SLUDGE GENERATION, HANDLING AND DISPOSAL AT PHOSPHORUS CONTROL FACILITIES

by

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1 INTRODUCTION

The problems of estimating sludge quantity, deciding how to handle the sludge and how to ultimately dispose of it have been with civilized man for sometime, but have been mainly ignored. The concern regarding sludge quantities, handling and disposal is generally proportional to population density, and the degree and complexity of industrialization.

For example, consider for a moment that even when going back to early biblical records, nowhere does it mention that in the construction of the ark Noah considered, or even anticipated the monumental sludge handling problem he would have to face once he had all his animals on board. His solution when faced with the problem once adrift, is left to your imagination.

It would appear that still too frequently design engineers today suffer from the "Noah Syndrome".

Early man considered sludge as a resource, something to be recycled. Many less industrialized nations still pursue this philosophy. Even, highly industrialized nations, not blessed with an abundance of resources have prescribed to a similar philosophy. In North America, it took an energy crisis to redirect our thinking to the point where sludge is looked at from a utilization rather than disposal perspective.

It has been said that "history repeats itself". This then would also appear to be true when dealing with sludge.

This paper will focus on providing information on the effect of adding metal salts to existing wastewater treatment plants for phosphorus removal to 1 mg/L total as it impacts on sludge quantity, handling and disposal/utilization.

The information is based on data from 185 waste treatment plants surveyed in the Province of Ontario. The completeness of data varies considerably.

2 SLUDGE QUANTITIES

Waste treatment process design engineers are continually plagued by lack of information when it comes to designing sludge handling and disposal/utilization facilities. The length of the short cut to data acquisition is pretty well proportional to the degree of confidence to be placed in the process capacity design.

Good data is hard to get and costs money. The original error made in sludge quantity estimation can and is increased when attempting to estimate resulting sludge quantities due to chemical addition for phosphorus removal requirements. This error becomes greater as the degree of phosphorus removal increases from a target of 1 $mg \cdot L^{-1}$ to 0.1 $mg \cdot L^{-1}$, and can be attributed to increasingly greater deviations from stoichiometric relationships between influent P and effluent target P.

Sludge production is influenced by a number of variables. For chemical sludge production, the chemical used, wastewater characteristics and point of chemical addition all play an important role. For biological sludge production, the type of process used in the conversion of substrate greatly affects the amount of biomass produced. The amount of sludge produced also varies with the nature of substrate oxidized. Higher sludge volumes result in winter than in summer because the auto-oxidation rate depends on temperature. The total volume of sludge produced from biological and physical/chemical systems, or any combination thereof is also influenced by clarifier performance, sludge recycle and the degree of operator attention to the system.

The literature abounds with sludge production data. Figure 1 is just one example for municipal sludges and illustrates the degree of

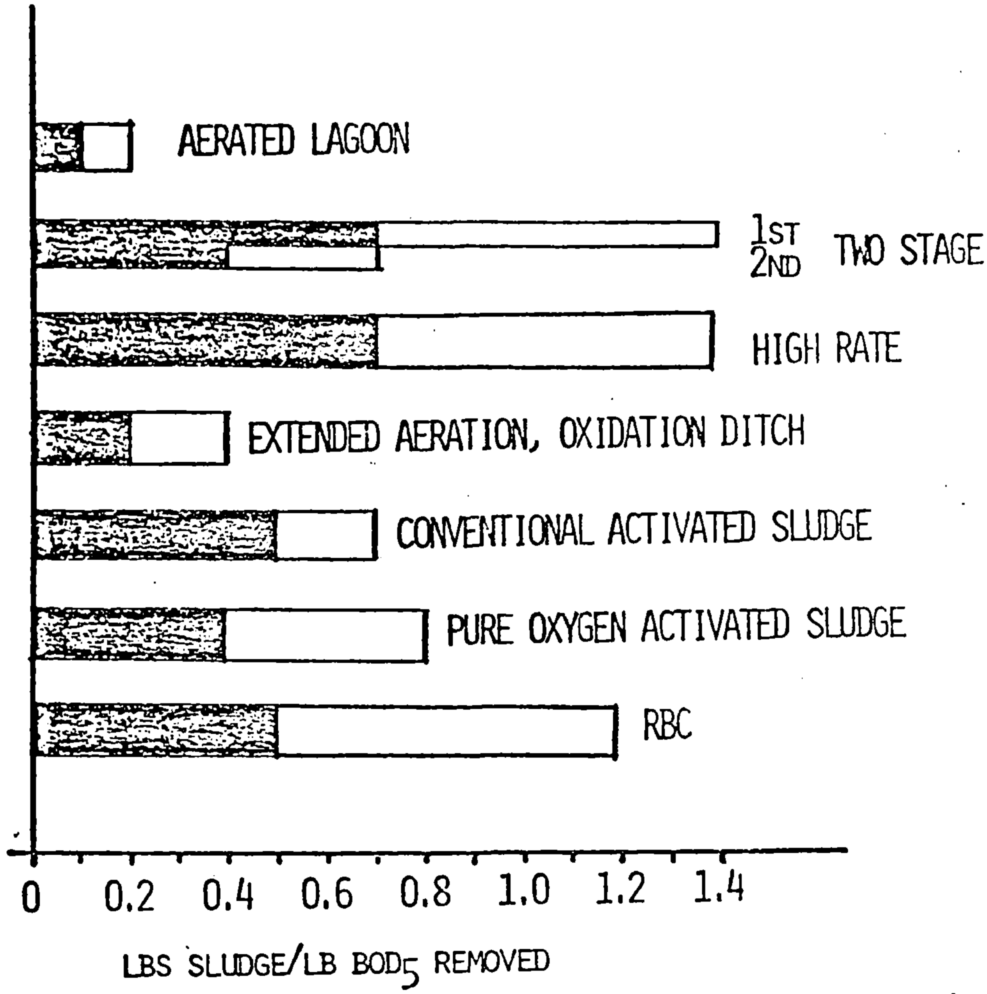

FIGURE 1. BIOLOGICAL SLUDGE PRODUCTION [1]

variability which can be in excess of 100%.

A most useful method of sludge quantity estimation consists of performing a mass balance around various treatment process components and coupling this with process efficiency assumptions (2).

Calculations to determine chemical sludge quantities based on stoichiometric relationships have been illustrated by Campbell (3).

Pilot Scale Activated Sludge P and N Removal Studies

A long-term pilot scale study for the removal of phosphorus and nitrogen (4) was conducted at the Wastewater Technology Centre (WTC). Sludge production was monitored over a 16-day consecutive period. Comparing the observed to calculated sludge production values for ferric iron addition based on stoichiometric relationships shows a 65% increase 50% of the time, as illustrated in Figure 2.

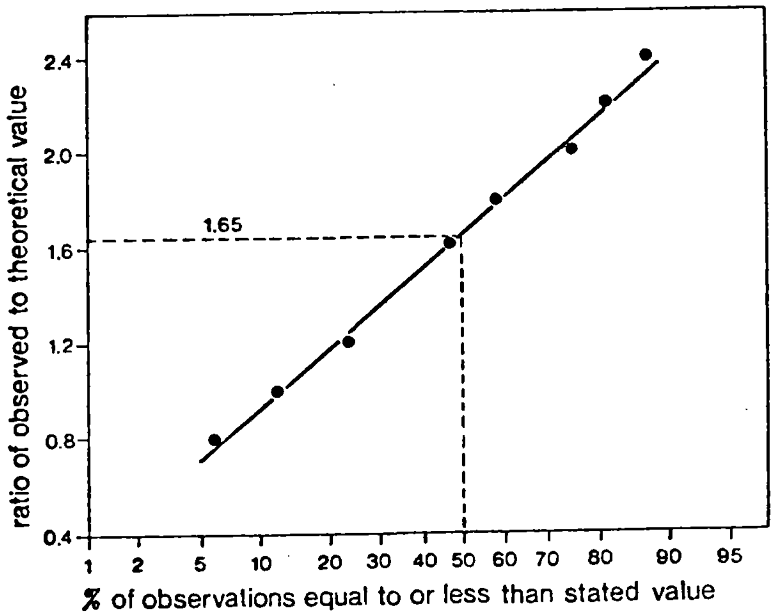

FIGURE 2. OBSERVED TO THEORETICAL SOLIDS PRODUCTION RATIO-FERRIC IRON ADDITION AT A NITROGEN AND PHOSPHORUS REMOVAL ACTIVATED SLUDGE PLANT[4]

Full Scale P-Removal Studies - Primary Plant

Full scale phosphorus removal studies were conducted at the primary wastewater treatment plant at C.F.B. Borden (5). The study lasted ten months and covered three phases of chemical addition for phosphorus removal using lime, alum and ferric chloride. While the major objective of this study was to determine the optimum phosphorus removal precipitant and its dosage to achieve an effluent P objective of $\leq$ 1 mg/L, information on sludge production under various operational conditions was also collected. These data as summarized in Table 1 were compared to calculated sludge production values and are shown as a frequency distribution in Figure 3. In this case, the amount of sludge produced was overestimated by 28%, 50% of the time.

TABLE 1. CAMP BORDEN SLUDGE PRODUCTION - PRIMARY PLANT[5]

P-Removal Precipitant		Sludge Mass Produced				Ratio of Measured to Calculated Value
Chemical	Dosage	Calculated		Measured		
-	mg/l	kg/m³	lbs/10⁶gal	kg/m³	lbs/10⁶gal	
Baseline	-	116	255	191	420	1.65
Lime	151[1]	1186	2609	1148	2526	0.97
	197	1389	3056	1400	3080	1.01
	275	3184	6426	1697	3425	0.53
	210	1876	3857	1399	2676	0.76
Alum	4.4[2]	201	520	332	859	1.65
	7.5	385	1020	283	750	0.74
	14.8	645	1730	253	679	0.39
	18.5	604	1601	294	779	0.49
Ferric Chloride	9.6[3]	290	760	304	796	1.05
	14.6	321	872	307	834	0.95
	19.0	502	1331	312	827	0.62
	26.6	515	1382	343	920	0.67

[1] as $Ca(OH)_2$

[2] as Al^{3+}

[3] as Fe^{3+}

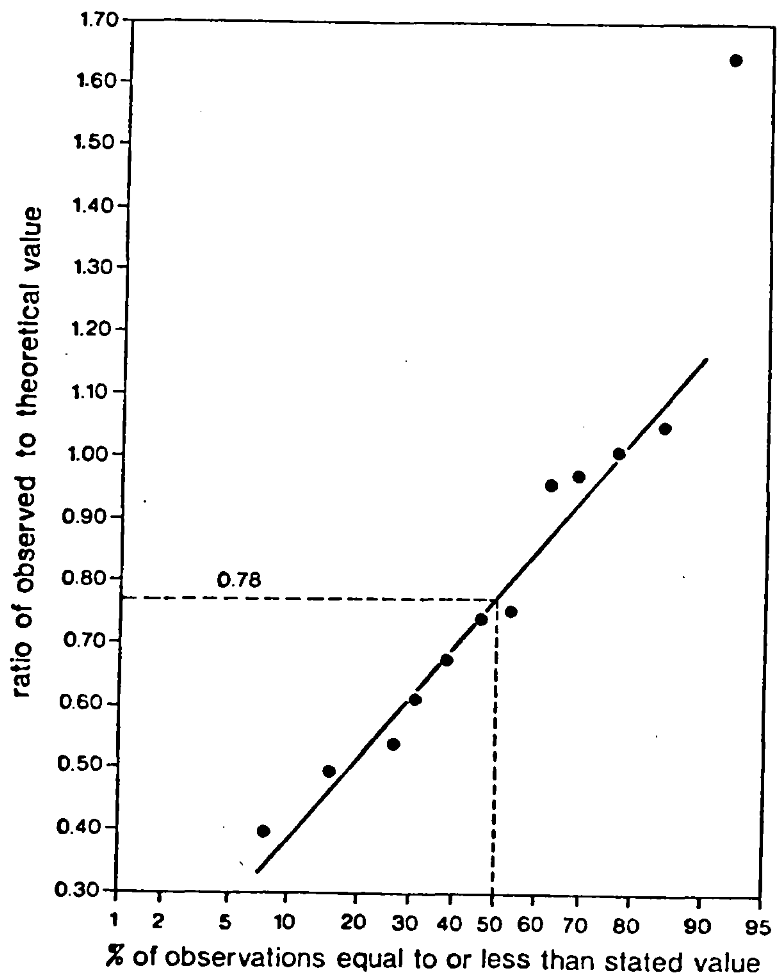

FIGURE 3. OBSERVED TO THEORETICAL SOLIDS PRODUCTION RATIO-PRECIPITANT ADDITION TO A FULL SCALE PRIMARY PLANT[5]

Ontario Treatment Plant Survey Data

Sludge production data were obtained in a 1975 survey of Ontario wastewater treatment plants where records prior to phosphorus removal were compared with plant records following installation of phosphorus precipitation systems (6).

Figure 4 summarizes the data from 15 conventional, primary plants (without precipitant addition) surveyed covering a range of hydraulic loadings from 0.26 to 11 MGD*. The data show that 50% of time 1 995 gallons of sludge are produced for each million gallons of wastewater treated. This translates to 1 140 lbs dry solids for each million gallons treated (Figure 5). The total solids concentrations of the raw primary sludges varied from 3.5 to 8% with a mean of 5.7%.

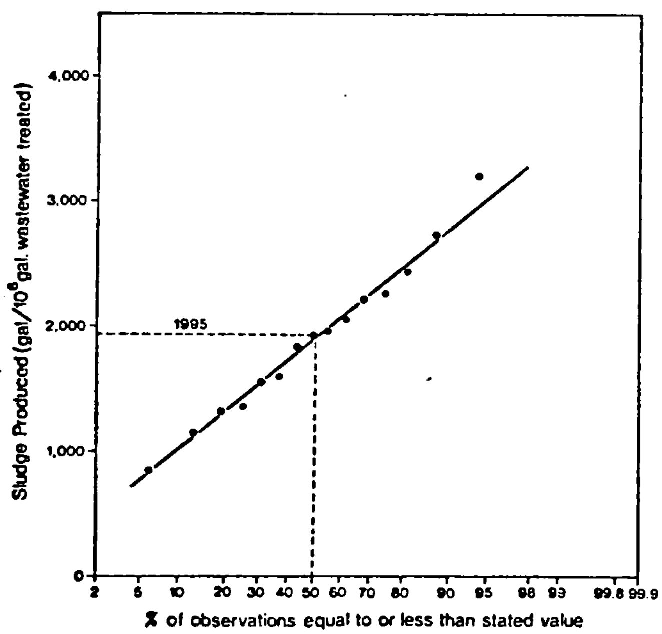

FIGURE 4. PROBABILITY DISTRIBUTION FOR SLUDGE VOLUME PRODUCED AT CONVENTIONAL PRIMARY PLANTS [6]

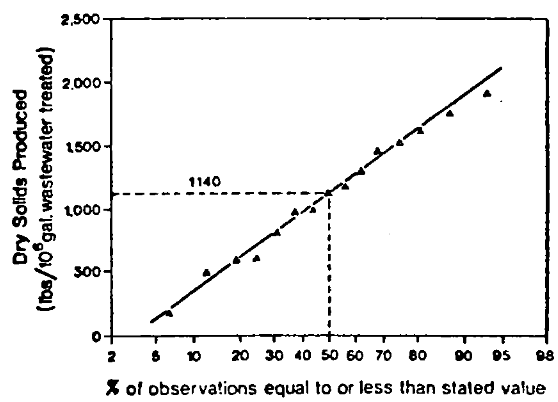

FIGURE 5. SLUDGE MASS PRODUCED AT CONVENTIONAL PRIMARY PLANTS[6]

*Imperial gallons used throughout this paper

The impact of chemical addition for phosphorus removal at primary plants is illustrated in Figure 6 for seven upgraded plants. In these plants, the average sludge solids concentration decreased from 6.0 to 5.3% after chemical addition. The sludge mass increased by 40%.

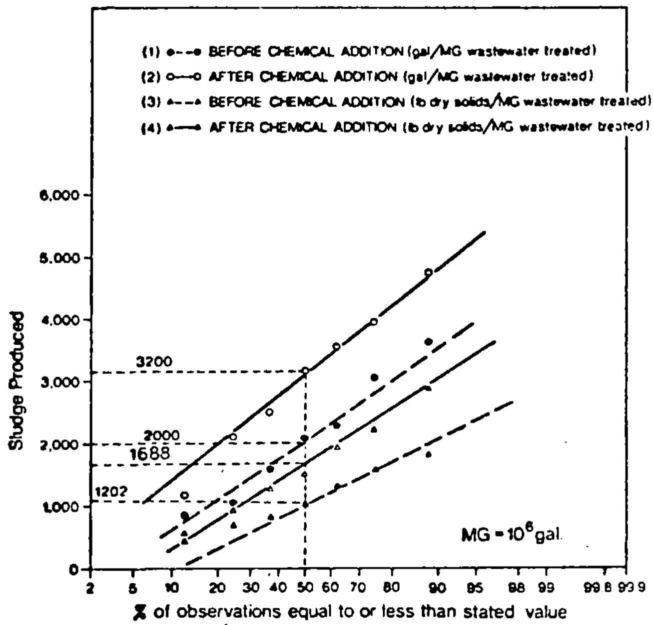

FIGURE 6. PROBABILITY DISTRIBUTION FOR SLUDGE PRODUCED AT PRIMARY PLANTS WITH ADDITION OF METAL SALTS [6]

Sludge production data from 42 secondary plants using the conventional activated sludge process were analyzed. The plants have flow capacities ranging from 0.3 to 170 MGD. The raw sludge produced consists of both primary and waste activated sludge. In the case of conventional activated sludge plants, Figure 7 shows that 50% of the time at least 3 905 gallons of sludge are produced per million gallons treated. Solids concentrations varied from 2 to 7%, with a weighted average of 4.6%. Similarly, the dry weight of solids produced at conventional activated sludge plants was equal to or less than 1 786 lbs dry solids per million gallons of wastewater treated, 50% of the time (Figure 8).

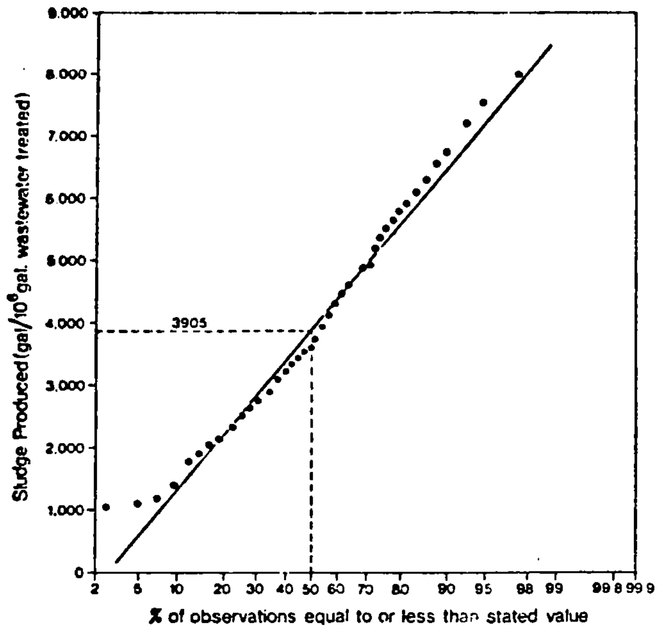

FIGURE 7. PROBABILITY DISTRIBUTION FOR SLUDGE VOLUME PRODUCED AT CONVENTIONAL SECONDARY (C.A.S.) PLANTS [6]

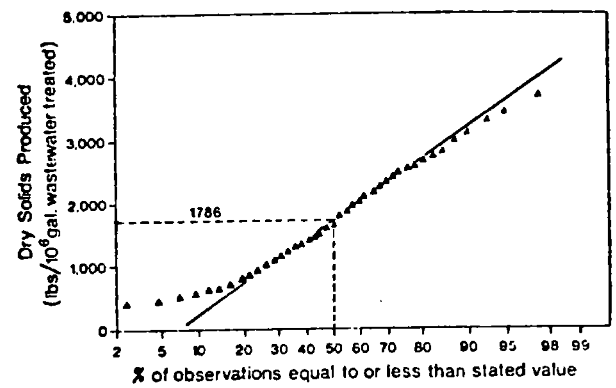

FIGURE 8. SLUDGE MASS PRODUCED AT CONVENTIONAL SECONDARY (C.A.S.) PLANTS [6]

Sludge production data for 15 upgraded secondary plants (primary and waste activated,chemical sludge) is illustrated in Figure 9. Fifty percent of the observations showed a solids production equal to or less than 1 725 lbs dry solids per million gallons before chemical addition. This increased to 2 175 lbs of dry solids per million gallons after chemical addition and represents a 26% increase in sludge mass. Following precipitant addition, the average total solids concentration decreased from 4.5 to 4.2%.

While metal salts are generally added to the aeration tanks, data analyzed from four installations where metal salts were added to the primary settling tank showed a decrease in solids produced. In this instance, the lower organic loading to the aeration tank due to additional organics removed in the primary, resulted in reduced biosynthesis.

Summary of Sludge Production

Sutton (4) underestimated sludge production by 65% when using stoichiometric relationships for a biological system with chemical addition. Stepko (5) however, overestimated sludge production resulting from chemical addition to a primary plant by 28%. These studies exemplify the problems associated with estimating sludge production from chemical stoichiometry.

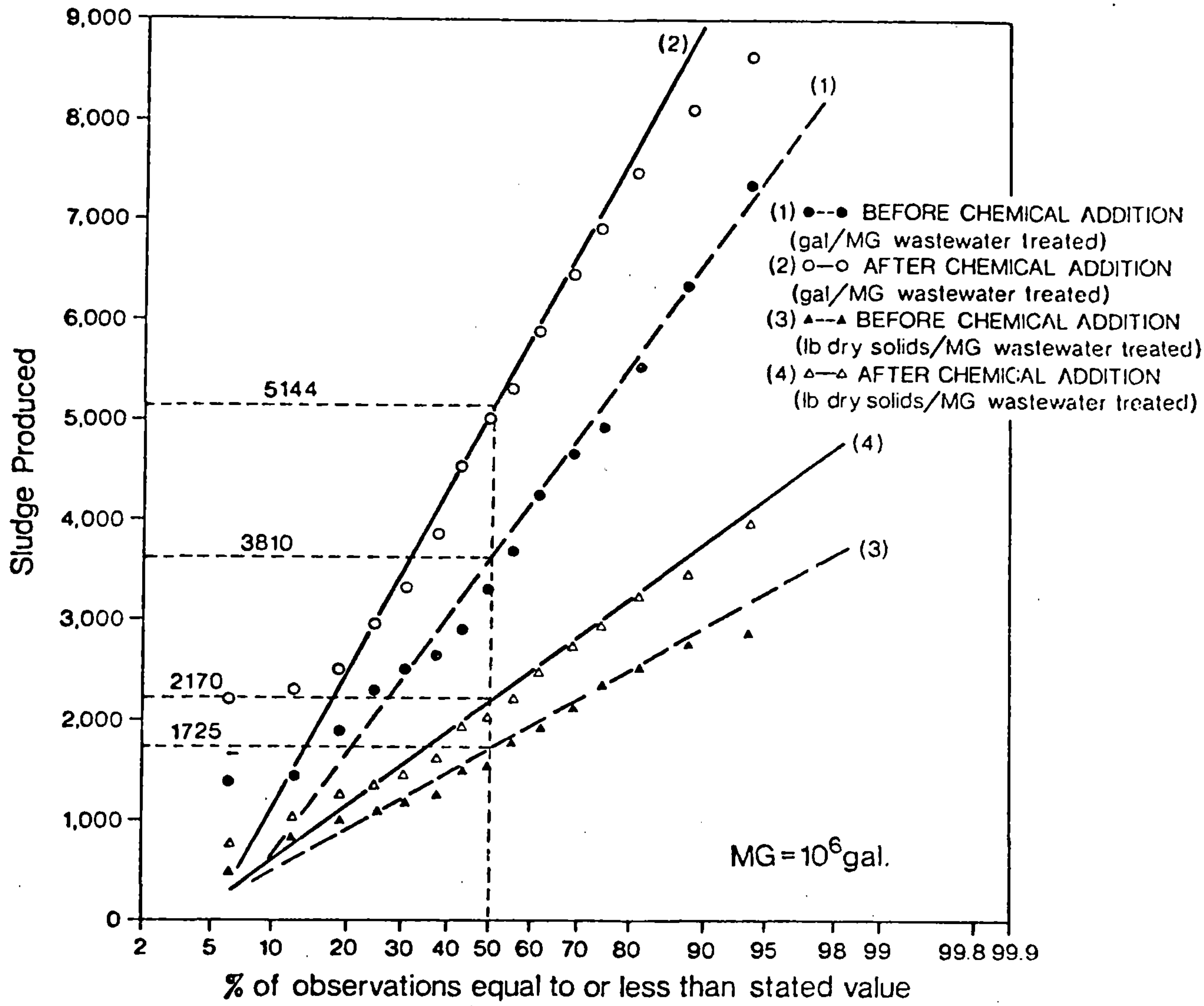

FIGURE 9. PROBABILITY DISTRIBUTION FOR SLUDGE PRODUCED AT SECONDARY (C.A.S.) PLANTS WITH ADDITION OF METAL SALTS TO AERATION TANK [6]

From our experience, the best data base for sludge production exists in the Ontario survey of full scale treatment plants (6). The data presented in earlier figures are summarized in Tables 2 and 3 for primary and activated sludge plants, respectively.

TABLE 2. PRIMARY SLUDGE PRODUCTION DATA[6]

Description	Units	Sludge Production		
		Prior to Chemical Addition	After Chemical Addition	Percent Change
Volume	$gal/10^6$ gal	2 000	3 200	+ 60
	gal /capita	0.29	0.46	-
	% of influent Q	0.20	0.32	-
Mass	$lbs/10^6$ gal	1 202	1 688	+ 40
	lbs/capita	0.17	0.24	-
Solids	percent	6.0	5.3	|-0.7|
Number of Plants	-	7	7	-

TABLE 3. ACTIVATED SLUDGE PRODUCTION DATA [6]

Description	Units	Sludge Production		
		Prior to Chemical Addition	After Chemical Addition	Percent Change
Volume	$gal/10^6$ gal	3 810	5 144	+ 35
	gal/capita	0.55	0.75	-
	% of influent Q	0.38	0.51	-
Mass	$lbs/10^6$ gal	1 725	2 175	+ 26
	lbs/capita	0.25	0.32	-
Solids	percent	4.5	4.2	|-0.3|
Number of Plants	-	15	15	-

Based on the results of the Ontario survey (6), some generalizations concerning sludge production design data are shown in Table 4.

TABLE 4. SLUDGE PRODUCTION - SUGGESTED DESIGN DATA*

System	lbs pcd	Sludge Quantity	
		Volume % of Influent	lbs d.s./10^6 gal
Conventional Primary	0.17	0.20	1 200
Upgraded Primary	0.24	0.32	1 700
Conventional A.S**	0.25	0.38	1 725
Upgraded A.S.**	0.32	0.51	2 175

* based on Q = 145 gpcd
d.s. = dry solids
pcd = per capita/day

** primary + waste activated

The rule-of-thumb that sludge volume approaches 0.5% of the influent hydraulic load to a conventional plant is a good approximation. By using this estimate, the apparent margin of safety would allow upgrading of a conventional plant to include chemical phosphorus removal to 1.0 mg/L total phosphorus using metal salts without major expansion of sludge handling facilities.

Because few Ontario plants practice P removal using lime, no substantive data base for sludge quantity estimation exist. However, based on past experience at a number of pilot and full scale facilities practicing P removal using lime, reasonable estimates of sludge production can be made.

The mass of sludge produced will depend largely on the wastewater alkalinity and the lime dosage required to attain a specific pH at which the target P effluent level is achieved.

Figure 10 illustrates that, having determined the pH at which the P effluent target will be achieved, the correlation indicates the lime/alkalinity ratio required. Knowledge of the wastewater alkalinity enables calculation of the required lime dosage (7). Another correlation (9) for raw wastewaters from 20 Ontario municipalities showing alkalinity/lime dosage requirements to attain pH 10 and 11 is shown in Figure 11.

Sludge Quantities After Anaerobic Digestion

The sludge production data summarized earlier, facilitates the design of sludge handling and volume reduction facilities. When designing facilities for ultimate disposal, the sludge volume after anaerobic digestion must be known. Such data are difficult to obtain. In many instances, this can be attributed to incomplete records concerning volume of sludge disposed of, as well as problems associated with solids concentration determinations.

The Ontario survey (6), while incomplete, provides the best, currently available data base on this subject. The data relating sludge volumes disposed from standard primary plants to population served were subjected to regression analysis (Figure 12).

The equation expressing this relationship for 17 plants is shown as:

$$\text{Sludge Disposed} = 0.0169\ (\text{Population} \times 10^{-3})^{1.131} \qquad (1)$$
$$(\times 10^{6}\ \text{gal/yr})$$

Figure 12 illustrates the fact that digester problems will result in substantial increases in sludge volumes requiring disposal.

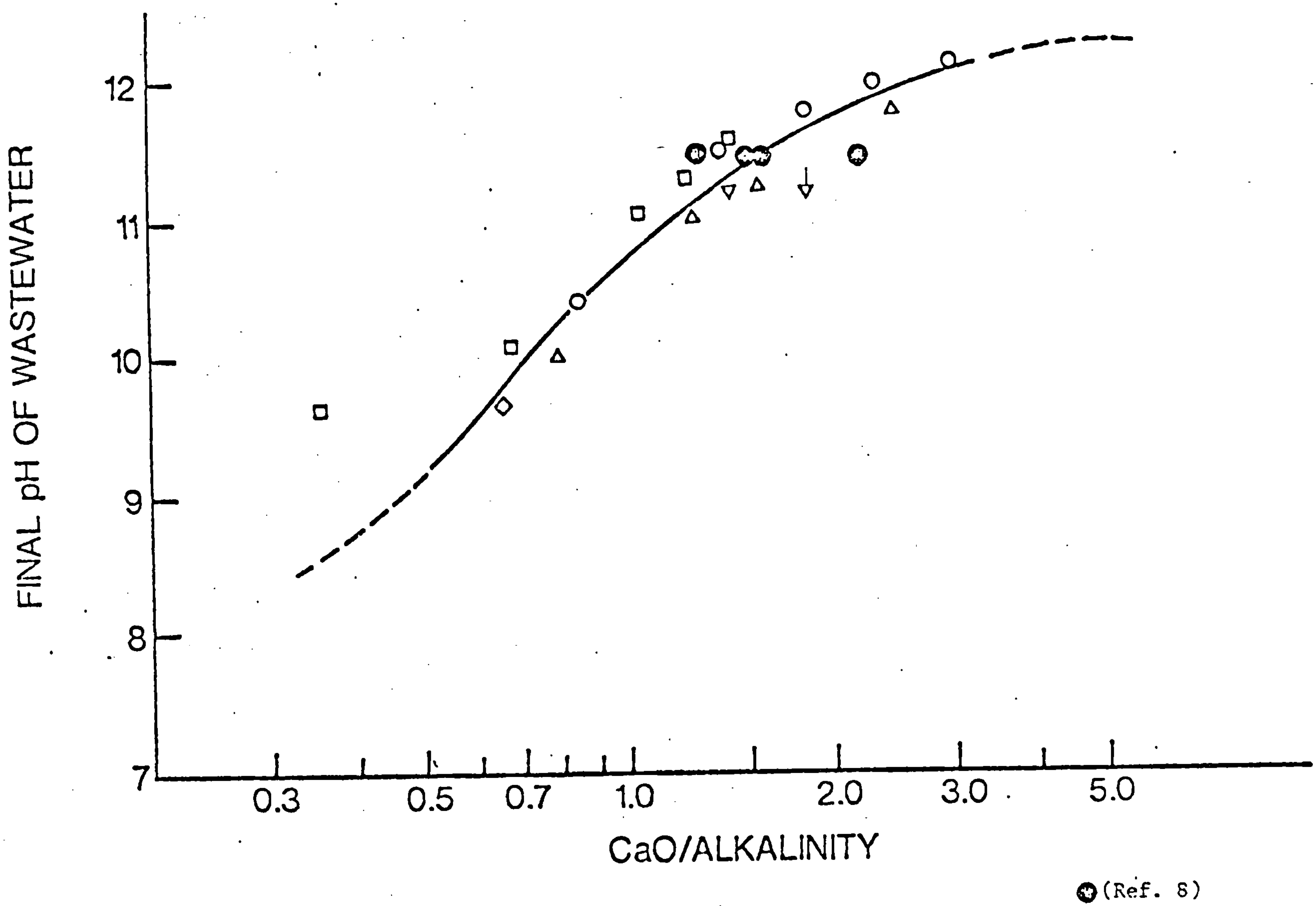

FIGURE 10. RATIO OF LIME DOSAGE (MG/L) TO INITIAL WASTEWATER ALKALINITY[7]

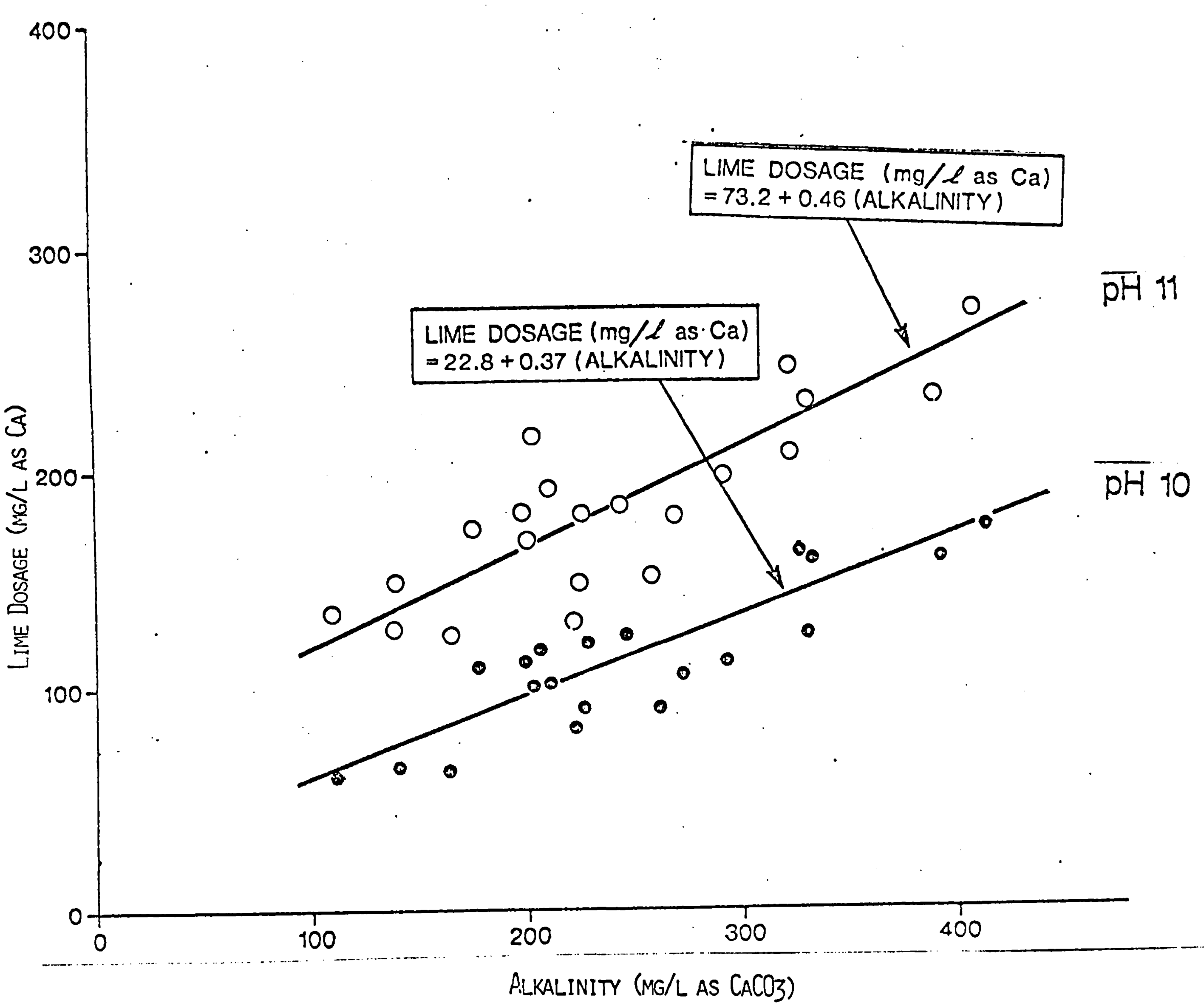

FIGURE 11. LIME DOSAGE VS. WASTEWATER ALKALINITY [9]

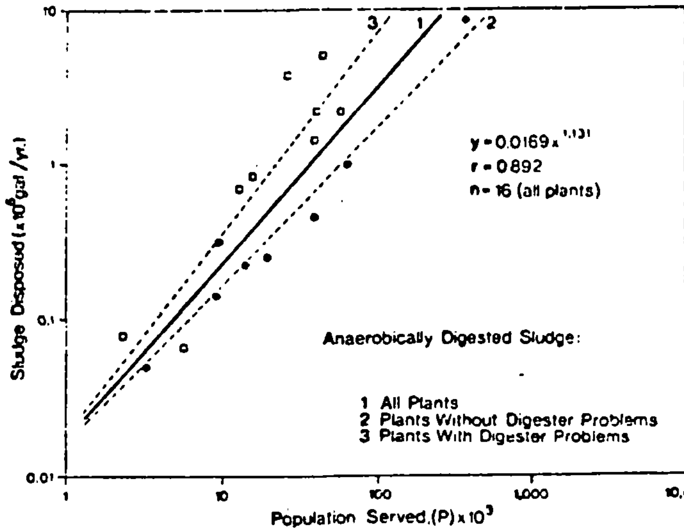

FIGURE 12. SLUDGE DISPOSAL AT STANDARD PRIMARY PLANTS-SLUDGE VOLUME VS. POPULATION SERVED 6

Similarly, Figures 13 to 16 illustrate from the available Ontario data (6) various relationships between volume or mass of sludge to be disposed of from activated sludge plants after anaerobic digestion as a function of population served. The equations are summarized in Table 5.

TABLE 5. SUMMARY OF ANAEROBICALLY DIGESTED SLUDGE DISPOSAL–RELATIONSHIPS WITH POPULATION SERVED[6]

Standard C.A.S. Plants		
n = 22	Sludge disposed = 0.131 (Population x $10^{-3})^{0.973}$ (x10^6 gal/yr)	(2)
n = 23	Sludge disposed = 11.53 (Population x $10^{-3})^{1.097}$ (TS, ton/yr)	(3)
Upgraded C.A.S. Plants		
n = 22	Sludge disposed = 0.105 (Population x $10^{-3})^{1.089}$ (x10^6 gal/yr)	(4)
n = 23	Sludge disposed = 13.71 (Population x $10^{-3})^{1.146}$ (TS, ton/yr)	(5)

Figure 17 summarizes all the pertinent water pollution control plant data from the Ontario survey (6).

Sludge Quantity Predictions for Lower Than 1 mg$\cdot$L^{-1} Effluent P Targets

The aforenoted information does not address the question of "how much more sludge would be generated when imposing point source controls for effluent total phosphorus concentrations of 0.5 mg$\cdot$L^{-1} or even 0.1 mg$\cdot$L^{-1}?".

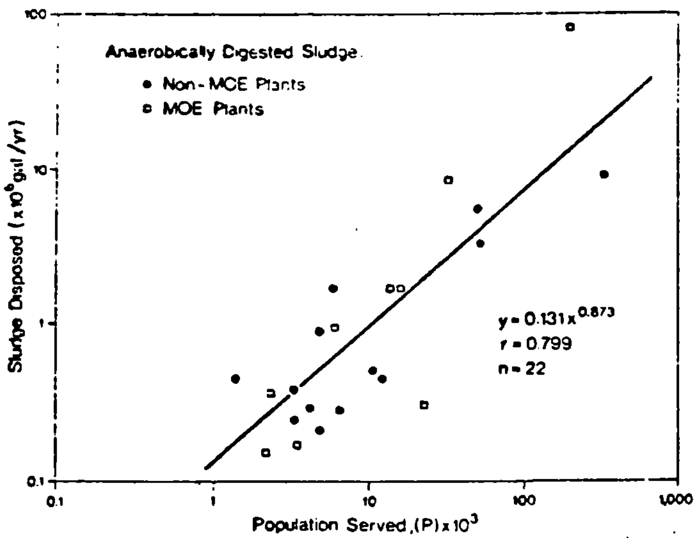

FIGURE 13. SLUDGE DISPOSAL AT STANDARD C.A.S. PLANTS-SLUDGE VOLUME VS. POPULATION SERVED [6]

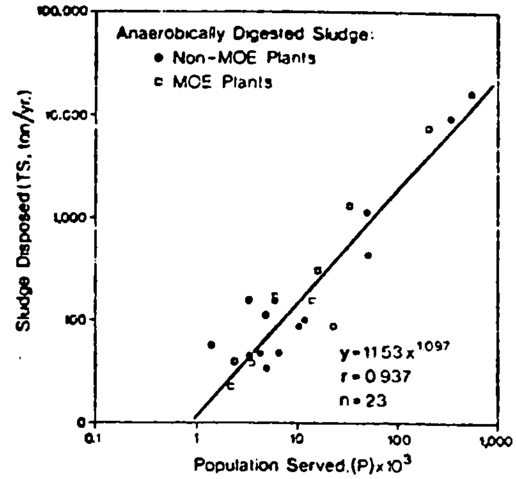

FIGURE 14. SLUDGE DISPOSAL AT STANDARD C.A.S. PLANTS-DRY WEIGHT OF SLUDGE VS. POPULATION SERVED

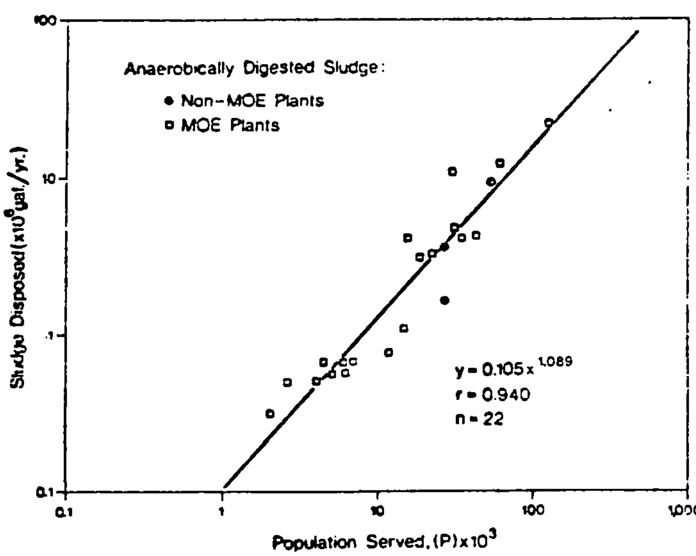

FIGURE 15. SLUDGE DISPOSAL AT UPGRADED C.A.S. PLANTS-SLUDGE VOLUME VS. POPULATION SERVED [6]

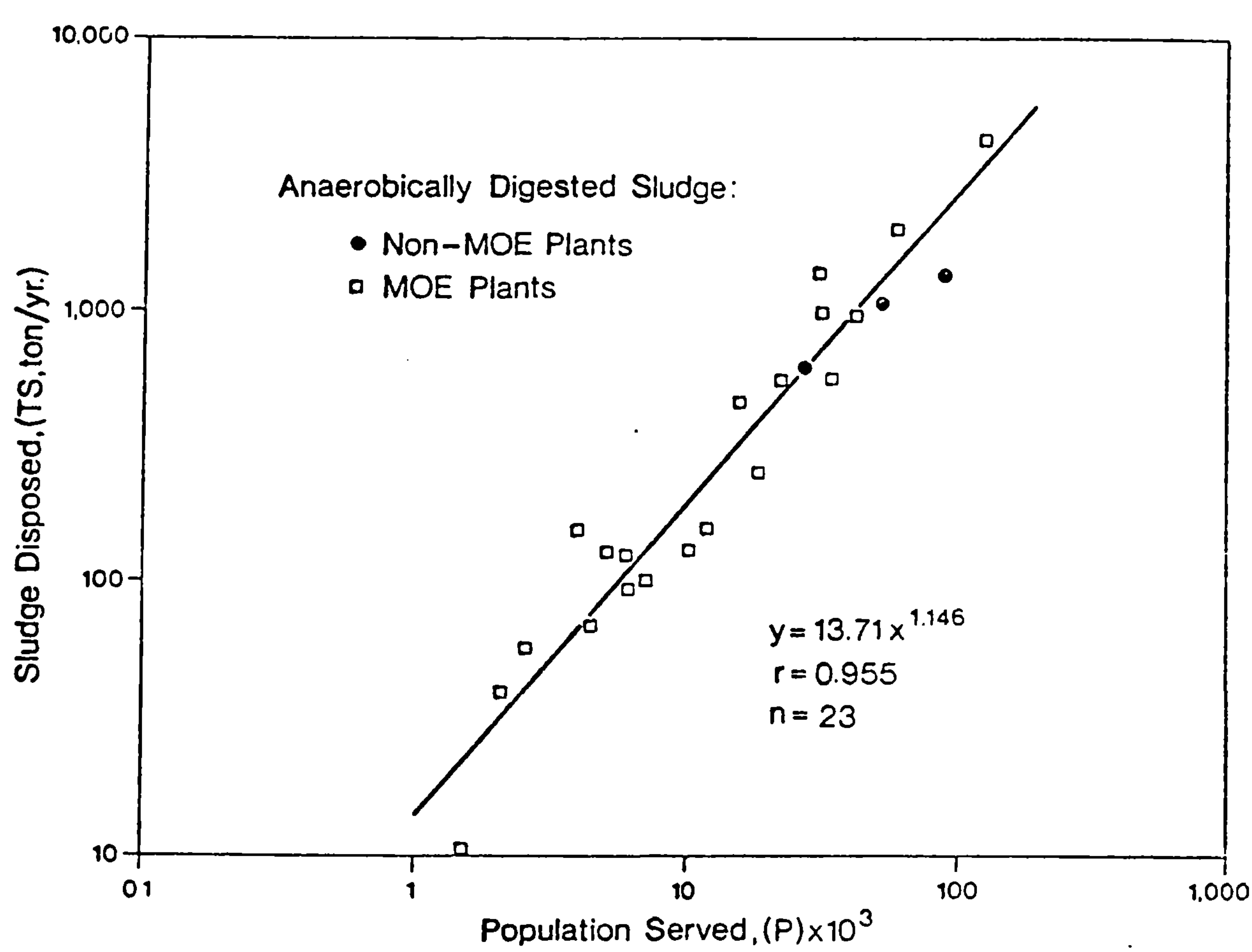

FIGURE 16. SLUDGE DISPOSAL AT UPGRADED C.A.S. PLANTS-DRY WEIGHT OF SLUDGE VS. POPULATION SERVED[6]

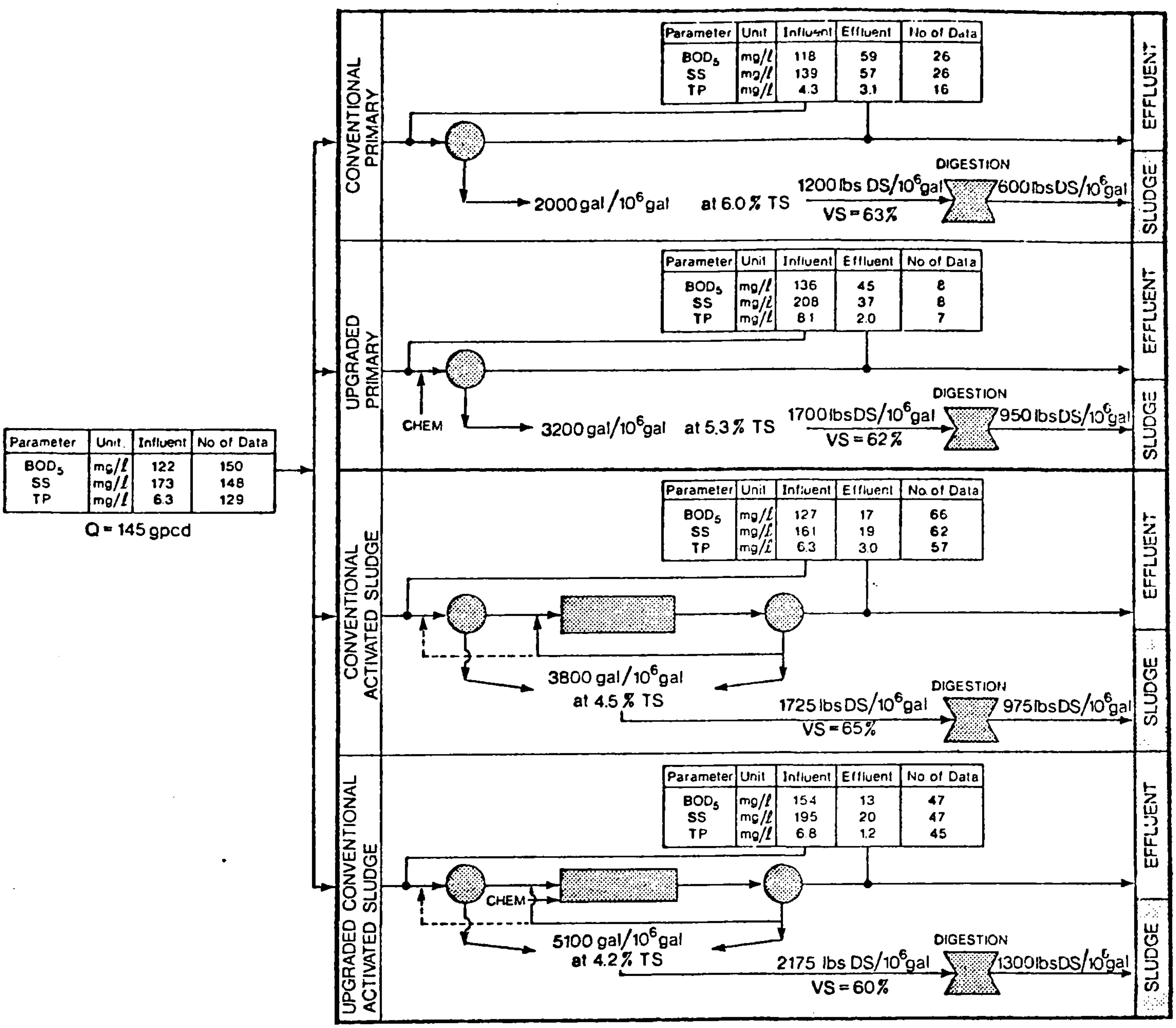

FIGURE 17. SUMMARY OF ONTARIO WATER POLLUTION CONTROL PLANT SLUDGE PRODUCTION AND DISPOSAL DATA[6]

A recent document (10) made a first attempt at answering this question by reporting on a computer simulation of required process modifications to meet various point source P control scenarios and the resulting sludge quantities. Figure 18 is a typical illustration of the dramatic increases in sludge mass over baseline conditions of no phosphorus removal. The example shows a simulation for 17 Canadian plants in the Lake Ontario drainage basin and represents a total flow of 582 MGD for a sewered population of 3.8 million persons. The simulation predicts a sludge mass increase from 34% over baseline conditions (no chemical addition) for an effluent total phosphorus target concentration of 1.0 $mg \cdot L^{-1}$.

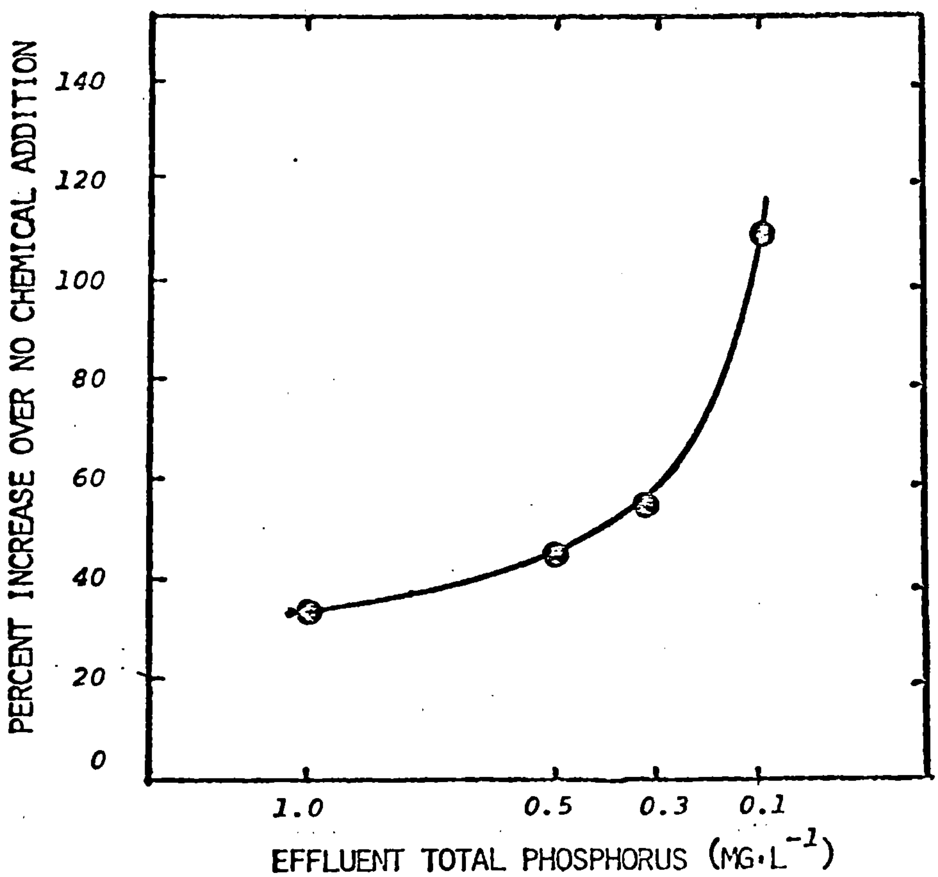

FIGURE 18. INCREASE IN SLUDGE MASS DUE TO CHEMICAL ADDITION TO MEET VARIOUS EFFLUENT TOTAL PHOSPHORUS TARGETS

This prediction compares favourably with the 1975 Ontario sludge survey data (6) indicating a 26% sludge mass increase. Treatment process modifications required to attain an effluent objective of 0.1 $mg \cdot L^{-1}$ total phosphorus predicts a 108% increase in sludge mass over baseline levels (no chemical addition).

It is the intent of the Phosphorus Management Strategy Task Force to update and refine the prediction model and input available data for U.S. and Canadian plants in the Great Lakes Basin. This will then enable the Task Force to identify the impact of various P control point source control scenarios at municipal plants on sludge quantities that might be generated.

The updated version of the model will also generate capital as well as O&M costs. This will allow for a relative cost comparison of the various P control scenarios.

3 SLUDGE HANDLING

Experience has demonstrated that metal salt addition to wastewater treatment processes for P removal not only results in increased sludge volumes and mass, but reduced solids concentration. The increased inorganic content due to chemical addition has the additional effect of lowering calorific values if incineration is selected as the volume reduction process. More ash is produced.

With regard to sludge dewatering, waste activated alum sludges, because of their gelatenous nature, are generally not dewatered by themselves but mixed with primary sludge, thickened and then dewatered. Table 6 illustrates the effects of implementing phosphorus removal at two Ontario treatment plants. The West Windsor Treatment Plant is a primary facility which upon chemical addition showed reduced filter yield and cake solids concentration. Filtrate solids and conditioning costs increased. These effects were more pronounced with alum than ferric chloride. The North

TABLE 6. FULL SCALE VACUUM FILTRATION OF SLUDGES FROM PHOSPHORUS REMOVAL FACILITIES

Description	West Windsor[1]			North Toronto[1]	
Phosphorus Removal Chemical	None	Fe^{3+}	Al^{3+}	None	Fe^{3+}
Type of Sludge	primary			digested elutriated	
Solids Concentration (%)	11.9	8.6	7.9	8.1	7.6
Conditioning Chemicals (% lime) (% ferric chloride)	 9.9 1.3	 15.9 0.1	 24.0 1.2	 9.5 0	 11.8 6.6
Conditioning Cost[2] ($/ton of dry solids)	4.01	6.69	7.39	Not Recorded	Not Recorded
Filter Yield ($lbs/ft^2 \cdot h$)	12.4	9.6	6.7	3.8	3.9
Filter Cake Solids (%)	31	21	17	23	19
Filtrate SS (mg/L)	2 830	3 660	13 900	5 550	7 690

[1] Campbell et al (11)
[2] Cost Figures as of December, 1975

Toronto Sewage Treatment Plant experience using ferric chloride also showed a decrease in filter cake solids and increases in sludge conditioning requirements. No decrease in filter yield was noted.

Similar experiences are related by Farrell (7), Campbell (11) and others (12).

Lime based sludges have invariably superior dewatering characteristics than metal salt based sludges. This is well documented in the literature (7 ,13,14).

Sludge Characteristics

One of the factors impacting on potential sludge utilization schemes is that of sludge characteristics.

Sludge characteristics are modulated not only by the type of waste treatment processes employed but are a function of the constituent inputs to municipal sewerage systems. More specifically, industrial discharges to municipal sewers may contain heavy metals, nitrogenous compounds, phosphates, a diversity of complex organic compounds, etc. In biological and physical/ chemical treatment systems, most of these compounds are complexed, broken down and/or sorbed by sludge flocs. In most instances, additional chemicals such as lime and/or iron salts are added to enhance the dewatering characteristics of the sludge. Furthermore as phosphorus removal is practiced, sludges not only contain appreciable amounts of phosphorus, the precipitant used to complex the phosphorus, but higher metal concentrations.

In sludge application to land, a number of factors must be considered. For instance, the heavy metal concentration in the sludge will dictate the total amount of sludge that can safely be applied over the lifetime of a site. The "total" metals are generally considered as an indicator of the likely ultimate effect and is used by many to calculate sludge application rates. If an "immediate" effect needs to be ascertained, then this is represented by the "available" fraction of the metal(s) as determined using suitable reagents for extraction. It is important to recognize the potential cumulative and thus, long term effect of metal addition to soil in excess of the small amounts taken up by plants and that lost due to leaching.

The nitrogen content of a sludge will dictate the annual application rate and should be consistent with use of nitrogen by agronomic crops. This will reduce the potential for nitrate pollution of groundwater.

Sludge as a Source of Pollutants

As noted earlier, the major problem in the area of sludge utilization on land concerns the content of potentially toxic substances. However, the level and nature of the substance(s) will also dictate the choice of land utilization alternative. More specifically, sludge may be used as a soil builder and/or organic fertilizer, for land reclamation or application to agricultural land.

Sludge from wastewater treatment facilities practicing chemical phosphorus removal contains almost all of the metals which are discharged into sewers. In the case of heavy metals occurrence in Ontario sludges, Table 7 summarizes this information from 40 Ontario water pollution control plants (10 primary, 30 secondary).

TABLE 7. ONTARIO FLUID SLUDGES - HEAVY METAL CONCENTRATIONS [6]

Component	Primary Plants* Anaerobically digested Sludges			Secondary Plants ** Anaerobically and Aerobically Digested Sludges		
	Range mg/l	Mean*** mg/l	Stand. Dev. ± mg/l	Range mg/l	Mean mg/l	Stand. Dev. ± mg/l
Zinc	2.8 - 130	74.3	48.3	4 - 225	55.5	57.4
Copper	4.6 - 150	54.5	46.9	7 - 148	34.8	30.2
Nickel	0.7 - 15	4.4	4.7	0.26 - 16.8	6.5	14.9
Chromium	2 - 68	16.5	20.9	2 - 430	41.6	51.7
Lead	11 - 86	40.9	30.3	3.7 - 60	21.8	25.1
Cadmium	0.2 - 2.6	0.7	0.7	0.1 - 8.7	1.4	2.0
Cobalt	<0.6 - 1.4	1.0	0.3	0.3 - 3.6	0.8	0.8

*No. of Plants = 10
**No. of Plants = 30
***Arithmetic Mean.

The concentrations of heavy metals in digested sludges from primary and secondary plants are similar except for chromium which is three times lower in primary digested sludges.

In 1975, approximately 34% (53 000 tons dry weight) of the sludge produced in Ontario was applied to agricultural land. This resulted in annual, heavy metal loadings as shown in Table 8.

TABLE 8. ANNUAL HEAVY METAL LOADINGS TO SLUDGED ONTARIO SOILS (1975 ESTIMATE) [6]

Metal	Average mg/kg soil	Average kg/ha *	Total tonnes
Zn	3.4	6.9	76.7
Cu	2.2	4.4	48.9
Ni	0.4	0.8	8.5
Cr	2.4	4.8	53.1
Pb	1.4	2.8	31.4
Cd	0.1	0.2	1.8
Co	0.05	0.1	1.1

* multiply by 5.5 = lbs/acre

Sludge as a Fertilizer

Major plant nutrients, nitrogen, phosphorus and potassium are contained in sewage sludge. Typical concentrations are 3% nitrogen, 2.5% phosphorus and 0.5% potassium on a dry weight basis. The nutrients in sludge are at a level of 1/5 of the usual chemical fertilizers.

Sludge quality data from the Ontario sludge survey (6) were obtained for 43 water pollution control plants (10 primary, 33 secondary). Forty of these plants disposed of sludge in fluid form, two disposed of sludge cake and one disposed of composted sludge. Table 9 summarizes data on TS, VS, Ammonia

TABLE 9. ONTARIO FLUID SLUDGES - NUTRIENT CHARACTERISTICS 6

Constituent	Primary Plants* Anaerobically Digested Sludge			Secondary Plants** Anaerobically Digested Sludge			Secondary Plants*** Aerobically Digested or Waste Activated Sludge		
	Range	Mean	Stand. Dev. $\pm\sigma$	Range	Mean	Stand. Dev. $\pm\sigma$	Range	Mean	Stand. Dev. $\pm\sigma$
Total Solids - TS%	2.8 - 12.5	8.8	2.9	2.0 - 12	4.1	1.8	2.2 - 4.5	2.75	0.95
Volatile Solids - VS%	24 - 61	43.4	10.5	36 - 70	51	8.5	41 - 69	55.8	9.9
Ammonia Nitrogen - N mg/l	100 - 590	326	78	250 - 1200	628	245	20 - 180	110	24.8
Total Kjeldahl Nitrogen - N mg/l	950 - 2900	1736	913	1600 - 3000	2114	495	650 - 2300	1358	576
Total Phosphorus - P mg/l	240 - 2600	713	399	390 - 2900	975	603	440 - 1200	730	303

* No. of Plants = 10
** No. of Plants = 25
***No. of Plants = 8

Nitrogen, Total Kjeldahl Nitrogen (TKN) and Phosphorus for digested sludges at primary and secondary plants.

In applying 296 x 10^6 gallons (53 000 dry wt tons) of digested sludge to agricultural land in Ontario, the amount of nutrients applied during one year are summarized in Table 10. The data also indicate a relationship between TKN and total solids for anaerobically digested sludge from 23 secondary plants practicing metal salt addition for P removal (Figure 19). This relationship can be used to calculate the TKN loading to farmland as follows:

$$\% \text{ TKN} = 16.6 \ (\% \text{ TS})^{-0.799} \qquad (6)$$

The survey data showed an ammonia nitrogen to TKN ratio varying between 12 and 57% (average 30%). The ammonia nitrogen loading to farmland can thus be approximated by using this average value.

TABLE 10. SLUDGE NUTRIENTS APPLIED ANNUALLY TO ONTARIO FARMLAND (ESTIMATE)[6]

Constituent	Amount tonnes/yr
TKN	2 800
NH_4-N	810
Total P as P	1 280
K	270
TS	53 000
VS	30 000

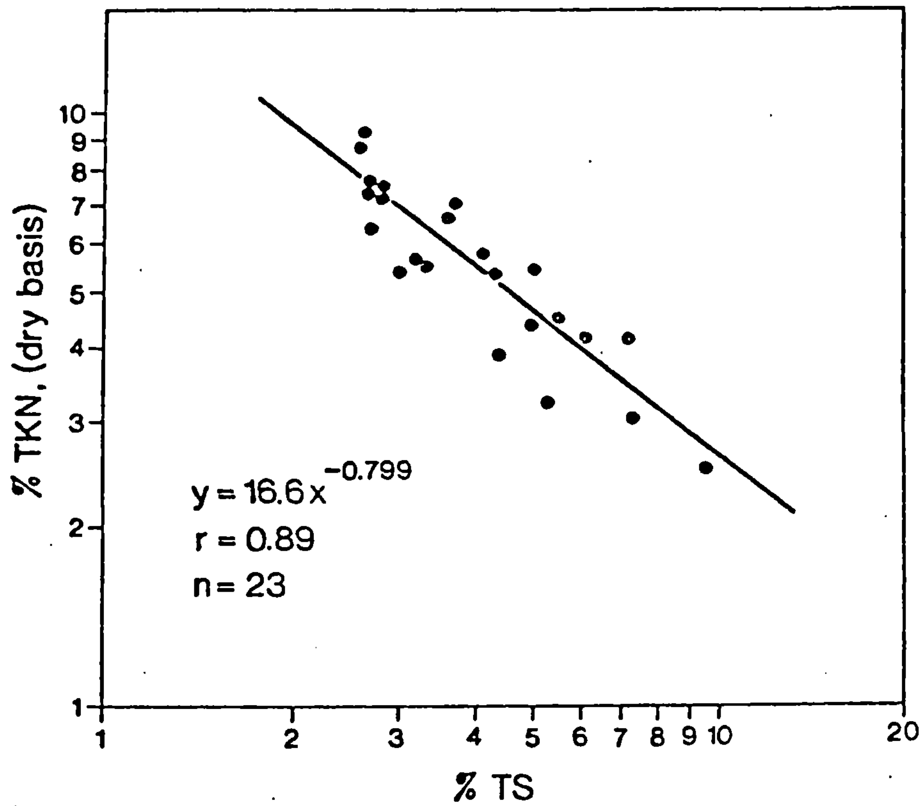

FIGURE 19. TOTAL KJELDAHL NITROGEN VS. TOTAL SOLIDS IN ANAEROBICALLY DIGESTED SLUDGE AT STANDARD C.A.S. PLANTS [6]

By making a number of assumptions it is possible to estimate the potential nutrient value of sludge when applied to farmland in Ontario:

1. the 'available' nitrogen in fluid sludge is equal to the soluble nitrogen (NH_4-N) (a conservative estimate),

2. only one-half of the total phosphorus in liquid sludge is potentially plant available (15) (a conservative estimate),

3. the 'available' potassium in fluid sludge is equal to the total potassium,

4. based on commercial fertilizer prices (October, 1978) the prices for nitrogen, phosphorus and potassium are 23¢, 25¢ and 13¢ per lb respectively.

Using the amounts of nutrients applied to farmland as shown in Table 10 and the aforenoted assumptions, the sludge fertilizer value can be calculated as follows:

NH_4-N =	810 tons/a x 2 200 lbs/ton x \$0.23/lb	≈ \$409 900
P =	1 280 tons/a x 2 200 lbs/ton x 0.5 x \$0.25/lb	≈ \$352 000
K =	270 tons/a x 2 200 lbs/ton x \$0.13/lb	≈ \$ 77 200
	TOTAL	≈ \$839 100

This analysis shows that the fertilizer value of the sludge now applied to farmland is approximately \$900 000 per annum (\$30./acre). This excludes any other potential benefits such as the presence of calcium, magnesium or the considerable amount of organic matter in the sludge. If the farmer required organic matter to improve soil structure (and moisture retention capacity) sludge could have a value of approximately \$20./ton. Based on the volatile solids applied to farmland, the sludge would be worth \$600 000 per annum.

The farmers interviewed for the Ontario survey (6) attempted to quantify yield increases due to sludge application. The average increase in hay yield was estimated at 8 tonnes/ha and in corn yield at 1 tonne/ha. Benefits resulting from cattle weight gain were also noted. A reasonable estimate of the benefits of sludge use on agricultural land in Ontario lies somewhere between \$2 000 000 and \$3 000 000 per annum (16). At this time, the farmers receive sludge free of charge with the transportation costs charged against disposal costs, borne by the municipalities. In 1975, sludge haulage to farmland costs were approximately \$2 250 000.

To date, no negative effects on crop yields were reported by farmers applying sludge for periods in excess of five years. However, long term studies are required to assess whether heavy metals will have negative effects on plants, soil or leachate.

Field monitoring of soil, plants and leachate quality at selected sites where sludges containing high concentrations of heavy metals have been applied for extended periods, would be desirable. A preliminary study in this regard is in progress at the Wastewater Technology Centre (17).

Continuing Studies

Investigations concerning sludge/soil interactions at laboratory greenhouse, field trial and lysimeter scale have been in progress since 1973 at the University of Guelph (18-22) and the Wastewater Technology Centre (23-26). Some of the more significant conclusions from these studies are:

- Sewage sludges supplied nitrogen and phosphorus for crop production but were low in potassium. Sludges produced crop yields at least as high as were obtained with chemical fertilizers.
- Sewage sludge application did not result in marked increases in runoff of nutrients, heavy metals or bacteria on 2% and 6% slopes except when heavy rain occurred immediately after sludge application.
- Soil salinity was not a problem in the field under Ontario conditions. It might pose a problem in less humid areas. Boron levels in some sludges tested would also be expected to pose a problem in arid regions.
- Re-application of the sludges between crops did not lead to increased metal concentrations in the plant materials.
- Large amounts of metals were added to soils in some sludges and their removal by crop uptake or leaching was very limited.
- The organic nitrogen in sludges was mineralized gradually and the mineralization rate varied from one sludge to another. As with other sources of nitrogen, applications in excess of crop requirements lead to high levels of nitrate in the soil solution.
- The average NH_4^+-N content of sludges studied was 1.3% on a dry weight basis or 27% of the total nitrogen. In two experiments 40% and 48% of the NH_4^+-N was lost by volatilization from sewage sludge applied to the soil surface. This loss occurred in five and eight days, respectively.

- Salmonella were isolated from five of 207 sludge samples tested. If vegetables are not grown and animals not grazed immediately following sludge application and if reasonable care is exercised in spreading, sludge does not pose a serious health hazard.
- At least twice as much nitrogen must be applied in fluid sludge as in commercial fertilizer to obtain equivalent yields.
- The Cd, Cr, Cu, Ni, Pb and Zn concentrations in orchard grass and wheat plant materials have not exceeded suggested maximum "tolerance" or "toxic" levels.
- The maximum concentrations of Cd, Cr, Cu, Ni, Pb and Zn in leachates have not exceeded drinking water standards.
- Soluble P in the leachates from fluid sludge treatments ranged as high as 10 mg/L during summer 1977. Soluble P from the air-dried sludge treatments never exceeded 2 mg/L.
- Total organic carbon in leachates from both the fluid and air-dried sludge experiments were greater than 50 mg/L in 1976 at the highest sludge loading rates. Static bioassay toxicity tests using Daphnia showed no toxicity in these leachate samples.

Ontario Guidelines for Sludge Utilization on Agricultural Land

The amount of NH_4-N applied to Ontario farmland in 1975 was 810 tonnes/yr (Table 10). Combining this information with the data on heavy metal application to farmland (Table 8) allows for an assessment as to whether or not Ontario sludge is generally suitable for land application if the criteria of the Provisional Guidelines for Sewage Sludge Utilization on Agricultural Land (27) are applied. This assessment is summarized in Table 11 and shows that the sludge is generally suitable for agricultural land application. The exception is the cadmium content. Sources of high cadmium content sludges are few and isolated. It is important to stress that average values are extremely misleading and that it is imperative that each sludge source be characterized separately in order to determine its limits of suitability for application to farmland.

TABLE 11. SUITABILITY OF ONTARIO SLUDGE FOR UTILIZATION ON FARMLAND[6]

Constituent[1]			NH_4-N:Heavy Metal		Suitability
NH_4-N	Heavy Metal		Actual Ratio	Minimum Required Ratio[2]	
810					
	Zn	76.7	11	4	Yes
	Cu	48.9	17	10	Yes
	Ni	8.5	95	40	Yes
	Cr	53.1	15	15	Yes
	Pb	31.4	26	15	Yes
	Cd	1.8	450	500	No
	Co	1.1	736	50	Yes

[1]in tons (metric)/yr (Tables 8 and 10)

[2]Provisional Guidelines for Sewage Sludge Utilization on Agricultural Land[27]

5 CLOSING REMARKS

The information presented represents a summary of Canada's experience in the Province of Ontario with increased sludge production due to chemical removal of phosphorus to 1.0 mg/L total phosphorus when using metal salts.

Ontario's current sludge management strategy consists of applying the most cost-effective and environmentally acceptable solution. Sludge utilization for its nutrient value on agricultural land is one such management strategy followed by an increasing number of municipalities who, as well as the farmers, are concerned about potentially long-term harmful impacts on soils due to heavy metal addition.

While technological solutions to phosphorus point source control to 0.1 mg/L are available, the impact on sludge quantities generated, handling and disposal still remains to be more closely defined. Only with information on relative costs between alternatives to achieve these goals can an effective point source phosphorus control management strategy be proposed.

Computer simulation is one approach to assess potential management strategies. It may well turn out that point source control to levels substantially lower than currently practiced will cause more problems elsewhere. The current activities of the IJC's Phosphorus Management Strategies Task Force address this subject.

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KEY WORDS

- sludge quality, quantity, estimation, phosphorus removal, sludge utilization/disposal