Sludge Disposal by Landspreading Techniques

POLLUTION TECHNOLOGY REVIEW No. 58

ndc

Table 7.1: Potential Inorganic Pollutants

Element	Major Uses of the Element and Its Compounds	Maximum Acceptable Contaminant Levels	Remarks
Aluminum	Abundantly present under natural soil conditions. Used in water treatment (alum), alloys, lightweight castings, manufacture of paper, glass, ceramics, dyes, inks.	1.5 mg/l (Marine-hazardous)* None††	At pH values of 5.5 to 8.0 soils have great capacities to precipitate aluminum and eliminate its toxicity.*
Arsenic	Production of glass pigment, textiles, paper, metal adhesives, ceramics, medicines, pesticides, wood preservatives, paints.	0.05 mg/l (Marine-hazardous)* 0.1 mg/l (Public Supply-toxic)* 0.05 mg/l††	Little is known about the chemistry of arsenic in soils.** Resonably heavy applications of arsenical pesticides over a period of years have resulted in accumulation of soil arsenic to toxic levels; however, most soils have the capacity to tie up arsenates.***
Barium	Production of paper, fabric printing and dyeing, synthetic rubber production	1.0 mg/l (Public Supply-toxic)* 1.0 mg/l††	Barium ions are thought to be rapidly precipitated, or if not, are removed from solution by adsorption and sedimentation.*
Beryllium	Electroplating, organic chemical manufacturing, nuclear reactors, rocket fuels.	0.1 mg/l (Plants-toxic)* 1.5 mg/l (Marine-hazardous)* None††	Experimental results indicate beryllium tends to be more active in soils of low pH.*
Boron	Detergents, glass, fertilizer, gasoline additive.	5.0 mg/l (Marine-hazardous)* None††	Relatively soluble in soils and can be leached especially from sandy, acid soils:* Plant micronutrient.***
Cadmium	Alloys, rust-proofing of steel, batteries, pigments, fertilizers, pesticides, electroplating, zinc-galvanized iron. Generally found in any operation involving zinc.	0.01 mg/l (Public Supply-toxic)** 0.01 mg/l††	The exact reaction products that precipitate in soils are not known, but the activity decreases with increased pH.** Because of its chemical similarity to zinc, it would be expected to behave in soils much the same way as zinc.***
Calcium	Abundantly present under many natural soil conditions. Used in insecticides, acetylene production, dentifrices, polishes, lime, cement.	250 mg/l as calcium chloride (Public Supply-taste)* None††	Since it is abundantly present under natural soil conditions, its presence in groundwater is not expected to constitute any great hazard.** Plant macronutrient.***
Chlorine	Water purification, bleaches, chemical production.	0.003 mg/l free res. chlorine (F.W. Fisheries-toxic)* None††	Plant micronutrient.***
Chromium	Alloy steels, metal plating, pigments. Found in blow-down from cooling towers and recirculating water from refrigeration equipment where it has been used for corrosion resistance.	0.05 mg/l (Public Supply-toxic)* 0.05 mg/l††	In soils it is generally precipitated at pH 5 and greater.*,**

(continued)

:E ELEMENTS
SLUDGE

rganic elements and a few
it may be present in the sludge
as landfill, and the avenues
udge. The next chapter will
on land to which sludge has
ls in their use.

ed in this chapter. A table
urce IV); the first sections of
ignon, R.A. Craig and N.A.
ories prepared for the Munici-
ry of the EPA in Cincinnati,
Heavy Metals in Wastewater
d; and a short discussion on
nicipal sludge plus a long table
as been taken from PB-263 006,
f Toxic Substances of the EPA,
ic Substances in the Applica-
and Pastureland: A Back-
IX). Details of the report
page 370. References cited
l of the chapter.

ollutants, showing the uses of the
n acceptable contaminant levels,

which the sludge is applied,

ach into groundwater.

Table 7.1: (continued)

Element	Major Uses of the Element and Its Compounds	Maximum Acceptable Contaminant Levels	Remarks
Cobalt	Ceramic pigmentation, paint pigments, paint driers.	0.05 mg/l for continuous use on all soils (Plants-toxic)* None††	Immobilized in soils at neutral to basic pH values.* Most problems are due to deficiencies.** Plant micronutrient.***
Copper	Electrical transmission devices, brass, bronze, pigments, insecticides, utensils.	0.05 mg/l (Marine-hazardous)* None (old limit 1.0 mg/l)††	Relatively insoluble in a basic medium and readily adsorbed on colloids.* There is a 100-fold decrease in activity for each unit increase in soil pH, but exact reaction products that precipitate in soils are unknown.** Plant micronutrient.***
Fluorine	Electrolytic reduction, disinfectants, insecticides, steel manufacturing flux, glass production, wood preservatives, refrigerants, spray-can propellants, enamels.	As the temperature goes from 32.5° to 12.0°C allowance levels go from 1.4 to 2.4 mg/l * Same as above ††	May exist in groundwater at detrimental levels.* The compounds formed in soils are highly insoluble, with least solubility in basic soil.***
Iron	Abundantly present under many natural soil conditions. Mineral production, steel pickling and corrosion.	0.3 mg/l (Public Supply-taste)* None (old limit was 0.3 mg/l)††	May exist in groundwater at high levels.* Forms highly insoluble compounds in well aerated soils at high pH.** Micronutrient.***
Lead	Gasoline additive, batteries, solders, cable coverings, fertilizers, pesticides	0.03 mg/l (F.W. Fisheries-toxic)* 0.05 mg/l††	Forms relatively insoluble compounds in soils.**,*** Soils of high pH, upon becoming acidic, could release lead at future time.** Most is found in the surface soil, indicating little if any downward movement.***
Lithium	Pharmaceuticals, perfume manufacturing, metallurgy, ceramics, plastics, fireworks, medicine.	2.5 mg/l (Plants-toxic)* None††	One of the most mobile cations in soils. Not precipitated by any known process.* While compounds have been used to treat mental disorders, it is toxic at high concentrations.
Magnesium	Abundant under many natural soil conditions. Lightweight alloys, flares, fireworks, flash bulbs, optical mirrors, zinc substitute in batteries, precision instruments, insecticides, medicine, leather, textiles.	250 mg/l as magnesium chloride (Public Supply-taste)* None††	Presence in groundwater due to leaching is not expected to constitute any great hazard.** Plant macronutrient.***
Manganese	Abundant under many natural soil conditions. Alloys, inks, dyes, paints, varnishes, glass, ceramics, fireworks, batteries, fertilizers.	0.05 mg/l (Public Supply-taste)* 0.1 mg/l (Marine-hazardous)* None (old limit 0.01 mg/l)††	Forms highly insoluble compounds in well-aerated soils at high pH.**,*** Plant micronutrient.***

(continued)

Table 7.1: (continued)

ium table nt Levels	Remarks
for con- se on all ts-toxic)*	Immobilized in soils at neutral to basic pH values.* Most problems are due to deficiencies.** Plant micronutrient.***
(Marine- s)* limit ††	Relatively insoluble in a basic medium and readily adsorbed on colloids.* There is a 100-fold decrease in activity for each unit increase in soil pH, but exact reaction products that precipitate in soils are unknown.** Plant micronutrient.***
nperature 32.5° to lowance rom 1.4)* bove ††	May exist in groundwater at detrimental levels.* The compounds formed in soils are highly insoluble, with least solubility in basic soil.***
ublic aste)* limit was ††	May exist in groundwater at high levels.* Forms highly insoluble compounds in well aerated soils at high pH.** Micronutrient.***
(F.W. -toxic)* ††	Forms relatively insoluble compounds in soils.**,*** Soils of high pH, upon becoming acidic, could release lead at future time.** Most is found in the surface soil, indicating little if any downward movement.***
Plants-	One of the most mobile cations in soils. Not precipitated by any known process.* While compounds have been used to treat mental disorders, it is toxic at high concentrations.
as magne- oride Supply-	Presence in groundwater due to leaching is not expected to constitute any great hazard.** Plant macronutrient.***
l (Public taste)* (Marine- us)* l limit l/l)††	Forms highly insoluble compounds in well-aerated soils at high pH.**,*** Plant micronutrient.***

(continued)

Element	Major Uses of the Element and Its Compounds	Maximum Acceptable Contaminant Levels	Remarks
Mercury	Dental amalgams, drugs, fluorescent lights, scientific instruments, plastics, pulp and paper, fungicides, paints, detonators.	0.002 mg/l (Public-Supply-toxic)* 0.002 mg/l††	Inorganic compounds react quickly with the organic matter and clay minerals to form insoluble compounds, so little movement occurs. This condition may be changed by poorly drained soils at low pH.**,***
Molybdenum	Special tool steels, chemicals, ceramic glazes.	None* None††	Tends to be more soluble at lower pH. At pH above 7.0, it is still sufficiently available to plants to induce toxicity in grazing animals.*,** Plant micronutrient.***
Nickel	Stainless steel and other alloys, gasoline additives, electroplating, ceramic paints, batteries, inks, spark plugs, fabric dyes.	0.1 mg/l (Marine-hazardous)* None††	Exact reaction products that precipitate in soils are not known.** Activity decreases with increased pH.*,**,*** Nickel salts can substantially inhibit biochemical oxidation of sewage.*
Nitrogen	Constitutes about ⅘ of the volume of the atmosphere and is present in combined form in animal and vegetable tissues. Ammonia, cyanide, explosives, fertilizers, dyes.	0.02 mg/l as ammonia (F.W. Fisheries-toxic)* 10 mg/l as nitrate nitrogen††	Plant macronutrient.***
Phosphorus	Necessary constituent in plant and animal life. Matches, fertilizers, dehydrating agents.	0.001 mg/l as elemental phosphorus (Marine-hazardous)* None††	Forms relatively insoluble reaction products in both acid and basic soils and should not cause long-term problems. Transport to surface waters could lead to their eutrophication.** Macronutrient.***
Potassium	Abundant under many natural soil conditions. Fertilizers, glass, analytical chemistry, pigments, photography, soap, metallurgy.	None* None††	Presence in groundwater due to leaching is not expected to constitute any great hazard.** Plant macronutrient.***
Selenium	Photometry, ruby glass, wireless telegraphy, photography, vulcanizing rubber, insecticides, fertilizers.	0.01 mg/l (Public Supply-toxic)* 0.01 mg/l††	Highly insoluble and requires oxidation to selenite or selenate before appreciable quantities appear in water.* Solubility expected to increase with increasing pH.†

(continued)

Table 7.1: (continued)

Element	Major Uses of the Element and Its Compounds	Maximum Acceptable Contaminant Levels	Remarks
Silver	Coins, plating, jewelry, medicine, chemicals, photography.	0.005 mg/l (Marine-hazardous)* 0.05 mg/l††	Rarely detected in water above 0.001 mg/l because of low solubility.*
Sodium	Abundant under many natural soil conditions. Insecticides, herbicides, wood preservatives, medicine, bleaches, water treatment, dyes, fertilizers.	250 mg/l as sodium chloride (Public Supply-taste)* None††	Presence in groundwater is not expected to constitute any great hazard. High concentrations in solutions low in other salts cause certain clay-bearing soils to change in structure and lose permeability.**
Zinc	Vulcanized rubber, galvanized iron, alloys, wood preservatives, disinfectants, medicine, rodent poisons, paints, cosmetics.	0.1 mg/l (Marine-hazardous)* None (old limit 5.0 mg/l)††	The exact reaction products that precipitate are not known. Approximately a 100-fold decrease in activity with each unit increase in pH.** Ordinarily, at pH values above 6.5, it tends to be only slowly available. Plant micronutrient.***

**Recommendations*, Environmental Studies Board, National Academy of Science (1972). The recommendations of the ESB covered these categories:

Water to be treated for public consumption (Public Supply);
Fresh water fisheries (F.W. Fisheries);
Marine environment (Marine); and
Agriculture (Plants).

The reason for establishing each recommendation is given with the recommendation.

**Lindsay (28)

***Brady (5)

†Geering et al (20)

††EPA (15)

Source: IV

Table 7.28: Trace Elements and Substances Found in Municipal Sludge

	Concentration Range in Municipal Sludge (ppm dry weight)	Concentration Range in Unamended Soil (ppm dry weight)	Mean Level in Dry Soil (ppm)
Elements			
Aluminum	8,100-51,200	10,000-300,000	71,000
Antimony	2.6-44.4	2-10	6
Arsenic	3.0-50	0.1-40	6
Boron	4-1,430	2-100	10
Barium	272-1,066	100-3,000	500
Beryllium	<4-<15	0.1-40	6
Bismuth	0.03-55.8	–	–
Bromine	13.7-165	1-10	5
Cadmium	2-1,100	0.01-7	0.06
Calcium	1,760-116,400	7,000-500,000	13,700
Cerium	12.4-272	–	50
Cesium	0.45-2.9	0.3-25	6
Chlorine	500-17,800	–	100
Chromium	22-30,000	5-3,000	100
Cobalt	2-800	1-40	8
Copper	84-17,000	2-100	20
Dysprosium	0.7-19.8	–	–
Erbium	0.2-4.5	–	–
Europium	0.7-12.2	30-300	200
Fluorine	2.2-738	–	–
Gadolinium	1.1-22.7	–	30
Gallium	0.9-54	–	1
Germanium	1.1-10.5	–	–
Gold	0.21-7.00	–	6
Hafnium	1.3-10.7	–	–
Holmium	0.07-0.67	–	–
Indium	0.07-3.7	–	5
Iodine	1.0-17.1	–	–
Iridium	0.04-0.46	–	38,000
Iron	1,000-144,000	7,000-550,000	30
Lanthanum	5.1-380	1-5,000	10
Lead	80-26,000	2-200	–
Lutetium	0.04-0.34	–	–
Magnesium	2,000-14,035	600-6,000	5,000
Manganese	32-8,800	100-4,000	850
Mercury	0.1-89	0.01-0.3	0.3
Molybdenum	1.2-1,000	0.2-5	2
Neodymium	0.6-8.6	–	–
Nickel	12-8,000	10-1,000	40
Nitrogen	16,000-66,000	200-2,500	1,000
Osmium	0.06-3.18	–	–
Palladium	0.5-16.2	–	–
Phosphorus	8,000-40,000	–	650
Platinum	0.05-0.74	–	–
Protactinium	1.1-119	–	–
Rhenium	0.03-0.98	–	–
Rubidium	4.3-94.6	20-600	100
Ruthenium	0.21-7.05	–	–
Samarium	1.0-14.2	–	–
Scandium	0.5-7.1	10-25	7
Selenium	1.7-8.7	0.01-2	0.2

(continued)

Table 7.28: (continued)

	Concentration Range in Municipal Sludge (ppm dry weight)	Concentration Range in Unamended Soil (ppm dry weight)	Mean Level in Dry Soil (ppm)
Silver	ND-960	0.01-5	0.1
Sodium	567-8,800	750-7,500	6,300
Strontium	ND-2,230	50-1,000	300
Sulfur	9,000-11,000	30-900	700
Tantalum	0.11-1.45	–	–
Tellurium	0.07-1.52	–	–
Terbium	0.27-4.83	–	–
Thorium	3.1-16.8	0.1-12	5
Thulium	0.06-3.31	–	–
Tin	40-700	2-200	10
Titanium	1,080-4,580	1,000-10,000	5,000
Tungsten	0.9-99.6	–	–
Uranium	0.8-6.4	0.9-9	1
Vanadium	ND-2,100	20-500	100
Ytterbium	0.29-1.30	–	–
Yttrium	0.8-10.1	25-250	50
Zinc	72-50,000	10-300	50
Zirconium	4.8-319	60-2,000	300
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-1,700	–	–

Note: ND is not detected.

Source: IX, from (1)(4)(10)(16)(18)(19)(21)(24)(29)(35)(41)

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 7.28 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

ncentration Range Unamended Soil ppm dry weight)	Mean Level in Dry Soil (ppm)
0.01-5	0.1
750-7,500	6,300
50-1,000	300
30-900	700
–	–
–	–
–	–
0.1-12	5
–	–
2-200	10
1,000-10,000	5,000
–	–
0.9-9	1
20-500	100
–	–
25-250	50
10-300	50
60-2,000	300
–	–
–	–
–	–
–	–
–	–
–	–
–	–

24)(29)(35)(41)

derived from municipal sludge,
Milorganite has been analyzed
gh cadmium and chromium levels.
found cadmium at 117 mg/kg and
it use of municipal sludge such as
o small plots of land. Use is not
pplied to vegetable gardens as
o FDA monitoring, nor are con-
commercial food distribution
tion of a family's diet.

may contain persistent organic
inated pesticides. Data are scarce
largely due to lack of research in
(over 100) reported for drinking
ould be present in municipal sludge.
ight be present in municipal sludges
ocarbons, long chain hydrocarbons,
asses 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 (6).

REFERENCES

(1) Allaway, W.H., "Agronomic Controls over the Environmental Cycling of Trace Elements," *Advance Agron.*, 20:235 (1968).

(2) Anonymous, "Lead in Soils and Plants: Its Relationship to Traffic Volume and Proximity to Highways," *Envir. Sci. and Tech.*, 4(3):231 (1970).

(3) Benard, and Martin, E.J., *Part II-Cadmium Loadings on the Pittsburgh Wastewater Treatment Plant,* EPA Document (1975).

(4) Bowen, H.J.M., *Trace Elements in Biochemistry*, Academic Press, New York (1966).

(5) Brady, N., *The Nature and Properties of Soils*, Macmillan, New York (1974).

(6) Braude, G.L., Jelinek, C.F., and Corneliussen, P., "FDA's Overview of the Potential Health Hazards Associated with the Land Application of Municipal Wastewater Sludges," *Proceedings of the 1975 National Conference on Municipal Sludge Management and Disposal* (1975).

(7) Breeze, V.G., "Land Reclamation and River Pollution Problems in the Croal Valley Caused by Waste from Chromate Manufacture," *J. Applied Ecol.*, 10:513 (1973).

(8) Brown, H.G., Hensley, C.P., McKinney, G.L., and Robinson, J.L., "Efficiency of Heavy Metals Removal in Municipal Sewage Treatment Plants," *Environmental Letters*, 5(2):103 (1973).

(9) Caballero, R., Private Communication (1976).

(10) Chaney, R.L., "Crop and Food Chain Effects of Toxic Elements in Sludges and Effluents," in *Recycling Municipal Sludges and Effluents on Land, Proceedings of Joint Conference* (1973).

(11) Colston, V., *Characterization and Treatment of Urban Land Runoff*, EPA-670/2-74-096 (1974).

(12) Davis, J.A. III, and Jacknow, J., "Heavy Metals in Wastewater in Three Urban Areas," *Journal WPCF*, 47(9):2292 (1975).

(13) Dean, R.B., "Disposal and Reuse of Sludge and Sewage: What Are the Options," in *Proceedings of Conference on Land Disposal of Municipal Effluents and Sludges,* Rutgers University (March 1973).

(14) Environmental Protection Agency, Draft Development for Proposed Effluent Guidelines and New Source Performance Standards for the Automatic and Other Laundries Point Source Category (1974).

(15) Environmental Protection Agency, "National Interim Primary Drinking Water Regulations," *Federal Register*, p. 59565 (Dec. 24, 1975).

(16) Environmental Protection Agency, *Review of PCB Levels in the Environment,* EPA 560/7-76-001 (1976).

(17) Fleischer, M., Sarofim, A.F., Fasset, D.W., Hammond, P., Shacklette, H.T., Nesbit, I.C.T., and Epstein, S., "Environmental Impact of Cadmium: A Review by the Panel on Hazardous Trace Substances," *Environmental Health Perspectives*, p. 253 (1974).

(18) Furr, A.K. et al, "Study of Guinea Pigs Fed Swiss Chard Grown on Municipal Sludge-Amended Soil," *Archives of Env. Health*, 31:87 (1976).

(19) Furr, A.K. et al, "Multielement and Chlorinated Hydrocarbon Analysis of Municipal Sewage Sludges of American Cities," *Environ. Sci. and Tech.*, 10:683 (1976).

(20) Geering, H., Cary, E., Jones, L., and Allaway, W., "Solubility and Redox Criteria for the Possible Forms of Selenium in Soils," *Soil Sci. Soc. Am. J.*, 32:35 (1968).

(21) Giordano, P.M., Mortvedt, J.J., and Mays, D.A., "Effect of Municipal Wastes on Crop Yields and Uptake of Heavy Metals," *J. Environ. Qual.*, 4:394 (1975).

(22) Greater Cincinnati Sewer Districts, Unpublished Data and Personal Communication (1976).

(23) Hergert, S.L., "Urban Runoff Quality and Modeling Study," Master's Thesis, Nebraska University (1972)
(24) Jelinek, C.F., Braude, G.L., and Read, R.B., "Management of Sludge Use on Land, FDA Considerations," Presented at the Association of Metropolitan Sewerage Agencies Conference on Sludge Management, Houston (1976)
(25) Klein, L.D., Land, M., Nash, N., and Kirschner, S.I., "Sources of Metals in New York City Wastewater," *Journal WPCF*, 46(12):2653 (1974)
(26) Korte, N.E., Skopp, J., Niebla, E.E., and Fuller, W.H., "A Baseline Study on Trace Metal Elution from Diverse Soil Types," *Water, Air and Soil Pollution*, 5:150 (1975)
(27) Lagerwerff, J.V. and Specht, A.W., "Contamination of Roadside Soil and Vegetation with Cadmium, Nickel, Lead, and Zinc," *Environ. Sci. and Tech.*, 4(7):583 (1970)
(28) Lindsay, W., "Inorganic Reactions of Sewage Wastes with Soils," in NASULGC, *Recycling Municipal Sludges and Effluents on Land,* Washington, D.C. (1973)
(29) Lisk, D.J., "Trace Metals in Soils, Plants and Animals," *Advance Agron.,* 24:267 (1972)
(30) Maruyama, T., Hannah, S.A., and Cohen, J.M., "Metal Removal by Physical and Chemical Treatment Processes," *JWPCF,* 47(5):962 (1975)
(31) McCuen, R.H., *Flood Runoff from Urban Areas,* University of Maryland, Water Resources Research Center (1975).
(32) Mytelka, A.I., Czachor, J.S., Guggino, W.B., and Golub, H., "Heavy Metals in Wastewater and Treatment Plant Effluents," *JWPCF,* 45(9):1859 (1973)
(33) Nightengale, H.I., "Lead, Zinc, and Copper in Soils of Urban Storm-Runoff Retention Basins," *Am. Water Works Assoc. Journal,* 67(8):443 (1975)
(34) Nilsson, R., "Removal of Metals by Chemical Treatment of Municipal Wastewater," *Water Research*, 5:51, Pergamon Press (1971)
(35) Page, A.L., *Fate and Effects of Trace Elements in Sewage Sludge When Applied to Agricultural Lands. A Literature Review Study*, EPA-670/2-74-005, PB-231 171 (1974)
(36) Pitt, R.E. and Amy, G., *Toxic Materials Analysis of Surface Street Contaminants,* EPA-R2-73-283 (1973)
(37) Roberts, P., Hegl, H., Weber, A., and Krahenbuhl, H., "Metals in Municipal Wastewater and Their Elimination in Sewage Treatment," *EAWAG News,* Swiss Federal Institute of Technology, Federal Institute for Water Resources and Water Pollution Control (1975)
(38) Salotto, B.V., Grossman III, E., and Farrell, J.B., "Elemental Analysis of Wastewater Sludges from 33 Wastewater Treatment Plants in the United States," Presented at the Research Symposium on Pretreatment and Ultimate Disposal of Wastewater Solids, EPA 902/9-74-002 (1974)
(39) Sanjour, W., "Cadmium and Environmental Policy," Draft Document, EPA Office of Water and Hazardous Materials (1974)
(40) Sartor, J.D. and Boyd, G.B., *Water Pollution Aspects of Surface Street Contaminants,* EPA-R2-72-081 (1972)
(41) Shipp, R.F. and Baker, D.E., "Pennsylvania's Sewage Sludge Research and Extension Program," *Compost Sci.*, 16(2) (1975)
(42) Stumm, W. and Morgan, J.J., *Aquatic Chemistry: An Introduction Emphasizing Chemical Equilibria in Natural Waters*, Wiley Interscience, New York (1970)
(43) Van Loon, J.C. and Lichwa, J., "A Study of the Atomic Absorption Determination of Some Important Heavy Metals and Domestic Sewage Plant Sludges," *Environmental Letters*, 4(1):1 (1973)
(44) Zenz, D. et al, "U.S. EPA Guidelines on Sludge Utilization and Disposal—A Review of Its Impact Upon Municipal Wastewater Treatment Agencies," Presented by the MSD of Greater Chicago to the 48th WPCF Conference, Miami Beach (1975)