STATION BULLETIN 503 March, 1975

A Survey of New Hampshire Sewage Sludges as Related to Their Suitability for On-Land Disposal

by

Robert D. Harter

NEW HAMPSHIRE
AGRICULTURAL EXPERIMENT STATION
UNIVERSITY OF NEW HAMPSHIRE
DURHAM, NEW HAMPSHIRE

PREFACE

This publication is a result of the research program of the Institute of Natural and Environmental Resources. The Institute is a multi-disciplinary group of scientists involved in a coordinated program of research, teaching and extension. The research effort encompasses investigations of: problems affecting the quality of the environment, economics of agriculture, forest and wildlife resources, the efficient use and conservation of water and soil, and regional and community planning and development.

The author wishes to express his appreciation to the sewage plant operators, who so willingly cooperated with this project, and to Mr. Douglas Lash for his assistance in sludge sampling and analysis.

Introduction

Disposal of sewage sludge is rapidly becoming the major environmental problem in New Hampshire. State and Federal regulations enacted during the last decade require that all sewerage collection systems provide at least primary treatment, and regulations further require most New Hampshire towns to initiate plans for secondary treatment. Although the quantities of sludge thereby produced by New Hampshire towns are relatively small when compared with large cities of the U.S., its disposal presents significant problems to many individual communities.

Nationwide, many imaginative techniques for disposal of sewage sludge are being developed. However, most of these disposal techniques are geared toward large quantities of sludge. As such, they are too expensive for use by small New Hampshire towns, many of which produce less sludge in a year than a medium-size city produces in a day. Considering the amounts produced by most towns and the relatively large areas of undeveloped land in the state, land disposal of the sludge is probably the best disposal method. However, if sludge is to be placed on the land, it is paramount that its impact on the plant and animal (including human) community is considered.

The U.S. Environmental Protection Agency requires that sludge be disposed in a manner that does not present a human health hazard, with primary concern being on disease-causing organisms. These organisms can usually be destroyed by proper pretreatment and disposal techniques. The inorganic constituents of sludge present a less obvious, but potentially more dangerous hazard to plant and animal life, as well as to human health. Certain potentially toxic elements may build up in the soil, and be taken up by plants in quantities toxic to the plant or to animals feeding on the plant. Conversely, some elements may leach into groundwater supplies, an equally undesirable situation.

Since little information was available concerning the inorganic constituents of New Hampshire sludges, a survey of the materials conducted as a preliminary step to possible development of on-land disposal techniques.

Methods

During October and November, 1973, sludge samples were collected from 22 N.H. sewage treatment plants. Samples were not collected from several communities which have treatment systems, since disposal is via small lagoons, or an anaerobic digester is emptied only once a year.

Nitrogen was determined by Kjeldahl method (Bremner 1965), and carbon by the Walkley-Black wet oxidation method (Allison, 1965). Phosphorus, potassium, calcium, magnesium, sodium, manganese, iron, boron, copper, zinc, aluminum, strontium, barium, and molybdenum were determined at the Ohio Research and Development Center's Spetrographic Laboratory. Silver, beryllium, cadmium, cobalt, chromium, lithium, nickel, lead, antimony, and tin were determined by emission spectroscopy at the University of New Hampshire's Center for Industrial and Institutional Development.

Errors in Measurement

Due to high cost of analysis and limited research funds, only one sample was collected from each of the treatment plants. Thus, the chemical analyses are merely indicative of the sludge composition on a given calendar date. They may or may not be representative of sludge composition if measured over a longer period of time, since sludges from the same source can vary considerably in their composition, even on a daily basis. For example, Sommers and Nelson (1974) found that, in analyzing sludges from nine Indiana cities over a two-year period, constituent variations of 60 percent or greater from the average values were not uncommon. Relative magnitudes are, however, indicative of what one might find in the sludges of New Hampshire.

In addition, the precision of analysis must be considered. Errors in analysis of nitrogen and carbon may be assumed to be no greater than two percent. However, error in spectrophotometric analyses tend to be somewhat greater. The reported values for the elements other than nitrogen and carbon are considered to be within thirty percent of the actual value.

Results and Discussion

For comparative purposes, the towns from which sludge samples were obtained were divided into three groups: (1) those containing little or no industry, (2) those having a moderate amount of industry, and (3) those which are heavily industrial. (Table 1). The latter group is of greatest interest since the sludge from industrial towns is the most likely to contain potentially toxic elements in substantial quantities. The sludges of all towns having probable industrial input to the treatment plant were analyzed for ten potentially toxic elements. This included all the towns of groups 2 and 3 (Salem was inadvertently omitted). In addition, three sludges were included from Group 1: Durham, because of the unknown input from the University; Goffstown, because of a

Table 1: Some data pertaining to amount and nature of sewage sludges produced. Blanks indicate information is not readily available.

Town	Population served by plant[1]	Volume waste water treated (mgd)	Capacity of plant (mgd)	Type of industry[5]	Type of industrial waste[5]	Volume of Sludge[7]	Type of Sludge[6]	Additives	Other
1) Domestic									
Durham	(621)[2]	1.1	1.5	(university)		35 yd^3/wk.	P-DW	$FeCl_3$ lime	Up to 2,000 lb. grease/day
Goffstown	(400)	.4	.4			26 yd^3/yr.	P-AD	lime	Septic wastes
Hampton, winter	10,000	1.2	2.5			14,280 lb./mo.	P-DW	lime	Some dyes may periodically reach plant.
summer	20,000	1.7				53,500 lb./mo.			
Hanover	8-9,000	1.4	3	(university)		15 yd^3/mo.	P-AN-DW	lime	Grease and rag problem
Littleton	5,000	1	11.2[4]			18-30 yd^3/wk.	P-DW	$FeCl_3$ lime	Septic wastes
New London		.25					P-AD	alum.	
Pease AFB			1				P-AN-AD		

Rollinsford		.07	.15			68,000 gal/wk.	AC-DW		
Wolfeboro							P-AD		
2) Domestic-Industrial									
Bristol	1,750	.24	.23	Rubber products, plating	Cooling water 500 gal. $ZnPO_4$/wk.	"low yield"	AC-AD		
Keene							P-AD		
Laconia		8.5[3]	3.5			6,400 gal/mo.	P-AN-AD		Grease problem
Meredith		.1	.2	asbestos			P-AD		Grease problem
Newmarket	2,800	.2	2		wire insulation		P-AN-AD		Methane production
Plymouth		.38	.4			8-9 yd^3/wk.	P-DW	$FeCl_3$ lime	Grease problem

Table 1 *(Cont'd.)* **Some data pertaining to amount and nature of sewage sludges produced. Blanks indicate information is not readily available.**

Town	Population served by plant[1]	Volume waste water treated (mgd)	Capacity of plant (mgd)	Type of industry[5]	Type of industrial waste[5]	Volume of Sludge[7]	Type of Sludge[6]	Additives	Other
Industrial									
Claremont		2	4	cloth re-processor, dairy	dyes, milk wastes		P-AN-AD		
Dover	4,4-4,700	1.8	3.9	rubber products, tannery, machine tools	cooling water, corrosives, hair, grease	60 yd^3/wk.	P-DW	anionic polymer	
Merrimack	None	3	10.5	brewery, printing	brewery wastes, wash-down water	"high volume"	AC-DW	$FeCl_3$ lime	
Nashua	5,000	3	8.5	"many"	?	115,000 lb./mo. (ave.)	P-DW		

Newport	(900)	.5	1.26	arms	bluing salts, chromic acids	2500-3000 lb./wk.	P-DW	$FeCl_3$ lime	Septic wastes
Portsmouth		2+	3	wire and cable fabrication		10,000 lb./wk.	P-DW		
Salem	10,400	.9	1.2	race track			AC-AN-AD		Methane production

Footnotes

[1]Numbers in parentheses are domestic units, rather than population.

[2]Excludes dorms and apartments

[3]Greater than a one-day interval, but plant does operate at over capacity.

[4]Includes ability to handle storm water.

[5]Only industries known to be on sewer and wastes that are known to be contributing are included. Many operators do not know who is connected nor what they contribute.

[6]P = primary sludge

AC = activated sludge

AN = anaerobic digestion

AD = air dried

DW = dewatered

[7]The volumes are as provided by the plant operators. Different solids contents makes reporting of all volumes on the same basis impossible.

suspected industrial input, and Pease AFB, because of unknown influences of operations there. Results of these analyses are tabluated in Table 2.

From the information presented in Table 2, it may be concluded that, despite the industrial component within the town, the Plymouth and Portsmouth treatment plants are not handling any significant amounts of industrial wastes. In terms of sludge usage, these towns could be included with those in Group 1. Apparently, the university contributes negligible amounts of potentially toxic elements, so Durham sludge, along with that of Plymouth and Portsmouth, can probably be considered typical of domestic sludges. The Pease AFB sludge is moderately high in tin (500 ppm) and very high in silver (210 ppm) compared to other towns of New Hampshire. Levels of these two elements are not normally reported, so it is unknown how these values compare to other sludges throughout the United States. Berrow and Webber (1972) have, however, reported the presence of these two elements in 42 sewage sludges from locations in England and Wales. They found silver to range between 5 and 150 ppm, with a median value of 20 ppm. Tin ranged from 40 to 700 ppm, with a median of 120 ppm. Based on these data, the Pease AFB sludge should probably be classed as high in both silver and tin, and be included with the group 2 towns. The 720 ppm lead and 450 ppm tin in the Goffstown sludge is of moderate concern, but the 1,000 ppm antimony is sufficient to tentatively place Goffstown in group three. (Again, there is little information on nation-wide sludges with which this can be compared.)

Based on data for content of sludges nationwide (Page, 1974), only Dover and Newport sludges might be considered to have high chromium concentrations, with Dover sludge having chromium levels in excess of any values cited in the literature. Newport sludge is also moderately high in nickel. Lead appears to be the most prevalent metal in New Hampshire sludges. Lead concentration of greater than about 1,000 ppm in sludge would normally indicate a substantial industrial waste input (Page, 1975). The cadmium concentrations of the Keene, Laconia, Meredith and Claremont sludges are of considerable concern since this element is highly toxic to both plants and animals, (Allaway, 1968). Although the cadmium concentrations are much lower than those reported for many industrial sludges (Page, 1974), they are above that which might be considered "common" for sludges. On the basis of the English and Wales data (Berrow & Webber, 1972), high concentrations of tin are present in several New Hampshire sludges. The other elements listed in Table 2 are not present in sufficient concentrations to cause undue alarm.

To provide a criterion for determining whether and how much sludge can be safely disposed on land, Table 3 lists the soil concentrations of several toxic elements. It is assumed that the common soil concentration can be equaled by sludge input, but that it would be unwise to exceed this level of addition until further information on the fate of toxic elements in soil is obtained. Thus, Tables 2 and 3 can be used in conjunction to determine safe addition levels. For example, the toxic element concentrations of Merrimack sludge are not high enough to limit the application of this material to land, whereas, only one ton of dry Dover sludge would increase the common chromium concentration by 99 percent. Although the silver content of most sludges would limit application, on this basis, the common soil concentration is so low that the soil concentration of this element could probably be increased to 1 ppm with no adverse effects.

Table 2. **Quantities of some potentially toxic elements in selected New Hampshire Sludges.**

Town	Silver	Beryllium	Cadmium	Cobalt	Chromium	Lithium	Nickel	Lead	Antimony	Tin
	ppm									
1) Domestic										
Durham	25	<3	<5	1	40	<10	23	81	<3	320
Goffstown	23	<3	<5	4	110	<10	57	720	1,000	450
Pease AFB	210	<3	<5	7	97	<10	77	100	<3	500
2) Domestic-industrial										
Bristol	14	<3	<5	5	80	<10	51	15,000	<3	850
Keene	38	<3	12	4	150	<10	38	8,500	<3	260
Laconia	57	<3	45	7	230	<10	100	4,400	<3	850
Meredith	73	<3	30	7	53	<10	49	7,700	<3	400
Newmarket	26	<3	<5	3	140	<10	73	660	85	1,200
Plymouth	40	<3	<5	2	30	<10	37	140	<3	240
3) Industrial										
Claremont	38	<3	13	18	160	<10	38	10,000	<3	510
Dover	<3	<3	<5	3	99,000	<10	82	85	<3	230
Merrimack	<3	<3	<5	<1	200	<10	35	13	<3	140
Nashua	<3	<3	<5	11	160	<10	76	650	<3	300
Newport	11	<3	<5	4	940	<10	190	100	<3	180
Portsmouth	40	<3	<5	2	30	<10	37	140	<3	240

On this basis, the sludges have been *tentatively* classified into low, medium, and high-risk categories as related to their possible detrimental effects if placed on the land (Table 4). Although the concentrations of potentially toxic elements in the "low-risk" sludges are not of major concern, certain of the elements may be accumulated in the soil. Therefore, care should be exercised that excessive amounts of these sludges are not applied to soils. An average of four to six tons (dry) per acre per year would probably be acceptable. The "medium-risk" sludges should probably not be applied to land at rates exceeding one or two tons (dry) per acre per year. Until additional information on the fate of heavy metals added to land is available, the "high-risk" sludges should probably not be added to land. If no other disposal technique is available, the sludge should be spread very thinly over the land, adding no more than one or two tons (dry) of sludge, to any one area within a ten-year period.

As a fertilizer material, none of the sludges would be particularly good. All are low in potassium and usage of the sludges as a fertilizer would, therefore, require additions of this element. Whether additional phosphorus would be required, will depend upon the amount of sludge applied, the amount of phosphorus in the soil, and the phosphorus requirements of the plants to be grown. Whether additional nitrogen needs to be applied is more dependent upon the C/N ratio than on the total nitrogen content of the material. If organic materials have a C/N ratio of greater than 15 or 20 to 1, additional nitrogen may be needed to prevent temporary nitrogen deficiencies in the plants. Sludge from secondary treatment plants using activated sludge and primary plants having an anaerobic digester have a satisfactory C/N ratio. (Table 5). However, most of the primary sludges that were not digested had a rather high C/N ratio. Thus, when using these sludges as fertilizer , additional nitrogen may be needed.

While all the elements listed in Table 4, except sodium, barium and strontium, are required by plants, several may become toxic if present in too large quantities. This list would include manganese, boron, copper, zinc, and molybdenum. In most circumstances, manganese in soil is sufficiently insoluble that plants would be unlikely to absorb toxic quantities. Furthermore, boron, zinc, and molybdenum are probably not present in quantities large enough to cause plant nutritional problems if applied to soils at the suggested rates. The potential for copper toxicity depends on the sludge copper content in excess of 200 ppm. While sodium is not highly toxic to plants, high sodium levels can alter the physical and chemical properties of soils. In addition, sludge containing high sodium levels should not be used on food crops where they will be consumed by persons suffering hypertension.

Table 3: Amount of toxic elements, as listed by Allaway (1968), in soil and amount of sludge of given concentrations needed to increase the common concentration by 100%.

Element	Concentration in soils (ppm)[1]		Assumed concentration (ppm) in sludge[2]	Amount of sludge required to increase common soil concentration by 100% (dry tons)[3]
	common	range		
Beryllium	6	1-40	3	2,000
Boron	10	2-100	20	50,000
Cadmium	.06	0.01-7	10	6
Chromium	100	5-3000	100	1,000
Copper	20	2-100	200	100
Lead	10	2-200	1,000	10
Molybdenum	2	0.2-5	30	70
Nickel	40	10-1000	50	800
Silver[4]	.01	.01-5	50	.2
Tin[4]	10	2-200	500	20
Zinc	50	10-300	200	250

[1]From Page (1974) and Allaway (1968)

[2]The assumed sludge concentrations were chosen as being representative of the majority of New Hampshire sludges.

[3]This assumes that the sludge is well mixed with the upper six inches of soil, as would occur in most tilled fields. Where the sludge is not incorporated, as might occur in the forest, the accumulation in the surface soil would be far more rapid.

[4]No information on the toxicity or non-toxicity of silver and tin was found. Therefore, these two elements were included in this listing.

Table 4: **Quantities of several plant nutrients in New Hampshire sewage sludges.**[1]

Town	Nitrogen	Phosphorus	Potassium	Calcium	Magnesium	Manganese	Iron[2]	Boron	Copper[2]	Zinc[2]	Molybdenum	Sodium[3]	Barium[3]	Strontium[3]
	%					ppm								
a) low risk														
Durham	2.83	0.90	<0.30	5.20	0.07	55	2600	9	158	157	18	500	41	45
Hampton	1.65	0.65	<0.30	2.79	0.24	33	3053	19	>200	151	17	1400	54	48
Hanover	1.60	1.10	<0.30	5.07	<0.03	121	3566	12	>200	263	>30	100	80	46
Littleton	1.37	0.69	<0.30	4.83	0.04	116	3654	11	>200	195	>30	700	89	47
New London	3.39	>2.0	0.32	0.28	<0.03	31	3005	20	>200	256	>30	300	111	24
Plymouth	1.52	0.63	<0.30	5.21	<0.03	171	3303	9	>200	212	26	400	58	103
Portsmouth	2.09	0.60	<0.30	2.29	0.28	18	3078	18	>200	131	16	1500	112	55
Rollinsford	4.50	>2.0	0.36	1.35	0.27	482	>4000	23	>200	285	>30	1000	56	61
Wolfeboro	2.00	0.81	<0.30	3.13	<0.03	60	3290	14	>200	242	18	100	110	58
Merrimack	4.99	1.26	<0.30	5.22	<0.03	93	>4000	17	167	163	>30	700	26	52
b) medium risk														
Nashua	1.86	0.58	<0.30	2.79	0.05	84	3059	15	>200	216	>30	400	81	45
Pease AFB	2.16	>2.0	<0.30	5.30	<0.03	252	3756	13	>200	275	>30	200	71	68
Newport	1.43	0.75	<0.30	3.34	0.10	195	>4000	16	>200	193	29	600	83	51

c) **high risk**

Bristol	4.02	1.44	0.38	0.74	0.15	97	3439	19	>200	294	>30	500	67	42
Claremont	3.46	1.26	0.31	1.85	0.09	100	2184	25	>200	255	27	1500	105	45
Dover	3.96	0.58	< 0.30	5.18	0.29	126	2541	73	>200	136	>30	1200	21	73
Goffstown	1.79	0.74	< 0.30	3.24	< 0.03	29	3504	15	>200	279	>30	400	88	37
Keene	2.68	0.49	< 0.30	0.49	< 0.03	23		18			8	700	90	27
Laconia	2.61	1.95	< 0.30	2.51	0.07	184		22			>30	700	109	53
Meredith	2.76	0.85	< 0.30	1.45	< 0.03	80	3281	18	>200	261	24	300	109	36
Newmarket	2.83	1.87	< 0.30	3.80	0.08	115	3240	18	>200	269	>30	700	88	57
Salem[4]	3.28	1.80	0.30	2.58	0.13	221	3438	19	>200	279	24	800	100	65

Footnotes:

[1] All except nitrogen were analyzed at the Ohio Spectrographic Laboratory. This laboratory is set up for plant tissue analysis, so over range and under range values indicate sludge contents in relation to that normally found in plants.

[2] Expected range of iron, copper, and zinc were not found in the Keene and Laconia sludges, indicating an analytic difficulty.

[3] Sodium, barium, and strontium are not plant nutrients, but may be absorbed by plants.

[4] Salem is tentatively assigned to the high risk category, since it was not analyzed for potential toxic elements and industry does exist in the town. No industry is known to be connected to the plant, however.

Table 5: **Carbon/Nitrogen Ratios of the Different Types of Sludge.**

Town	Sludge Type: Primary	Activated Sludge	Anaerobic Digestion	Dewatered	Air Dried	C %	N %	C/N
Salem		x	x		x	30	3.3	9.1
Bristol		x			x	30	4.0	7.5
Merrimack		x		x		29	5.0	5.8
Rollinsford		x		x		29	4.5	6.4
Claremont	x		x		x	39	3.5	11.1
Laconia	x		x		x	29	2.6	11.1
Newmarket	x		x		x	35	2.8	12.5
Pease AFB	x		x		x	20	2.2	9.1
Hanover	x		x	x		19	1.6	11.9
Goffstown	x				x	44	1.8	24.4
Keene	x				x	48	2.7	17.8
Meredith	x				x	38	2.8	13.6
New London	x				x	28	3.4	8.2
Wolfeboro	x				x	39	2.0	19.5
Durham	x			x		43	2.8	15.4
Dover	x			x		40	4.0	10.0
Hampton	x			x		46	1.7	27.0
Littleton	x			x		30	1.4	21.4
Nashua	x			x		38	1.9	20.5
Newport	x			x		43	1.4	30.7
Plymouth	x			x		39	1.5	26.0
Portsmouth	x			x		42	2.1	20.0

Summary

New Hampshire sewage sludges were analyzed for several inorganic elements which are necessary for plant growth and others which could be toxic to humans or animals if present in large amounts. About one half of the sludges did contain substantial quantities of the potentially toxic elements. Lead was the element most commonly found, but one sludge contained nearly 10 percent chromium. The remainder of the sludges did not contain any element in quantities that could be considered dangerous if applied to the land in moderate amounts. Generally, the sludges could not be considered as a complete fertilizer material and, at minimum, additional potassium should be added with the sludge. Until further information is compiled on rates of element build up in the soil and uptake by plants, sludge usage in any one area should be kept to moderate amounts.

LITERATURE CITED

Allaway, W. H. 1968. Agronomic controls over the environmental cycling of trace elements. Adv. Agronomy 20:235-274.

Allison, L. E. 1965. Organic Carbon *in* C. A. Black (Ed.-in-Chief) Methods of Soil Analysis. Agronomy 9:1367-1378. American Society of Agronomy, Madison, Wisconsin.

Berrow, M. L. and J. Webber. 1972. Trace elements in sewage sludges. J. Sci. Food, Agric. 23:93-100.

Bremner, J. M. 1965. Total Nitrogen *in* C. A. Black (Ed.-in-Chief) Methods of Soil Analysis. Agronomy 9:1149-1178. American Society of Agronomy, Madison, Wisconsin.

Page, A. L. 1974. Fate and effects of trace elements in sewage sludge when applied to agricultural lands: a literature survey. U.S. Environ. Protection Agency Report No. EPA-670/2-74-005.

Sommers, L. E. and D. W. Nelson. 1974. Variations in the chemical composition of sewage sludges, Agry. Abst. 66:39.

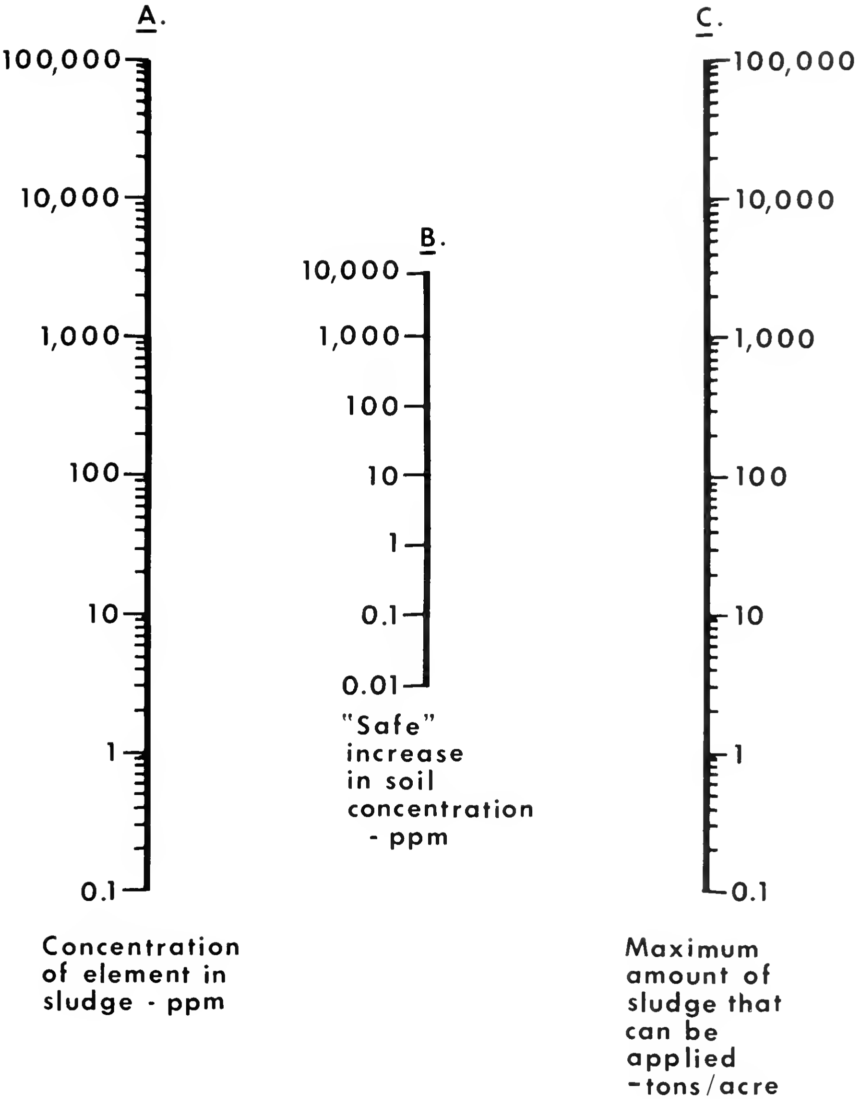
APPENDIX

Use of Nomograph

Find the sludge concentration of the element of interest in Column A.Find the "safe" increase in soil concentration in Column B (normally, an addition equal to the common concentration, Table 3, can be considered "safe"). When a ruler is laid to intersect these two points, Column C will be intersected at the maximum amount of sludge, in tons per acre, that can be applied to the land in order not to exceed the "safe" increase (see example, below). Either wet or dry basis can be used for columns A and C, but they should not be mixed. If the concentration (Column A) is on a dry weight basis, the addition will be in dry tons per acre, and if the concentration is on a wet basis, the addition will be on a wet ton basis. The values in Column C are calculated on the assumption that the sludge wili be thoroughly mixed with the upper six inches of soil. If it is not mixed to this level, the amount applied should be decreased accordingly, i.e., if it mixed to three inches, apply only half the indicated amount.

EXAMPLE: The Keene sludge contained 8,500 ppm lead (Table 2). Soils commonly contain about 10 ppm lead (Table 3), so it would probably be safe to add this amount to the land. Drawing a line to intersect 8,500 in Column A and 10 in Column B, we find that we should not add more than 1-½ tons of dry Keene sludge per acre.

The amount of any given sludge applied should be the lowest quantity indicated by the presence of different elements. Although the total effects of all elements should be considered, no appreciable problems should be encountered if the common soil concentration of the most restricting element is not increased by more than 100 percent (see Table 3).


A.
100,000
10,000
1,000
100
10
1
0.1
Concentration of element in sludge - ppm
B.
10,000
1,000
100
10
1
0.1
0.01
"Safe" increase in soil concentration - ppm
C.
100,000
10,000
1,000
100
10
1
0.1
Maximum amount of sludge that can be applied -tons/acre