)	0.06-3.31	--	--
	Tin (Sn)	40-700	2-200	10
	Titanium (Ti)	1080-4580	1,000-10,000	5,000
	Tungsten (N)	0.9-99.6	--	--
	Uranium (U)	0.8-6.4	0.9-9	1
	Vanadium (V)	ND-2100	20-500	100
	Ytterbium (Yb)	0.29-1.30	--	--
	Yttrium (Y)	0.8-10.1	25-250	50
	Zinc (Zn)	72-50,000	10-300	50
	Zirconium (Zr)	4.8-319	60-2000	300
B)	Organics			
	Aldrin	ND-16	--	--
	Chlordane	ND-32.2	--	--
	DDD	ND-1.0	--	--
	DDT	ND-1.1	--	--
	Dieldrin	0.8-2.2	--	--
	fluorescent whitening agents	12-50	--	--
	PCBs	ND-1700	--	--

III. Plant Uptake of Chemical Substances from Municipal Sludge-Amended Soil

A limited amount of data were located on the uptake of metals and other substances by plants from soil, especially the uptake of non-essential elements from sludge-amended soils. Many factors have been recognized as having an effect on plant accumulation of toxic metals; however, few definitive studies have been conducted to allow a precise description of soil-plant relationships for all factors for any element or substance.

Knowledge of the chemical forms preferentially absorbed from the soil by plants is an important factor in estimating plant uptake. Considerable research is necessary to define plant-available forms. Any factor that affects the availability of elements in the soil also may affect plant accumulation. Table 2 is a partial list of factors known to influence plant uptake. In addition, there are probably several unknown factors which contribute to the complexity of this problem.

Table 3 lists some of the elements and types of plants for which uptake has been observed. An uptake of 50% or greater over controls was the criterion for inclusion on the list. The cited studies are not directly comparable with each other and do not adequately describe all aspects of uptake for any element. The elements and substances listed (except manganese) have been considered non-essential for plants. Excess concentrations of the essential elements also may accumulate in plant tissue from sludge and/or soil substrate. In some cases, excess nutrient may be toxic to the plant. When plant injury occurs due to toxicity, there is some protective value for those (animals and humans) who may choose not to consume damaged crops; however the accumulation of substances in crops without phytotoxicity raises some concern with respect to the human food chain. Even though some elements are essential nutrients for plants, their importance as potential toxic hazards when plant accumulation occurs should not be overlooked when additions of municipal sludge are made to soils used to grow crops in the human food chain.

Table 2. Factors Influencing Plant Uptake of Chemical Substances

Soil/Sludge Factors

pH
organic matter content
cation exchange capacity
phosphate (amounts) availability
specific metal characteristics
presence of competing ions
soil distribution of metals
soil variables - moisture, temperature, aeration (O_2), composition
soil solubility status

Plant Factors

rooting depth
plant age
plant species and variety, tissue differences with species

Other

climatic (seasonal) effects

TABLE 3. STUDIES ON PLANT UPTAKE OF CHEMICAL SUBSTANCES FROM SLUDGE-AMENDED SOIL

Element* or Substances	Plants in which Uptake has been observed **	Type of Study***	literature Citation
arsenic	fodder rape	F	(2)
cadmium	bush beans, corn	F	(24)
	barley	X	(38)
	wheat	X,X,F,F	(6,43,60)
	corn	X,F,X,X	(6,4,13,15)
	corn	F,F,F	(36,39,59)
	rye	X,X	(13, 15)
	soybeans	X,X	(6, 35)
	sorghum	X	(45)
	tomatoes (leaves)	X	(9)
	sudan grass	X	(9)
	alfalfa	X	(9)
	white clover (forage)	X	(7)
	tall fescue	X	(7)
	bermuda grass	X	(7)
	Swiss chard	F	(23)
	spinach, lettuce, curly cress	X	(6)
	fescue (forage)	F	(8)
	carrots, radishes, potatoes	X	(18)
	peas (vines, pods), tomatoes	X	(18)
	corn, lettuce	X	(18)
chromium	barley	X	(17)
	corn, rye	X,X	(13, 14)
	fescue (forage)	F	(8)
	fodder rape	F	(2)
lead	barley	X	(17)
	fodder rape	F	(2)
	fescue (forage)	F	(8)
	Swiss chard	F	(23)
manganese	fescue (forage)	F	(8)
	corn, rye	X	(13)
	corn	X	(15)
mercury	fodder rape	F	(2)
nickel	barley	X	(17)
	corn, rye	X	(13)
	soybeans (grain, leaves)	F	(4)
	carrots, beets, leeks	F	(42)
	corn, bush beans	F	(24)
PCBs	grain, corn	F	(3)

* without regard to oxidation state or compound
**without regard to tissue
***Type of Study
F= field study
X = experimental/greenhouse

Some specific element interactions have been observed to influence plant uptake. Due to the insolubility of lead phosphate ($Pb_3(PO_4)_2$) lead uptake and accumulation by plants may be significantly mediated by phosphate levels in the substrate. Zinc and cadmium interactions also have been observed to influence plant uptake. Control of zinc:cadmium ratios to 100:1 or greater has been proposed by some investigators to protect against cadmium accumulation by plants (Chaney, 1973).

The utilization/disposal of municipal sludge on croplands and pasturelands emphasizes the need for definitive data on plant uptake of synthetic organic chemicals. The Food and Drug Administration (FDA) has indicated that based on uptake studies, edible parts of plants contain some of the pesticides listed in table 1B), but the levels are 5 to 20 percent of the levels in the soils used and that, in general, root crops take up more chlorinated organics from the soil than other types of crops. However, other studies have shown that chlordane, heptachlor and dieldrin are translocated from soil into soybeans and stored in the oil of the seed. Although the pesticides levels found were low, these data revealed that sludge can be a source of recycling of chemical contaminants from sludge back into the food supply (Jelinek et al., 1976).

Table 4 reports plant uptake of certain elements (known to be in sewage sludge at variable concentrations) where sewage sludge was not part of the substrate employed in the experiment. These studies are listed because many of them were cited frequently in the past as indicating the potential for plant uptake of heavy metals from sludge-amended soils. Cunningham et al. (1975) has urged caution in attempting to evaluate phytotoxicity or uptake from sludge-amended soils based on such studies.

It should be recognized that surface contamination of the above ground portions of plants is also a potential problem in sludge application to croplands and pasturelands. Recent work by the United States Department of Agriculture for the FDA showed that dried grass contained about 5% by weight of sludge, when the grass had been mowed 80 days after it had been sprayed with the sludge. In this case about 30% of the applied sludge remained on the grass. It is noteworthy that the grass in this study was grown in the East; not an arid section of the country. This work indicated a potential for contamination by persistent synthetic organics such as organochlorine pesticides and PCBs as a result of sludge application (Jelinek et al., 1976).

TABLE 4. PLANT UPTAKE OF TRACE ELEMENTS FROM OTHER SUBSTRATES*

Element or Substance	Plants in which increased Uptake has been observed	Literature Citation
cadmium	lettuce, radish, celery, green pepper, soybeens, wheat	(25)
	corn, turnips, beets, beans, tomatoes, cabbage, lettuce, green pepper, barley	(51)
	lettuce, broccoli, spinach, cauliflower, peas, oats, radish, carrots	(32,33)
	raddish, lettuce	(34)
lead	lettuce, oats	(33)
	corn, alfalfa	(41)
	tree seedlings (8 species)	(54)
	pasturage herbage (mixed clovers)	(47)
	wild oats	(53)
	corn	(5)
nickel	oats, soybeens	(56)
	oats, barley, clover, turnip potatoes, beets, cabbage, kale	(27)
	oats, beans, peas, sunflowers tomatoes	(12)
	wheat, barley, cotton, peanut ryegrass, rice, sorghum	(62)
selenium	grasses, clovers, garden vegetables	(40)
	alfalfa	(10)
	wheat, corn	(55)

*Specific metal additions to soils or hydroponic solutions.

IV. Health Effects Aspects

The chronic effects resulting from low-level dietary exposure to many of the trace elements and substances (found in sewage sludge) that make their way into the food chain are not known. A major health concern is that application of municipal sewage sludge to cropland and pastureland can result in plant uptake and accumulation of heavy metals and other toxic substances. Chronic exposure to the increased amounts of these materials in food could give rise to adverse health effects. Although FDA expressed concern (Jelinek *et al.*, 1976) about the application of sludge to land used to grow crops in the human food chain, no quantitative guidance, except for PCBs, was given as to what levels of metals or other substances in sludge or plants would protect human health. In view of the uncertainties and real lack of data on this subject, a controversy has ensued as to whether such practices are "safe".

Past presentations in the literature on this subject have not always clearly distinguished phytotoxicity from animal toxicity. It is recognized that toxic effects to crops can provide some protection for crop consumers (animal and human). However, accumulation of elements or toxic substances in crops without manifest phytotoxicity provides the opportunity for human exposure to potentially harmful substances. The reported levels in plant tissue are sometimes subject to misinterpretation. Care must be taken to distinguish between data on the edible and non-edible portions of the plant. However, even the "non-edible" portions may be used for animal feed so that a particular substance of concern may still enter the food chain. Also, non-harvested portions of the plant may remain in the soil where the elements accumulated could contribute to local increases in soil levels.

Cadmium

The most frequently cited concern, with a specific toxic chemical in sludge, is the potential for adverse chronic effects such as kidney disease (renal tubular dysfunction) from increased cadmium intake. The Joint Food and Agricultural Organization/ World Health Organization (FAO/WHO) Expert Committee on Food Additives proposed a tolerable weekly intake for cadmium of 400 to 500 micrograms (about 57-71 micrograms/day) (WHO, 1972). In comparison, the FDA estimates (based on their market basket surveys)the present daily cadmium intake (including drinking water) to be approximately 72 micrograms per day (Jelinek et al., 1976). Even though only six percent of ingested cadmium has been shown to be accumulated by the body, most of the accumulation is by the kidney so that even at low concentrations in food, the concentration of cadmium in the kidney will gradually increase (Friberg et al., 1974). The Joint FAO/WHO Expert Committee on Food Additives recommended that cadmium levels in food should not be allowed to rise further. It is recognized that soil improvement with nutrient supplements is a source of cadmium entry into the food chain. The practice of applying municipal sludge to croplands has been shown to increase up to several fold the cadmium content of some crops. The Swedish National Board of Health and Welfare in 1973 established a regulation that limits the application of sludge on available land to one metric ton of dry matter per hectare annually (English equivalent 0.446 ton/acre), with the cadmium concentration limited to 15 milligrams per kilogram of dry matter (Stenstrom, 1974). By comparison, the typical U.S. rate of sludge application is high, 10-20 dry/tons/acre with a range of 2-1,100 ppm cadmium in sludges analyzed.

A recent review of cadmium as an environmental problem concluded that food intake is the major exposure route (EPA, 1975). The report indicated that the mechanisms involved in the transfer of cadmium into food chains are not adequately understood. It also pointed out that knowledge is insufficient regarding the cycling of cadmium in the environment. The document did not address land application of municipal sludge as a possible source/mechanism for entry of cadmium into the food chain although it did mention the use of super-phosphate fertilizers which can contain significant amounts of cadmium.

Lead

The World Health Organization has recommended a tolerable weekly intake for adult humans of 3 milligrams of lead (430 micrograms/day). Infants and children are considered a high-risk group. An HEW-appointed _ad hoc_ committee of experts on pediatric lead toxicity has proposed a tolerable daily intake of lead of 300 micrograms per day for 1 to 3 year olds. No level has been proposed for infants, but it would probably be lower due to smaller body size and greater gastrointestinal absorption of lead (Jelinek, 1975).

The potential exists for increased levels of lead in foods as a result of sludge application. Considering the often limited lead uptake by plants, especially under pH conditions greater than 5.5 and with the presence of phosphate in the substrate, the margin of safety seems to be greater than that for cadmium. However, since lead accumulates in bones, liver, and kidneys, its ingestion via dietary intake cannot be ignored.

Mercury

The Joint FAO/WHO Expert Committee on Food Additives established a provisional tolerable weekly intake of 0.3 mg of total mercury per person, of which no more than 0.2 mg should be present as methyl/mercury (WHO, 1972). Little or no mercury has been found in plant produce. The principal source of mercury in the diet is fish (Mahaffey _et al._, 1975). There is, however, a potential for mercury uptake by plants grown on sludge-amended soil since the presence of mercury in municipal sludge has been documented. The limited data available indicate little plant uptake of mercury; however, since mercury is a cumulative poison and biological methylation yields highly toxic alkyl forms, the potential cannot be ignored.

PCBs

The recent discovery (April, 1976) of PCBs in the milk of a family cow in Bloomington, Indiana, illustrated one potential consequence of municipal sludge application to pastures when industrial discharge contaminates the sludge. This cow grazed on pasture to which 12 tons per acre of city sludge from the Winston-Thomas treatment plant had been applied in November 1975. Subsequent analysis of the sludge samples from that plant showed 105 ppm and 240 ppm PCBs (dry weight basis). The cow's milk contained 5 ppm PCBs (Arochlor 1016) on a fat basis, which is twice the FDA limit of 2.5 ppm (Jordan, 1976). Transfer of PCBs to the cow was probably related to grazing habits resulting in consumption of the contaminant rather than uptake by the pasturage. In this instance, the FDA limit did not provide direct control since the product was not shipped in interstate commerce.

Other Substances of Concern

The Food and Drug Administration has expressed concern about "heavy metals" in foods in the U.S. and is according highest priority to mercury, lead, cadmium, arsenic, selenium, and zinc in its program on toxic elements in foods. Specifically, it is suggested that new developments, such as widespread application of municipal sludge to land used for growing crops, should not be initiated on such a substantial scale that a significant increase of cadmium in the diet would result (Jelinek, 1975). More recently, "In regards to methods of disposal of sludge, FDA prefers that the sludge be disposed of by means other than on productive land, if at all possible. If sludge is to be applied to productive land, we would prefer it be used to grow plants not in the human food chain, such as trees, ornamentals, grass on rights of way, etc. Finally, it if <u>is</u> to be used for growing crops in the human food chain, we prefer that it be applied to the land itself, rather than sprayed on the growing crops," (Jelinek *et al*., 1976).

A recently published study involving feeding a vegetable (Swiss chard) grown on sludge-amended soil to guinea pigs has indicated that other chemical elements may deserve some attention. Analysis for 41 elements showed elevated concentrations of some elements in certain animal tissues. Accumulations were noted for antimony in adrenals, cadmium in kidneys, manganese in liver, and tin in kidney, muscle, and spleen. The animals did not reveal any observed toxicological effects after 28 days on a 45% Swiss chard diet (subsequent to a week of graduated introduction to the 45% amount). This study involved only a small number of animals for a short period of time and must be treated with caution in drawing inferences. The authors concluded that the preliminary data developed are inconclusive, but emphasized the need for conducting similar replicated feeding studies over a long term and with a greater number of animals. A similar study is being conducted under EPA and FDA sponsorship with cattle grazing on pasture to which sludge has been applied. The results will be available within several months (FDA, 1976).

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APPENDIX

SLUDGE INFORMATION SUMMARY*

1. Quantities of sludge (estimated)

	dry tons/day	
	Current	Secondary Treatment (next 10 years)
Domestic	10,000	13,000
Industrial users of municipal plants	7,000	10,000
Total municipal sludge	17,000	23,000

2. Current disposition of sludge

Method	% Total Sludge	Reliability of Estimate
Landfill	25%	Good
Ocean dump	15%	Good
Incineration	35%	Good
Land application	25%	Good
Croplands	(20%)	Poor
Others	(5%)	Poor

*Derived from background information to the Technical Bulletin on Municipal Sludge Management: Environmental Factors, Fed. Reg. 41, 108: 22532-22543, (June 3, 1976).

3. 1972 Land Spreading Survey (Liquid Sludge Only)

EPA Regions 2, 3, 4, 5, and 9
Mailed 1909, Responded 745 (39%)

Region	Currently Use	Will Use	Do Not Use
2 (NJ,NY)	6%	6%	88%
3 (DE,MD, PA VA,WV)	27%	5%	68%
4 (AL,FL,GA, KY,MS,NC, SC,TN)	18%	12%	70%
5 (IL,IN,MI, MN,OH,WI)	36%	9%	55%
9 (CA,HI,NV)	14%	6%	80%
Total	25%	8%	67%

Size MGD*	Currently Use	Will Use	Do Not Use
1-10	27%	8%	65%
10-100	15%	9%	76%
Greater than 100	7%	13%	80%

4. Total Costs for Various Sludge Methods

Includes operating and construction costs

	$/Dry Ton		
	1 MGD	10 MGD	100 MGD
Land Application	127-168	53-71	57-84
Landfill	171-208	77-116	63-98
Incineration	250-320	111-174	79-120
Ocean Dumping	376-417	93-134	56-93

* MGD = million gallons/day

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15. SUPPLEMENTARY NOTES

16. ABSTRACT

This report presents background information pertinent to an assessment of the potential health hazards from toxic substances when disposing/utilizing municipal sludge on agricultural lands, particularly croplands and pasturelands where products enter the human food chain.

17. KEY WORDS AND DOCUMENT ANALYSIS

a. DESCRIPTORS	b. IDENTIFIERS/OPEN ENDED TERMS	c. COSATI Field/Group
municipal sludge soil amendment trace elements heavy metals PCBs cadmium	plant uptake food chain	02/A,D 06/F,H,I,T 07/B,C

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