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Full Scale Demonstration of Lime Stabilization

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FULL SCALE DEMONSTRATION OF LIME STABILIZATION

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FOREWORD

The Environmental Protection Agency was created because of increasing public and government concern about the dangers of pollution to the health and welfare of the American people. Noxious air, foul water, and spoiled land are tragic testimony to the deterioration of our national environment. The complexity of that environment and the interplay between its components require a concentrated and integrated attack on the problem.

Research and development is that necessary first step in problem solution and it involves defining the problem, measuring its impact, and searching for solutions. The Municipal Environmental Research Laboratory develops new and improved technology and systems for the prevention, treatment, and management of wastewater and solid and hazardous waste pollutant discharges from municipal and community sources, for the preservation and treatment of public drinking water supplies, and to minimize the adverse economic, social, health, and aesthetic effects of pollution. This publication is one of the products of that research; a most vital communications link between the researcher and the user community.

Development of safe and economical methods for disposing of the sludges produced from wastewater treatment operations is one of the most pressing environmental needs. This publication provides information on the stabilization of municipal sludge which will be a valuable tool for Engineers and Treatment Plant Managers who are responsible for the management and disposal of sewage sludge.

Francis T. Mayo, Director
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ABSTRACT

The objective of the full scale research project was to demonstrate and evaluate the feasibility, economics, and benefits of stabilizing primary, waste activated, septic, and anaerobically digested sludges by lime addition. The project confirmed the findings of previous laboratory and pilot scale tests and focused on the application of lime stabilization and land disposal techniques to a wastewater treatment plant operating in the range of 3,785 to 5,675 cu m/day (1.0 to 1.5 MGD).

Emphasis was placed on the chemical, bacterial, and pathological properties of raw, lime stabilized and anaerobically digested sludges. The effects of long-term storage on the chemical and bacterial characteristics of lime stabilized sludges were also determined.

Ultimate disposal of all lime stabilized sludges was accomplished by spreading as a liquid on agricultural land and on controlled test plots. Full scale land application was practiced over an eight month period, beginning in early March and extending through October 1976. Lime stabilized sludge was applied to wheat, hay, and soybeans. Test plots included corn, soybeans, and swiss chard.

Lime stabilized sludges had negligible odor, minimum potential for pathogen regrowth and were suitable for application to farmland. Pathogen concentrations in lime stabilized sludges were 10-1,000 times lower than for comparable anaerobically digested sludges.

Actual construction costs were summarized for incorporating the lime stabilization facilities into the existing treatment plant. Estimates of capital and annual operation and maintenance costs for comparable anaerobic digestion and lime stabilization facilities were also developed, including costs for land application of the stabilized sludges.

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LIST OF ABBREVIATIONS AND SYMBOLS

ABBREVIATIONS

average	avg
five day biochemical oxygen demand	BOD_5
British thermal unit	BTU
cation exchange capacity	CEC
centimeter	cm
chemical oxygen demand	COD
cubic centimeter	cc
cubic foot (feet)	cu ft
cubic feet per minute	cfm
cubic yard	cu yd
cubic meter	cu m
degree(s)	deg
degree Celsius	°C
degree Fahrenheit	°F
diameter	dia
feet (foot)	ft
feet per second	fps
gallon(s)	gal
gallons per day	gpd
gallons per minute	gpm
hectare	ha
horsepower	HP
hour(s)	hr
inch(es)	in
kilograms per hectare	kg/ha
kilogram(s)	kg
liter	l
membrane filter	MF
milligram(s) per liter	mg/l
milligram(s) per kilogram	mg/kg
millimeter	mm
million gallons per day	MGD
minute(s)	min
most probable number	MPN
number per 100 ml	#/100 ml
oven dry weight	ODWT
percent	%
pound(s)	lb
pounds per acre	lb/ac
side water depth	SWD
square foot (feet)	sq ft

square meter	m^2
suspended solids	SS
standard cubic foot (feet)	scf
standard cubic feet per minute	scfm
temperature	temp
thousand kilograms	kkg
thousand kilograms per hectare	kkg/ha
total dissolved solids	TDS
total dynamic head	TDH
total solids	TS
volatile solids	VS
waste activated sludge	WAS
weight	wt
year(s)	yr

SYMBOLS

aluminum	Al
Ammonia/ammonium	NH_3/NH_4
boron	B
cadmium	Cd
calcium hydroxide (hydrated lime)	$Ca(OH)_2$
calcium oxide (quicklime)	CaO
carbon dioxide	CO_2
chlorine	Cl_2
cobalt	Co
ferric chloride	$FeCl_3$
hydrogen sulfide	H_2S
iron	Fe
lead	Pb
magnesium	Mg
manganese	Mn
mercury	Hg
nickel	Ni
nitrite	NO_2
nitrate	NO_3
oxygen	O_2
phosphorus	P
sulfur	S
sulfur dioxide	SO_2
sulfuric acid	H_2SO_4
zinc	Zn

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Mark Kipp of Burgess & Niple, Limited operated the lime stabilization and land application phases of the research. Kay Wilson was responsible for typing the final manuscript.

SECTION 1

CONCLUSIONS

Lime stabilization was shown to be an effective sludge disposal alternative when there is a need to:

- provide alternate means of sludge treatment during the period when existing sludge handling facilities (e.g. anaerobic or aerobic digesters) are out of service for cleaning or repair.

- supplement existing sludge handling facilities (e.g. anaerobic or aerobic digesters, incineration or heat treatment) due to the loss of fuel supplies or because of excess sludge quantities above design.

- upgrade existing facilities or construct new facilities to improve odor, bacterial, and pathogenic organism control.

Lime stabilization effectively eliminates odors. Regrowth of pathogens following lime stabilization is minimal. Of the organisms studied, only fecal streptococci have a potential for remaining viable.

Lime stabilized sludges are suitable for application to agricultural land; however, lime stabilized sludges have lower soluble phosphate, ammonia nitrogen, total Kjeldahl nitrogen, and total solids concentrations than comparable anaerobically digested primary/waste activated sludge mixtures.

Lime stabilization facilities can be constructed and operated at lower capital and annual operation and maintenance costs than comparable anaerobic digestion facilities, and present an attractive alternative either as a new process or to upgrade existing sludge handling facilities.

SECTION 2

BACKGROUND

Sludge constitutes the most significant by-product of wastewater treatment; its treatment and disposal is perhaps the most complex problem which faces both the designer and operator. Raw sludge contains large quantities of microorganisms, mostly fecal in origin, many of which are pathogenic and potentially hazardous to humans. Sludge processing is further complicated by its variable properties and relatively low solids concentration. Solutions have long been sought for better stabilization and disposal methods which are reliable and economical and able to render sludge either inert or stable.

Historically, lime has been used to treat nuisance conditions resulting from open pit privies and from the graves of domestic animals. Prior to 1970, there was only a small amount of quantitative information available in the literature on the reaction of lime with sludge to make a more stable material. Since that time, the literature contains numerous references concerning the effectiveness of lime in reducing microbiological hazards in water and wastewater.(1)(2)(3) Information is also available on the bactericidal value of adding lime to sludge. A report of operations at the Allentown, Pennsylvania wastewater treatment plant states that conditioning an anaerobically digested sludge with lime to pH 10.2 to 11, vacuum filtering and storing the cake destroyed all odors and pathogenic enteric bacteria.(4) Kampelmacher and Jansen(5) reported similar experiences. Evans(6) noted that lime addition to sludge released ammonia and destroyed bacillus coli and that the sludge cake was a good source of nitrogen and lime to the land.

Lime stabilization of raw sludges has been conducted in the laboratory and in full scale plants. Farrell et al(7) reported, among other results, that lime stabilization of primary sludges reduced bacterial hazard to a negligible value, improved vacuum filter performance, and provided a satisfactory means of stabilizing sludge prior to ultimate disposal.

Paulsrud and Eikum(8) reported on the effects of long-term storage of lime stabilized sludge. Their research included laboratory investigations of pH and microbial activity over periods up to 28 days.

Pilot scale work by C.A. Counts et al[9] on lime stabilization showed significant reductions in pathogen populations and obnoxious odors when the sludge pH was greater than 12. Counts conducted growth studies on greenhouse and outdoor plots which indicated that the disposal of lime stabilized sludge on cropland would have no detrimental effect.

A research and demonstration contract was awarded to Burgess & Niple, Limited in March, 1975 to complete the design, construction, and operation of full scale lime stabilization facilities for a 3,785 cu m/day (1 MGD) wastewater treatment plant, including land application of treated sludges. The contract also included funds for cleaning, rehabilitating, and operating an existing anaerobic sludge digester. Concurrent with the research and demonstration project, a considerable amount of full scale lime stabilization work was completed by cities in Ohio and Connecticut. Wastewater treatment plant capacities which were representative ranged from 3,785 to 113,550 cu m/day (1 to 30 MGD). A summary of these results has previously been reported.[10]

SECTION 3

LIME STABILIZATION FACILITIES

GENERAL

Facilities for lime stabilization of sludge were incorporated into an existing 3,785 cu m/day (1.0 MGD) single stage activated sludge wastewater treatment plant located at Lebanon, Ohio. Lebanon has a population of about 8,000, and is located in southwestern Ohio, 48.27 km (30 mi) northeast of Cincinnati. The surrounding area is gently rolling farmland with a small number of light industries, nurseries, orchards, and truck farms.

Major unit processes at the wastewater treatment plant include influent pumping, preaeration, primary clarification, conventional activated sludge, and anaerobic sludge digestion. Average influent BOD_5 and suspended solids concentrations are 180 and 243 mg/l, respectively. The treatment plant flow schematic is shown on Figure 1.

Prior to completing the sludge liming system, the existing anaerobic sludge digester was inoperative and was being used as a sludge holding tank. The digester pH was approximately 5.5 to 6.0. Grit and sand accumulations had reduced its effective volume to 40-50% of the total. Waste activated sludge was being returned to the primary clarifiers and resettled with the primary sludge. Combined primary/waste activated sludge was being pumped to the digester and ultimately recycled to the primary clarifiers via the digester supernatant. Typical supernatant suspended solids concentrations were in the range of 30,000 to 40,000 mg/l. When possible, sludge was withdrawn from the digester and dewatered on sand drying beds.

USEPA made the decision to utilize lime stabilization at Lebanon not only as a full scale research and demonstration project, but also as a means of solids handling during the period while the anaerobic digester was out of service for cleaning and repair.

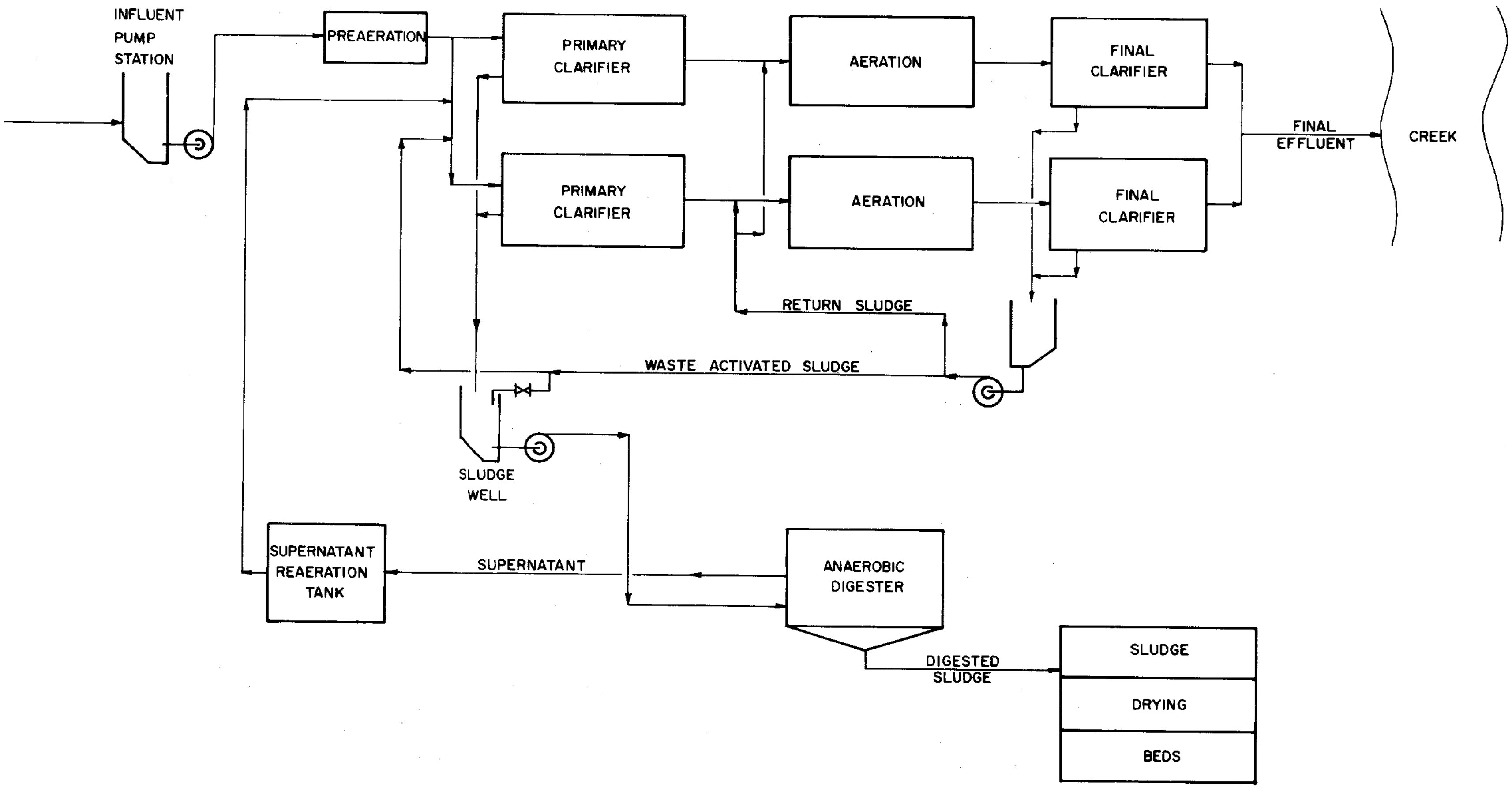

Figure 1. Treatment Plant Flow Schematic Prior to Incorporating Lime Stabilization

REVISIONS TO THE EXISTING WASTEWATER TREATMENT PLANT

Lime Stabilization

The lime stabilization process was designed to treat raw primary, waste activated, septic tank, and anaerobically digested sludges. The liming system was integrated with the existing treatment plant facilities, as shown on Figure 2. Hydrated lime was stored in a bulk storage bin and was augered into a volumetric feeder. The feeder transferred dry lime at a constant rate into a 94.6 l (25 gal) slurry tank which discharged an 8-10% lime slurry by gravity into an existing 25 cu m (6,500 gal) tank. The lime slurry and sludge were mixed with diffused air. A flow schematic for the lime stabilization facilities is shown on Figure 3. Design data are shown in Table 1.

TABLE 1. DESIGN DATA FOR LIME STABILIZATION FACILITIES

Mixing Tank	
Total volume	30 cu m (8,000 gal)
Working volume	25 cu m (6,500 gal)
Dimensions	3.05 m x 3.66 m x 2.38 m (10' x 12' x 7.8')
Hoppered bottom	0.91 m (3') @ 27° slope
Type of diffuser	Coarse bubble
Number of diffusers	4
Air supply	14-34 cu m/min (500-1,200 cf/min)
Bulk Lime Storage	
Total volume	28 cu m (1,000 cu ft)
Diameter	2.74 m (9')
Vibrators	2 ea Syntron V-41
Fill system	Pneumatic
Discharge system	15 cm (6") dia. auger
Material of construction	Steel
Type & manufacturer	Columbian Model C-95
Volumetric Feeder	
Total volume	0.28 cu m (10 cu ft)
Diameter	71 cm (28")
Material of construction	Steel
Type & manufacturer	Vibrascrew LBB 28-10
Feed range	45-227 kg/hr (100-500 lb/hr)
Average feed rate	78 kg/hr (173 lb/hr)

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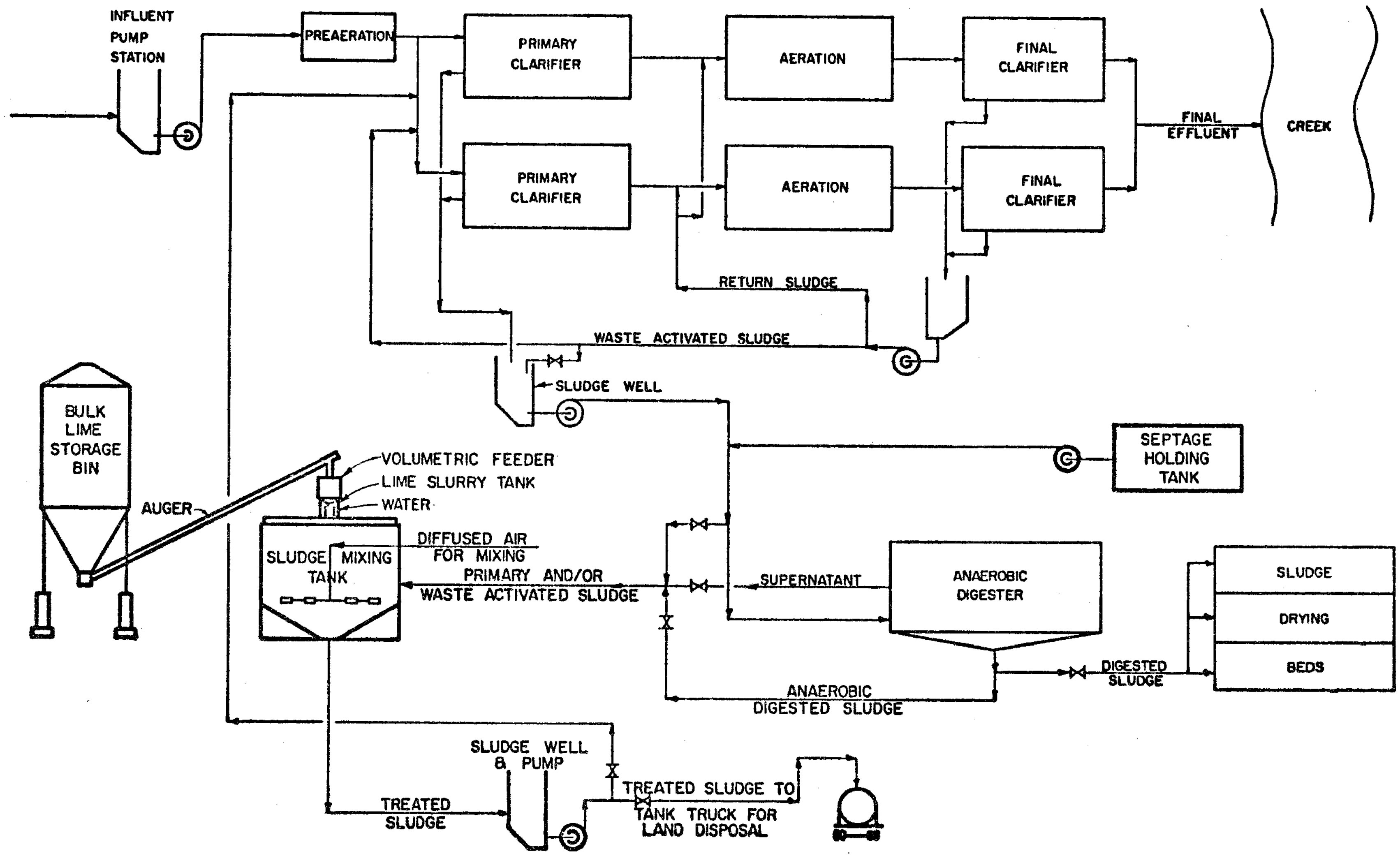

Figure 2. Treatment Plant Flow Schematic After Incorporating Lime Stabilization

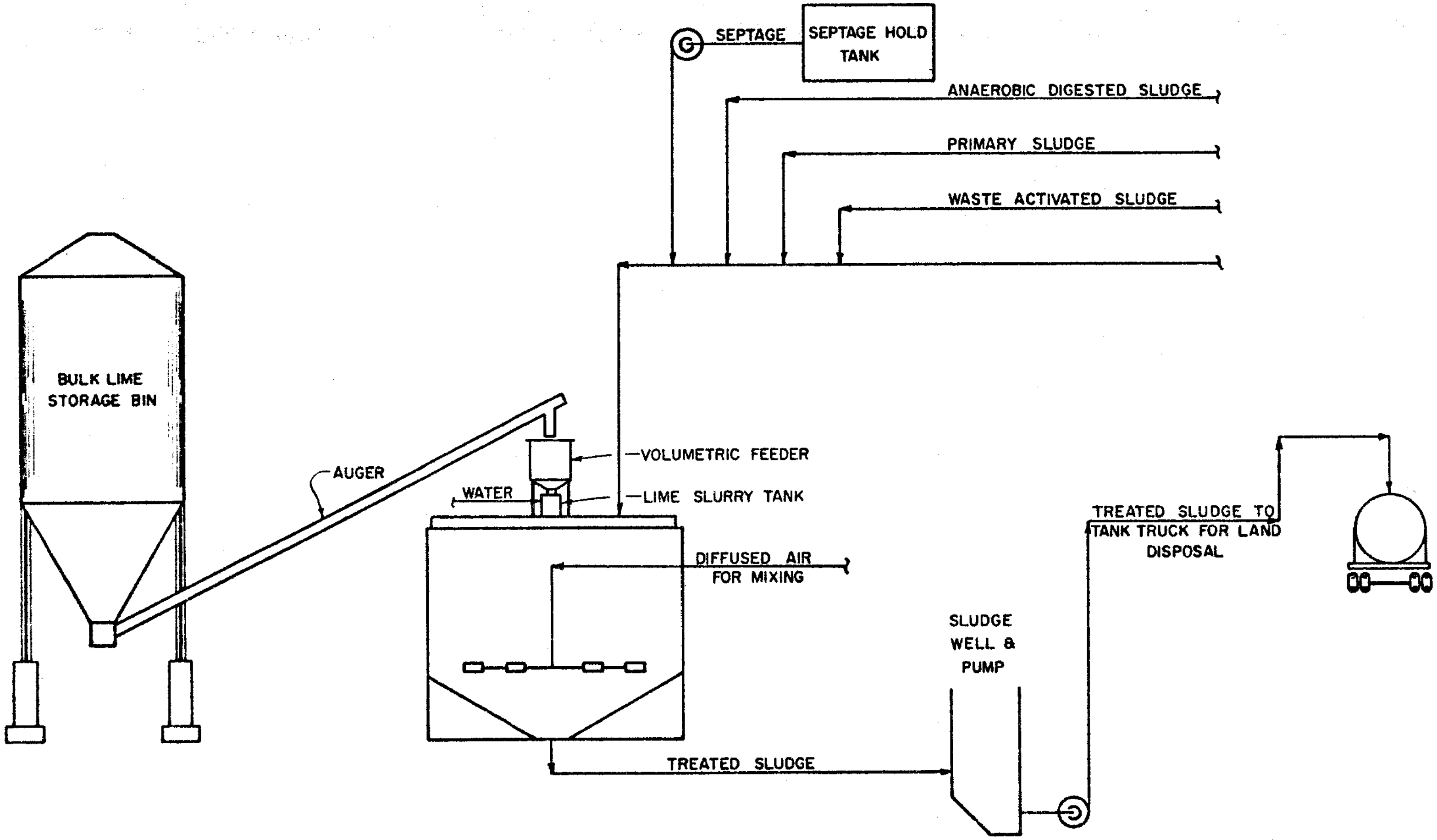

Figure 3. Lime Stabilization Process Flow Diagram

TABLE 1 (continued)

Lime Slurry Tank	
Total volume	94.6 l (25 gal)
Diameter	0.61 m (2')
Septic Tank Sludge Holding Tank (Septage Tank)	
Total volume	18.4 cu m (650 cu ft)
Working volume	15 cu m (4,000 gal)
Dimensions	3.66 m x 1.92 m x 2.62 m (12'x6.3'x8.6')
Mixing	Coarse bubble
Number of diffusers	1
Air supply	2.8-8.4 cu m/min (100-300 cf/min)
Transfer Pumps	
Raw and treated sludge	1,136 l/min (300 gpm)
Septage transfer pump	379 l/min (100 gpm)

Anaerobic Digester

As previously described, the existing single stage anaerobic sludge digester was inoperative and was being used as a sludge holding tank. The digester and auxiliary equipment were completely renovated and returned to good operating condition which allowed a comparison of anaerobic digestion and lime stabilization. The digester was cleaned, a new boiler and hot water circulating system was installed, and all necessary repairs were made to piping, valves, pumps, and electrical equipment.

The anaerobic digester design data are shown in Table 2.

TABLE 2. ANAEROBIC DIGESTER REHABILITATION DESIGN DATA

Tank dimensions	15 m (50') dia. x 6.1 m (20') SWD
Total volume	1,223 cu m (43,200 cu ft)
Actual volatile solids loading	486 g VSS/cu m (0.03 lb VSS/ft^3)
Hydraulic detention time	36 days
Sludge recirculation rate	757 l/min (200 gpm)
Boiler capacity	240,000 BTU/hr

Septage Holding Facilities

Because the Lebanon wastewater treatment plant routinely accepted septic tank pumpings, an 18.4 cu m (5,000 gal) tank was installed to hold septic tank sludges prior to lime treatment. The tank was equipped with a transfer pump which could be used to either feed the lime stabilization process or transfer septage to the primary tank influent at a controlled rate.

Ultimate Sludge Disposal

Treated sludges were applied to sand drying beds, to test plots, and to three productive agricultural sites. Land spreading operations began in early March and continued through October 1976. The sludge hauling vehicle was a four-wheel drive truck with a 2.3 cu m (600 gal) tank.

OPERATION AND SAMPLING

Raw sludge, e.g., primary, waste activated, septage or digested sludge, was pumped to the mixing tank where it was mixed by diffused air. Four coarse bubble diffusers were mounted approximately 30.5 cm (1 ft) above the top of the tank hopper and 38 cm (1.25 ft) from the tank wall. This location permitted mixing to roll sludge up and across the tank at which point lime slurry was fed. Lime which was used for the stabilization of all sludges was industrial grade hydrated lime with CaO and MgO contents of 46.9% and 34%, respectively. All lime requirements have been converted and are expressed as 100% $Ca(OH)_2$ except as noted. Samples were taken from the untreated, but thoroughly mixed, sludge for chemical, pH, bacteria, and parasite analyses.

After the initial pH determination, the lime slurry addition was started. Hydrated lime was augered from the lime storage bin to the volumetric feeder which was located directly above the sludge mixing tank. The lime was slurried by the tangential injection of water into a 94.6 l (25 gal) slurry tank. The lime solution (8-10% by weight) then flowed by gravity into an open channel with three feed points into the sludge mixing tank.

The sludge pH was checked every 15 min as the lime slurry was added until the sludge reached a pH of 12, at which time it was held for 30 min. During the 30 min period, lime slurry continued to be added. After 30 min, samples were taken for chemical, bacteria, and parasite analyses. Air mixing was then discontinued, allowing the limed sludge to concentrate. The sludge then flowed by gravity to a sludge well from which it was pumped to the land disposal truck.

SECTION 4

RAW SLUDGE CHARACTERISTICS

GENERAL

Samples of raw and treated sludges were taken during each operating day of the lime stabilization operations. Anaerobically digested sludge samples were taken at the same time and analyzed for use in comparisons of chemical, bacterial, and pathogen properties.

Sample preservation and chemical analysis techniques were performed in accordance with procedures as stated in "Methods for Chemical Analysis of Water and Wastes," USEPA,[11] and "Standard Methods for the Examination of Water and Wastewater."[12]

Salmonella species and Pseudomonas aeruginosa were determined by EPA staff using the method developed by Kenner and Clark.[13] Fecal coliform, total coliform, and fecal streptoccocus were determined according to methods specified in "Standard Methods for Examination of Water and Wastewater." Parasite analyses were performed by the Tulane University School of Medicine.

Several authors have previously attempted to summarize the chemical and bacterial compositions of sewage sludges.[14][15][16] Recent data on the nutrient concentrations for various sludges as prepared by Sommers[15] have been included for reference in Table 3. Data on lime stabilized sludges have been included in a following section.

Bacterial data on various sludges as presented by Stern[17] have been summarized in Table 4 for reference.

TABLE 3. CHEMICAL COMPOSITION OF SEWAGE SLUDGES[a] (15)

Component	Number of Samples	Range,* mg/kg	Median Percent	Mean Percent
Total N	191	0.1 - 17.6	3.3	3.9
NH_4-N	103	0.1 - 6.8	0.1	0.7
NO_3-N	45	0.1 - 0.5	0.1	0.1
P	189	0.1 - 14.3	2.3	2.5
K	192	0.1 - 2.6	0.3	0.4
Ca	193	0.1 - 25.0	3.9	4.9
Mg	189	0.1 - 2.0	0.5	0.5
Fe	165	0.1 - 15.3	1.1	1.3

[a]Data are from numerous types of sludges (anaerobic, aerobic, activated, lagoon, etc.)

*Dry Solids

TABLE 4. BACTERIA DATA FOR LIQUID SLUDGES (17)

Sludge Type	Salmonella #/100 ml	Pseudomonas aeruginosa #/100 ml	Fecal Coliform, MF
Raw Primary	460	4.6×10^4	11.4×10^6
Raw Waste Activated-A	74	1.1×10^3	2.8×10^6
Raw Waste Activated Thickened-B	9.3×10^3	2.0×10^3	2.0×10^7
Raw Waste Activated-C	2.3×10^3	2.4×10^4	2.0×10^6
Anaerobic Digested Primary	29	34	3.9×10^5
Anaerobic Digested Waste Activated	7.3	1.0×10^3	3.2×10^5
Aerobic Digested Waste Activated	N/A	0.66	N/A
Trickling Filter	93	1.1×10^5	1.15×10^7

CHEMICAL PROPERTIES

Analyses for heavy metals were conducted on grab samples of Lebanon, Ohio, raw primary, waste activated, and anaerobically digested sludges. These data have been reported in Table 5 as mg/kg on a dry weight basis and include the average and range of values.

TABLE 5. HEAVY METAL CONCENTRATIONS IN RAW SLUDGES AT LEBANON, OHIO

	Raw Primary Sludge	Waste Activated Sludge	Anaerobic Digested Sludge
Cadmium, average mg/kg	105	388	137
Cadmium, range mg/kg	69-141	119-657	73-200
Total Chromium, average mg/kg	633	592	882
Total Chromium, range mg/kg	287-979	133-1,050	184-1,580
Copper, average mg/kg	2,640	1,340	4,690
Copper, range mg/kg	2,590-2,690	670-2,010	4,330-5,050
Lead, average mg/kg	1,379	1,624	1,597
Lead, range mg/kg	987-1,770	398-2,850	994-2,200
Mercury, average mg/kg	6	46	0.5
Mercury, range mg/kg	0.4-11	0.1-91	0.1-0.9
Nickel, average mg/kg	549	2,109	388
Nickel, range mg/kg	371-727	537-3,680	263-540
Zinc, average mg/kg	4,690	2,221	7,125
Zinc, range mg/kg	4,370-5,010	,250-3,191	6,910-7,340

Chemical data for Lebanon, Ohio, raw primary, waste activated, anaerobically digested, and septage sludges have been summarized in Table 6. Data for each parameter include the average and range of the values observed.

TABLE 6. CHEMICAL COMPOSITION OF RAW SLUDGES AT LEBANON, OHIO

Parameter	Raw Primary Sludge	Waste Activated Sludge	Anaerobically Digested Sludge	Septage Sludge
Alkalinity, mg/l	1,885	1,265	3,593	1,897
Alkalinity Range, mg/l	1,264-2,820	1,220-1,310	1,330-5,000	1,200-2,690
Total COD, mg/l	54,146	12,810	66,372	24,940
Total COD Range, mg/l	36,930-75,210	7,120-19,270	39,280-190,980	10,770-32,480
Soluble COD, mg/l	3,046	1,043	1,011	1,223
Soluble COD Range, mg/l	2,410-4,090	272-2,430	215-4,460	1,090-1,400
Total Phosphate, mg/l as P	350	218	580	172
Total Phosphate Range, mg/l as P	264-496	178-259	379-862	123-217
Soluble Phosphate, mg/l as P	69	85	15	25
Soluble Phosphate Range, mg/l as P	20-150	40-119	6.9-34.8	21.6-27.9
Total Kjeldahl Nitrogen, mg/l	1,656	711	2,731	820
Total Kjeldahl Nitrogen Range, mg/l	1,250-2,470	624-860	1,530-4,510	610-1,060
Ammonia Nitrogen, mg/l	223	51	709	92
Ammonia Nitrogen Range, mg/l	19-592	27-85	368-1,250	68-116
Total Suspended Solids, mg/l	48,700	12,350	61,140	21,120
Total Suspended Solids Range, mg/l	37,520-65,140	9,800-13,860	48,200-68,720	6,850-44,000
Volatile Suspended Solids, mg/l	36,100	10,000	33,316	12,600
Volatile Suspended Solids Range, mg/l	28,780-43,810	7,550-12,040	27,000-41,000	3,050-30,350
Volatile Acids, mg/l	1,997	N/A	137	652
Volatile Acids Range, mg/l	1,368-2,856	N/A	24-248	560-888

PARASITE ANALYSES

Parasite data for Lebanon, Ohio raw primary, waste activated, anaerobically digested and septage sludges have been summarized in Table 7. Species which were identified were in general agreement with other investigations. In addition to these parasites, mites (adult, larva and eggs) and nematodes (adult, larva and eggs) were found in all sludges.

TABLE 7. IDENTIFIED PARASITES IN LEBANON, OHIO RAW SLUDGES

Primary	Waste Activated Sludge	Septage	Anaerobic Digested
Toxacara	Toxacara	Toxacara	Toxacara canis Toxacara cati
Trichuris vulpis		Ascaris lumbricoides	Ascaris
Trichuris trichiura		Trichuris trichiura	Trichuris vulpis
Enterobius vermicularis larva		Trichuris vulpis	

PATHOGENIC PROPERTIES

Pathogen data for Lebanon, Ohio raw primary, waste activated, anaerobically digested, and septage sludges have been summarized in Table 8. In general, the data are in agreement with the values reported by Stern, with the exception of Salmonella and Pseudomonas aeruginosa, which are lower than the reported values.

TABLE 8. PATHOGEN DATA FOR RAW SLUDGES AT LEBANON, OHIO

Parameter	Raw Primary Sludge	Waste Activated Sludge	Anaerobically Digested Sludge	Septage Sludge
Salmonella avg. #/100 ml	62	6	6	6
Salmonella range, #/100 ml	11-240	3-9	3-30	3-9
Ps. aeruginosa avg., #/100 ml	195	5.5×10^3	42	754
Ps. aeruginosa range, #/100 ml	75-440	$91-1.1 \times 10^4$	3-240	$14-2.1 \times 10^3$
Fecal coliform avg. Mf, #/100 ml	N/A	2.65×10^7	2.6×10^5	1.5×10^7
Fecal coliform range MF, #/100 ml	N/A	$2.0x10^7-3.3x10^7$	$3.4x10^4-6.6x10^5$	$1.0x10^7-1.8x10^7$
Fecal coliform avg. MPN, #/100 ml	8.3×10^8	N/A	1.45×10^6	N/A
Fecal coliform range MPN, #/100 ml	$1.3x10^8-3.3x10^9$	N/A	$1.9x10^5-4.9x10^6$	N/A

(continued)

TABLE 8 (continued)

Parameter	Raw Primary Sludge	Waste Activated Sludge	Anaerobically Digested Sludge	Septage Sludge
Total coliform avg. MF, #/100 ml	N/A	8.33×10^8	2.42×10^7	2.89×10^8
Total coliform range MF, #/100 ml	N/A	$1.66 \times 10^8 - 1.5 \times 10^9$	$1.3 \times 10^5 - 1.8 \times 10^8$	$1.8 \times 10^7 - 7 \times 10^8$
Total coliform avg. MPN, #/100 ml	2.9×10^9	N/A	2.78×10^7	N/A
Total coliform range MPN, #/100 ml	$1.3 \times 10^9 - 3.5 \times 10^9$	N/A		N/A
Fecal streptococci avg., #/100 ml	3.9×10^7	1.03×10^7	2.7×10^5	6.7×10^5
Fecal streptococci range, #/100 ml	$2.6 \times 10^7 - 5.2 \times 10^7$	$5 \times 10^5 - 2 \times 10^7$		$3.3 \times 10^5 - 1.2 \times 10^6$

SECTION 5

RESULTS AND ANALYSIS

GENERAL

During the period March-October 1976, approximately 868,700 l (229,500 gal) of primary, waste activated, septage, and anaerobically digested sludges from the Lebanon, Ohio wastewater treatment plant were lime stabilized. Ultimate disposal of all lime stabilized sludges was accomplished by spreading as a liquid on agricultural land and on controlled test plots. The results of these studies are summarized as follows.

LIME REQUIREMENTS

The lime dosage required to exceed pH 12 for at least 30 min was found to be affected by the type of sludge, its chemical composition, and percent solids. As an operational procedure, a target of pH 12.5 was selected to insure that the final pH would be greater than 12. A summary of the lime dosage required for various sludges is shown in Table 9. Of the total amount of lime which was required, an excess of 0 to 50% was added after pH 12 was reached in order to maintain the pH. Figure 4 shows the combined lime dosage vs. pH for primary, anaerobically digested, waste activated, and septage sludges. Figures 5-8 have been included in the Appendix and describe the actual lime dosages which were required for each sludge type.

Table 10 compares the Lebanon results with the data previously presented by Farrell, et. al, Counts, et. al, and Paulsrud and Eikum for raw primary sludges. In general, excellent correlation was achieved.

Counts[9] has proposed the following equation for predicting the lime dosage required for primary and secondary sludges from the Richland, Washington trickling filter plant:

$$\text{Lime Dose} = 4.2 + 1.6\ (TS)$$

When: Lime dose is expressed in grams $Ca(OH)_2$ per liter of sludge and TS is the total solids fraction in the sludge.

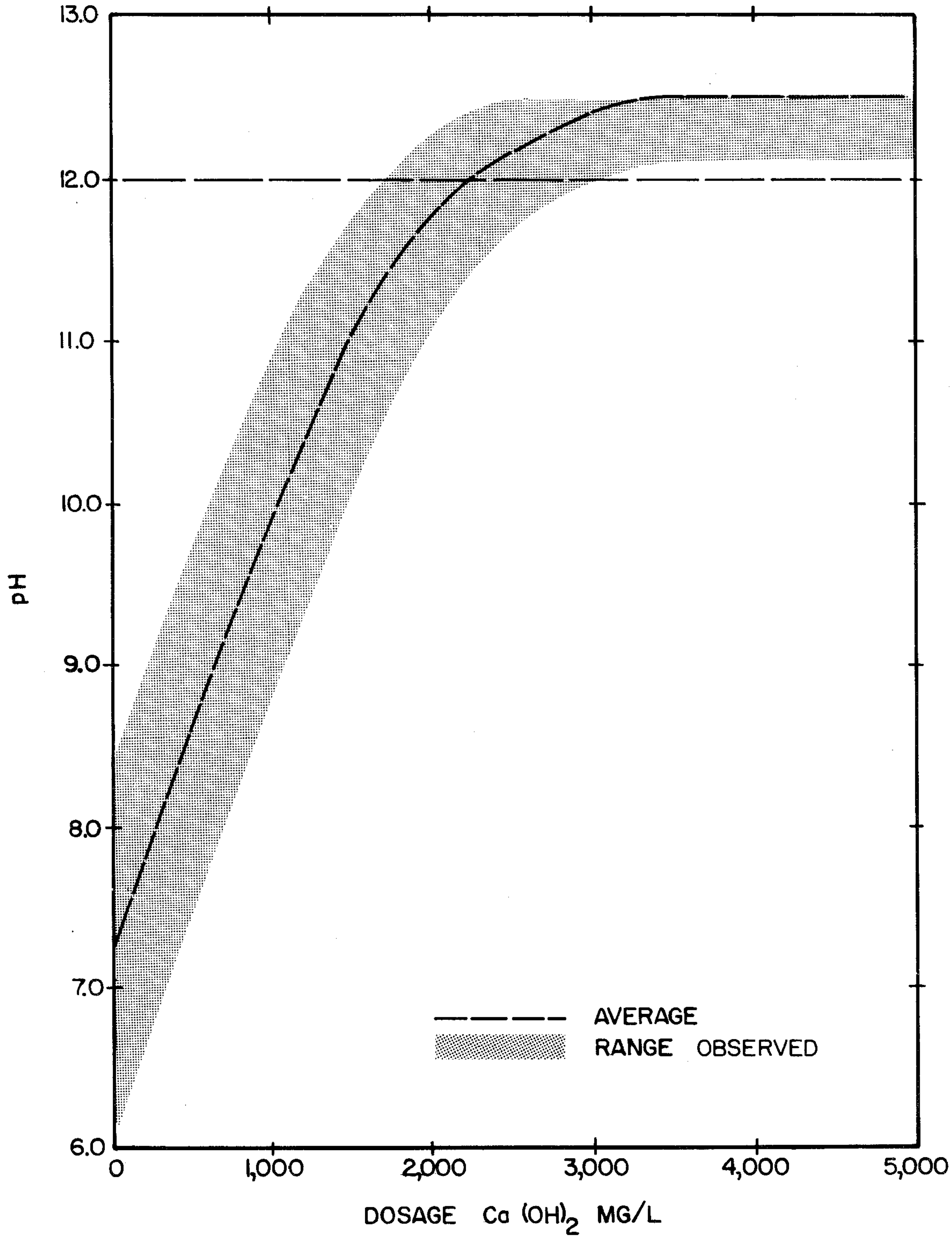

Figure 4. Combined Lime Dosage vs. pH For All Sludges

TABLE 9. LIME REQUIRED FOR STABILIZATION TO pH 12 FOR 30 MINUTES

Sludge Type	Percent Solids	Average Lbs[2] $Ca(OH)_2$/Lbs Dry Solids	Range Lbs[2] $Ca(OH)_2$/Lbs Dry Solids	Total[3] Volume Treated (gal)	Average Total Solids, mg/l	Average Initial pH	Average Final pH
Primary sludge[1]	3-6	0.12	0.06-0.17	136,500	43,276	6.7	12.7
Waste activated sludge	1-1.5	0.30	0.21-0.43	42,000	13,143	7.1	12.6
Septage	1-4.5	0.20	0.09-0.51	27,500	27,494	7.3	12.7
Anaerobic	6-7	0.19	0.14-0.25	23,500	55,345	7.2	12.4

[1]Includes some portion of waste activated sludge

[2]Numerically equivalent to Kg $Ca(OH)_2$ per kg dry solids

[3]Multiply gallons x 3.785 to calculate liters

TABLE 10. COMPARISON OF LIME DOSAGES REQUIRED TO TREAT RAW PRIMARY SLUDGE

Investigator	Lime Dose,* kg lime/kg sludge dry solids
Present Investigators	0.120 [b]
Farrell, et al	0.098 [c]
Counts, et al	0.086 [a]
Paulsrud, et al	0.125 [b]

(a) Based on 4.78% solids
(b) Based on pH 12.5 for sludges reported
(c) Based on pH 11.5 for sludges reported
*As 100% $Ca(OH)_2$

Table 11 compares the values predicted by the Counts equation to the Lebanon data for raw primary, waste activated, anaerobically digested, and septage sludges:

TABLE 11. COMPARISON OF LIME DOSAGES PREDICTED BY THE COUNTS EQUATION TO ACTUAL DATA AT LEBANON, OHIO

Sludge Type	Percent Solids	Actual Lime Dose, kg lime/kg D.S.	Counts' Lime Dose, kg lime/kg D.S.
Raw primary	4.78	0.120	0.086
Waste activated	1.37	0.300	0.305
Anaerobically digested	6.40	0.190	0.065
Septage	2.35	0.200	0.180

With increasing solids concentrations, the Counts equation results in lower than actual lime dosages.

pH VERSUS TIME

Previous research has attempted to determine the magnitude of pH decay versus time and to quantify the variables which affect pH decay. Paulsrud[8] reported that negligible pH decay occurred when the sludge mixture was raised to pH 12 or greater or when the lime dose was approximately five times the dose to reach pH 11. In either case, for raw primary sludge, Paulsrud's dose was in the range of 0.100 to 0.150 kg lime/kg dry solids, which was approximately the dosage used at Lebanon.

Counts[9] hypothesized that pH decay was caused by the sludge chemical demand which was exerted on the hydroxide ions supplied in the lime slurry. He further concluded that the degree of decay probably decreased as the treated sludge pH increased because of the extremely large quantities of lime required to elevate the pH to 12 or above. However, this pH phenomenon is probably because pH is an exponential function, e.g., the amount of OH^- at pH 12 is ten times more than the amount of OH^- at pH 11.

In the full scale work at Lebanon, all sludges were lime stabilized to pH 12 or above and held for at least 30 min with the addition of excess lime. All treated sludges had less than a 2.0 pH unit drop after six hours. Limed primary sludge was the most stable with septage being the least stable. During the full scale program, only the pH of limed primary sludge was measured for a period greater than 24 hours, which showed a gradual drop to approximately 11.6 after 18 hours beyond which no further decrease was observed.

The total mixing times from start through the 30 min contact time at Lebanon were as follows:

Primary sludge	2.4 hours
Waste activated sludge	1.7 hours
Septic tank sludge	1.5 hours
Anaerobic digested sludge	4.1 hours

Mixing time was a function of lime slurry feed rate and was not limited by the agitating capacity of the diffused air system. Mixing time may have been reduced by increasing the capacity of the lime slurry tank.

To further examine the effects of excess lime addition above the levels necessary to reach pH 12, a series of laboratory tests were set up using a standard jar test apparatus. The tests were made on six one-liter portions of primary sludge with 2.7% total solids. The pH of each of the samples was increased to 12 by the addition of 10% hydrated lime slurry. One sample was used as a control. The remaining samples had 30%, 60%, 90%, 120%, and 150% by weight of the lime dose added to the control. The samples were mixed continuously for six hours and then again ten minutes prior to each additional pH measurement. There was a negligible drop in pH over a ten day period for those tests where excess lime was added.

A second laboratory scale test was completed using a 19 l (5 gal) raw primary sludge sample which was lime stabilized to pH 12.5 and allowed to stand at 18° C. Samples were withdrawn weekly and analyzed for pH and bacteria concentration. The results of the pH and bacteria studies are shown on Figures 9 and 12, respectively. After 36 days, the pH had dropped to 12.0.

In conclusion, significant pH decay should not occur once sufficient lime has been added to raise the sludge pH to 12.5 and maintain that value for at least 30 min.

ODORS

Previous work(9) stated that the threshold odor number of raw primary and trickling filter sludges was approximately 8,000, while that of lime stabilized sludges usually ranged from 800 to 1,300. By retarding bacterial regrowth, the deodorizing effect can be prolonged. Further, it was concluded that by incorporating the stabilized sludge into the soil, odor potential should not be significant.

During the full scale operations at Lebanon, there was an intense odor when raw sludge was first pumped to the lime stabilization mixing tank which increased when diffused air was applied for mixing. As the sludge pH increased, the sludge odor was masked by the odor of ammonia which was being air stripped from the sludge. The ammonia odor was most intense with anaerobically digested sludge and was strong enough to cause nasal irritation. As mixing proceeded, the treated sludge acquired a musty humus like odor, with the exception of septage which did not have a significant odor reduction as a result of treatment.

As described later, all treated sludges were applied to farmland. At the Glosser Road site, shown on Figure 10, the sludge was not incorporated into the soil and one complaint was received from a resident whose house was approximately 76 m (250 ft) southeast of the land spreading site. On the day the complaint was received, the wind direction was directly toward the house. The weather was very humid with warm daytime temperatures and relatively cool nights.

Following the receipt of the odor complaint, land spreading operations were switched to a second site as shown on Figure 11. This site was approximately 152 m (500 ft) from the nearest residence, with a woods separating the site and the adjacent land in the direction of the prevailing wind. No complaints were received at this site. Lime stabilized sludge was incorporated into the soil approximately 2-3 weeks following application. Lime stabilized sludges were also spread on a hay field at this site.

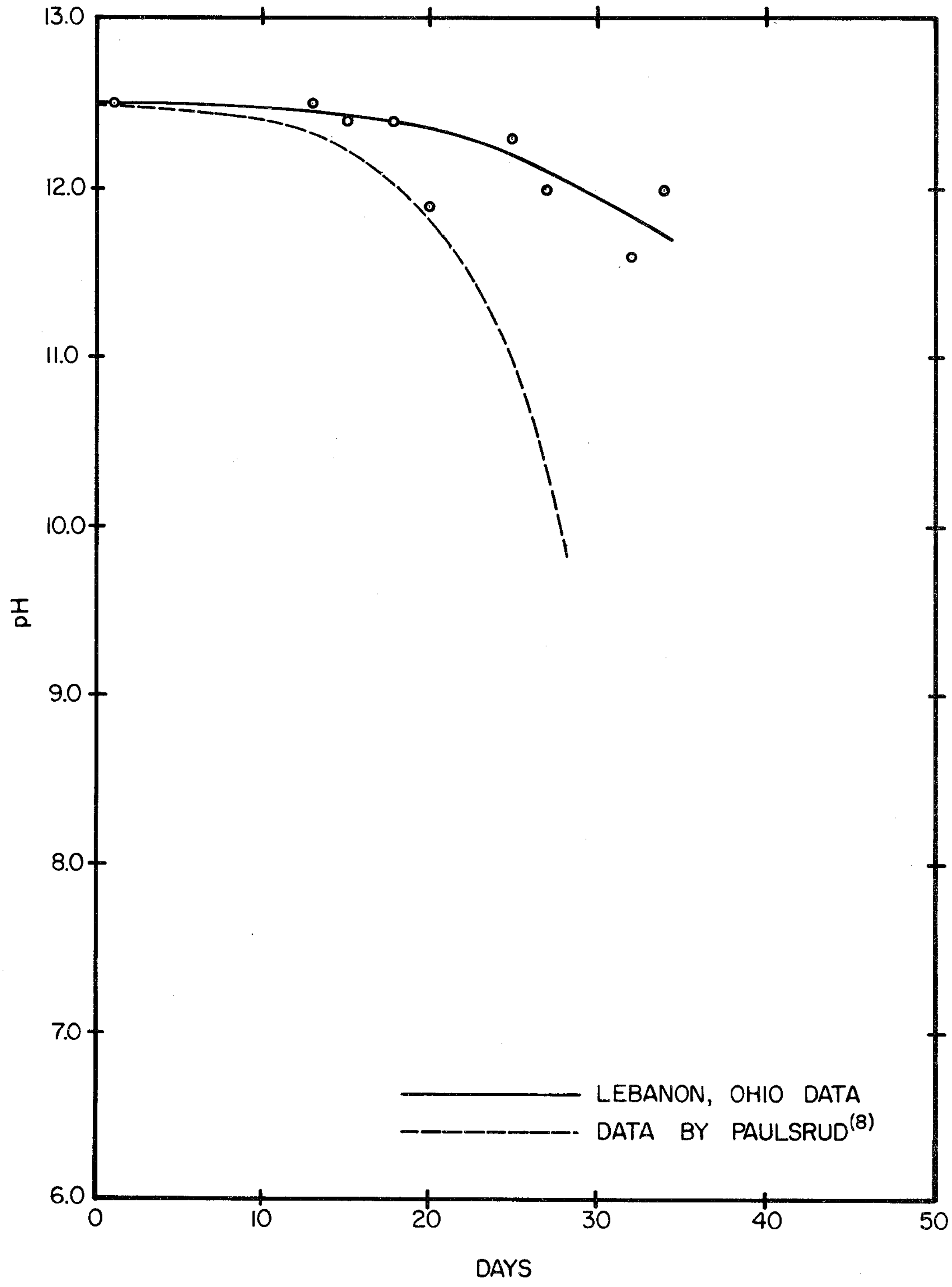

Figure 9. Lime Stabilized Primary Sludge pH vs Time

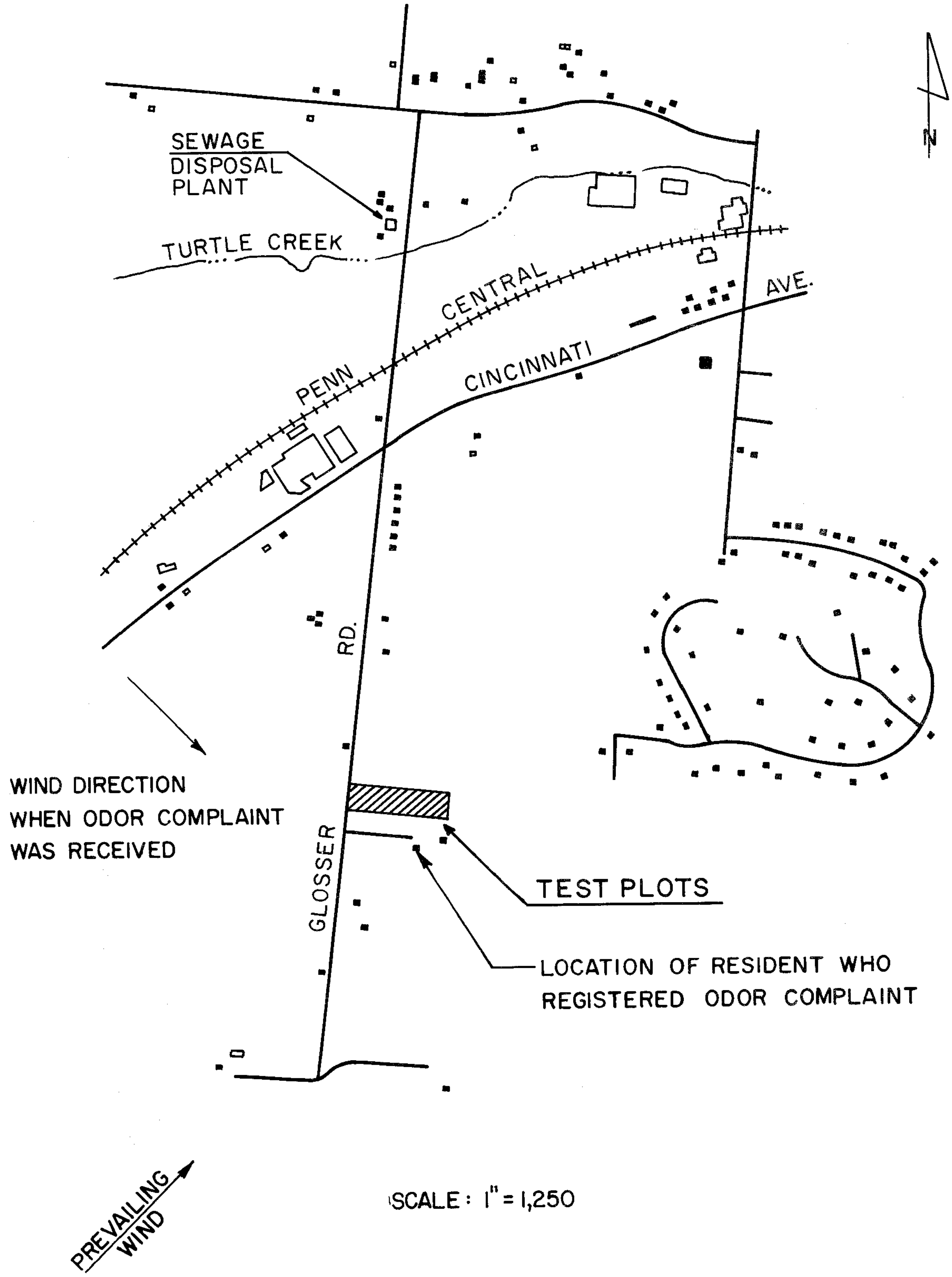

Figure 10. Site Plan. Glosser Road Land Disposal Area

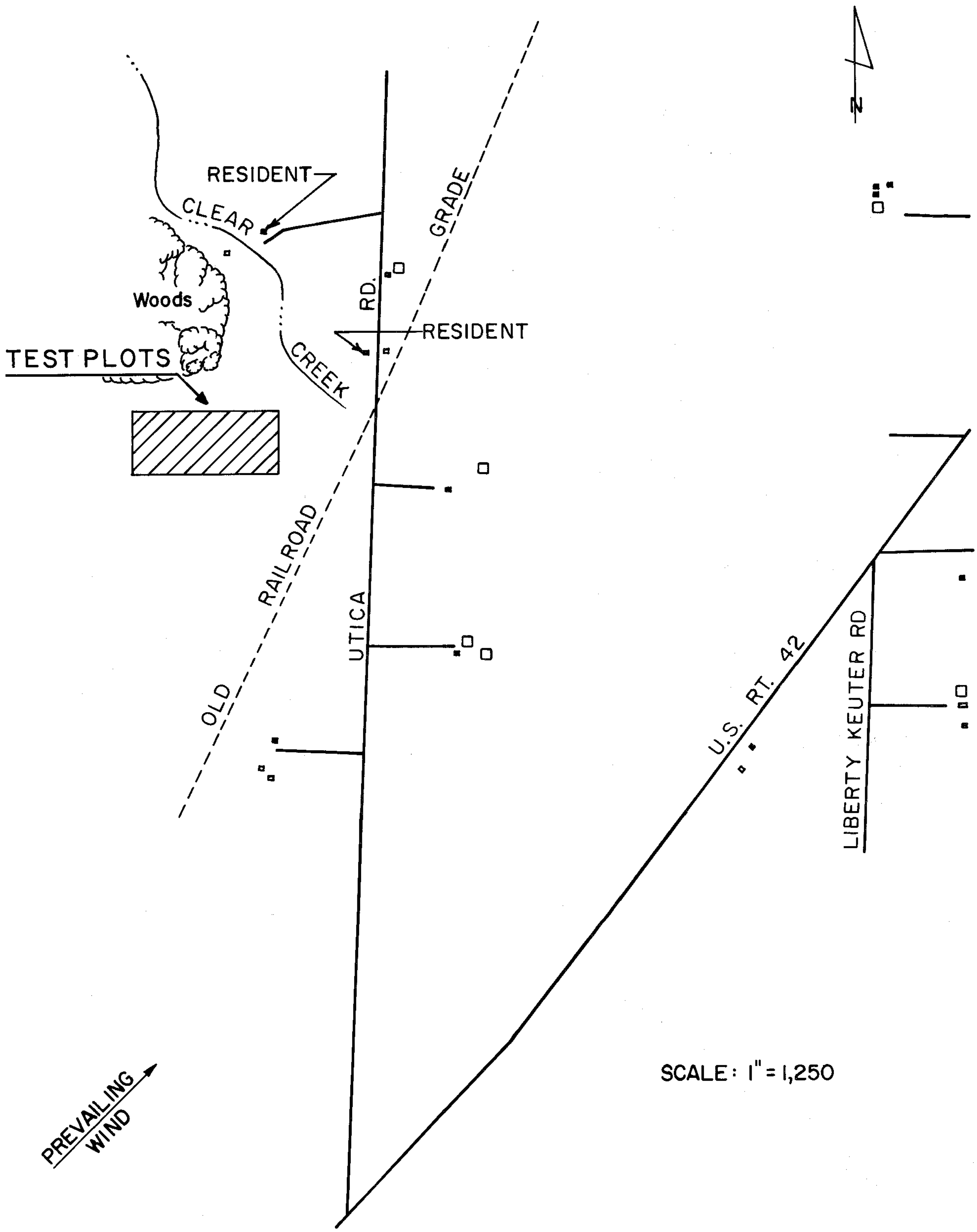

Figure 11. Site Plan. Utica Road Land Disposal Area

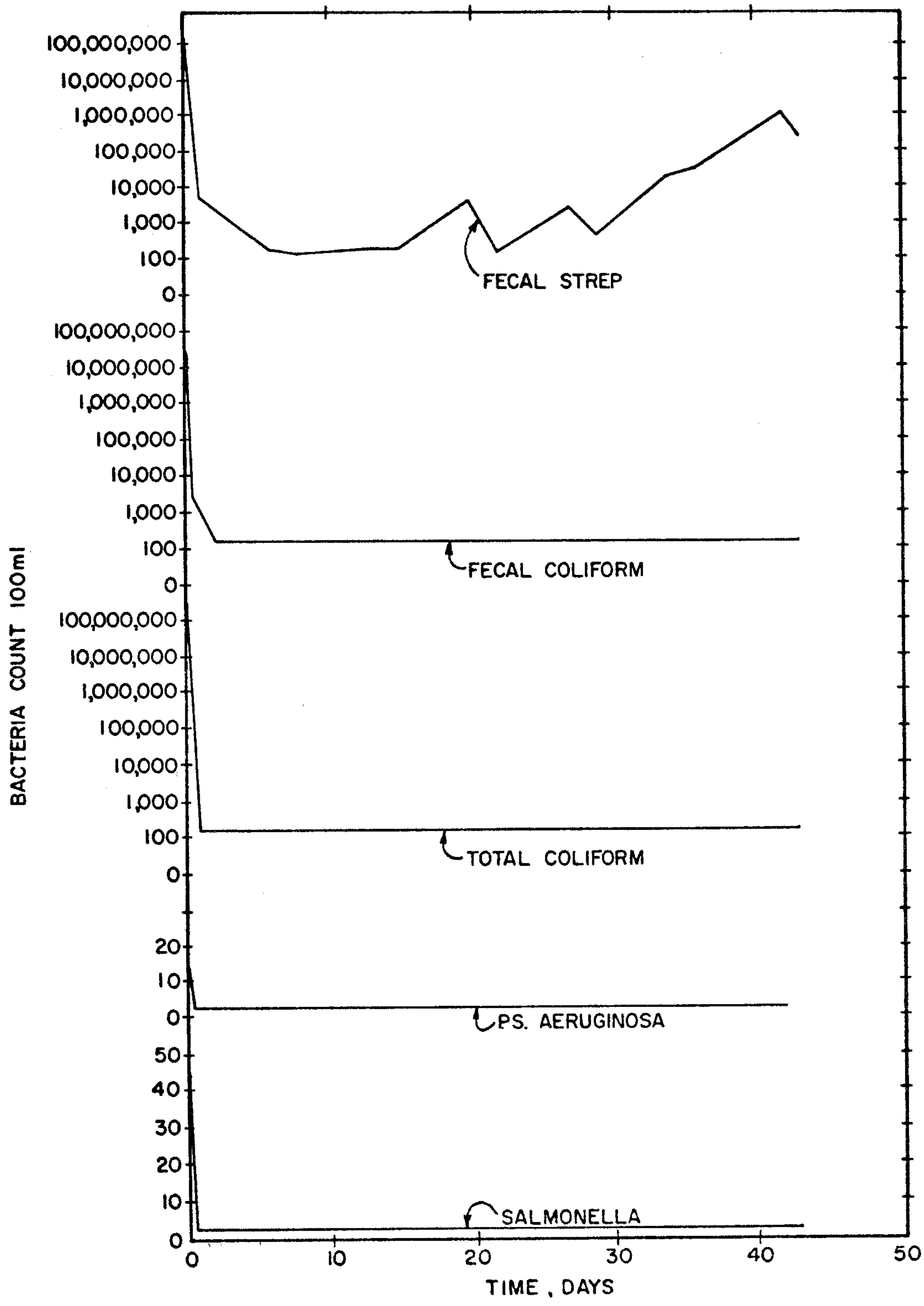

Figure 12. Bacteria Concentration vs Time Laboratory Regrowth Studies

CHEMICAL PROPERTIES

The addition of lime and mixing by diffused air altered the chemical characteristics of each sludge. In all sludges, lime stabilization resulted in an increase in alkalinity and soluble COD and a decrease in soluble phosphate. Total COD and total phosphate decreased for all sludges except waste activated. Ammonia nitrogen and total Kjeldahl nitrogen decreased for all sludges except waste activated. The results of the chemical analyses are summarized in Table 12.

TABLE 12. CHEMICAL COMPOSITION OF LIME STABILIZED SLUDGES AT LEBANON, OHIO

Parameter	Raw Primary Sludge	Waste Activated Sludge	Anaerobically Digested Sludge	Septage Sludge
Alkalinity, mg/l	4,313	5,000	8,467	3,475
Alkalinity range, mg/l	3,830-5,470	4,400-5,600	2,600-13,200	1,910-6,700
Total COD, mg/l	41,180	14,700	58,690	17,520
Total COD range, mg/l	26,480-60,250	10,880-20,800	27,190-107,060	5,660-23,900
Soluble COD, mg/l	3,556	1,618	1,809	1,537
Soluble COD range, mg/l	876-6,080	485-3,010	807-2,660	1,000-1,970
Total Phosphate, mg/l	283	263	381	134
Total Phosphate range, mg/l	164-644	238-289	280-460	80-177
Soluble Phosphate, mg/l	36	25	2.9	2.4
Soluble Phosphate range, mg/l	17-119	17-31	1.4-5.0	1.4-4.0
Total Kjeldahl nitrogen, mg/l	1,374	1,034	1,980	597
Total Kjeldahl nitrogen range, mg/l	470-2,510	832-1,430	1,480-2,360	370-760
Ammonia nitrogen, mg/l	145	64	494	110
Ammonia nitrogen range, mg/l	81-548	36-107	412-570	53-162
Total suspended solids, mg/l	38,370	10,700	66,350	23,190
Total suspended solids range, mg/l	29,460-44,750	10,745-15,550	46,570-77,900	14,250-29,600
Volatile suspended solids, mg/l	23,480	7,136	26,375	11,390
Volatile suspended solids range, mg/l	19,420-26,450	6,364-8,300	21,500-29,300	5,780-19,500

The volatile solids concentrations of raw and lime stabilized sludges are shown in Table 13. The actual volatile solids concentrations following lime stabilization are lower than those which would result only from the addition of lime. Neutralization, saponification, and hydrolysis reactions, which convert solids into soluble forms with the lime probably result in the lower volatile solids concentrations.

TABLE 13. VOLATILE SOLIDS CONCENTRATION OF RAW AND LIME STABILIZED SLUDGES

Sludge Type	Raw Sludge Volatile Solids Solids Concentration, mg/l	Lime Stabilized Sludge Volatile Solids Solids Concentration, mg/l
Primary	73.2	54.4
Waste activated	80.6	54.2
Septage	69.5	50.6
Anaerobically digested	49.6	37.5

Heavy metal analyses were not performed on lime stabilized sludges.

In terms of the agricultural value, lime stabilized sludges had lower soluble phosphate, ammonia nitrogen, total Kjeldahl nitrogen, and total solids concentrations than anaerobically digested primary/waste activated mixtures at the same plant, as shown in Table 14. The significance of these changes are discussed in the section on land disposal.

TABLE 14. NITROGEN AND PHOSPHORUS CONCENTRATIONS IN ANAEROBICALLY DIGESTED AND LIME STABILIZED SLUDGE

Sludge Type	Total Phosphate as P, mg/l	Total Kjeldahl Nitrogen as N, mg/l	Ammonia Nitrogen as N, mg/l
Lime Stabilized Primary	283	1,374	145
Lime Stab. Waste Activated	263	1,034	53
Lime Stabilized Septage	134	597	84
Anaerobic Digested	580	2,731	709

PATHOGEN REDUCTION

Considerable research has been conducted on the degree of bacterial reduction which can be achieved by high lime doses. In general, the degree of pathogen reduction increased as sludge pH increased with consistently high pathogen reductions occurring only after the pH reached 12.0. Fecal streptococci appeared to resist inactivation by lime treatment particularly well in the lower pH values; however, at pH 12, these organisms were also inactivated after one hour of contact time.[9]

The indicator organisms which were used during the full scale project at Lebanon were the Salmonella species, Pseudomonas aeruginosa, fecal coliforms, total coliforms, and fecal streptococci. In all sludges, Salmonella and Pseudomonas aeruginosa concentrations were reduced to near zero. Fecal and total coliform concentrations were reduced greater than 99.99% in the primary and septic sludges. In waste activated sludge, the total and fecal coliform concentrations decreased 99.97% and 99.94%, respectively. The fecal streptococci kills were as follows: primary sludge, 99.93%; waste activated sludge, 99.41%; septic sludge, 99.90%; and anaerobic digested, 96.81%. (Based on raw sludge data as shown in Table 7 and lime stabilized sludge values as shown in Table 15).

Pathogen concentrations for the lime stabilized sludges are summarized in Table 15.

Anaerobic digestion is currently an acceptable method of sludge stabilization.[19] For reference, lime stabilized sludge pathogen concentrations at Lebanon have been compared in Table 16 to those observed for well digested sludge from the same plant.

Pathogen concentrations in lime stabilized sludge range from 10 to 1,000 times less than for anaerobically digested sludge.

A pilot scale experiment was completed in the laboratory to determine the viability and regrowth potential of bacteria in lime stabilized primary sludge over an extended period of time.

The test was intended to simulate storing stabilized sludge in a holding tank or lagoon when weather conditions prohibit spreading. In the laboratory test, 19 l (5 gal) of 7% raw sludge from the Mill Creek sewage treatment plant in Cincinnati was lime stabilized to pH 12.0. Lime was added until equivalent to 30% of the weight of the dry solids which resulted in a final pH of 12.5. The sample was then covered with foil and kept at room temperature 18.3 C. (65° F.) for the remainder of the test. The contents were stirred before samples were taken for bacterial analysis.

TABLE 15. PATHOGEN DATA FOR LIME STABILIZED SLUDGES AT LEBANON, OHIO

Parameter	Raw Primary Sludge	Waste Activated Sludge	Anaerobically Digested Sludge	Septage Sludge
Salmonella avg., #/100 ml	<3*	<3*	<3*	<3*
Salmonella range, #/100 ml	<3*	<3*	<3*	<3*
Ps. aeruginosa avg., #/100 ml	<3*	13	<3*	<3*
Ps. aeruginosa range, #/100 ml	<3*	<3*-26	<3*	<3*
Fecal coliform avg. MF #/100 ml	N/A	1.62×10^4	3.3×10^3	2.65×10^2
Fecal coliform range MF, #/100 ml	N/A	$3.3x10^2$-$3.2x10^4$	3.3×10^3	$2x10^2$-$3.3x10^2$
Fecal coliform avg. MPN, #/100 ml	5.93×10^3	N/A	18	N/A
Fecal coliform range MPN, #/100 ml	560-1.7×10^4	N/A	18	N/A
Total coliform avg. MF, #/100 ml	N/A	2.12×10^5	N/A	2.1×10^3
Total coliform range MF, #/100 ml	N/A	$3.3x10^3$-$4.2x10^5$	N/A	200-4×10^3
Total coliform avg. MPN, #/100 ml	1.15×10^5	N/A	18	N/A
Total coliform range MPN, #/100 ml	640-5.4×10^5	N/A	18	N/A
Fecal streptococci avg., #/100 ml	1.62×10^4	6.75×10^3	8.6×10^3	665
Fecal streptococci range, #/100 ml	$4.0x10^3$-$5.5x10^4$	$1.5x10^3$-$1.35x10^4$	$3.3x10^2$-$1.4x10^4$	$3.3x10^2$-$1x10^3$

*Detectable limit = 3

TABLE 16. COMPARISON OF BACTERIA IN ANAEROBIC DIGESTED VERSUS LIME STABILIZED SLUDGES

	Fecal Coliform #/100 ml	Fecal Streptococci #/100 ml	Total Coliform #/100 ml	Salmonella #/100 ml	Ps. Aeruginosa #/100 ml
Anaer. digested	$1,450x10^3$	$27x10^3$	$27,800x10^3$	6	42
Lime stabilized*					
Primary	$4x10^3$	$23x10^3$	$27.6x10^3$	<3**	<3**
Waste activated	$16x10^3$	$61x10^3$	$212x10^3$	<3**	13
Septage	265	665	2,100	<3**	<3**

*To pH equal to or greater than 12.0
**Detectable limit = 3

The results are shown on Figure 12, and indicate that a holding period actually increases the bacteria kill. *Salmonella* in the raw sludge totaling 44 per 100 ml were reduced to the detection limit by lime stabilization. *Pseudomonas aeruginosa* totaling 11 per 100 ml in the raw sludge were reduced to the detection limit by lime stabilization. The initial fecal coliform count of 3.0×10^7 was reduced to 5×10^3 after lime stabilization, and after 24 hours was reduced to less than 300. The raw sludge contained 3.8×10^8 total coliform, but 24 hours after lime stabilization the total coliform were less than 300. The fecal strep count in the raw sludge was 1.8×10^8 which decreased to 9.6×10^4 after lime stabilization. After 24 hours, the count was down to 7.0×10^3 and after six days reduced to less than 300. The count increased to 8×10^5 after 40 days.

PARASITES

The high pH of the sludge seemed to have little or no effect on the viability of the parasites in the limed sludges. Viable parasites were found in both limed and unlimed samples with reduced numbers in the limed samples. All the sludges had similar parasites as shown in Table 17 with *Toxacara*, mites, and nematodes common to each of the sludges. Viable parasites were found in both anaerobic digested and limed sludges.

TABLE 17. IDENTIFIED PARASITES IN LEBANON, OHIO LIME STABILIZED SLUDGES

Primary	Waste Activated Sludge	Septage	Anaerobic Digested
Toxacara	Toxacara	Toxacara	Toxacara Canis Toxacara cati
Trichuris vulpis		Ascaris lumbricoides	Ascaris
Trichuris trichura		Trichuris trichiura	Trichuris vulpis
Enterobius vermicularis larva		Trichuris vulpis	

SECTION 6

LAND APPLICATION

GENERAL

Numerous references[14][15][19][20] are available regarding the application of anaerobically digested sludges to agricultural land. The application of sewage sludge on land has generally been viewed from two standpoints, either as a rate of application consistent with the utilization of nutrients in sludge by growing plants (i.e., agricultural utilization), or as the maximum amount of sludge applied in a minimum amount of time (i.e., disposal only). USEPA guidelines[19] generally favor the former approach. The successful operation of a program utilizing the application of sewage sludge on land is dependent upon a knowledge of the particular sludge, soil, and crop characteristics.

Organic matter content, fertilizer nutrients, and trace element concentrations are generally regarded as being vital to the evaluation of the applicability of land application of sewage sludge. The range of nitrogen, phosphorus, and potassium concentrations for sewage sludges have been reported by Brown et al[14] as shown in Table 18.

TABLE 18. RANGE OF N, P AND K CONTENTS OF SEWAGE SLUDGE[14]

Component	Range of Percent by Weight	Range of Kg/1,000 Kg
Total Nitrogen	3.5-6.4	70-128
Organic Nitrogen	2.0-4.5	40- 90
P as phosphorus	0.8-3.9	16- 78
P_2O_5	1.8-8.7	36-174
Potassium	0.2-0.7	4-14
K_2O (potash)	0.24-0.84	5-17

Sommers(15) has also summarized fertilizer recommendations for crops based primarily on the amount of major nutrients (nitrogen, phosphorus, and potassium) required by a crop and on the yield desired. The amounts of nitrogen, phosphorus, and potassium required by the major agronomic crops are shown in Table 19.

TABLE 19. ANNUAL N, P AND K UTILIZATION BY SELECTED CROPS[a]

Crop	Yield kg/hectare	N	P kg/hectare	K
Corn	9,413	208	39	200
	11,296	269	49	223
Corn silage	71,717	225	39	228
Soybeans	3,362	289[b]	24	112
	4,034	377[b]	33	135
Grain sorghum	8,964	281	45	186
Wheat	4,034	140	25	102
	5,379	209	27	150
Oats	3,586	168	27	140
Barley	5,600	168	27	140
Alfalfa	17,929	505[b]	39	447
Orchard grass	13,447	337	49	349
Brome grass	11,206	186	33	237
Tall fescue	7,844	152	33	173
Bluegrass	6,723	225	27	167

[a]Values reported are from reports by the Potash Institute of America and are for the total above-ground portion of the plants. For the purpose of estimating nutrient requirements for any particular crop year, complete crop removal can be assumed.

[b]Legumes obtain nitrogen from symbiotic N_2 fixation so fertilizer nitrogen is not added.

As shown for corn, the yield desired will determine the amount of nitrogen, phosphorus, and potassium required. Since cropping systems alter the level of plant available nutrients to different extents, the previous crop exerts an influence on the nitrogen recommendations for corn at different yield levels (Table 20). These differences arise because crops such as legumes actually increase the nitrogen availability in soils through symbiotic nitrogen fixation. Primary emphasis in developing sludge guidelines is placed on the ability of sludges to satisfy the nitrogen needs of a crop.

TABLE 20. INFLUENCE OF PREVIOUS CROP ON N FERTILIZATION RATES FOR CORN[a]

Previous Crop	Yield Level, kkg/ha 6.28-6.90	6.97-7.84	7.91-9.41	9.48-11.0	11.0-12.0
	Kg N/hectare				
Good legume (alfalfa, red clover, etc.)	45	79	112	135	168
Average legume (legume-grass mixture or poor stand)	67	112	157	180	202
Corn, soybeans, small grains, grass sod	112	135	180	213	247
Continuous corn	135	157	191	224	258

[a]Purdue University Plant and Soil Testing Laboratory Mimeo, 1974.

Counts[(9)] conducted greenhouse and test plot studies for lime stabilized sludges which were designed to provide information on the response of plants grown in sludge-soil mixtures ranging in application rate from 11 to 220 metric tons per hectare (5 to 100 tons/acre). Counts concluded that sludge addition to poor, e.g., sandy, soils would increase productivity, and therefore would be beneficial. The total nitrogen and phosphorus levels in plants grown in greenhouse pots, which contained sludge-soil mixtures, were consistently lower than plants which were grown in control pots. The control set, which contained only soil with no sludge additions received optimum additions of chemical fertilizer during the actual plant growth phase of the studies. Calcium concentration in plant tissues from the sludge-soil pots were higher than those for the controls. The pH values of the various sludge-soil mixtures were lower after plant growth than before. Counts attributed the decrease to carbon dioxide buildup in the soil which resulted from biological activity.

LAND APPLICATION RESULTS

Land application studies at Lebanon, Ohio were conducted by spreading liquid sludge on agricultural land and on controlled test plots. Winter wheat, soybeans, and hay were grown on fields which were in normal agricultural production. Corn, swiss chard, and soybeans were grown on 22 test plots, each with an area of 0.0085 ha (0.021 acre).

Sludge application was accomplished by spreading as a liquid using a four-wheel drive vehicle which was equipped with a 2.3 cu m (600 gal) tank. The width of sludge spread per pass was approximately 60 cm (24 in).

Two agricultural areas were used for disposal of lime stabilized sludges. The Glosser Road site, as previously shown on Figure 10, comprised a total area of 16 ha (40 acres). The predominant soils were of the Russell and Miami-Xenia-Wynn associations which are light colored silt loams and are moderately well drained.

The entire field had been planted in winter wheat the previous fall. At that time, a fertilizer application of 281 kg/ha (250 lbs/acre) of 16-16-16 was made. Approximately two weeks prior to starting land application, an additional 55 pounds/acre of urea were applied to all areas except those which were to receive sludge.

Two 0.73 ha (1.8 acre) test areas ("A" and "B"), as shown on Figure 13, were used for land application studies. The wheat was approximately 2.54 cm (1 in) high when lime stabilized primary sludge was first applied on March 1, 1976. Weather permitting, lime stabilized sludge was applied twice weekly through April 19, 1976. The narrow sludge application swath, as previously described, required numerous trips across the field which resulted in some damage to the wheat. Secondly, the lime stabilized sludge formed a filamentous mat 0.32 to 0.64 cm (1/8-1/4 in) thick which, when dry, partly choked out the wheat plants. The mat partly deteriorated over time, but significant portions remained at the time of harvest. Application rates for nutrients have been summarized in Table 21.

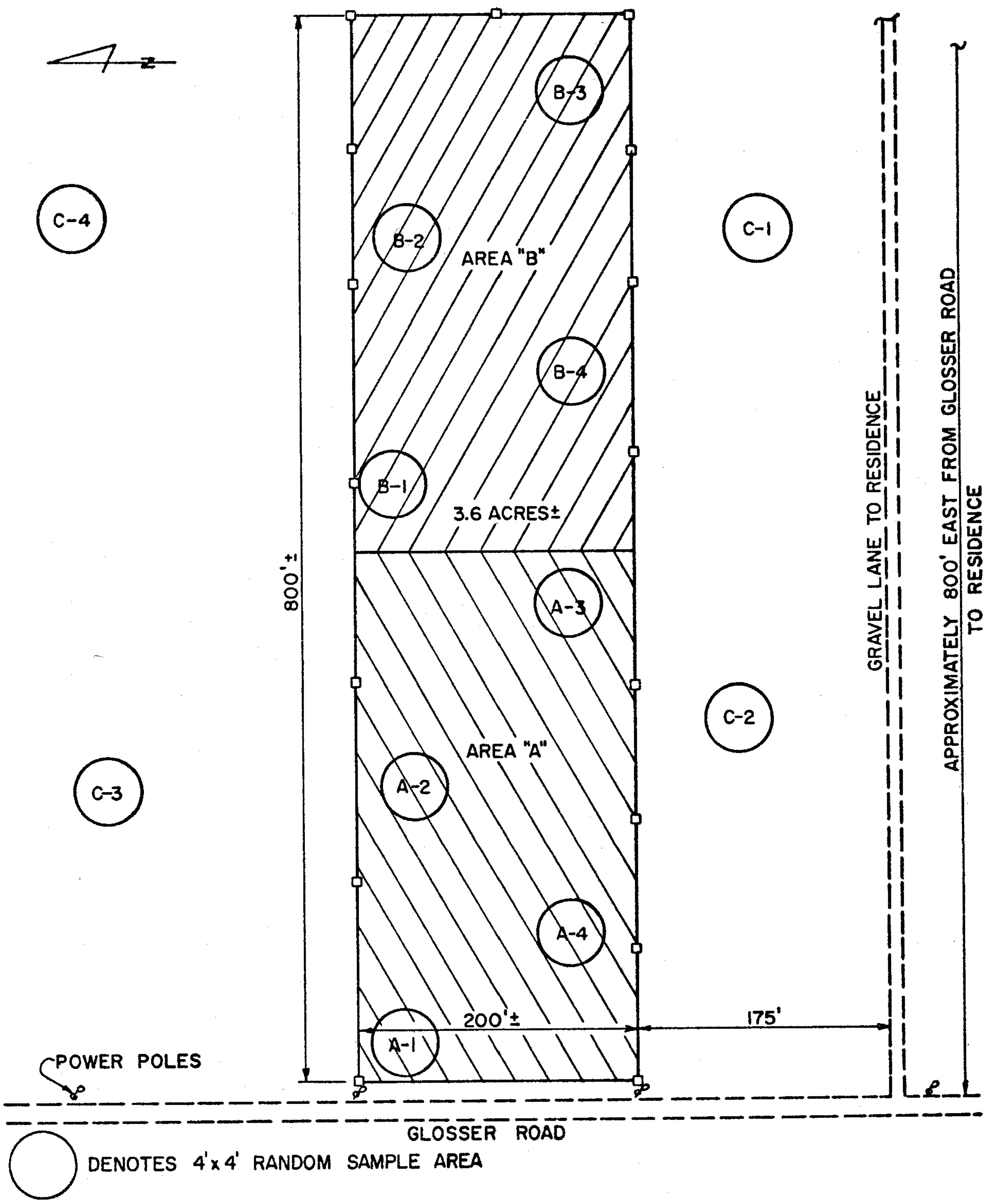

Figure 13. Layout of Glosser Road Land Disposal Area

TABLE 21. APPLICATION RATES FOR NUTRIENTS IN SLUDGE GLOSSER ROAD SITE

Parameters	Area "A" Kg/hectare	Area "A" Lb/acre	Area "B" Kg/hectare	Area "B" lb/acre
Lime as $Ca(OH)_2$	979	872	545	485
Total phosphorus as P_2O_5	110	98	52	46
Soluble phosphorus as P_2O_5	14.4	12.8	8.6	7.7
Total Kjeldahl nitrogen as N	238	212	135	120
Ammonia nitrogen as N	27	24	15.7	14

The sludge application rates were 8.19 metric tons per hectare (3.65 tons/acre) and 4.53 metric tons per hectare (2.02 tons/acre) to areas "A" and "B", respectively. (Values based on tons dry solids.)

Nitrogen application rates to the test areas were less than the fertilized control as shown below:

	Fertilizer Nitrogen kg/ha	Sludge* Nitrogen kg/ha	Total Available Nitrogen kg/ha
Test Area "A"	40	13	53
Test Area "B"	40	8	48
Control Field	107	0	107

*Assumes 50% loss of ammonia nitrogen in sludge due to volatilization

Random wheat samples were taken as shown on Figure 13. Areas C-1, C-2, C-3, and C-4 were used as controls. Areas A-1, A-2, A-3, and A-4 had approximately twice the sludge application rate as Areas B-1, B-2, B-3, and B-4. Yield data are shown in Table 22.

TABLE 22. GLOSSER ROAD WHEAT FIELD YIELD ANALYSIS

Area	No. Shafts Per 1.47 m^2 (4'x4') Area	Grain ODWT* kg/ha	Chaff kg/ha	Shaft ODWT* kg/ha	Biomass kg/ha	Yield, gm/head
Control						
C-1	657	3,426	397	2,571	6,394	0.775
C-2	747	3,500	323	2,645	6,468	0.696
C-3	N/A	N/A	N/A	N/A	N/A	N/A
C-4	672	3,210	478	2,248	5,936	0.710
Average	692	3,379	399	2,488	6,266	0.727
Area "B"						
B-1	386	1,602	195	1,184	2,981	0.617
B-2	441	1,817	202	1,238	3,257	0.612
B-3	487	2,302	209	1,629	4,139	0.702
B-4	495	1,945	202	1,359	3,506	0.584
Average	452	1,916	202	1,353	3,471	0.630
Area "A"						
A-1	522	1,709	350	1,777	3,836	0.487
A-2	288	1,306	316	1,036	2,658	0.674
A-3	620	2,053	424	1,629	4,247	0.477
A-4	662	2,672	565	2,207	5,445	0.600
Average	523	1,935	414	1,662	4,046	0.556

*ODWT = oven dry weight

Area "A" which had a greater level of mechanical abuse due to the extra sludge applications had higher biomass and shaft weights indicating slightly larger plants. Area "A" had a higher number of shafts per acre but had smaller grain sizes, thereby resulting in approximately the same yield as Area "B".

Both Areas "A" and "B" had significantly lower yields than the control area, resulting in part from the nitrogen deficiency.

A second land application area (Utica Road site), as shown on Figure 11, was utilized. Soils in this area were of the Fincastle-Brookston association. The predominant soil was Fincastle silt loam, which is a light colored, somewhat poorly drained soil. The Utica Road site had been previously tiled to compensate for the poor drainage. A total area of 263 ha (650 acres) were under production for corn, soybeans, and hay at this site.

Three major study areas were used at this site. Twenty-two 0.0085 ha (0.021 acre) test plots were used for corn, soybean, and swiss chard growth studies. An area of approximately 3.86 acres was divided into seven plots ranging in size from 0.11 to 0.78 ha (0.28 to 1.93 acres) and were managed as a part of normal farming operations. A third area of approximately 2 ha (5 acres) was in hay production and received lime stabilized sludges during the period July 19-October 5, 1976. Sludge was incorporated into the soil approximately two weeks after application on all areas except to the hay field.

A layout of the 22 test plots is shown on Figure 14. Table 23 summarizes the sludge types and application rates which were used.

TABLE 23. UTICA ROAD TEST PLOT SLUDGE APPLICATION DATA

Sludge Type	Dry Solids Application, kkg/ha	Dry Solids Application, tons/acre	Plot No.
Raw Primary	11	5	4,21,22
Anaerobically Digested	11	5	1,9,18
Lime Stabilized Anaer. Digested	11	5	14,19,20
Lime Stabilized Primary	11	5	5,12,17
Lime Stabilized Primary	22	10	7,15,16
Lime Stabilized Primary	44	20	3,11,13

Nitrogen, phosphorus, and potassium application rates for each of the test plots have been summarized in Table 24.

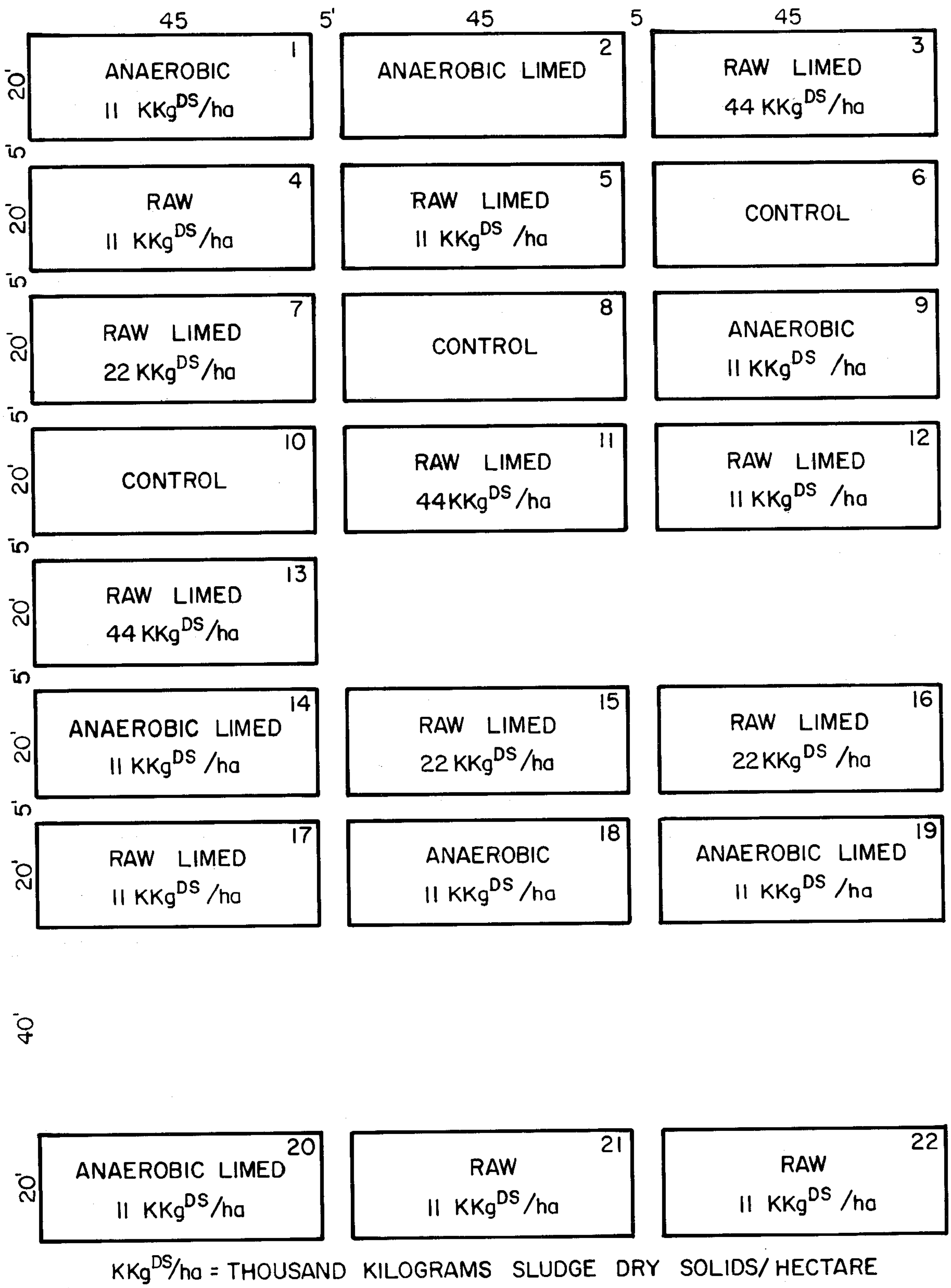

Figure 14. Layout of Utica Road Test Plots

TABLE 24. N AND P APPLICATION RATES TO UTICA ROAD TEST PLOTS

Sludge Type	Plot No.	N Applied kg/ha	P Applied* kg/ha
Raw Primary	4,21,22	46	65
Anaerobically Digested	1,9,18	160	131
Lime Stabilized Anaer. Digested	14,19,20	110	86
Lime Stabilized Primary	5,12,17	28	52
Lime Stabilized Primary	7,15,16	56	103
Lime Stabilized Primary	3,11,13	112	207

*Based on total P in sludge, reported as P

The test plots received no fertilizer or herbicide applications prior to sludge application. Yields for corn and soybeans are summarized in Tables 25 and 26, respectively.

Actual application rates for nitrogen, phosphorus, and potassium have been compared to the targets previously shown in Table 19 as follows:

Crop	Target N kg/ha	Target P*** kg/ha	Target K kg/ha	Actual Range N kg/ha	Actual Range P*** kg/ha	Actual Range K kg/ha
Corn*	208	39	200	46-160	52-207	N/A
Soybeans**	-	24	112	46-160	52-207	N/A

*9,413 kg/ha (150 bu/acre) yield
**3,362 kg/ha (50 bu/acre) yield
***reported as P

With the exception of 44 kkg/ha raw limed sludge, all sludge applications increased the corn yield above the control. Increasing lime stabilized raw primary sludge resulted in decreasing corn yields, even though the nitrogen requirements were approached at the higher sludge application rates. Soybean yields were similarly influenced.

Swiss chard was utilized as an indicator for heavy metal uptake; however, at the time of this writing, the data are not available.

TABLE 25. CORN YIELD ANALYSIS FOR UTICA ROAD TEST PLOTS

Treatment	Rep 1 Grain kg/ha	Rep 2 Grain kg/ha	Rep 3 Grain kg/ha	Grain kg/ha avg	Average bu/acre	Number of Plants Rep 1	Number of Plants Rep 2	Number of Plants Rep 3	Average Number of Plants
Control	6,253	3,726	4,840	4,940	73	42	30	41	38
Raw (11 kkg/ha)	6,896	5,397	6,125	6,139	91	47	37	40	41
Raw Limed (11 kkg/ha)	5,996	7,282	5,397	6,225	92	46	48	47	47
Raw Limed (22 kkg/ha)	7,068	5,612	4,883	5,854	87	43	44	42	43
Raw Limed (44 kkg/ha)	5,654	4,112	3,384	4,383	65	38	32	29	33
Anaerobic (11 kkg/ha)	6,468	6,039	5,012	5,840	86	45	45	41	44
Anaerobic Limed (11 kkg/ha)	7,239	5,569	5,654	6,154	91	48	36	47	44

TABLE 26. SOYBEAN YIELD ANALYSIS FOR UTICA ROAD TEST PLOTS

Treatment	Rep 1 Grain kg/ha	Rep 2 Grain kg/ha	Rep 3 Grain kg/ha	Soybean kg/ha avg	Average bu/acre	Number of Plants Rep 1	Rep 2	Rep 3	Average Number of Plants
Control	2,104	2,300	2,057	2,154	38	179	177	178	178
Raw (11 kkg/ha)	2,193	2,343	2,453	2,330	42	153	174	204	177
Raw Limed (11 kkg/ha)	2,229	2,009	2,109	2,116	38	182	186	205	191
Raw Limed (22 kkg/ha)	1,731	2,035	1,952	1,906	34	158	186	203	182
Raw Limed (44 kkg/ha)	1,799	1,552	1,362	1,571	28	172	154	165	164
Anaerobic (11 kkg/ha)	2,099	1,810	2,251	2,053	37	155	156	183	165
Anaerobic Limed (11 kkg/ha)	2,067	1,959	2,459	2,162	39	167	158	209	178

Seven plots were used, as shown on Figure 15, for the full scale field studies. Plot Nos. 2 and 5 were 0.22 ha (.55 acre) and Plot Nos. 3, 4, and 6 were 0.11 ha (.275 acre). Plot Nos. 1 and 7 were used as control. The limed primary sludge was applied after the field had been plowed and roughly disked. The sludge formed a thick filamentous mat which was easily disked under before planting. All sites were planted with soybeans; site 1 the first week in May; sites 2, 3, and 4 the first week of June; and sites 5, 6, and 7 the first week of July. The test areas had been fertilized in previous years but did not receive fertilizer prior to sludge spreading. Sludge and nutrient application rates are shown in Table 27.

Table 28 summarizes a random selection of three soybean plants which were designated A, B, and C from individual plots. The data indicate that plots 2 and 5 with a higher sludge application rate would have a higher yield per acre than plots 1 or 4. Plant growth shows plots 2 and 5 yielded plants 5.1 cm taller than plots 1 and 4.

TABLE 28. PODS AND HEIGHTS OF SOYBEANS FROM VARIOUS PLOTS UTICA ROAD FULL SCALE FIELD STUDIES

	Pods per Plant				Plant Height in Centimeters			
Plot No.	A	B	C	Average	A	B	C	Average
1	49	32	33	38	95	84	81	81
4	48	33	33	38	90	88	99	92
2	39	44	37	40	99	74	97	90
5	29	34	58	40	94	104	94	97

A random sample of soybeans was selected for heavy metal analysis. The results are shown in Table 29. No consistent increase in metal concentration as a result of increasing sludge application was observed. Only zinc concentration increased with increasing sludge application rate. The lack of increases in other metals probably resulted from the relatively low concentrations of these elements in the sludge.

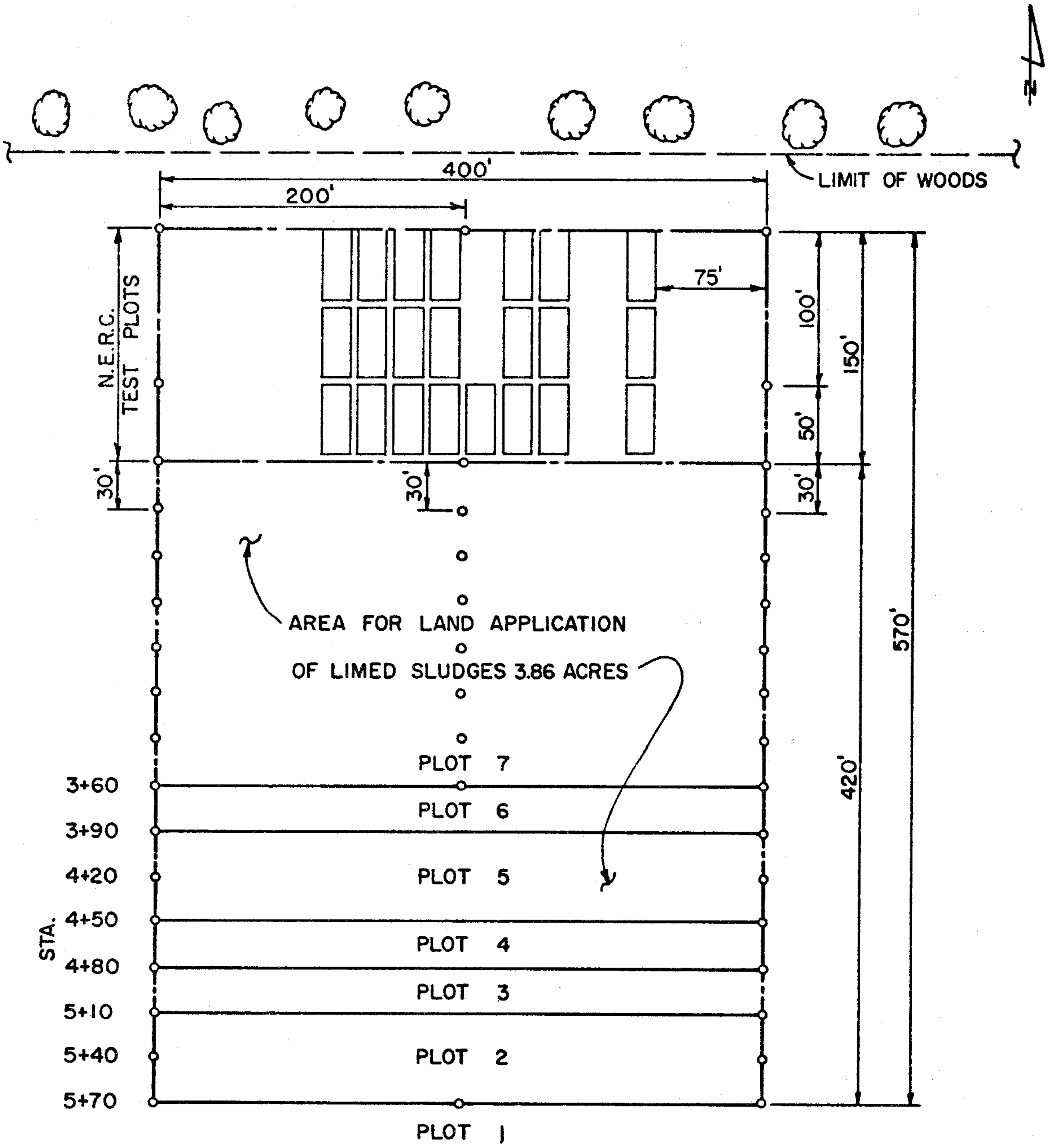

Figure 15. Layout of Utica Road Land Disposal Area

TABLE 27. APPLICATION RATES FOR NUTRIENTS IN SLUDGE FOR FULL SCALE FIELD STUDIES UTICA ROAD SITE

Parameter	Plot 2		Plot 3		Plot 5		Plot 6	
	Kg/ha	Lbs./Acre	Kg/ha	Lbs./Acre	Kg/ha	Lbs./Acre	Kg/ha	Lbs./Acre
Lime as $Ca(OH)_2$	1,226	1,092	849	756	989	881	520	463
Total Phosphorus as P_2O_5	236	211	120	107	161	144	102	91
Soluble Phosphorus as P_2O_5	40.4	36	20.2	18	28	25	18	16
Total Kjeldahl Nitrogen as N	438	391	220	196	297	265	188	168
Ammonia Nitrogen as N	56	50	28	25	38	34	24	21
Sludge Application Rate*	14,147	12,600	6,961	6,200	9,566	8,520	5,951	5,300

*Dry solids/acre

Note: Plots 1, 4 & 7 were used as control and received no sludge application.

TABLE 29. HEAVY METALS IN SOYBEANS
UTICA ROAD FULL SCALE FIELD STUDIES

Metals	No Sludge Plot 1 ppm*	Plot 4 ppm*	Plot 7 ppm*	Lime Stabilized Primary Sludge Plot 3 ppm*	Plot 6 ppm*	Plot 2 ppm*	Plot 5 ppm*
Cadium	0.35	0.20	0.1	0.3	0.2	0.45	0.3
Copper	6.3	6.2	13.6	6.9	11.0	8.6	12.6
Cobalt	1.9	1.7	0.4	1.6	1.0	1.4	1.0
Lead	0.5	0.5	0.3	0.5	0.5	0.3	0.5
Potassium as K	3,110	5,380	6,530	4,750	4,400	5,290	7,350
Potassium as K_2O	3,750	6,480	7,860	5,720	5,300	6,370	8,860
Mercury	1.5	4.0	4.0	5.5	0.3	6.5	0.3
Nickel	3.6	3.7	3.1	3.6	3.0	3.1	2.8
Zinc	5.5	5.4	5.1	9.3	9.3	5.6	11.6

*Results are recorded as ppm dry weight

Plot 2 = 14.1 kkg/ha   Plot 5 = 9.57 kkg/ha
Plot 3 = 6.96 kkg/ha   Plot 6 = 5.95 kkg/ha

Lime stabilized anaerobically digested, waste activated, and septage sludges were applied to a two hectare (5 acre) hayfield during the period July 19-October 5, 1976, after a second cutting of hay had been made.

Spontaneous growth of tomatoes was significant in both the test plots and full scale soybean field areas. Seeds were contained in the sludge and were not sterilized by the lime. These plants were absent at Glosser Road, even though no herbicide was applied, probably because of frequent frosts and the lack of sludge incorporation into the soil. During the next year's growing season, an increase in insect concentration was noticed on the fields which had received lime stabilized sludge.

SECTION 7

SLUDGE DEWATERING CHARACTERISTICS

GENERAL

Farrell et al[7] have previously reported on the dewatering characteristics of ferric chloride and alum treated sludges which were subsequently treated with lime. Trubnick and Mueller[21] presented, in detail, the procedures to be followed in conditioning sludge for filtration, using lime with and without ferric chloride. Sontheimer[22] presented information on the improvements in sludge filterability produced by lime addition.

RESULTS OF LEBANON STUDIES

Laboratory scale dewatering studies were not conducted at Lebanon. Standard sand drying beds which were located at the wastewater treatment plant were used for sludge dewatering comparisons. Each bed was 9.2 m x 21.5 m (30' x 70'). For the study, one bed was partitioned to form two, each 4.6 m x 21.5 m (15' x 70'). Limed primary sludge was applied to one bed with limed anaerobically digested sludge being applied to the other side. A second full sized bed was used to dewater unlimed anaerobically digested sludge. The results of the study are summarized on Figure 16.

Lime stabilized sludges generally dewatered at a lower rate than well digested sludges. After ten days, lime stabilized primary sludge had dewatered to approximately 6.5% solids as opposed to 9% for lime stabilized anaerobically digested sludge, and 10% for untreated anaerobically digested sludge.

The anaerobically digested sludge cracked first and dried more rapidly than either of the lime stabilized sludges. Initially, both of the lime stabilized sludges matted, with the digested sludge cracking after approximately two weeks. The lime stabilized primary sludge did not crack which hindered drying and resulted in the lower percent solids values.

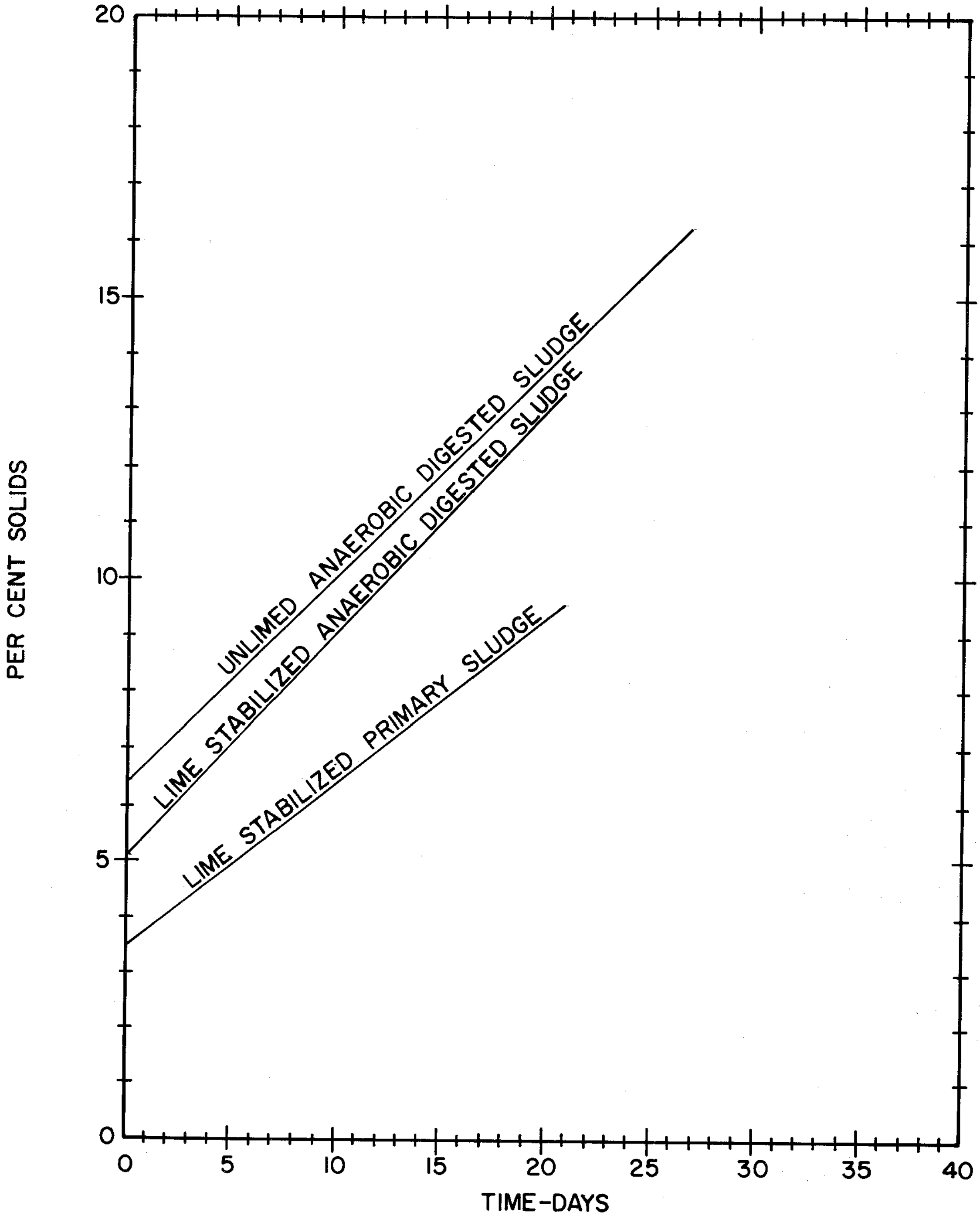

Figure 16. Dewatering Characteristics of Various Sludges on Sand Drying Beds

SECTION 8

ECONOMIC ANALYSIS

LEBANON FACILITIES

As previously described, the anaerobic sludge digestion facilities at Lebanon were essentially inoperable at the start of the lime stabilization project. Funds were allocated to construct lime stabilization facilities, as well as to rehabilitate the anaerobic digester. In both cases, the existing structures, equipment, etc., were utilized to the maximum extent possible. Table 30 includes the actual amounts paid to contractors, following competitive bidding, and does not include engineering fees, administrative costs, etc.

TABLE 30. ACTUAL COST OF DIGESTER REHABILITATION AND LIME STABILIZATION FACILITIES CONSTRUCTION

Anaerobic Digester Cleaning	
Cleaning contractor	$5,512.12
Temporary sludge lagoon	2,315.20
Lime for stabilizing digester contents	514.65
Temporary pump rental	300.30
Subtotal Digester Cleaning	$8,642.27
Anaerobic Digester Rehabilitation	
Electrical equipment, conduit, etc.	$1,055.56
Natural gas piping	968.76
Hot water boiler, piping, pump, heat exchanger repair	7,472.26
Control room rehabilitation	1,465.00
Sludge recirculating pump repair	771.00
Piping and valve rehabilitation	8,587.30
Floating cover roof repair	1,014.04
Repair utilities, drains	211.52
Miscellaneous	1,946.88
Subtotal Digester Rehabilitation	$23,492.32

(continued)

TABLE 30 (continued)

<u>Lime Stabilization Process</u>	
Electrical equipment, conduit, etc.	$1,692.00
3" & 4" sludge lines, supports, valves, and fittings	6,140.19
4" sludge crossover pipe, valves, and fittings	1,101.48
1 1/2" air line and diffusers	1,310.00
3/4" water lines and hose bibbs	865.00
Lime bin, auger, vibrators	7,229.44
Volumetric feeder, trough and gate	3,460.00
Existing pump repairs	3,399.00
Miscellaneous metal	1,200.00
Relocate sanitary service line	200.00
Repair utilities	134.00
Miscellaneous	934.34
Contractor's overhead	1,842.00
Subtotal Lime Stabilization	$29,507.45
<u>Septage Holding Tank</u>	
Septage holding tank and pump	$6,174.70
Subtotal Septage Holding Tank	$6,174.70
Total Cost for Digester Cleaning & Rehabilitation, Lime Stabilization, and Septage Facilities	$67,816.74

The cost of the lime stabilization facilities was $29,507.45 compared to $32,134.59 for cleaning and repair of the anaerobic sludge digester.

CAPITAL COST OF NEW FACILITIES

Capital and annual operation and maintenance costs for lime stabilization and anaerobic sludge digestion facilities were estimated assuming new construction as a part of a 3,785 cu m (1.0 MGD) wastewater treatment plant with primary clarification and single stage conventional activated sludge treatment processes.

The capital costs for lime stabilization facilities included a bulk lime storage bin for hydrated lime, auger, volumetric feeder and lime slurry tank, sludge mixing and thickening tank with a mechanical mixer, sludge grinder, all weather treatment building, electrical and instrumentation, interconnecting piping and transfer pumps, and 60 day detention treated sludge holding lagoon. The basis for design is as follows:

Daily primary sludge dry solids production	568 kg/day (1,250 lbs/day)
Average primary sludge volume @ 5% solids	11,015 l/day (2,910 gal/day)
Daily waste activated dry solids production	493 kg/day (1,084 lbs/day)
Average waste activated sludge volume @ 1.5% solids	32,470 l/day (8,580 gal/day)
Average lime dosage required per	0.20 kg/kg (0.20 lb/lb)
Daily lime requirement as $Ca(OH)_2$	216 kg/day (475 lb/day)
Treatment period	3 hrs/day
Bulk lime storage bin volume minimum	28 cu m (1,000 cu ft)
Bulk lime storage bin detention time	39 days
Lime feeder and slurry tank capacity (spared)	0.14-0.42 cu m/hr (5-15 cu ft/hr)
Influent sludge grinder capacity	757 l/min (200 gpm)
Sludge mixing tank volume	57 cu m (15,000 gal)
Sludge mixing tank dimensions	4.3 m x 4.3 m x 3 m (14'x14'x10' SWD)
Sludge mixer horsepower	15 HP
Sludge mixer turbine diameter	135 cm (53")
Turbine speed	68
Sludge transfer pump capacity (spared)	106 l/min (400 gpm)
Treated sludge percent solids	4%
Sludge holding lagoon volume	2,860 cu m (100,000 cu ft)
Sludge holding lagoon maximum detention time	60 days
Treatment building floor area	13.9 m^2 (150 ft^2)
Treatment building construction	Brick and block
Instrumentation:	pH record Treated sludge volume

Capital costs for the lime stabilization facilities were based on July 1, 1977 bid date, and were as follows:

Site work, earthwork & yard piping	$ 6,000
Lime storage bin and feeders	30,000
Treatment tank, pumps, sludge grinders, and building structure	52,000
Electrical and instrumentation	10,000
Sludge holding lagoon	20,000
Subtotal Construction Cost	$118,000
Engineering	12,000
Total Capital Cost	$130,000
Amortized cost @ 30 yrs., 7% int. (CRF = 0.081)	$ 10,500
Annual Capital Cost per unit feed dry solids	$ 24.65

Lime stabilization operation assumed one man, two hours per day, 365 days per year, at $6.50 per hour, including overhead. Maintenance labor and materials assumed 52 hours per year labor at $6.50 per hour and $800 per year for maintenance materials. The total quantity of 46.8% CaO hydrated lime required was 83 tons per year at $44.50 per ton.

The total annual cost for lime stabilization, excluding land application of treated sludge, has been summarized in Table 31.

TABLE 31. TOTAL ANNUAL COST FOR LIME STABILIZATION EXCLUDING LAND DISPOSAL FOR A 3,785 CU M/DAY PLANT

Item	Total Annual Cost	Annual Cost Per kkg Dry Solids	Annual Cost Per Ton Dry Solids
Operating labor	$ 4,700	$12.14	$11.03
Maintenance labor and materials	1,100	2.84	2.58
Lime	6,200	16.02	14.55
Laboratory	500	1.29	1.17
Capital	10,500	27.11	24.65
Total Annual Cost	$23,000	$59.40	$53.98

The basis for design of a single stage anaerobic sludge digester for the same treatment plant was as follows:

Daily primary sludge dry solids production	568 kg/day (1,250 lb/day)
Average primary sludge volume @ 5% solids	11,015 l/day (2,910 gal/day)
Daily waste activated dry solids production	493 kg/day (1,084 lb/day)
Average waste activated sludge volume @ 1.5% solids	32,470 l/day (8,580 gal/day)
Daily volatile solids production	743 kg/day (1,634 lb/day)
Volatile solids loading	0.81 kg/cu m/day (0.05 lb VSS/ft^3/ day)
Digester hydraulic detention time	21 days
Digester gas production	0.37 cu m/lb VSS feed (13 cu ft/lb VSS feed)
Average volatile solids reduction	50%
Digested sludge dry solids production	689 kg/day (1,515 lb/day)
Digested sludge percent solids	6%
Digester net heat requirement	186,000 BTU/hr
Mechanical mixer horsepower	15 HP
Sludge recirculation pumps (spared)	1,234 l/min ea. (350 gpm ea.)

Capital cost for the anaerobic sludge digestion facilities, including the control building, structure, floating cover, heat exchanger, gas safety equipment, pumps, and interconnecting piping, assuming July 1, 1977 bid date, and engineering, legal, and administrative costs is as follows:

Site work, earthwork, yard piping	$ 44,000
Digester	233,000
Control building	133,000
Electrical and instrumentation	47,000
Subtotal Construction Cost	$457,000
Engineering	46,000
Total Capital Cost	$503,000
Amortized cost @ 30 yrs, 7% int. (CRF = 0.081)	$ 40,700
Annual Capital Cost per unit feed dry solids	$ 95.54

Digester operation assumed one man, one hour per day, 365 days per year at $6.50 per hour, including overhead. Maintenance labor and material assumed 52 hours per year at $6.50 per hour and $1,500 per year for maintenance materials.

The cost of anaerobic digester operation was offset by assuming a value of $2.10 per million BTU for all digester gas produced above the net digester heat requirement.

The total annual cost for anaerobic sludge digestion, excluding land application has been summarized in Table 32.

TABLE 32. TOTAL ANNUAL COST FOR SINGLE STAGE ANAEROBIC SLUDGE DIGESTION EXCLUDING LAND DISPOSAL FOR A 3,785 CU M/DAY PLANT

Item	Total Annual Cost	Annual Cost Per kkg Dry Solids	Annual Cost Per Ton Dry Solids
Operating labor	$ 2,400	$ 6.20	$ 5.63
Maintenance labor and materials	1,800	4.65	4.23
Laboratory	500	1.29	1.17
Capital	40,700	105.09	95.54
Fuel credit	(2,900)	(7.49)	(6.81)
Total Annual Cost	$42,500	$109.74	$99.76

Both the lime stabilization and anaerobic digestion alternatives were assumed to utilize land application of treated sludge as a liquid hauled by truck. The capital cost for a sludge hauling vehicle was assumed to be $35,000, which was depreciated on a straight line basis over a ten year period. Alternatively, a small treatment plant could utilize an existing vehicle which could be converted for land application at a somewhat lower capital cost.

The assumed hauling distance was three to five miles, round trip. Hauling time assumed 10 minutes to fill, 15 minutes to empty, and 10 minutes driving, or a total of 35 minutes per round trip. The truck volume was assumed to be 5,680 liters (1,500 gal) per load. The cost of truck operations, excluding the driver and depreciation, were assumed to be $8.50 per operating hour. The truck driver labor rate was assumed to be $6.50 per hour, including overhead.

Truck operation time was based on hauling an average of 1,812 l (6,860 gal) of lime stabilized sludge, i.e., five loads and 777 l (2,940 gal) of anaerobically digested sludge, i.e., two loads per day. The reduced volume of anaerobically digested sludge resulted from the volatile solids reduction during digestion and the higher solids concentration compared to lime stabilized sludge.

Although it may be possible to obtain the use of farmland at no cost, e.g., on a voluntary basis, the land application economic analysis assumed that land would be purchased at a cost of $750 per acre. Sludge application rates were assumed to be ten dry tons per acre per year. Land costs were amortized at 7% interest over a 30 year period.

To offset the land cost, a fertilizer credit of $7.30 per ton of dry sludge solids was assumed. This rate was arbitrarily assumed to be 50% of the value published by Brown(14) based on medium fertilizer market value and low fertilizer content. The reduction was made to reflect resistance to accepting sludge as fertilizer. The land cost was further offset by assuming a return of $50 per acre, either as profit after farming expenses, or as the rental value of the land.

Capital and annual operation and maintenance costs for land application of lime stabilized and anaerobically digested sludges have been summarized in Table 33.

For each item in Table 33, the total annual cost was calculated and divided by the total raw primary plus waste activated sludge quantity, i.e., 387 kkg/year (426 tons/year). Anaerobically digested sludge land requirements were less than for lime stabilized sludge because of the volatile solids reduction during digestion. Truck driving and operation costs were similarly less for digested sludge because of the volatile solids reduction and more concentrated sludge (6% vs. 4%) which would be hauled. Fertilizer credit was less for digested sludge because of the lower amount of dry solids applied to the land. Land credit was based on the amount of sludge applied and was, therefore, less for digested sludge.

The total annual capital and annual operation and maintenance costs for lime stabilization and single stage anaerobic sludge digestion, including land application for a 3,785 cu m/day wastewater treatment plant, are summarized in Table 34.

TABLE 33. ANNUAL COST FOR LAND APPLICATION OF LIME STABILIZED AND ANAEROBICALLY DIGESTED SLUDGES FOR A 3,785 CU M/DAY PLANT

Item	Lime Stabilization Total Annual Cost	Lime Stabilization Annual Cost Per Kkg Solids	Lime Stabilization Annual Cost Per Ton Solids	Anaerobic Digestion Total Annual Cost	Anaerobic Digestion Annual Cost Per Kkg Solids	Anaerobic Digestion Annual Cost Per Ton Solids
Amortized cost of land	$ 2,600	$ 6.75	$ 6.14	$1,700	$ 4.39	$ 3.99
Truck depreciation	3,500	9.04	8.22	3,500	9.04	8.22
Truck driver	7,100	18.35	16.67	2,800	7.24	6.57
Truck operation	9,300	24.03	21.83	3,600	9.30	8.45
Laboratory	500	1.29	1.17	500	1.29	1.17
Fertilizer credit	(3,100)	(8.05)	(7.30)	(2,000)	(8.05)	(7.30)
Land credit	(2,200)	(5.68)	(5.16)	(1,400)	(3.62)	(3.29)
Total Annual Cost	$17,700	$45.73	$41.57	$8,700	$19.59	$17.81

TABLE 34. COMPARISON OF TOTAL ANNUAL CAPITAL AND ANNUAL O&M COST FOR LIME STABILIZATION AND ANAEROBIC DIGESTION INCLUDING LAND DISPOSAL FOR A 3,785 CU M/DAY PLANT

	Lime Stabilization		Anaerobic Digestion	
	Total Annual O&M Cost	Annual Cost Per Kkg Dry Solids	Total Annual O&M Cost	Annual Cost Per Kkg Dry Solids
Facilities	$23,000	$59.40	$42,500	$109.74
Land application	17,700	45.70	8,700	19.59
Total Annual Cost	$40,700	$105.10	$51,200	$129.33

SECTION 9

LIME STABILIZATION DESIGN CONSIDERATIONS

OVERALL DESIGN CONCEPTS

Lime and sludge are two of the most difficult materials to transfer, meter, and treat in any wastewater treatment plant. For these reasons, design of stabilization facilities should emphasize simplicity, straightforward piping layout, ample space for operation and maintenance of equipment, and gravity flow wherever possible. Lime transport should be by auger with the slurry or slaking operations occurring at the point of use. Lime slurry pumping should be avoided with transport being by gravity in open channels. Sludge flow to the tank truck and/or temporary holding lagoon should also be by gravity if possible.

Figures 17, 18, and 19 show conceptual designs for lime stabilization facilities at wastewater treatment facilities with 3,785; 18,925; and 37,850 cu m/day (1, 5 and 10 MGD) throughputs. The 3,785 cu m/day (1 MGD) plant, as shown on Figure 17, utilizes hydrated lime and a simple batch mixing tank, with capability to treat all sludges in less than one shift per day. Treated sludge could be allowed to settle for several hours before hauling in order to thicken, and thereby reduce the volume hauled. Alternately, the sludge holding lagoon could be used for thickening.

Figure 18 shows the conceptual design for lime stabilization facilities of an 18,925 cu m/day (5 MGD) wastewater treatment facility. Pebble lime is utilized in this installation. Two sludge mixing tanks are provided, each with the capacity to treat the total sludge production from two shifts. During the remaining shift, sludge could be thickened and hauled to the land disposal site. Alternately, the temporary sludge lagoon could be used for sludge thickening.

Figure 19 shows the conceptual design for lime stabilization facilities of a 37,850 cu m/day (10 MGD) wastewater treatment plant. A continuous lime treatment tank with two hours detention time is used to raise the sludge pH to 12. A separate sludge thickening tank is provided to increase the treated sludge solids content before land application. Sludge transport is assumed to be by pipeline to the land disposal site. A

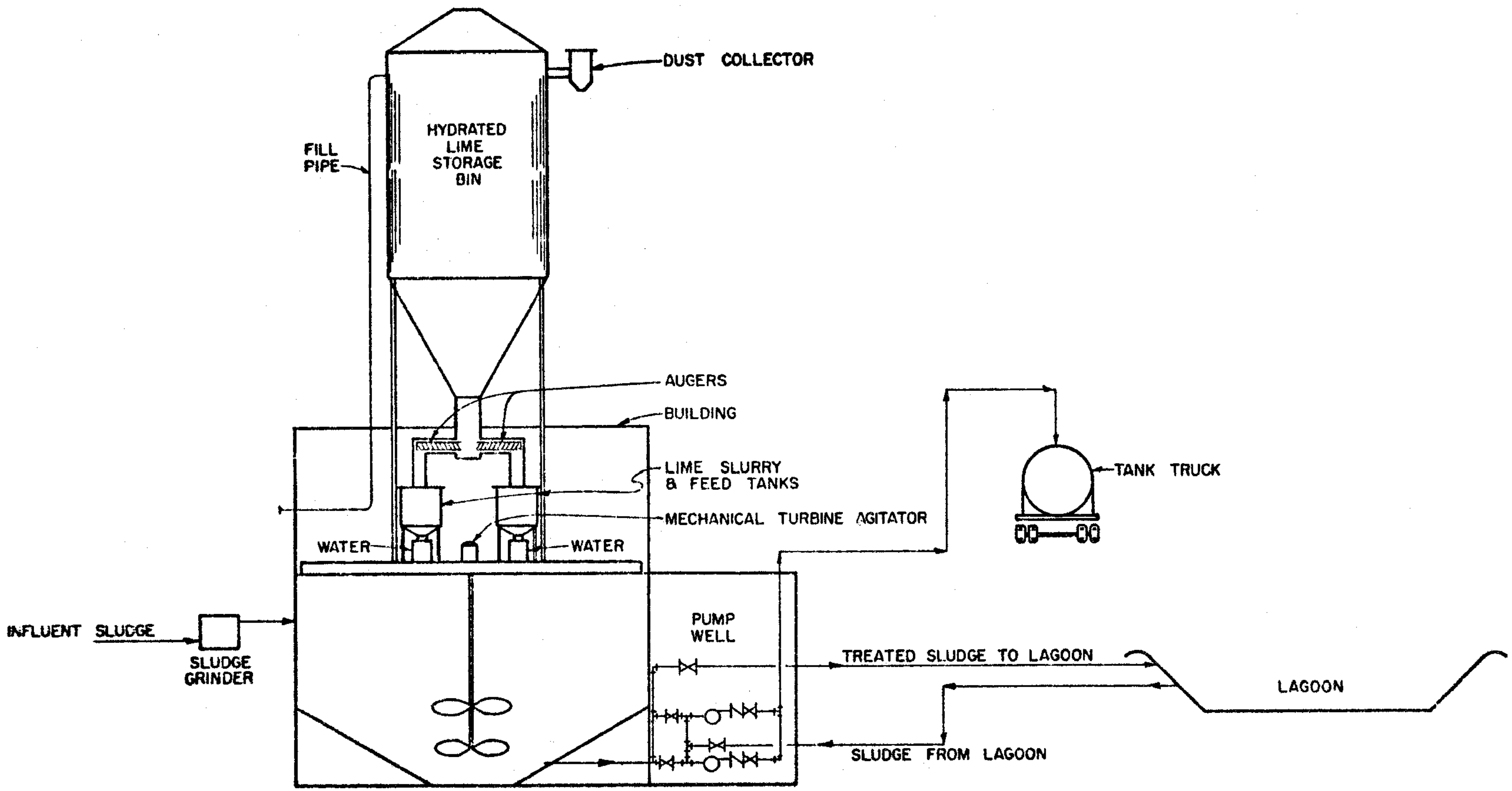

Figure 17. Conceptual Design For Lime Stabilization Facilities For A 3,785 cu. meter/day Treatment Plant

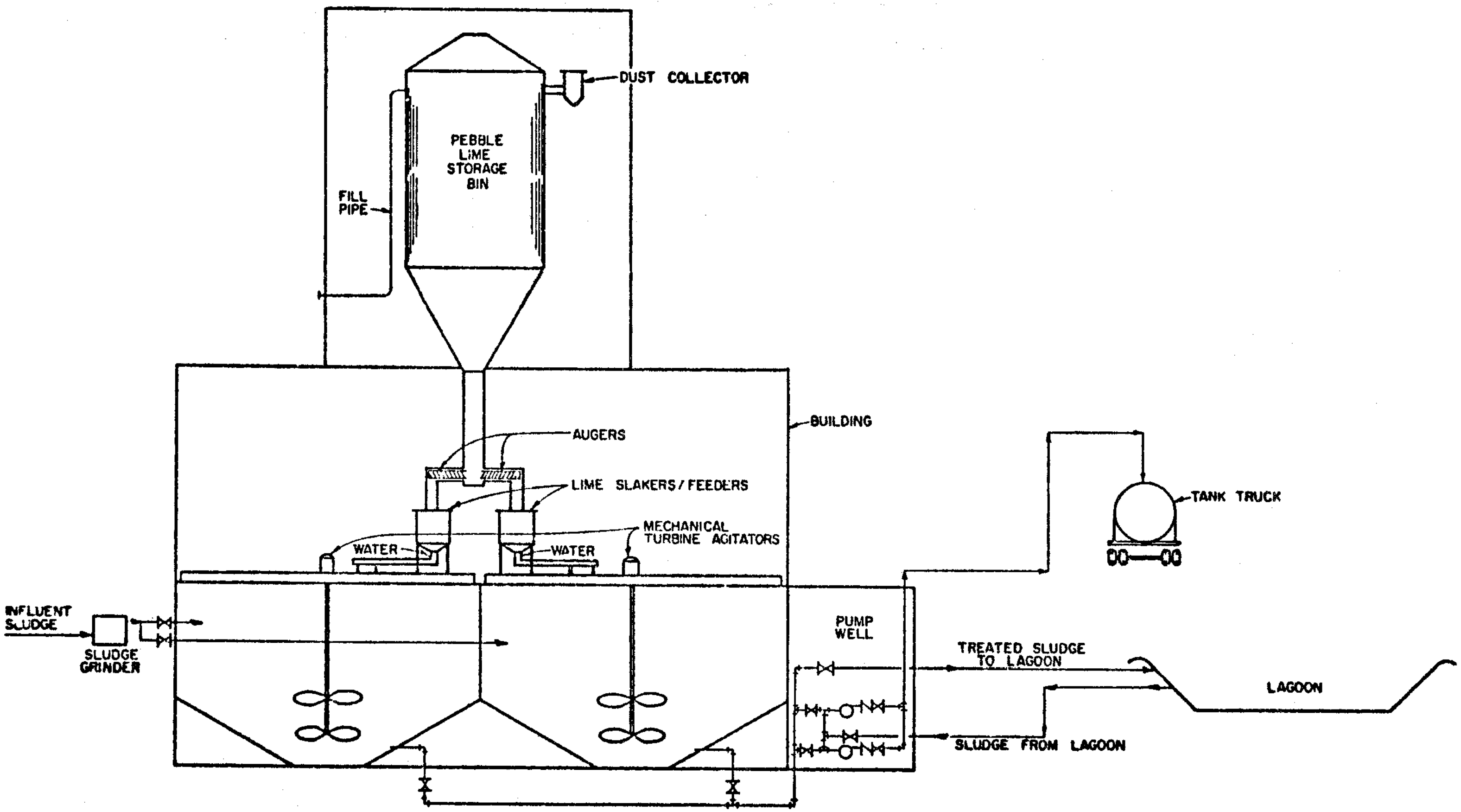

Figure 18. Conceptual Design For Lime Stabilization Facilities For An 18,925 cu. meter/day Treatment Plant

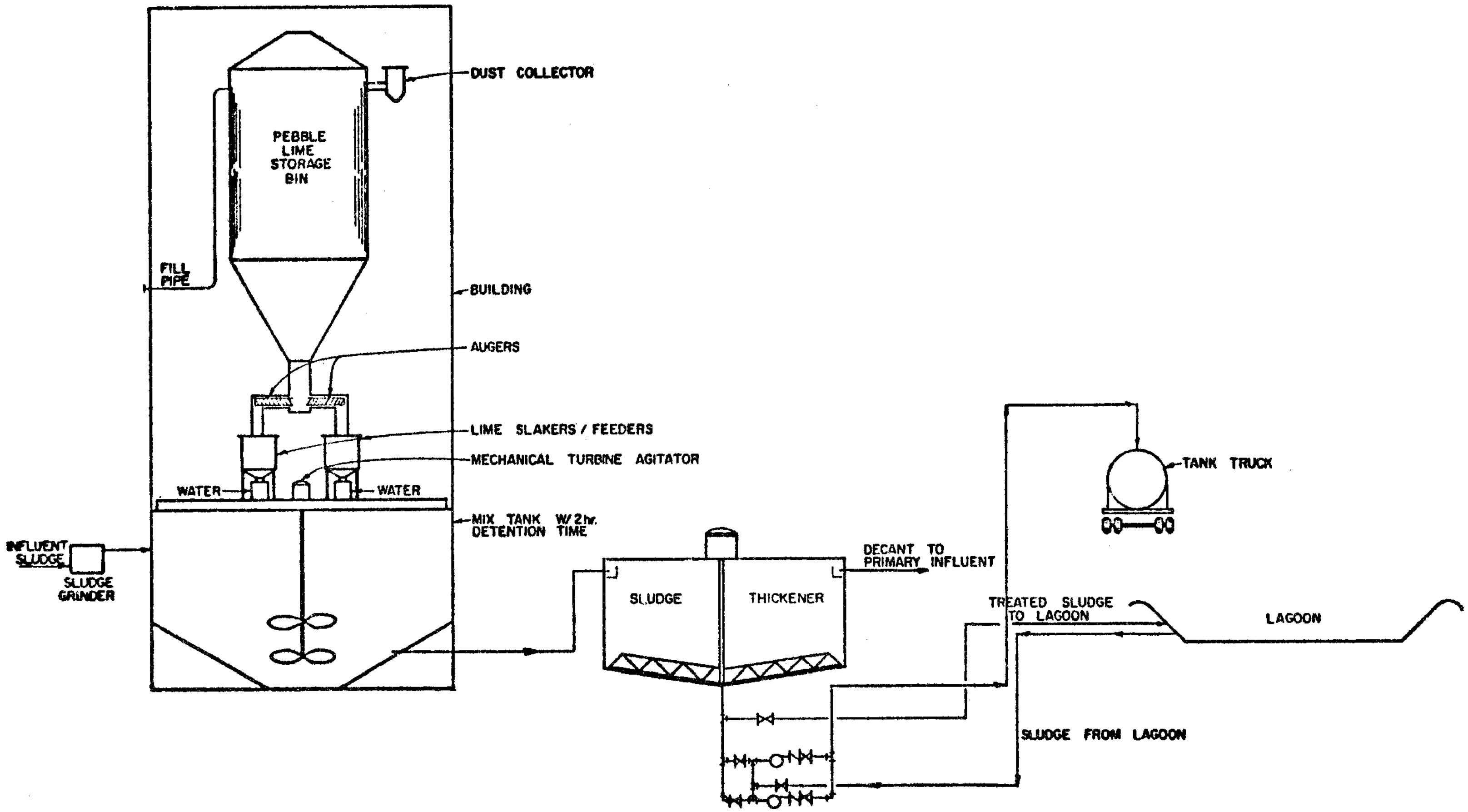

Figure 19. Conceptual Design For Lime Stabilization Facilities For A 37,850 cu. meter/day Treatment Plant

temporary sludge holding lagoon was assumed to be necessary, and would also be located at the land disposal site.

LIME REQUIREMENTS

The quantity of lime which will be required to raise the pH of municipal wastewater sludges to pH greater than 12 can be estimated from the data presented in Table 11 and from Figures 4-8. Generally, the lime requirements for primary and/or waste activated sludge will be in the range of 0.1 to 0.3 Kg per Kg (lb per lb) of dry sludge solids. Laboratory jar testing can confirm the dosage required for existing sludges.

TYPES OF LIME AVAILABLE

Lime in its various forms, as quicklime and hydrated lime, is the principal, lowest cost alkali. Lime is a general term, and is unfortunately often used indiscriminately. Lime, by strict definition, only embraces burned forms of lime - quicklime, hydrated lime, and hydraulic lime. The two forms of particular interest to lime stabilization, however, are quicklime and hydrated lime. Not included are carbonates (limestone or precipitated calcium carbonate) that are occasionally but erroneously referred to as "lime."[24]

Quicklime

Quicklime is the product resulting from the calcination of limestone and to a lesser extent shell. It consists primarily of the oxides of calcium and magnesium. On the basis of their chemical analyses, quicklimes may be divided into three classes:

1. High calcium quicklime - containing less than 5% magnesium oxide, 85-90% CaO

2. Magnesium quicklime - containing 5 to 35% magnesium oxide, 60-90% CaO

3. Dolomitic quicklime - containing 35 to 40% magnesium oxide, 55-60% CaO

The magnesium quicklime is relatively rare in the United States and, while available in a few localities, is not generally obtainable.

Quicklime is available in a number of more or less standard sizes, as follows:

1. Lump lime - the product with a maximum size of 20.3 cm (8") in diameter down to 5.1 cm (2") to 7.6 cm (3") produced in vertical kilns.

2. Crushed or pebble lime - the most common form, which ranges in size from about 5.1 to 0.6 cm (2" to 1/4"), produced in most kiln types.

3. Granular lime - the product obtained from Fluo-Solids kilns that has a particulate size range of 100% passing a #8 sieve and 100% retained on a #80 sieve (a dustless product).

4. Ground lime - the product resulting from grinding the larger sized material and/or passing off the fine size. A typical size is substantially all passing a #8 sieve and 40 to 60% passing a #100 sieve.

5. Pulverized lime - the product resulting from a more intense grinding that is used to produce ground lime. A typical size is substantially all passing a #20 sieve and 85 to 95% passing a #100 sieve.

6. Pelletized lime - the product made by compressing quicklime fines into about one inch size pellets or briquettes.

Hydrated Lime

As defined by the American Society for Testing and Materials, hydrated lime is: "A dry powder obtained by treating quicklime with water enough to satisfy its chemical affinity for water under the conditions of its hydration."

The chemical composition of hydrated lime generally reflects the composition of the quicklime from which it is derived. A high calcium quicklime will produce a high calcium hydrated lime obtaining 72% to 74% calcium oxide and 23% to 24% water in chemical combination with the calcium oxide. A dolomitic quicklime will produce a dolomitic hydrate. Under normal hydrating conditions, the calcium oxide fraction of the dolomitic quicklime completely hydrates, but generally only a small portion of the magnesium oxide hydrates (about 5 to 20%). The composition of a normal dolomitic hydrate will be 46% to 48% calcium oxide, 33% to 34% magnesium oxide, and 15% to 17% water in chemical combination with the calcium oxide. (With some soft-burned dolomitic quicklimes, 20% to 50% of the MgO will hydrate.)

A "special" or pressure hydrated dolomitic lime is also available. This lime has almost all (more than 92%) of the magnesium oxide hydrated; hence, its water content is higher and its oxide content lower than the normal dolomitic hydrate.

Hydrated lime is packed in paper bags weighing 23 kg (50 lb) net; however, it is also shipped in bulk.

Quicklime is obtainable in either bulk carloads or tanker trucks or in 36.3 kg (80 lb) multiwall paper bags. Lump, crushed, pebble, or pelletized lime, because of the large particle sizes, are rarely handled in bags and are almost universally shipped in bulk. The finer sizes of quicklime, ground, granular, and pulverized, are readily handled in either bulk or bags.

LIME STORAGE AND FEEDING

Depending on the type of lime, storage and feeding can be either in bag or bulk. For small or intermittent applications, bagged lime will probably be more economical. In new facilities, bulk storage will probably be cost effective. Storage facilities should be constructed such that dry lime is conveyed to the point of use and then mixed or slaked. Generally, augers are best for transporting either hydrated or pebble lime. Auger runs should be horizontal or not exceeding an incline of 30°.

The feeder facilities, i.e., dry feeder and slaking or slurry tank, should be located adjacent to the stabilization mixing tank such that lime slurry can flow by gravity in open channel troughs to the point of mixing. Pumping lime slurry should be avoided. Slurry transfer distances should be kept to a minimum. Access to feeder, slaker and/or slurry equipment should be adequate for easy disassembly and maintenance.

MIXING

Lime/sludge mixtures can be mixed either with mechanical mixers or with diffused air. The level of agitation should be great enough to keep sludge solids suspended and dispense the lime slurry evenly and rapidly. The principal difference between the resultant lime stabilized sludges in both cases is that ammonia will be stripped from the sludge with diffused air mixing. Mechanical mixing has been used by previous researchers for lime stabilization but only on the pilot scale.

With diffused air mixing, adequate ventilation should be provided to dissipate odors generated during mixing and stabilization. Coarse bubble diffusers should be used with air supplies in the range of 150-250 cu m/min per 1,000 cu m (150-250 cfm per 1,000 cu ft) of mixing tank volume. Diffusers should be mounted such that a spiral roll is established in the mixing tank away from the point of lime slurry application. Diffusers should be accessible and piping should be kept against the tank wall to minimize the collection of rags, etc. Adequate piping support should be provided.

With the design of mechanical mixers, the bulk velocity (defined as the turbine agitator pumping capacity divided by the cross sectional area of the mixing vessel) should be in the range of 4.6 to 7.9 m/min (15 to 26 fpm). Impeller Reynolds Numbers should exceed 1,000 in order to achieve a constant power number.[25] The mixer should be specified according to the standard motor horsepower and AGMA gear ratios in order to be commercially available.

For convenience, Table 35 was completed which shows a series of tank and mixer combinations which should be adequate for mixing sludges up to 10% dry solids, a range of viscosity, and Reynolds number combinations which were as follows:

Max. Reynolds number 10,000 @ 100 cp sludge viscosity
Max. Reynolds number 1,000 @ 1,000 cp sludge viscosity

TABLE 35. MIXER SPECIFICATIONS FOR SLUDGE SLURRIES

Tank Size, liters	Tank Diameter, meters	Prime Mover, HP/ Shaft Speed, rpm	Turbine Diameter, centimeters
18,925	2.9	7.5/125	81
		5/84	97
		3/56	109
56,775	4.2	20/100	114
		15/68	135
		10/45	160
		7.5/37	170
113,550	5.3	40/84	145
		30/68	155
		25/56	168
		20/37	206
283,875	7.2	100/100	157
		75/68	188
		60/56	201
		50/45	221
378,599	8.0	125/84	183
		100/68	198
		75/45	239

Table 35 can be used to select a mixer horsepower and standard AGMA gear combination depending on the volume of sludge to be stabilized. For example, for a 18,925 l (5,000 gal) tank, any of the mixer-turbine combinations should provide adequate mixing. Increasing turbine diameter and decreasing shaft speed results in a decrease in horsepower as shown.

Additional assumptions were that the bulk fluid velocity must exceed 7.9 m/min (26 ft/min), impeller Reynolds number must exceed 1,000, and that power requirements range from 0.5 to 1.5 HP per 3,785 l (0.5-1.5 HP/1,000 gal) is necessary. The mixing tank configuration assumed that the liquid depth equals tank diameter and that baffles with a width of 1/12 the tank diameter were placed at 90° spacing. Mixing theory and equations which were used were after Badger[25], Hicks[26] and Fair.[27]

RAW AND TREATED SLUDGE PIPING, PUMPS, AND GRINDER

Sludge piping design should include allowances for increased friction losses due to the non-Newtonian properties of sludge. Friction loss calculations should be based on treated sludge solids concentrations and should allow for thickening in the mixing tank after stabilization. Pipelines should not be less than 5.08 cm (2 in) in diameter and should have tees in major runs at each change in direction to permit rodding, cleaning, and flushing the lines. Adequate drains should be provided. If a source of high pressure water is available (either nonpotable or noncross-connected potable), it can be used to flush and clean lines.

Spare pumps should be provided and mounted such that they can be disassembled easily. Pump impeller type and materials of construction should be adequate for the sludge solids concentration and pH.

Sludge grinding equipment should be used to make the raw sludge homogenous. Sticks, rags, plastic, etc., will be broken up prior to lime stabilization to improve the sludge mixing and flow characteristics and to eliminate unsightly conditions at the land disposal site.

REFERENCES

1. Riehl, M. L. et al, "Effect of Lime Treated Water on Survival of Bacteria," Journal American Water Works Assn., 44,466 (1952).

2. Grabow, W.O.K. et al, "The Bactericidal Effect of Lime Flocculation Flotation as a Primary Unit Process in a Multiple System for the Advanced Purification of Sewage Works Effluent," Water Resources 3, 943 (1969).

3. Buzzell, J. C., Jr., and Sawyer, C. N., "Removal of Algal Nutrients from Raw Wastewater with Lime," Journal WPCF, 39, R16, 1967.

4. "How Safe is Sludge?" Compost Science 10 March-April 1970.

5. Kempelmacher, E. H. and Van Noorle Jansen, L. M., "Reduction of Bacteria in Sludge Treatment," Journal WPCF 44, 309 (1972).

6. Evans, S. C., "Sludge Treatment at Luton," Journal Indust. Sewage Purification 5, 381, 1961.

7. Farrell, J. B., Smith, J. E., Hathaway, S. W., "Lime Stabilization of Primary Sludges," Journal Water Pollution Control Federation, Vol. 46, No. 1, January 1974, pp 113-122.

8. Paulsrud, B. and Eikum, A. S., "Lime Stabilization of Sewage Sludges," Norwegian Institute for Water Research Volume 9, pp 297-305, 1975.

9. Counts, C. A., Shuckrow, A. J., "Lime Stabilized Sludge: Its Stability and Effect on Agricultural Land," EPA-670/2-75-012, April 1975.

10. Noland, R. F., Edwards, J. D., "Stabilization and Disinfection of Wastewater Treatment Plant Sludges," USEPA Technology Transfer Design Seminar Handout, May 1977.

11. USEPA, "Methods for Chemical Analysis of Wastes," USEPA, Cincinnati, Ohio, 1974.

12. Standard Methods for Examination of Water and Wastewater, 13th & 14th Editions, AWWA, APHA, WPCF, American Public Health Association, Washington, D.C.

13. "Enumeration of Salmonella and Pseudomonas aeruginosa," Journal WPCF, Vol #46, No. 9, Sept. 1974, pp 2163-2171.

14. Brown, R. E. et al, "Ohio Guide for Land Application of Sewage Sludge," Ohio Agricultural Research and Development Center, Wooster, Ohio, 1976.

15. Sommers, L. E., "Principles of Land Application of Sewage Sludge," USEPA Technology Transfer Design Seminar Handout, May 1977.

16. Sommers, L. E., et al, "Variable Nature of Chemical Composition of Sewage Sludges," Journal of Environmental Quality 5:303-306.

17. Stern, Gerald, "Reducing the Infection Potential of Sludge Disposal."

18. U. S. Environmental Protection Agency, "Process Design Manual for Sludge Treatment and Disposal," USEPA Technology Transfer, Oct., 1974.

19. U. S. Environmental Protection Agency, "Municipal Sludge Management: Environmental Factors," Federal Register, Vol. No. 41, No. 108, p. 22533.

20. Zenz, D. R., Lynam, B. T., et al, "USEPA Guidelines on Sludge Utilization and Disposal - A Review of Its Impact Upon Municipal Wastewater Treatment Agencies," presented at the 48th Annual WPCF Conference, Miami Beach, Fla., 1975.

21. Trubnick, E. H., Mueller, P. K., "Sludge Dewatering Practice," Sewage and Industrial Wastes 30, 1364 (1958).

22. Sontheimer, H., "Effects of Sludge Conditioning with Lime on Dewatering," Proc. 3rd Int'l Conference, Water Pollution Research, Munich, 1966, in Advances in Water Pollution Research.

23. "Application of Sewage Sludge to Cropland: Appraisal of Potential Hazards of the Heavy Metals to Plants and Animals," Council for Agricultural Science and Technology Report No. 64, Iowa State University.

24. National Lime Association, "Lime Handling Application and Storage in Treatment Processes Bulletin 213," National Lime Assoc., Washington, D.C., pp 1-3.

25. Badger and Banchero, "Introduction to Chemical Engineering," page 614, McGraw-Hill, 1955.

26. Hicks, R. W. et al, "How to Design Agitators for Desired Process Response," Chemical Engineering, April 26, 1976, pp 103-106 ff.

27. Fair, G. M. and Geyer, J. C., "Water Supply and Wastewater Disposal," John Wiley & Sons, New York, 1956.

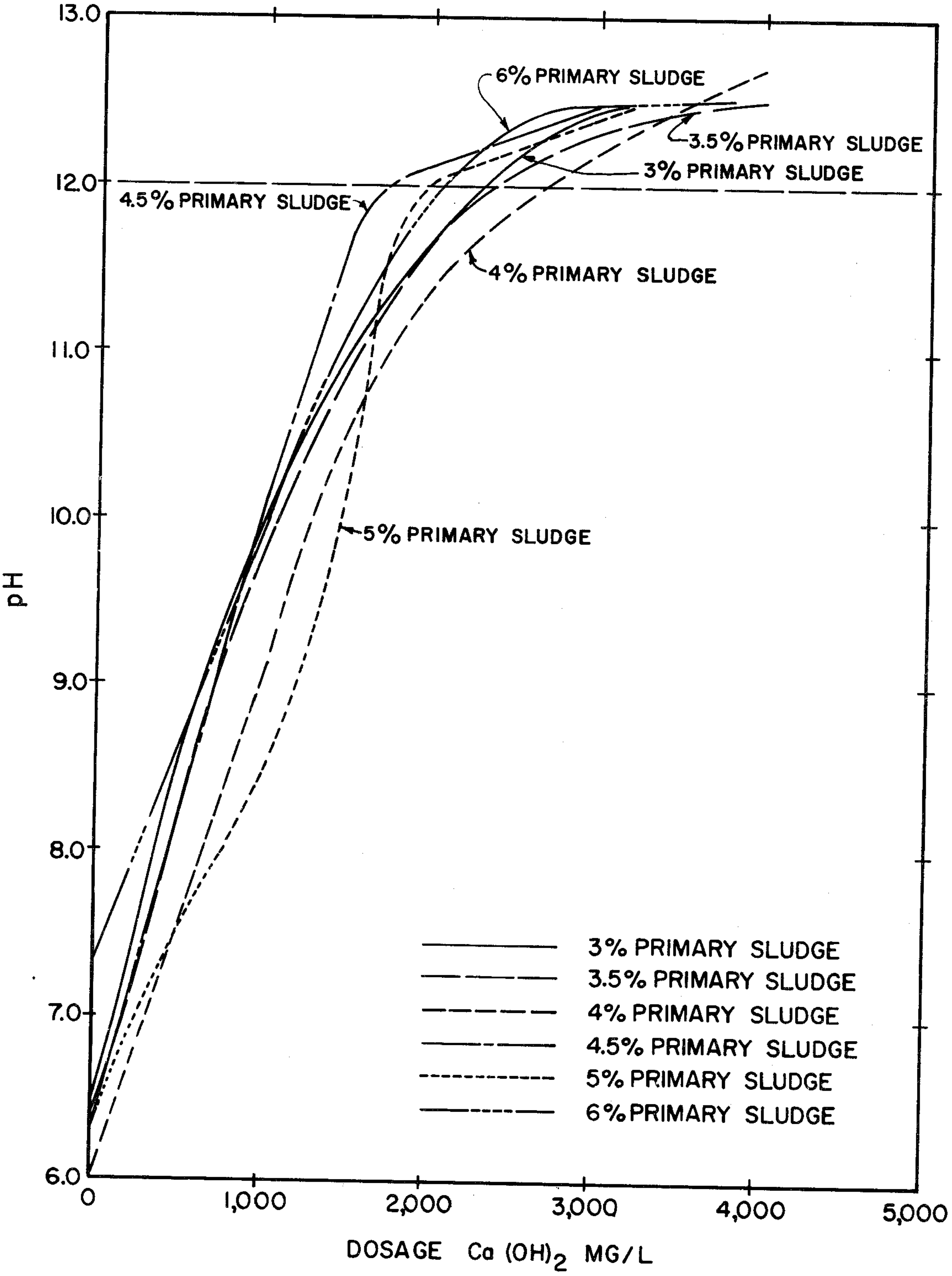

Figure 5. Lime Dosage vs pH Primary Sludge

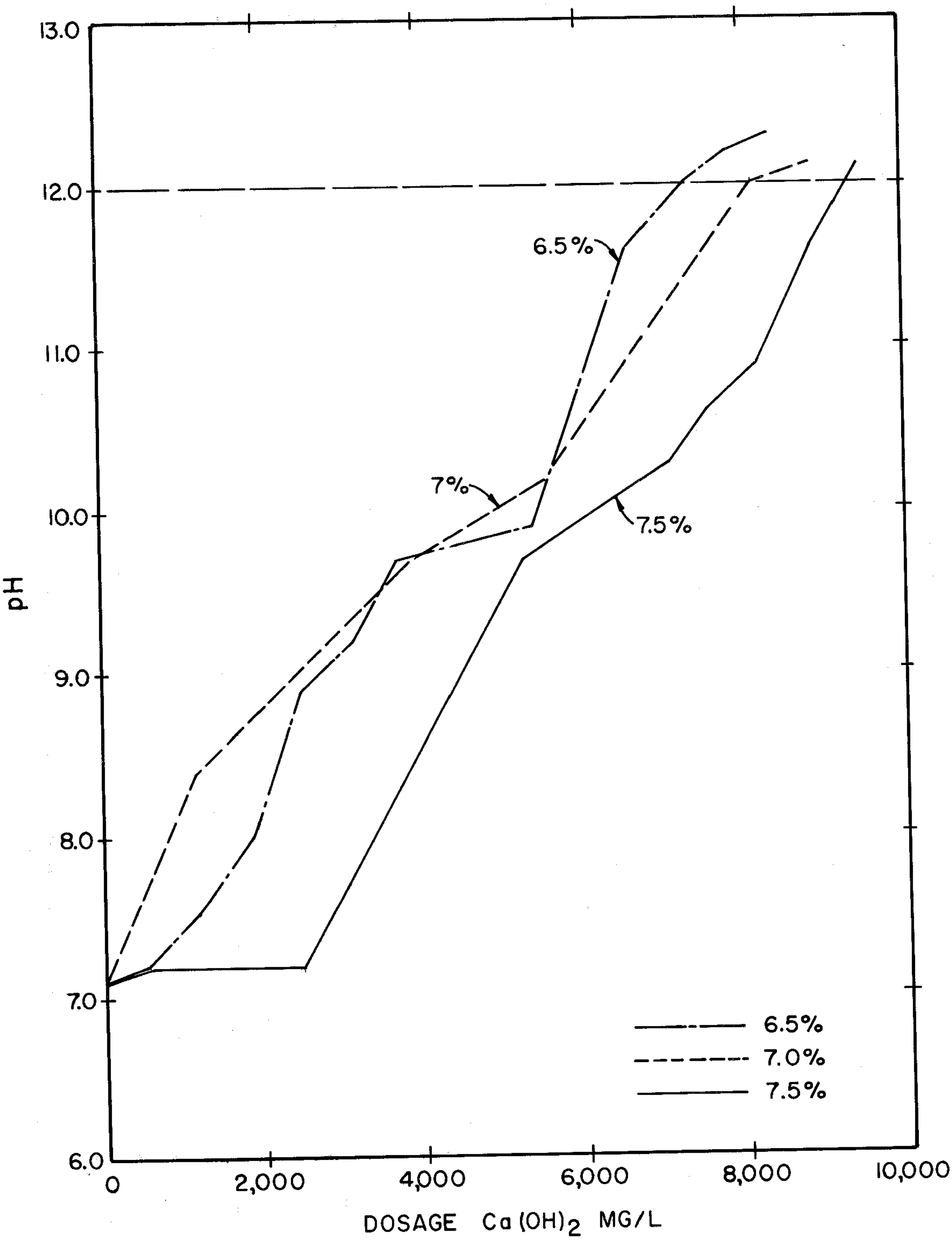

Figure 6. Lime Dosage vs pH Anaerobic Digested Sludge

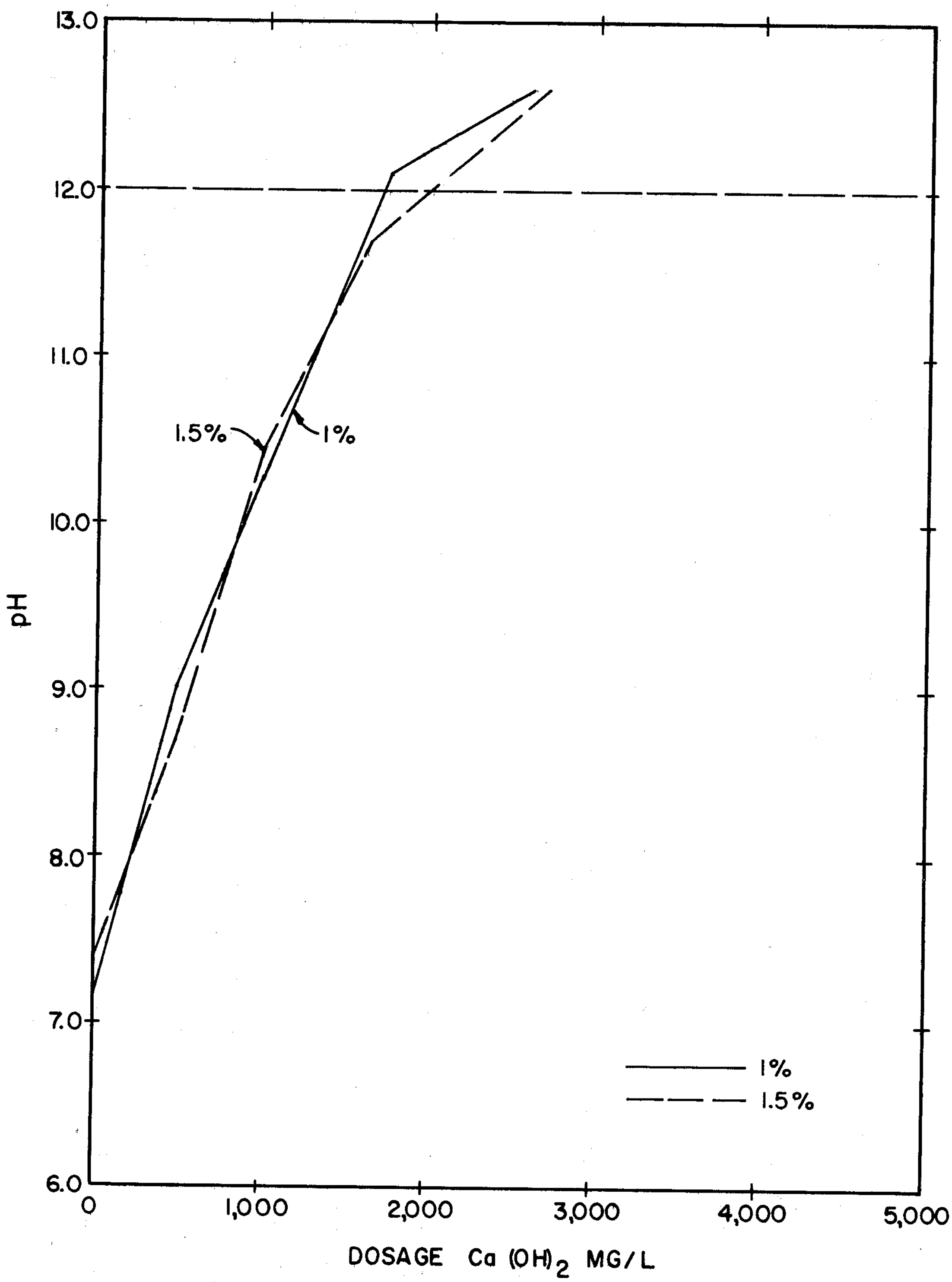

Figure 7. Lime Dosage vs pH Waste Activated Sludge

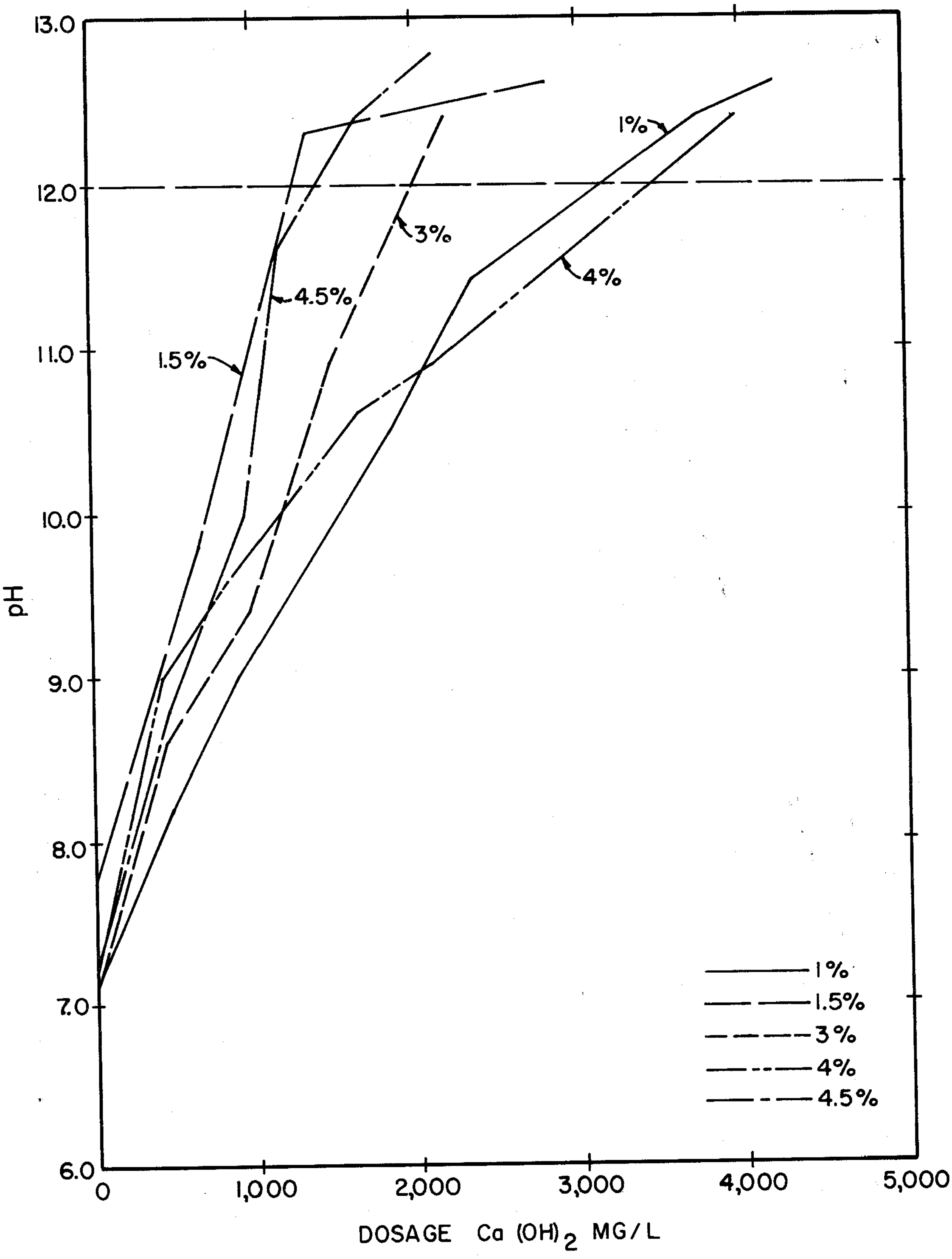

Figure 8. Lime Dosage vs pH Septage

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16. ABSTRACT

The project objective was to demonstrate and evaluate the feasibility, economics, and benefits of stabilizing primary, waste activated, septic, and anaerobically digested sludges by lime addition. The project confirmed the findings of previous laboratory and pilot scale tests and focused on the application of lime stabilization and land disposal techniques to a wastewater treatment plant operating in the range of 3,785 to 5,675 cu m/day (1.0 to 1.5 MGD).

Emphasis was placed on the chemical, bacterial, and pathological properties of raw, lime stabilized and anaerobically digested sludges. The effects of long-term storage on the chemical and bacterial characteristics of lime stabilized sludges were determined. Ultimate disposal of all lime stabilized sludges was accomplished by spreading as a liquid on agricultural land and on controlled test plots.

Lime stabilized sludges had negligible odor, minimum potential for pathogen regrowth and were suitable for application to farmland. Pathogen concentrations in lime stabilized sludges were 10-1,000 times lower than for comparable anaerobically digested sludges.

17. KEY WORDS AND DOCUMENT ANALYSIS

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