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Environmental Protection Technology Series

SEWAGE SLUDGE ENTRENCHMENT SYSTEM FOR USE BY SMALL MUNICIPALITIES

Municipal Environmental Research Laboratory
Office of Research and Development
U.S. Environmental Protection Agency
Cincinnati, Ohio 45268

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SEWAGE SLUDGE ENTRENCHMENT SYSTEM FOR USE BY SMALL MUNICIPALITIES

by

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This study was conducted
in cooperation with
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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 natural 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 economical methods of disposing of sludges produced by small wastewater treatment plants is an important environmental need. This report describes a method of incorporating sludge below the surface soil with conventional agricultural or light construction equipment.

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Director
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ABSTRACT

An economical method was developed and is described by which smaller municipalities can entrench dewatered sewage sludge (15-25% solids). By this method, 3 to 48 tons of freshly dewatered sewage sludge per day can be entrenched without problems of odor or surface water runoff. Equipment and personnel include a tractor/loader/backhoe, dump or concrete mixer trucks, and machine operators and truck drivers. Trenches are dug 60 cm wide x 60 cm deep x 60 cm apart (2 x 2 x 2 ft). The actual incorporation time for 12 tons of dewatered sludge at the entrenchment site is one hour. The estimated hired cost of sludge incorporation, including equipment, personnel and hauling 32 km (20 miles) each way, and drainage, monitoring and final land cultivation is less than $15.00 per dewatered ton. This estimate does not include land cost.

Sites, having previously been entrenched with sludge, can be retrenched with sludge when previously entrenched sludge has dewatered sufficiently. Minimal time after initial entrenchment is 2 years.

Liming sludge prior to dewatering and entrenchment is recommended to reduce the potential for metals moving through soils and becoming more available to plants. Trenching is not appropriate in some prime agricultural land because of the subsoil brought to the surface and the relatively large amount of heavy metals being applied. Entrenchment is most appropriate when sludges cannot otherwise be land spread because, in comparison to lower-rate surface application procedures, entrenchment is a resource-wasteful practice with potential for pollution of groundwater by nitrate nitrogen leaching.

The Agricultural Research Service has conducted this research demonstration study in cooperation with the Environmental Protection Agency during FY 1975 under Interagency Agreement No. EPA-IAG-D4-0510.

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SECTION 1

INTRODUCTION

Entrenchment is a feasible method for simultaneously disposing of dewatered sewage sludge (15-25% solids) and improving marginal land for plant growth (7, 8). Trenching is an appropriate system to use when surface application of sludge at fertilizer rates is not feasible, e.g., with metal-polluted, malodorous or undigested sewage sludge, when sufficient land and an alternative like composting is not available or during inclement weather. The trenching system was originally developed for use by large municipalities. The procedure involved use of large equipment, considerable site preparation and extensive monitoring. Its major constraint apparently was the possible contamination of surface and underground water with nitrate nitrogen.

The Agricultural Research Service (ARS) and the U. S. Environmental Protection Agency (EPA) jointly initiated a research demonstration study to develop a trenching system for use by small municipalities (4,000-100,000 population yielding 3 to 48 dewatered tons of sludge per day). The close cooperation of the Maryland Environmental Service and of the District of Columbia was also inherent in this work. These two groups have been using large-scale trenching as a means of sewage sludge disposal, and they are maintaining a continuing interest in studies on this procedure. The goal for this trenching system was that it be clean, safe, efficient, operable under essentially all weather conditions and of reasonable cost. For general applicability, a trenching system must work with different sludge types, soil textures, soil drainage conditions and should utilize readily available equipment.

The cooperative research between ARS and EPA was performed under Interagency Agreement No. EPA-IAG-D4-0510.

SECTION 2

CONCLUSIONS

Sewage sludge entrenchment is an economical method by which small municipalities can dispose of their solid residues from wastewater treatment. A method is described for entrenching 3 to 48 tons per day of freshly dewatered sludge (15-25% solids) without problems of odor, surface water runoff or ground and surface water pollution. Trenches are dug 60 cm wide x 60 cm deep x 60 cm apart and entrenched sludge is covered with soil to an average depth of 30 cm using a tractor/loader/backhoe. Sludges were hauled successfully in dump trucks (1.5 to 9.2 m^3 capacity) or in concrete mixer trucks (8.4 m^3 capacity) and easily transferred to trenches by the tractor/loader/backhoe or directly, respectively.

Costs were estimated for trenching sludge based upon actual experiences during the Beltsville pilot study. Costs for trenching 12 to 48 dewatered tons of sludge per day, assuming a 32 km haul distance each way, were estimated to be under $15.00 per dewatered ton (not including land costs) whether hauling and entrenchment was accomplished on a rental or purchase-self-operation basis. About 50% of the $15.00 cost was estimated to be for hauling and about 10% for draining the area where necessary, monitoring, leveling and reseeding after entrenchment. Estimated costs for a 3 ton per day operation were considerably higher because times were figured on an estimated minimum unit basis, rather than on the much shorter times actually required for the operations. If arrangements could be made for use of equipment and personnel more nearly based upon the actual operation time, costs for a 3 dewatered tons of sludge per day operation would also be about $15.00 per dewatered ton.

Sites, having previously been entrenched with sludge, can be retrenched with sludge when previously entrenched sludge has dewatered sufficiently. Minimal time after initial entrenchment is 2 years.

Entrenchment of raw and anaerobically digested sewage sludge was done successfully under all summer and winter weather conditions encountered in Beltsville by careful selection of soil types, drainage where necessary (needed only under special high water table conditions) and use of proper equipment. Temporary storage of sludge when raining or snowing would be a desirable backup.

Anaerobic digestion of these solid residues is not necessary for entrenchment, but an addition of lime, handling promptly in a fresh state and other suitable conditioning and handling is desirable to prevent possible odor problems during hauling and handling prior to covering with soil.

Liming sludge in soil prior to dewatering and entrenchment also helps keep heavy metals more immobilized and less available to plants.

Monitoring of a sludge entrenchment site should be the minimum necessary to detect potential harmful effects in the environment. Monitoring data should be readily available and acted upon when it warns that additional steps are needed to minimize environmental degredation. A simplified monitoring program is recommended.

SECTION 3

RECOMMENDATIONS

Entrenchment of sewage sludge is recommended for use when surface application is not feasible, e.g., with metal-polluted, malodorous or undigested sewage sludge, when sufficient land or an alternative like composting is not available or during inclement weather.

Entrenchment of sludge in prime agricultural land should be avoided because the surface soil becomes buried during the process by an approximate 30 cm layer of a subsoil-surface soil mixture.

Liming of sludges just prior to dewatering and entrenchment is recommended to reduce the potential for problems with odor, to reduce levels of pathogens and to reduce the potential for heavy metals moving through the soil and becoming more available to plants.

Various studies since 1971 all tend to indicate the feasibility of trenching as an appropriate method for sludge disposal. Nonetheless, considerable reduction in costs could be realized as a result of additional studies on the fate, with time after entrenchment, of sludge-borne nitrogen, heavy metals and virus. If the potential hazards from these sludge components were shown to be less of a problem than they are now considered, less monitoring, liming and backup would likely be required and sludge entrenchment rates could perhaps be increased.

It is recommended, therefore, that the above studies be continued which were anticipated when this procedural study was conducted. Variables were included during entrenchment for this purpose. Both digested and undigested sludges were placed in trenches with and without lime added at time of dewatering at various heights above the groundwater table. (Digestion and liming affect pathogen survival, metal availability and movement, and the form and amount of nitrogen; and closeness of the entrenched sludge to the groundwater table directly affects rate of sludge decomposition and thereby indirectly affects the fates of sludge-borne nitrogen, metals and pathogens.) Some sludges were seeded with virus, prior to dewatering, so that their fate could be followed (to be reported elsewhere).

While trace organics (possibly present in entrenched sludges) are not believed to pose a hazard, there have been no studies specifically on their fate, and we recommend that such studies be conducted.

SECTION 4

SLUDGES, SITES AND EQUIPMENT

SLUDGES

Raw and anaerobically digested sludges were chosen for the trenching study as described in Table 1. These sludges were representative of types that small municipalities might entrench. The dewatered sludges were a combination of primary and waste-activated sludges obtained from the Blue Plains Wastewater Treatment Plant which serves the Metropolitan Washington, D.C. area. Lime (CaO) was also added to some of the digested and undigested (raw) sludges. The sludges were all dewatered. Previous work indicated that sludges with less than about 10-12% solids were too fluid for proper entrenchment (8). Sludges with somewhat greater solids content may also be too fluid, depending upon the topography.

SITES

Six different areas were chosen for the entrenchment studies (Figure 1A-H). These areas contained soils that would require different handling during sludge entrenchment. Two of the areas also contained previously entrenched sludges. Determinations were made of the ease of handling the entrenchment procedure in some of the different soil types under different weather conditions and with different equipment. Characteristics of the soils in the different areas are given in Table 2. Recommended considerations for selecting a sludge entrenchment site can be obtained from the Soil Conservation Service and the literature (2-4, 6-8).

EQUIPMENT

Ordinary readily available equipment was used in the research demonstration studies. The tractor/loader/backhoe (TLB) machines and a number of different trucks used are listed in Table 3. The experiences, using these machines, are described in a later section.

TABLE 1. SLUDGE PROPERTIES

Sludge type	Date	Dewatered metric tons	% solids	pH	metric tons dry solids	kg/100 kg sludge solids Lime	$FeCl_3$	Polymer
Digested low	12-20-74	10.4	24.5	5.9	2.5	0	3.9	0.08
	1-2-75	9.9	26.4	6.1	2.6	0	3.4	0.08
	1-8-75	18.7	24.8	5.8	4.6	0	3.6	0.07
	1-9-75	17.9	23.0	5.6	4.1	0	4.8	0.10
	1-17-75	15.6	21.9	6.2	3.4	0	3.9	0.09
	1-24-75	3.4	22.7	5.9	0.8	0	4.2	0.09
	2-11-75	25.5	23.8	6.1	6.1	0	3.9	0.07
	2-13-75	11.8	25.5	6.1	3.0	0	3.8	0.07
	2-14-75	14.3	23.1	6.1	3.3	0	4.0	0.07
	2-19-75	21.4	26.4	6.3	5.6	0	3.9	0.08
	4-22-75	17.7	24.6	5.8	4.4	0	3.6	0.10
	7-16-75	17.9	21.1	6.2	3.8	7.3	3.2	2.90*
Digested high	2-4-75	42.6	24.7	8.1	10.5	0.5	4.1	0.09
	12-5-75	43.5	21.2	12.1	9.2	14.6	4.2	1.97*
Raw low	3-5-75	17.9	23.1	6.3	4.1	4.1	2.9	0.06
	3-6-75	27.4	24.4	5.9	6.7	0	1.3	0.05
	5-9-75	19.5	23.2	10.0	4.5	5.1	2.2	0.17

(continued)

TABLE 1. (continued)

Sludge type	Date	Dewatered metric tons	% solids	pH	metric tons dry solids	kg/100 kg sludge solids		
						Lime	$FeCl_3$	Polymer
Raw high	2-7-75	10.5	21.3	11.8	2.2	38	2.4	0.12
	2-11-75	8.8	26.0	12.1	2.3	14	1.0	0.20
	2-13-75	9.1	21.0	12.2	1.9	18	1.5	0.20
	2-14-75	1.5	26.0	12.1	0.4	17	1.0	0.19
	2-19-75	8.9	28.0	12.0	2.5	18	1.0	0.16
	2-20-75	16.1	26.0	12.3	4.2	25	2.2	0.26
	2-21-75	9.0	30.0	11.9	2.7	12	0.9	0.13
	2-24-75	9.1	27.8	11.9	2.5	15	1.6	0.21
	2-25-75	26.6	22.1	12.1	5.9	17	5.0	0.25
	2-28-75	9.4	21.8	7.3	2.0	17	0.7	0.07
	3-4-75	16.7	25.0	9.3	4.2	10	1.2	0.10
	3-19-75	23.2	24.1	9.6	5.6	7.3	2.3	0.10
	3-27-75	8.0	23.2	11.5	1.9	24	3.7	0.24
	6-18-75	6.6	19.4	12.1	1.3	2.8	1.9	0.10*
	6-24-75	24.7	23.0	8.9	5.7	8.8	2.6	3.48*
	6-25-75	23.7	23.7	8.3	5.6	8.2	1.9	2.40*
	6-30-75	24.4	23.1	11.3	5.6	5.9	2.2	2.23*
	7-12-75	7.8	24.0	11.5	1.9	8.1	2.6	1.47*

* The amount of polymer used is higher because of a switch to a less concentrated type.

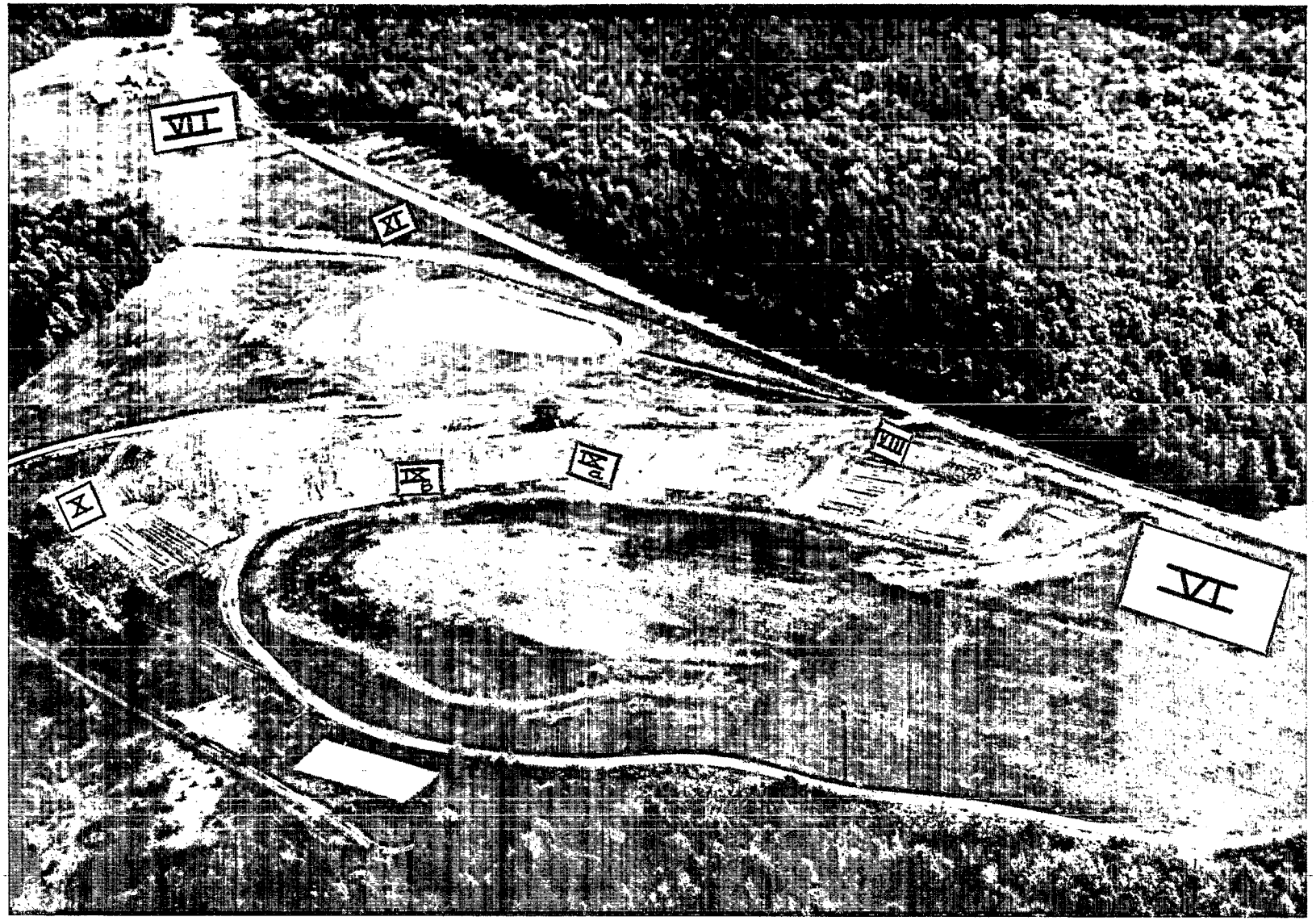

Figure 1. Location and details of plots receiving different sludges in different soil types.
A. Aerial photo overview of entire plot area showing individual plot locations VI to XI.

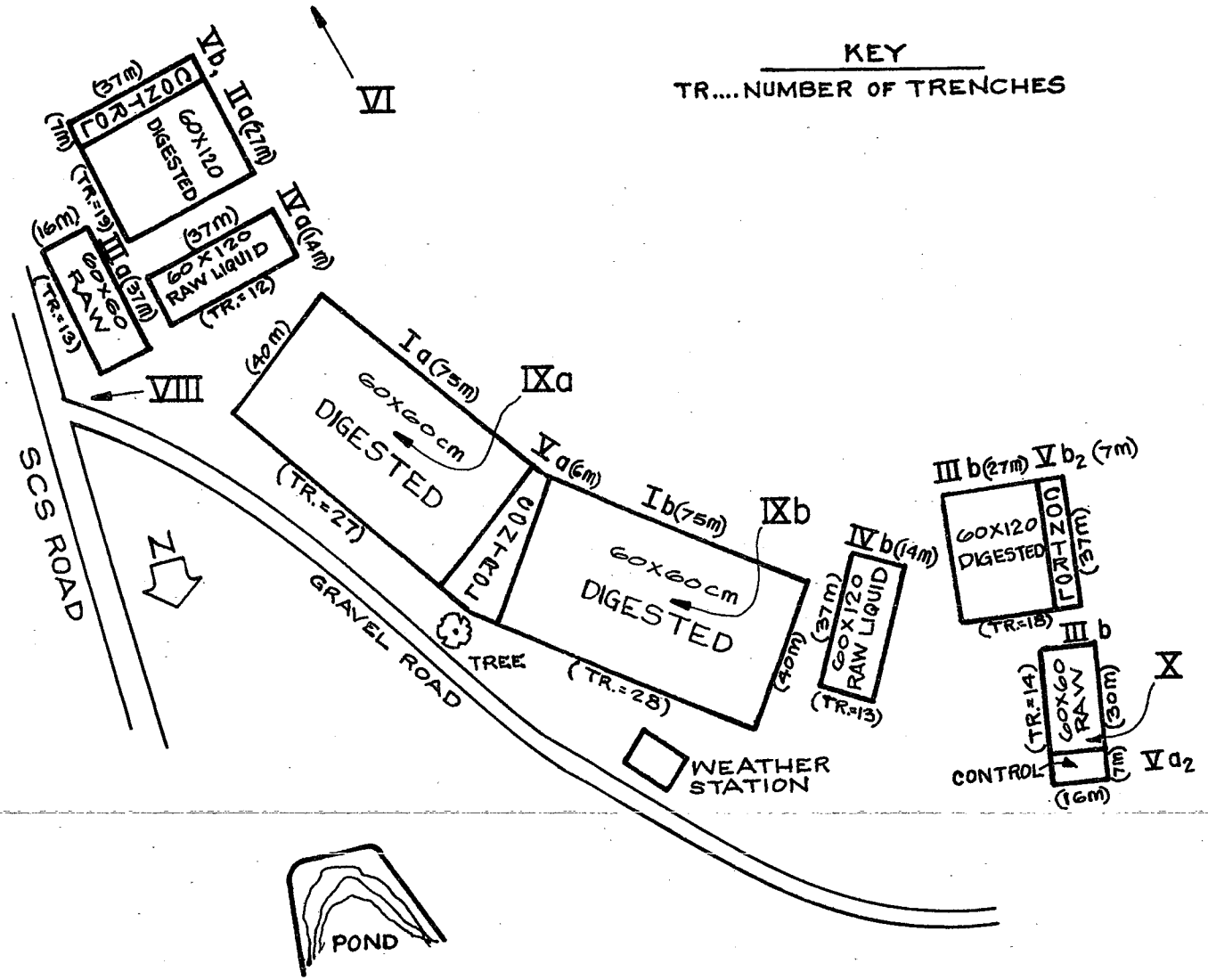

Figure 1. Location and details of plots receiving different sludges in different soil types.
B. Schematic of previously entrenched area showing old plots I to V and their relationship to new entrenchment plots VI, VIII, IX and X.

Key to Figure IC, Plot VI

Trench* spacing	Sludge type	Date	Hauling equip.	Metric tons Wet wt.	pH	% solids	Rep. + trenchs
60-120-120	Raw high-lime	2-20-75	Mixer	8.90	12.24	24.79	I A + B
		2-20-75	Dump	8.05	12.28	26.64	I C + D
		2-21-75	Dump	9.03	11.94	23.14	II C + D
		2-25-75	Mixer	9.07	11.98	24.56	II A + B
		2-25-75	Mixer	9.16	12.16	25.35	III A + B
		2-25-75	Dump	9.31	12.16	26.13	III C + D
		2-25-75	Mixer	9.01	12.16	25.35	IV C + D
		3-3-75	Mixer	9.38	7.38	24.41	IV A + B
		3-4-75	Mixer	8.25	9.67	22.56	V A + B
		3-4-75	Mixer	8.45	9.00	23.79	V C + D
60-60-60	Raw low-lime	3-5-75	Mixer	8.84	6.21	21.64	I ABCD
		3-5-75	Mixer	9.08	6.31	22.51	II ABCD
		3-6-75	Mixer	7.67	6.20	22.38	III ABCD
		3-6-75	Mixer	7.75	5.68	20.44	IV ABCD
		3-6-75	Mixer	9.27	5.74	20.35	V ABCD
60-60-60	Raw high-lime	2-7-75	Mixer	10.54	11.83	22.62	I ABCD + II D
		2-11-75	Mixer	9.20	12.12	24.41	II ABC + III D
		2-13-75	Mixer	9.08	12.23	26.48	III ABC + IV D
		2-19-75	Mixer	8.88	12.02	24.20	IV ABC + V D
		3-27-75	Mixer	6.93	11.54	24.51	V ABC

(continued)

Key to Figure 1C, Plot VI, (continued).

Trench* spacing	Sludge type	Date	Hauling equip.	Metric Tons Wet wt.	pH	% solids	Rep. + trenchs
30-60-60	Raw high-lime	3-18-75	Dump	8.82	7.69	23.31	I ABCD + II D
		3-18-75	Dump	5.47	9.46	22.41	III ABC
		3-19-75	Dump	8.91	10.60	22.26	III ABCD + IV D
		3-27-75	Dump	8.37	11.54	24.56	IV ABCD + V D
		3-27-75	Dump	6.37	11.47	24.24	V ABC
60-60-60	Digested high-lime	2-4-75	Dump	42.7**	7.54	24.12	I ABCD
		2-4-75	Dump		8.52	26.11	II ABCD
		2-4-75	Dump		8.92	27.25	III ABCD
		2-4-75	Dump		7.87	24.63	IV ABCD
		2-4-75	Dump		7.77	24.17	V ABCD
60-60-60	Digested low-lime	12-20-74	Dump	8.93	5.91	24.21	I ABCD
		1-2-75	Dump	8.93	6.16	23.65	II ABCD
		1-8-75	Dump	8.46	5.82	23.43	III ABCD
		1-17-75	Dump	8.24	6.28	24.86	IV ABCD
		1-24-75	Dump	6.35	5.92	26.70	V ABCD+*
	Virus Study Plot						
60-60-60	Raw low-lime	5-9-75	Dump	7.30	5.65	24.90	I ABCD
	Digested high-lime	5-9-75	Dump	8.27	6.25	25.25	II ABCD

* Cm wide x cm deep x cm edge to edge spacing between trenches.
** Did not have proper notes to assign individual weights to each replicate.
+* Short trenches about 3 meters long.

PLOT VI

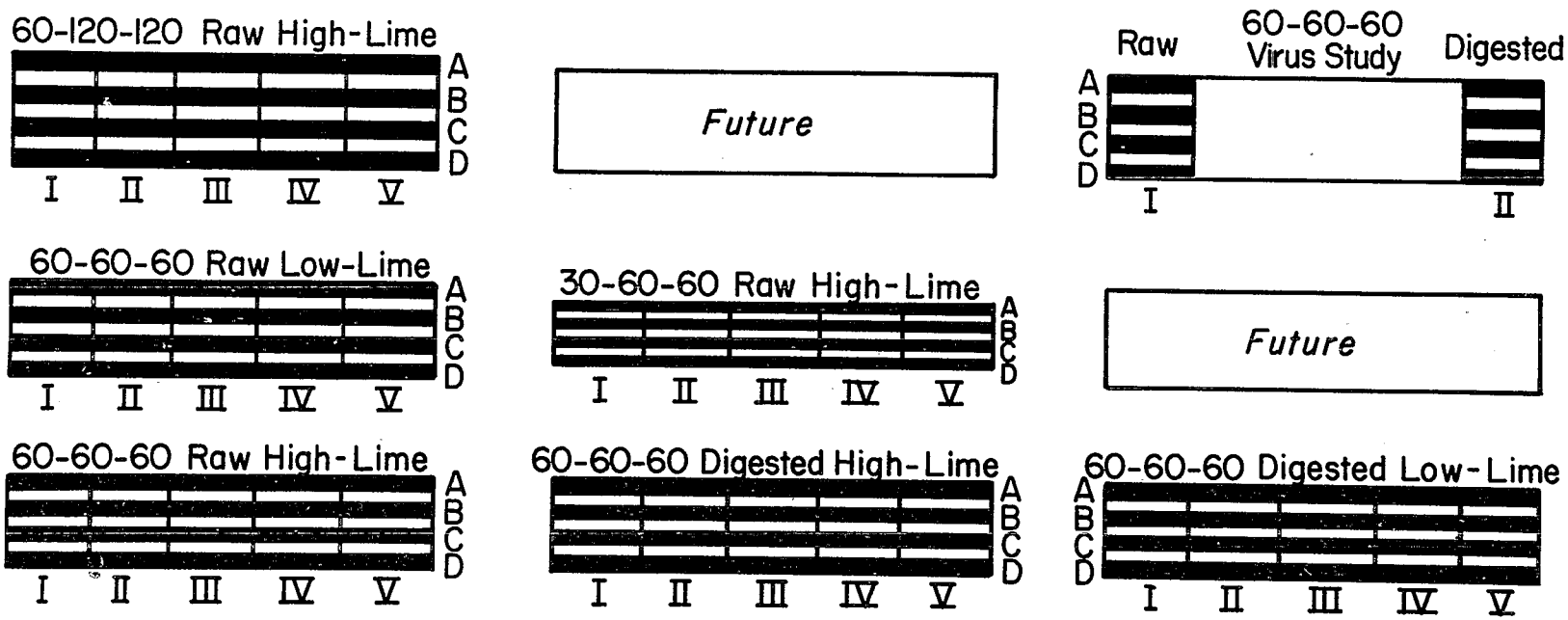

Figure 1. Location and details of plots receiving different sludges in different soil types.
C. Details of plot VI showing sludge placement in loamy sand.

Key to Figure 1D, Plot VII

Trench* spacing	Sludge type	Date	Hauling equip.	Metric tons Wet wt.	pH**	% solids	Rep. + Trenchs
60-60-60	Raw high-lime	6-24-75	Dump	8.58	8.64	23.65	III ABCD
		6-24-75	Dump	8.16	8.91	22.17	IV ABCD
		6-24-75	Dump	7.95	8.99	23.14	V ABCD
		6-25-75	Dump	7.59	7.96	23.42	I ABCD
		6-25-75	Dump	7.46	9.07	23.71	II ABCD
60-60-60	Digested high-lime	12-5-75	Mixer	9.46	12.43	20.81	I ABCD + ½II A
		12-5-75	Mixer	8.58	12.43	19.66	½II A + BCD + ½III A
		12-5-75	Mixer	9.07	12.42	21.88	½III A + BCD+* + IV A + ¼B
		12-5-75	Mixer	10.47	12.42	22.72	¾IV B + CD + V AB
		12-5-75	Mixer	5.89	12.42	20.70	V CD
60-60-60	Digested low-lime	7-10-75	Dump	8.89	6.18	21.29	V ABCD
		7-10-75	Dump	9.03	6.26	21.07	IV ABCD
	Virus Study Plot						
60-60-60	Raw low-lime	5-9-75	Dump	7.62	6.74	24.52	II ABCD
	Digested low-lime	5-9-75	Dump	8.08	6.23	26.27	I ABCD

* Cm wide x cm apart x cm edge to edge spacing between trenches.
** Low pH because $FeCl_3$ was added after the lime was added.
+* Trench collapsed before filling.

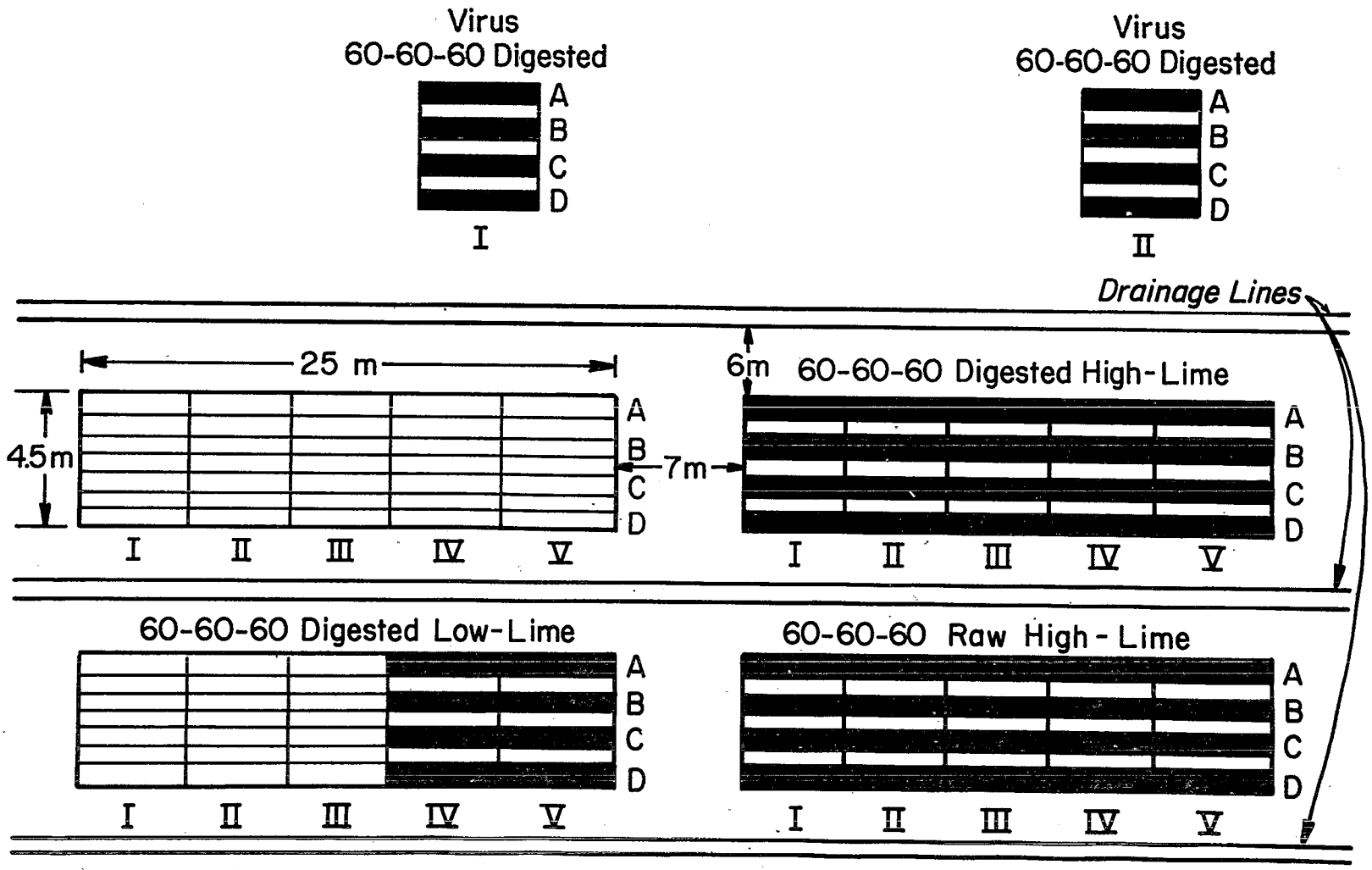

Figure 1. Location and details of plots receiving different sludges in different soil types.
D. Details of plot VII showing sludge placement in fine loamy sand (clay near surface) with drainage.

Key to Figure 1E, Plot VIII

Trench* spacing	Sludge type	Date	Hauling equip.	Metric tons Wet wt.	pH	% solids	Rep. + trenchs
60-60-60	Digested low-lime	1-8-75	Dump	9.41	5.81	23.52	I ABCD
		1-[illegible]	Dump	8.91	5.44	25.61	II ABCD
		1-9-7[illegible]	Dump	9.00	5.92	25.87	III ABCD
		1-17-75	Dump	8.39	6.21	24.98	IV ABCD

* Cm wide x cm deep x cm edge to edge spacing between trenches.

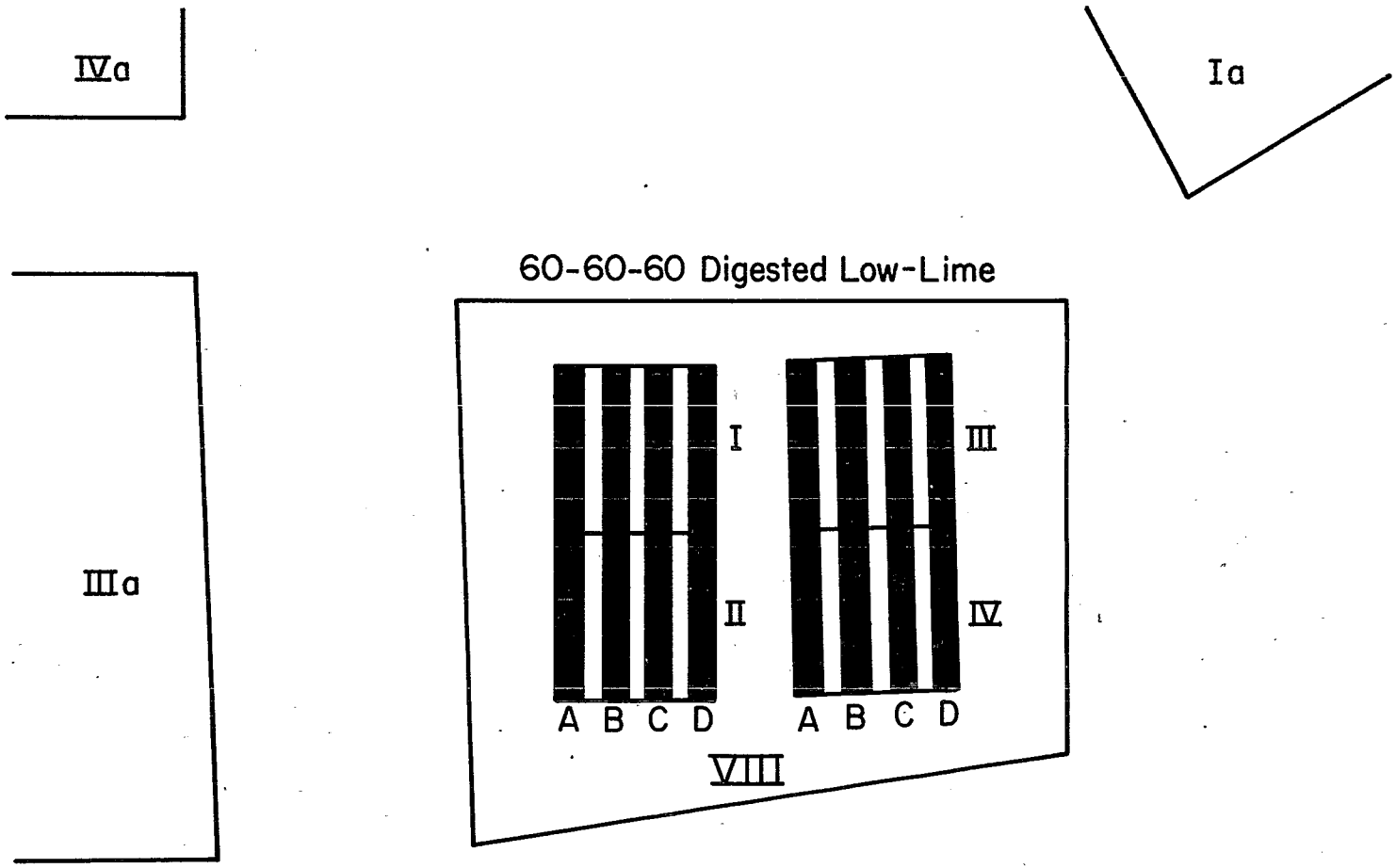

Figure 1. Location and details of plots receiving different sludges in different soil types.
E. Details of plot VIII showing sludge placement in fine loamy sand (clay near surface).

Key to Figure IF, Plot IX

Trench* spacing	Sludge type	Date	Hauling equip.	Metric tons Wet wt.	pH	% solids	Rep. + trenchs
			IXa				
60-60-60	Digested low-lime	2-14-75	Dump	8.34	6.16	24.59	I ABCD
		2-14-75	Dump	6.18	6.05	26.69	II ABC
		2-19-75	Dump	10.56	6.33	25.61	II D + III ABCD
		2-19-75	Dump	9.00	6.35	27.63	IV ABCD
			IXb				
60-60-60	Digested low-lime	2-11-75	Dump	7.37	6.08	23.07	I ABC
		2-11-75	Dump	8.50	6.10	24.10	I D + III AB½C
		2-11-75	Dump	8.64	6.09	23.39	III ½CD + II AB
		2-13-75	Dump	7.61	6.10	25.20	II CD + IV AB
		2-13-75	Dump	4.10	6.06	24.04	IV CD

* Cm wide x cm deep x cm edge to edge spacing between trenches.

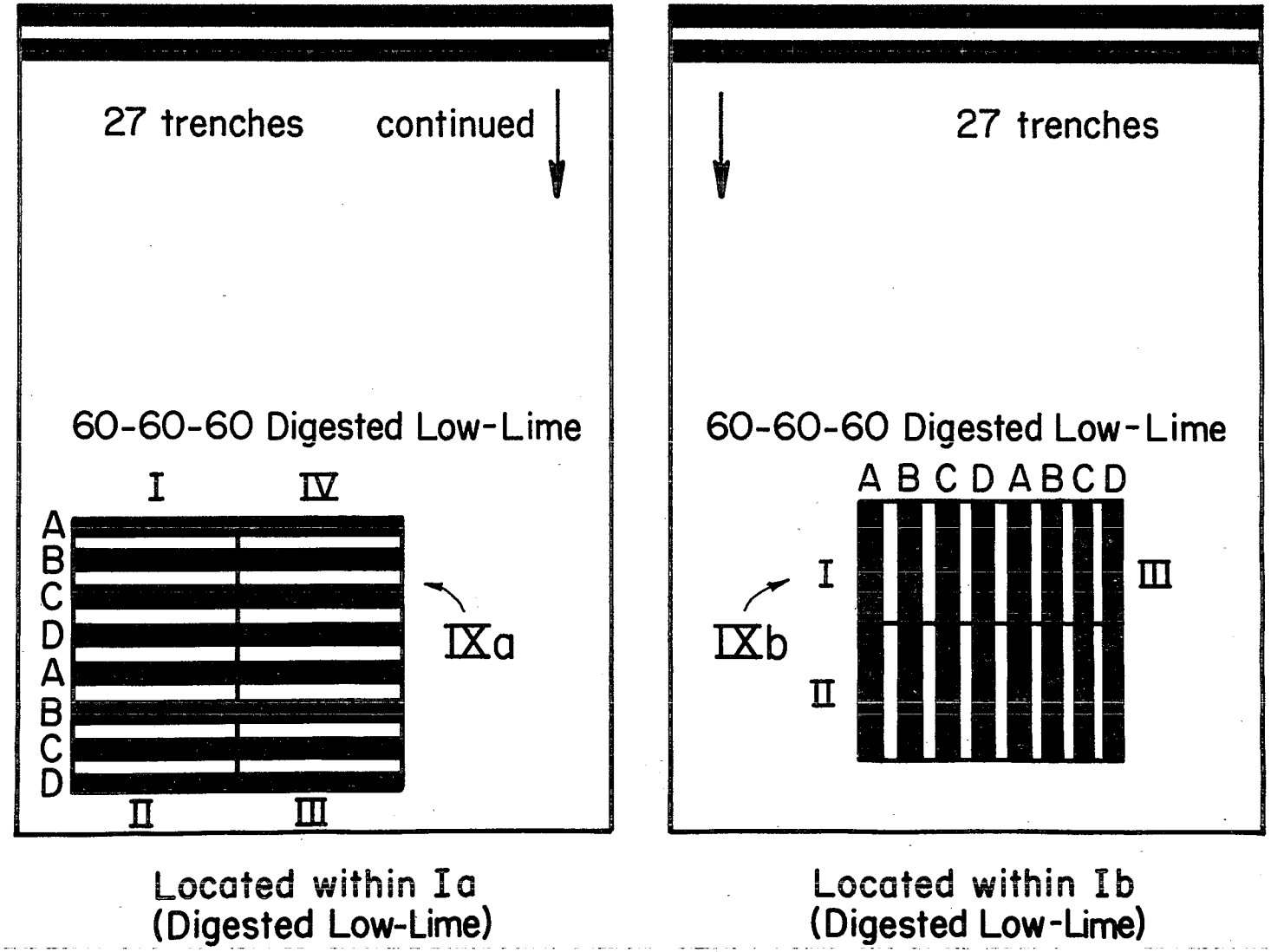

Figure 1. Location and details of plots receiving different sludges in different soil types.
F. Details of plot IXa and IXb showing sludge placement in areas (old area Ia and Ib) previously entrenched (May 1973) with digested low-lime sludge.

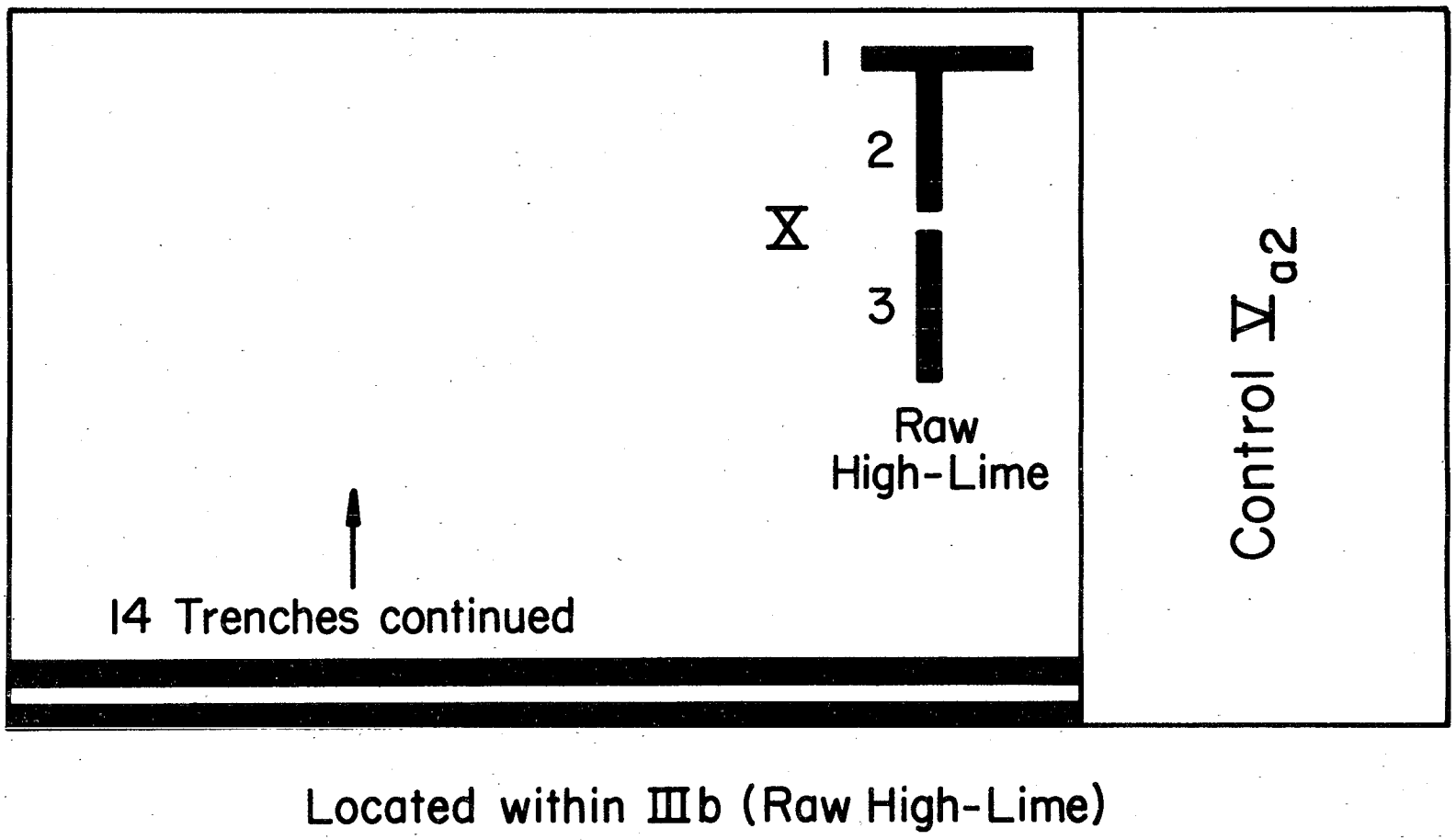

Figure 1. Location and details of plots receiving different sludges in different soil types.
G. Details of plot X showing sludge placement in parallel and perpendicular in an area (Old area IIIb) previously entrenched (May 1973) with raw high-lime sludge.

Key to Figure 1H, Plot XI

Trench* spacing	Sludge type	Date	Hauling equip.	Metric tons Wet wt.	pH	% solids	Rep. + trenchs
60-60-60	Raw high-lime	6-25-75	Dump	8.66	7.96	24.13	I ABCD
		6-30-75	Dump	8.06	9.65	21.51	II ABCD
		6-30-75	Dump	8.31	11.29	22.69	III ABCD
		6-30-75	Dump	8.33	11.19	22.46	IV ABCD
		7-12-75	Dump	7.80	11.52	24.02	V ABCD

* Cm wide x cm deep x cm edge to edge spacing between trenches.

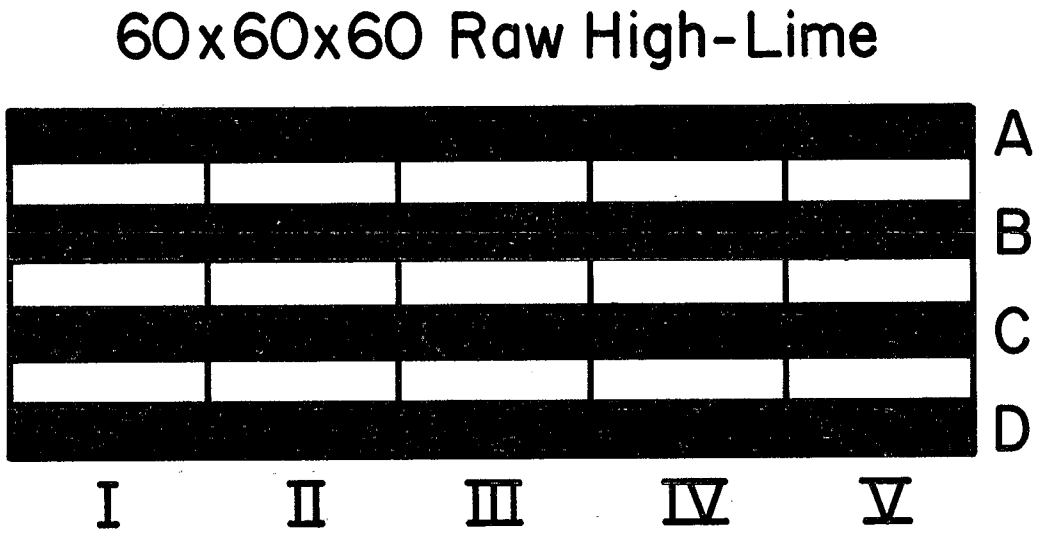

Figure 1. Location and details of plots receiving different sludges in different soil types.
H. Details of plot XI showing sludge placement in poorly drained fine loamy sand (clay layer near surface).

TABLE 2. SOILS AND WATER TABLE IN PLOT AREAS

Area*	Soil		Depth (meters) to		Comments
	Series	Classification	Groundwater	Clay	
VI	Galestown-Evesboro	loamy sand	1.5-5	3-6	
VII	Sunnyside	loamy fine sand	0.3-0.9	2	Drained and tiled 4/75
VIII	Keyport	loamy fine sand	1.5-2	2-2.1	High water table
IXa	Keyport	fine sandy loam	2-5	0.8-5	Trenched 6/72 digested
IXb	Galestown-Evesboro	loamy sand	0.5-1.5	0.5-1.5	Trenched 6/72 digested
X	Sunnyside	fine sandy loam	1-1.5	0.5-1.5	Trenched 6/72 raw
XI	Christiana	silt-loam	0.2-0.3	0.5-1	

* Plot areas are shown in Figure 1.

TABLE 3. EQUIPMENT

Type	Make and Model	Specifications
Tractor/loader/ backhoe (TLB)	Case 580	4.5m extension, loader bucket: 1.6 m wide and 0.6 m^3 capacity, 30 cm or 60 cm backhoe bucket.
	Case 580B*	5.4 m extension, loader bucket: 1.9 m wide and 0.7 m^3 capacity, 30 cm or 60 cm backhoe bucket.
Dump trucks	Ford 500	1.5 m^3 capacity, 580 loader fits, 6 wheels.
	International 1600 Loadstar	2.3 m^3 capacity, 580 loader fits, 6 wheels.
	International 190*	9.2 m^3 capacity, loader fits easily, 10 wheels.
Concrete mixer	Mack truck and Rex drum*	8.4 m^3 capacity, tilted mixer enables good discharge.
	Specially made stretch style mixer on trailer	5.4 m^3 + 11.5 m^3 horizontal mixer results in slow discharge.
Concrete pump	Putzmeister P-80* by American PECCO Corp.	60 m^3/hr
	Squeez-Crete 900 by Challenge-Cook Bros., Inc.	50 m^3/hr

* Most often used equipment.

SECTION 5

SLUDGE ENTRENCHMENT

IN AN UNSLUDGED SITE

A technique for sludge entrenchment was devised and tested by which an ordinary tractor/loader/backhoe (TLB) could be used to dig narrowly spaced ditches. The procedure is as follows:

(1) Dig a straight trench with a TLB 60 cm wide x 60 cm deep x about 4.5 meters long (the extension of the backhoe) and pile the spoil soil along one side as shown diagramatically in Figure 2, trench segment A, number 1.

(2) Obtain sludge from truck (Figure 3A and 3B) and fill trench A-1 (Figure 2) with sludge (Figure 3C).

(3) Dig a new straight trench (A-2, Figure 2) parallel to the previous trench 60 cm to its side and pile the spoil soil uniformly along over the sludge in the previously filled trench (shown pictorially in Figure 3D and 3E).

(4) Fill trench A-2 with sludge.

(5) Continue digging, filling with sludge and covering with soil, trenches A-3 through A-n, for the desired width of the area to be entrenched. In this manner the narrow 60 cm spacing between trenches can be maintained. Trench A-n may be covered with spoil soil left over from digging trench A-1 or from elsewhere as desired (Figure 3F).

(6) Dig a new straight trench, either B-1 or B-n (Figure 2) as an extension of either A-1 or A-n. If B-n were dug first, then parallel trenches would be dug in the order B-n, B-3, B-2, B-1. Assuming B-1 were dug first, then the order would be B-1, B-2, B-3, B-n.

(7) Dig and fill trench B-1 with sludge.

(8) Dig a new straight trench, B-2, 60 cm to the side and parallel to trench B-1, piling the spoil soil uniformly along over the sludge-filled trench B-1. Trench B-2 is an extension of A-2.

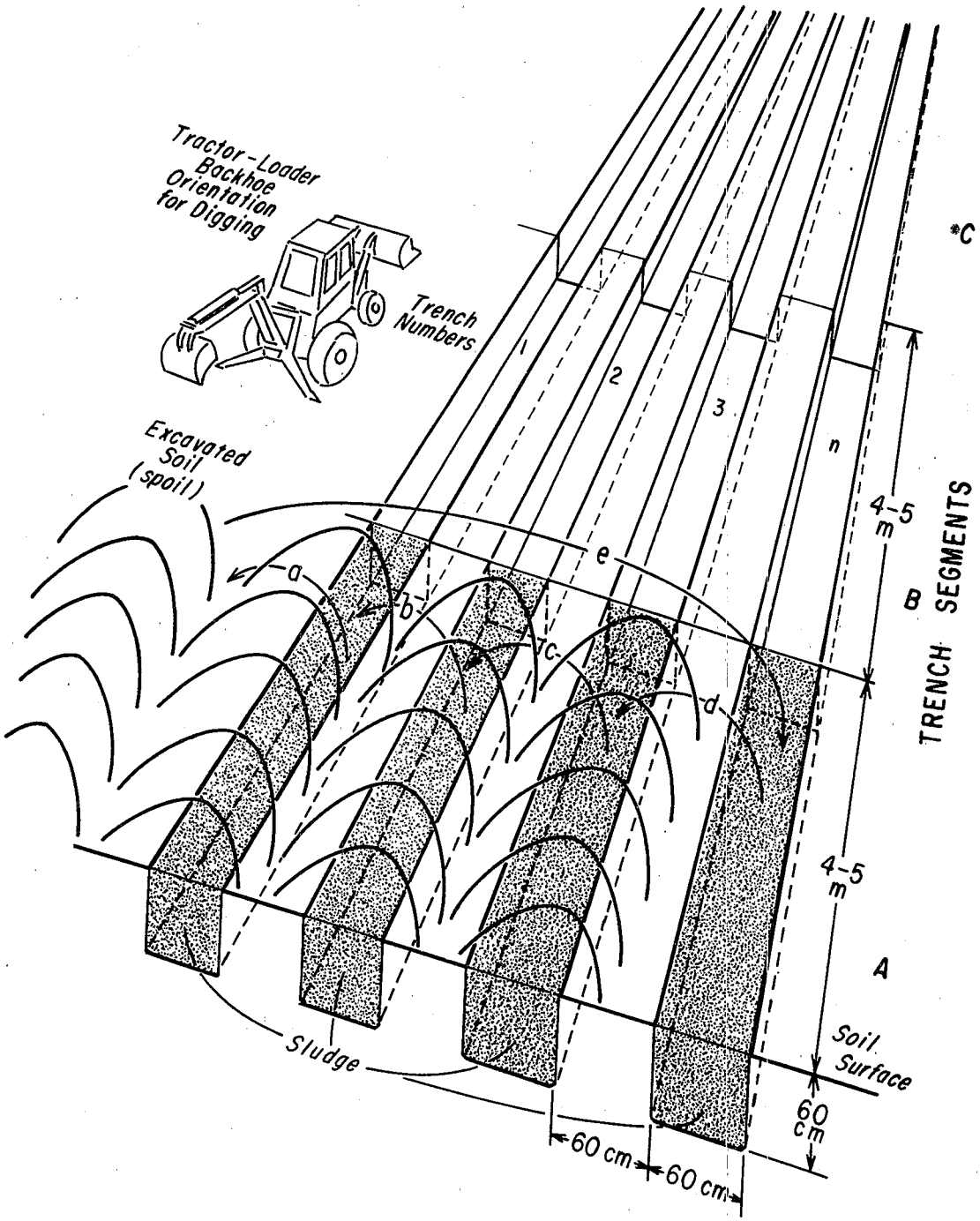

Figure 2. Schematic showing details of sludge entrenchment procedure. Order of digging and filling: Dig "A-1", excavated soil (spoil) is stored to side "a"; fill "A-1" with sludge, dig "A-2" and cover "A-1" with excavated spoil "b"; fill A-2 with sludge; last sludge filled trench in segment A can be filled with excavated spoil from trench A-1 if desired, "e". Repeat process for segments B and then C.

Figure 3. Sludge entrenchment.
A. Obtaining sludge from (9.2 m^3) dump truck with TLB.

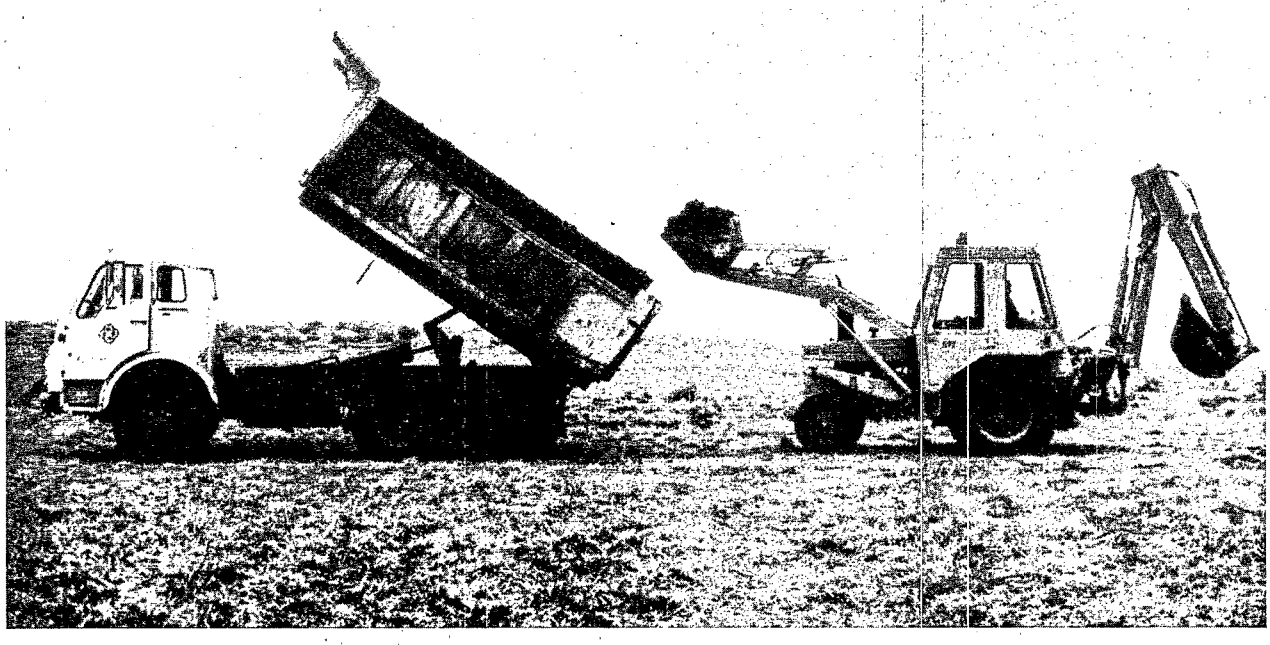

Figure 3. Sludge entrenchment.
B. Transporting sludges from truck to trench with TLB.

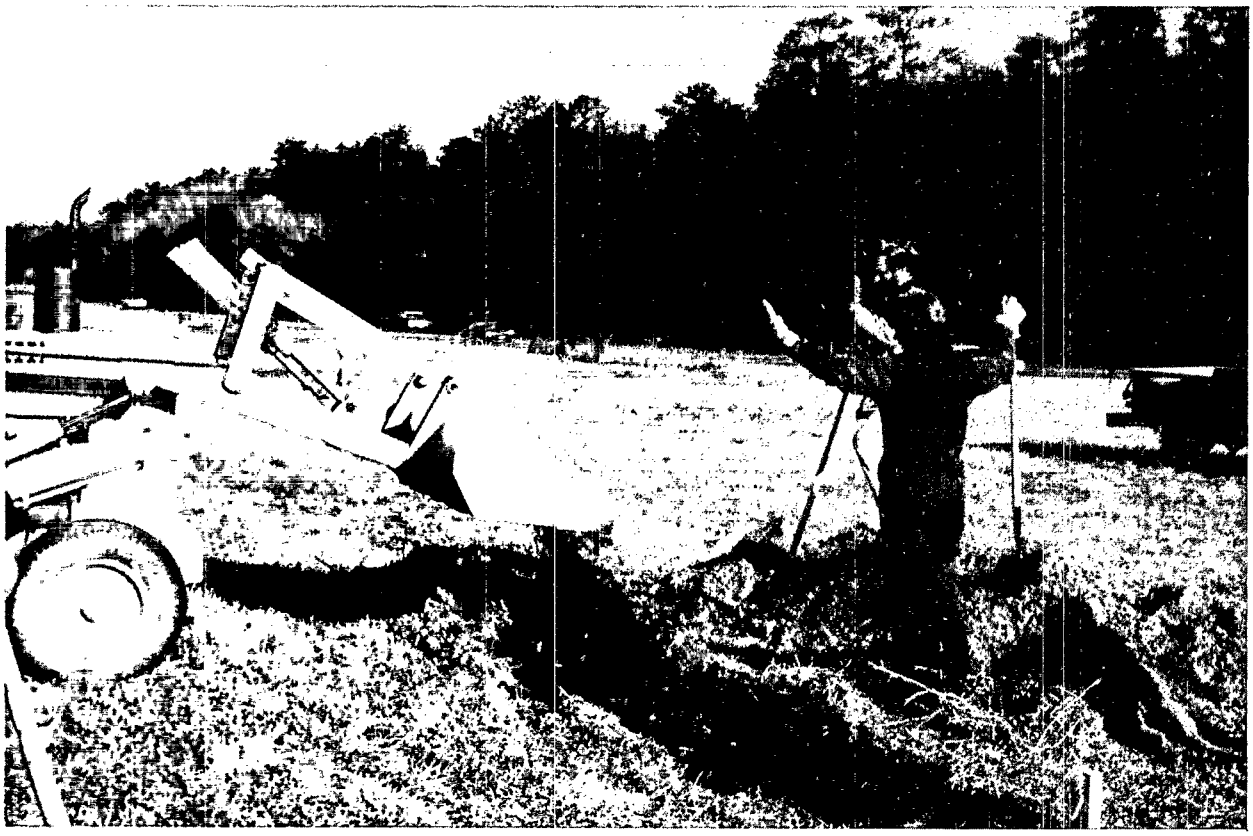

Figure 3. Sludge entrenchment.
C. Filling trench segment A-1 (Figure 2) with slude using TLB.

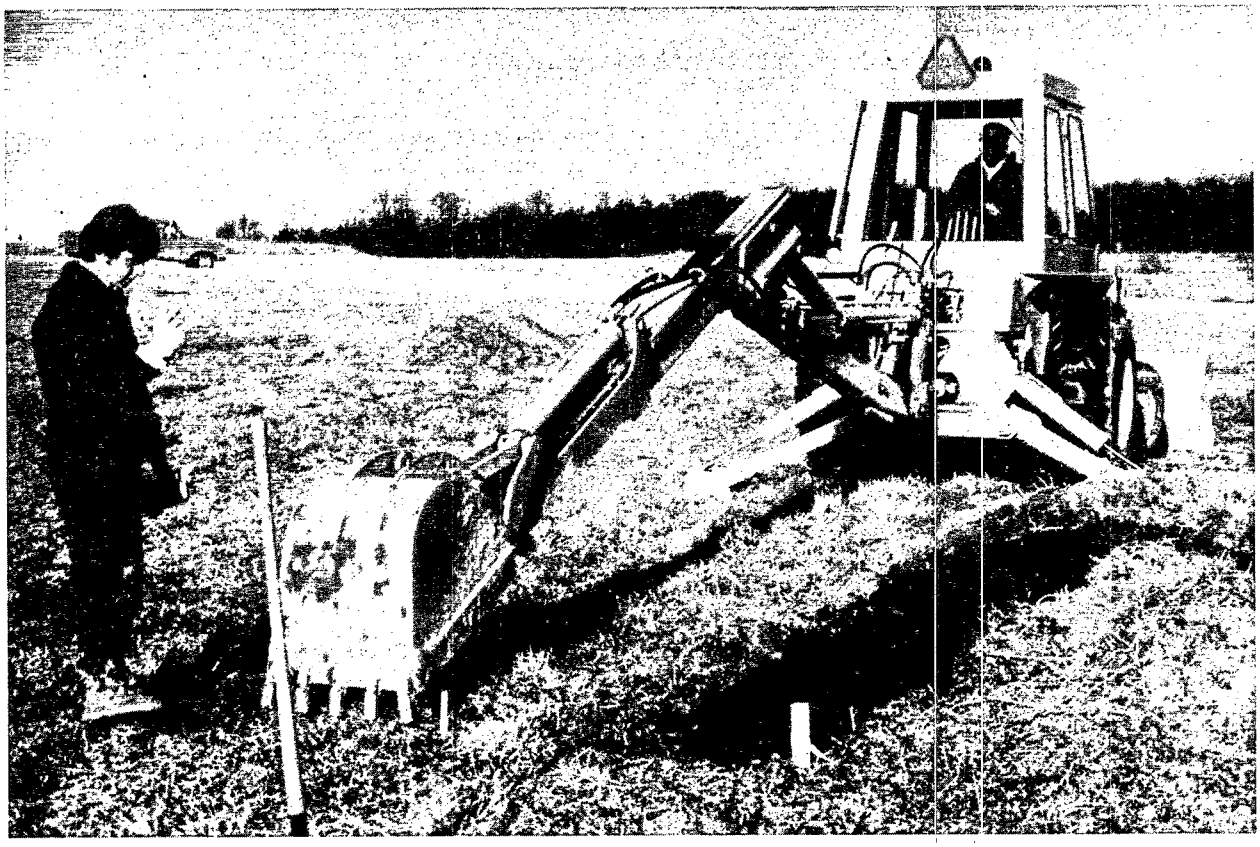

Figure 3. Sludge entrenchment.
D. Beginning to dig trench segment A-2 (Figure 2) beside sludge-filled trench segment A-1 (Figure 2) with TLB.

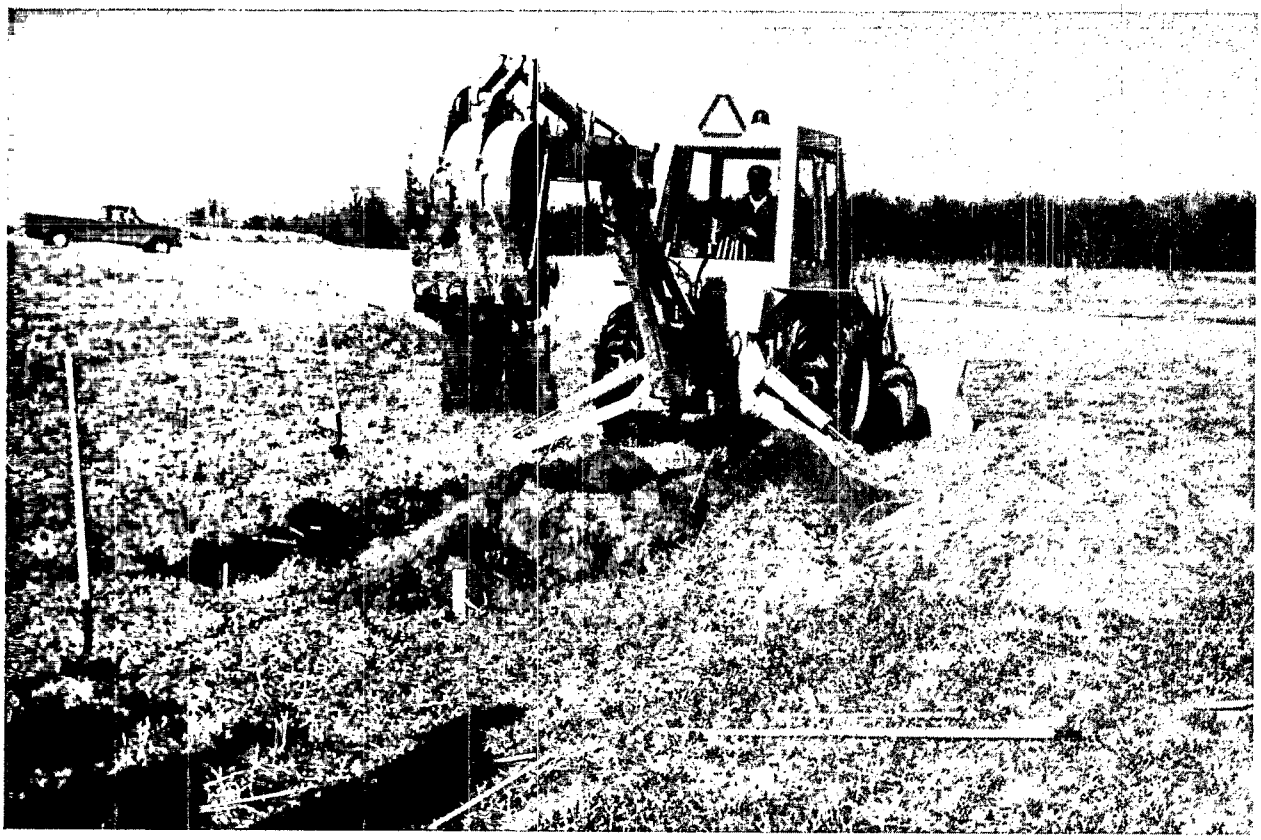

Figure 3. Sludge entrenchment.
E. Continuing digging trench segment A-2 (Figure 2) and covering sludge-filled trench segment with spoil soil A-1 (Figure 2), using TLB.

Figure 3. Sludge entrenchment.
F. Covering sludge-filled trench segment A-n (Figure 2) with spoil soil from trench segment A-1 (Figure 2) using TLB.

(9) Continue digging, filling with sludge and covering with soil through trench B-n for the desired width of the area to be entrenched.

(10) The length of the area to be entrenched will be achieved by extending trenches 1, 2, 3, ...n in the A, B, C, direction.

As an alternative procedure, one long trench could be dug the entire length of the area to be entrenched. This procedure, unfortunately, would not permit narrow spacing between trenches because the tires of the TLB would sink into the freshly filled sludge trench. Hence, a lesser total amount of sludge could be entrenched per given land area, and, with the increased spacing between trenches, crop cover would show a zebra-striped growth response (8).

IN A PREVIOUSLY SLUDGE-ENTRENCHED AREA

Dewatered sludge was also entrenched in areas containing previously entrenched sludges. In one test (Figure 1F, Plot IXb) sludge was entrenched at right angles to the previously entrenched digested sludge (Figure 4A and 4B). Some of the previously entrenched sludge was unearthed during the process. This procedure was performed about two and one-half years after the first sludge was entrenched. The sludge was still moist, but not malodorous in this test area where the water table was about 90 cm below the soil surface. No technical difficulties were encountered. This procedure, however, caused greater mixing of sludge with the soil and probably will cause faster breakdown of the sludge and release of nitrate-nitrogen which could potentially pollute ground and/or surface water.

In a second test (Figure 1F, Plot IXa), digested sludge was incorporated in new trenches that were dug both parallel and between trenches of previously (3 years earlier) entrenched digested sludge. Somewhat less sludge was brought to the surface when trenches were dug parallel rather than perpendicular. No real technical difficulties were encountered except that it was not possible to dig exactly between trenches of old sludge.

In a third test (Figure 1G), raw-limed sludge (limed to pH 11.5 at the time of dewatering) was incorporated in new trenches that were dug both parallel and between trenches of previously (3 years earlier) entrenched raw-limed sludge. The water table was periodically as close as 120 cm below the soil surface in this area. Some of the previously entrenched sludge was unearthed with the spoil during the process. Malodor was not a problem and there were no technical problems with trenching in the raw sludge area.

SLUDGE HANDLING AND TRENCH FILLING

Sludge was hauled in the different vehicles indicated in Tables 3 and 4. In one procedure, sludges were unloaded directly from dump truck bodies with the loader on the TLB and then placed in the trenches. In this manner, very little sludge was spilled onto the soil surface (Figure 3A, 3B, and 3C). In another procedure, sludge was directly discharged from concrete mixer trucks via chutes into the trenches (Figure 5A and 5B). This procedure caused even

less spillage on the soil surface. In the ranges of sludge solids contents experienced (given in the keys to Figure 1 A-H), all types of sludges could be loaded and unloaded adequately with the different types of equipment tested. Observations concerning each method of hauling and placing sludges are given in Tables 3 and 4, Figure 1A-H, and in the following narrative.

The loader bucket on the Case 580B TLB was too wide to fit into the body of the smallest 1.5 m^3 dump truck. Hence, sludge had to be dumped and scraped into the bucket to minimize spillage (Figure 6A). This procedure was time consuming and not particularly satisfactory. Direct unloading was nicely achieved with the smaller bucket on the Case 580 TLB from the small truck (Figure 6B), and with either TLB from the 9.2 m^3 dump trucks (Figure 3A and 3B). Direct unloading was possible even in a snow storm (Figure 7A and 7B). Directly unloading sludge with a TLB was advantageous because it avoided soil surface and possibly surface water contamination with sludge, odor and slippery surfaces from spilled sludge, and difficulties of gathering the jelly-like sludge into front-end loader buckets from dumped piles. The TLB's were quite maneuverable even on wet terrain. About one hour was required at the site to dig trenches, unload 7.7 m^3 of sludge from a dump truck, and fill and cover trenches with a TLB.

While dump trucks were very easy to fill at the treatment plant, liquid dripped from the bodies onto the highway during transit. A modification to dump trucks by a hauler for the Maryland Environmental Service suitably contained tailgate leakage. This modification consisted of a gasket, compression levers reinforcing the locking lugs and a trough along under the tailgate. Odor was not a problem but could have been, particularly in summer months.

Two types of concrete mixer trucks were also used to haul sludge. These trucks hauled sludge without spillage or malodor and could be maneuvered in good weather to discharge sludge directly into the trenches. The horizontal-type concrete mixer truck had to be level or positioned such that the discharge chute was tilted downhill to properly discharge the sludge. This required some additional maneuvering and restriction on operations. A very clean operation was possible with the concrete mixer trucks. The Rex more vertical-type mixer was more satisfactory. The trailer mounted extended body mixer lacked sufficient mobility at the entrenchment site and was used only in one trial. Overall operations took about the same length of time using dump or concrete mixer trucks.

In wet weather in soils incapable of bearing much traffic, sludge can be pumped into trenches via peristaltic-type pumps such as the concrete pumps being used to pump sludge in Figure 8. The Maryland Environmental Service has successfully used this type of machine to pump sludges through two hundred feet of flexible and rigid tubing (10 cm in diameter) into trenches at large-scale sludge entrenchment operations being performed under contract for the District of Columbia. Other less complicated pumps have been used for this purpose in more recent entrenchment operations of the Maryland Environmental Service. These types of machines, however, would add to the cost of the operation and may not be feasible for smaller municipalities. Temporary storage of sludge during wet weather would be a desirable backup. Several

TABLE 4. SLUDGE INCORPORATION

Sludge type	Date	Plot Area	Equipment*		Observations
			Trucks	Backhoe	
Digested low lime	12-20-74	VId1	International 1600 Loadstar	Case 580 & 580B	See footnote**
	1-2-75	VId1	International 190 and Ford 500	Case 580B	See footnote +
	1-8-75	VId1	International 190	Case 580B	
	1-8-75	VIId1	" "	" "	
	1-9-75	VIId1	" "	" "	
	1-9-75	VIId1	" "	" "	
	1-17-75	VIId1	" "	" "	4" ground frozen in a.m.
	1-17-75	VId1	" "	" "	
	1-24-75	VId1	" "	" "	Traction poor due to snow in a.m.
	2-11-75	IXb	" "	" "	Digested on Digested-no malodor
	2-13-75	IXb	" "	" "	"
	2-14-75	IXa	" "	" "	"
	2-19-75	IXa	" "	" "	"
	4-22-75	IXvd	" "	" "	
	4-22-75	VIIvd	" "	" "	
	7-10-75	VIId1	" "	" "	
Digested high lime	2-4-75	VIdh	" "	" "	Heavy snow
	12-5-75	VIdh	5 Rex mixers	" "	One trench collapsed while being filled.
Raw low lime	3-5-75	VIr1	2 Rex mixers	" "	
	3-6-75	VIr1	3 Rex mixers	" "	
	5-9-75	VIvr	International 190	" "	
	5-9-75	VIIvr	" "	" "	

(continued)

TABLE 4 (continued)

Sludge type	Date	Plot area	Equipment: Trucks	Equipment: Backhoe	Observations
Raw high lime	2-7-75	VIrh60	Rex Mixer	Case 580B	See footnote ++
	2-11-75	VIrh60	" "	" "	
	2-13-75	VIrh60	" "	" "	
	2-14-75	VIrh60	Stretch mixer	" "	Stretch mixer too slow
	2-19-75	VIrh60	Rex Mixer	" "	
	2-20-75	VIrh120	International 190 and Rex mixer	" "	
	2-21-75	VIrh120	" " "	" "	
	2-25-75	VIrh120	International 190 and 3 Rex mixers	" "	
	3-3-75	VIrh120	Rex mixer	" "	
	3-4-75	VIrh120	2 Rex mixers	" "	
	3-18-75	VIrh30	" " "	" "	
	3-19-75	VIrh30	Rex mixer	" "	
	3-27-75	VIrh30	International 190	" "	
	3-27-75	VIrh60	" "	" "	
	6-18-75	X	" "	" "	Raw on Raw - no malodor
	6-24-75	VIIrh	" "	" "	
	6-25-75	VIIrh	" "	" "	
	6-25-75	XI	" "	" "	
	6-30-75	XI	" "	" "	
	7-12-75	XI	" "	" "	

Key: VI to XI described in Figure 1A-H

d = digested
r = raw
h = high lime
l = low lime
v = virus study

30 = 60 x 30 cm trenches
60 = 60 x 60 cm trenches
120 = 60 x 120 cm trenches

* Site time for digging, filling and covering trenches was about 1 hour, whether using a TLB and dump truck or a TLB and mixer.

** Technique of dumping into the bucket was slow and done mostly by hand resulting in some spillage. Fitting the loader into the truck was a much faster method with less spillage.

\+ Large dump truck worked well, holds about 9.2 m^3, and can fill 3.5 to 4 trench segments 4.5 meters long. The Case 580B loader bucket fits into the truck beds. This combination of equipment was used most often.

++ Upright Rex mixer needs to be heading up hill in order for the sludge to move out faster.

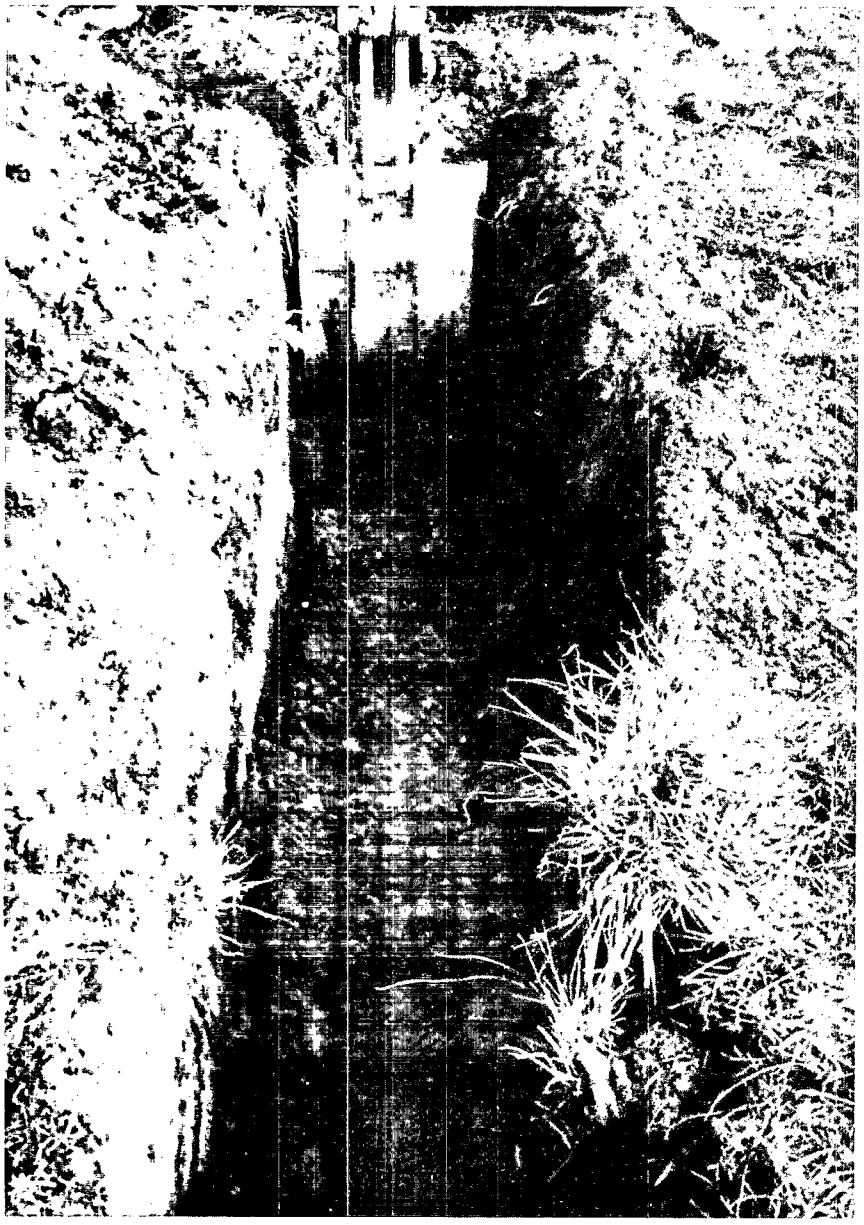

Figure 4. Sludge entrenchment in an area entrenched with sludge 2.5 years earlier.

A. Digging trench 60 cm wide x 60 cm deep at right angles to previously entrenched sludge.

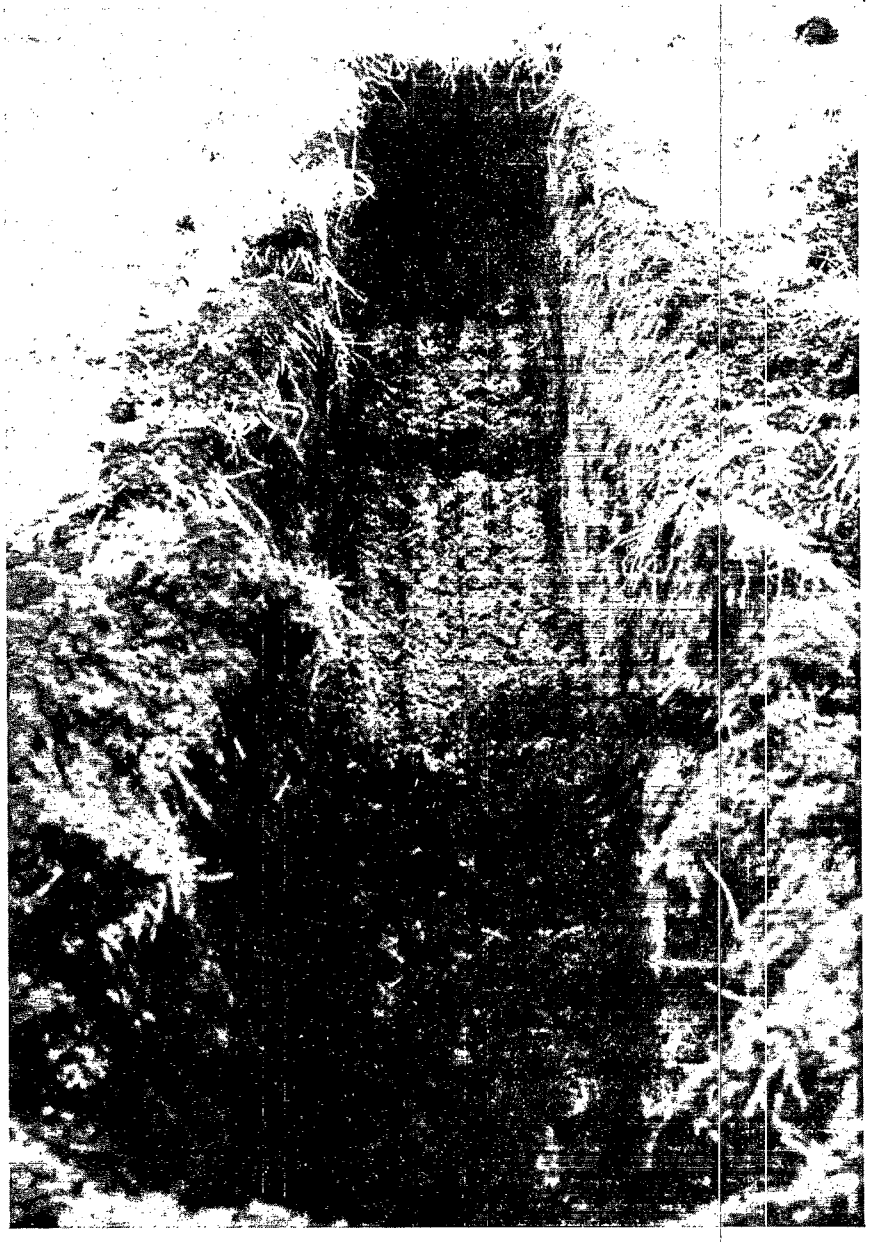

Figure 4. Sludge entrenchment in an area entrenched with sludge 2.5 years earlier.
B. Exposed previously entrenched sludge.

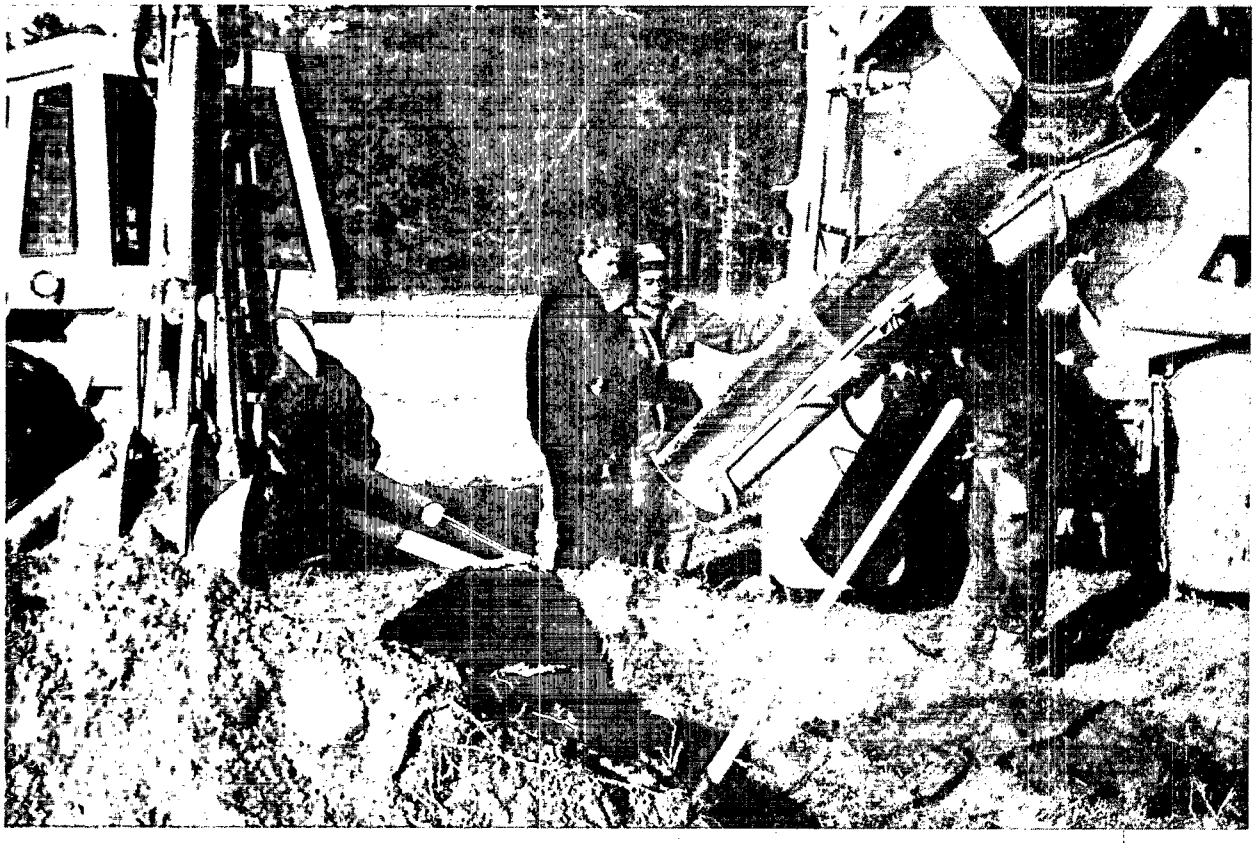

Figure 5. Sludge hauling and discharge into trenches from concrete mixer truck.
A. Preparation for sludge discharge into open trench.

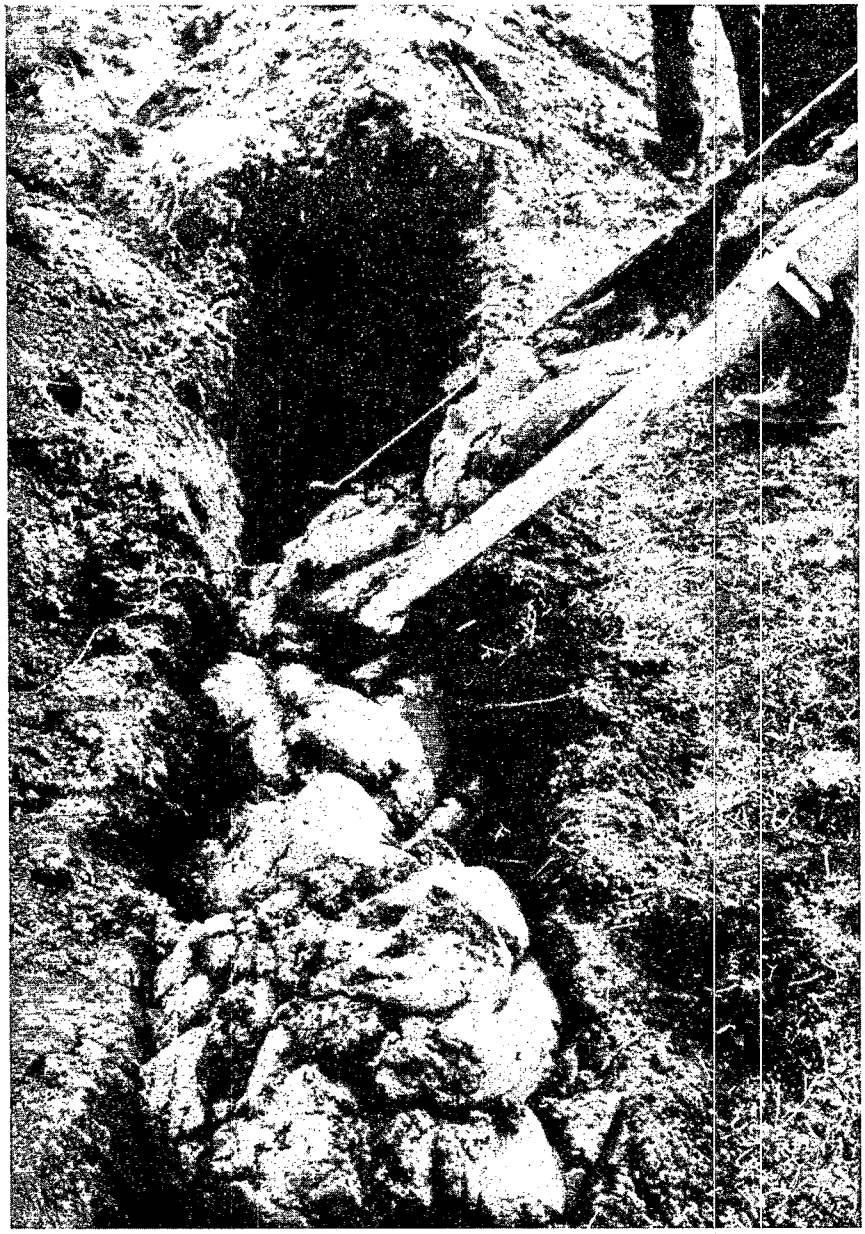

Figure 5. Sludge hauling and discharge into trenches from concrete mixer truck.
B. Sludge discharge into open trench.

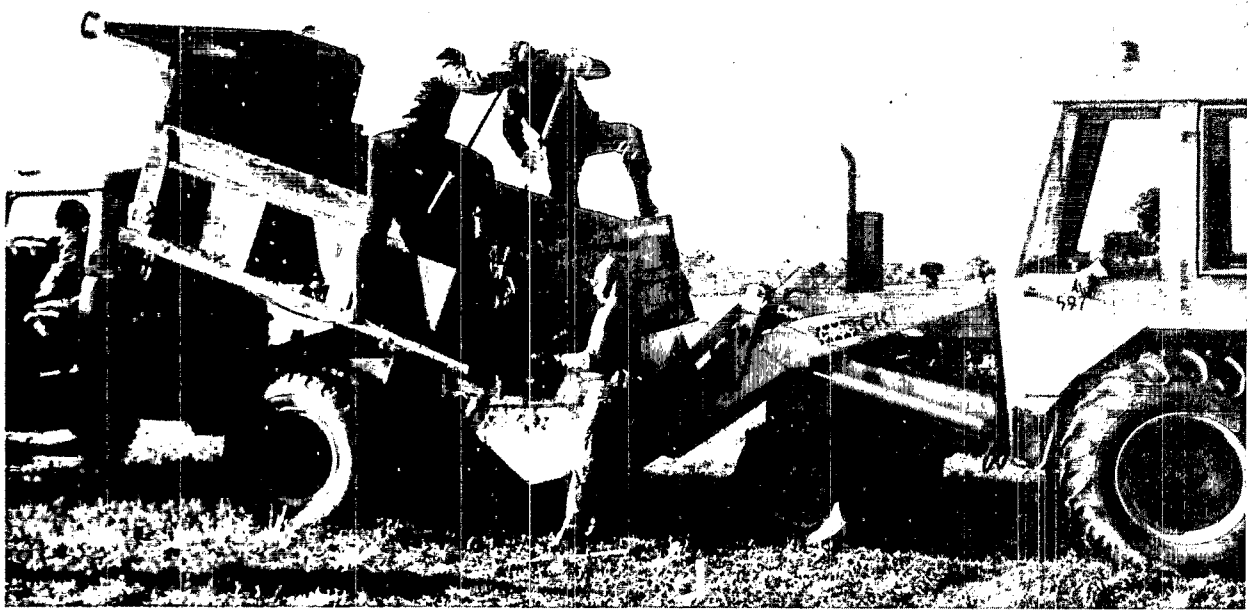

Figure 6. Sludge hauling and unloading with TLB from 1.5 m^3 dump truck.
A. Using a TLB with bucket too large for dump bed.

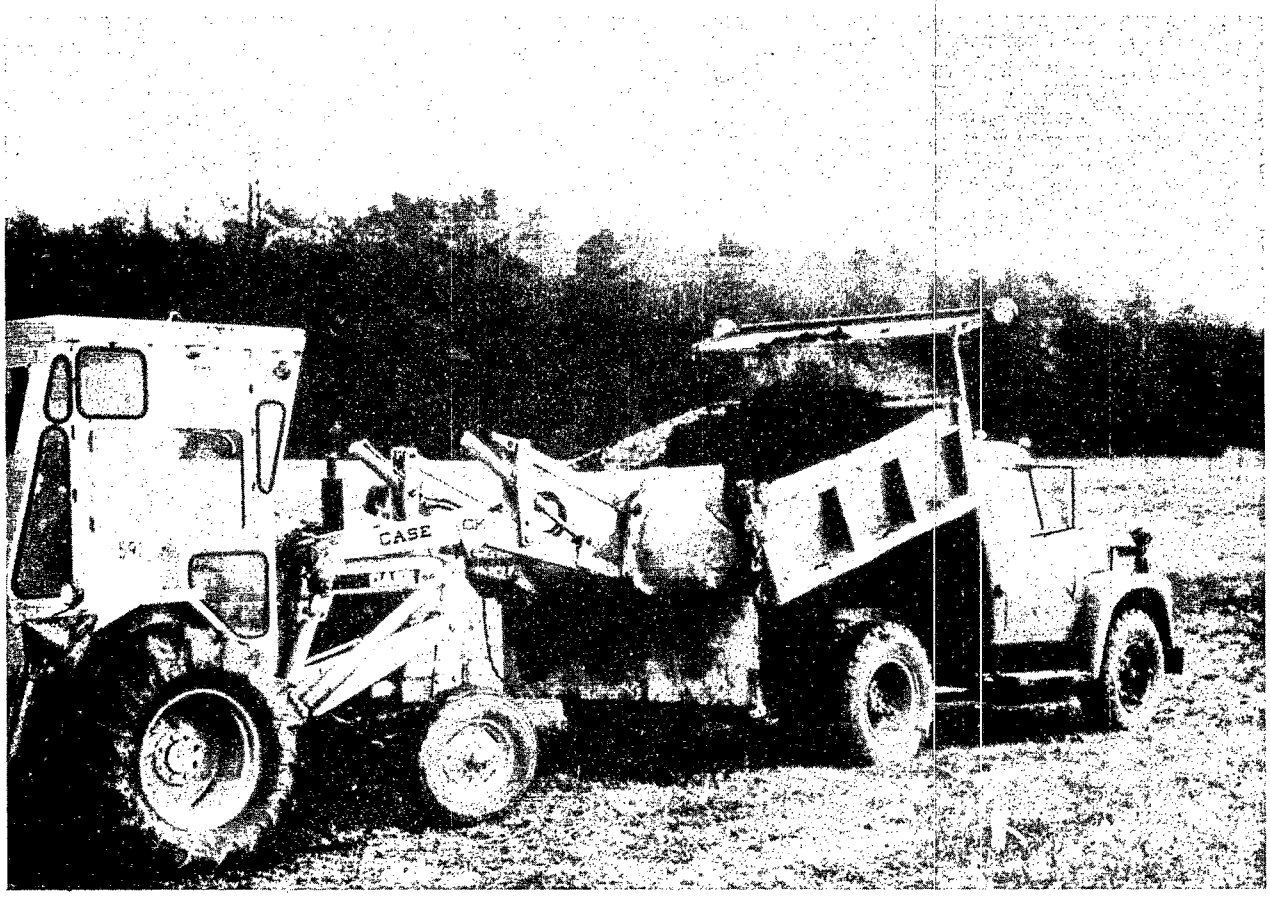

Figure 6. Sludge hauling and unloading with TLB from 1.5 m^3 dump trucks.
B. Using a TLB with smaller bucket, permitting direct unloading and minimum spillage.

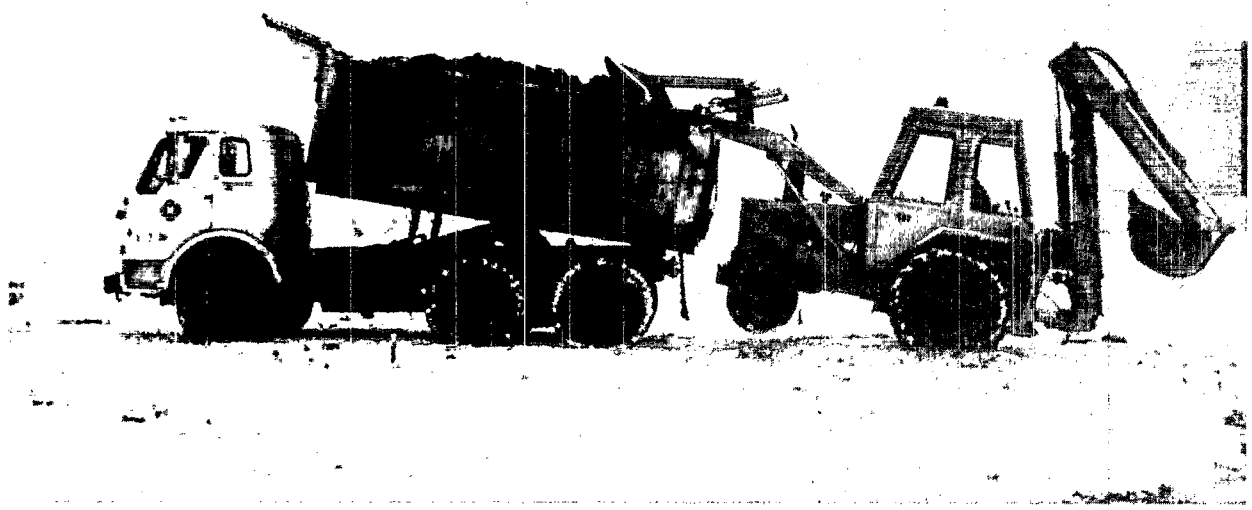

Figure 7. Sludge entrenchment in a snow storm.
A. Unloading 9.2 m^3 dump truck with TLB.

Figure 7. Sludge entrenchment in a snow storm.
B. Filling trench with sludge using TLB.

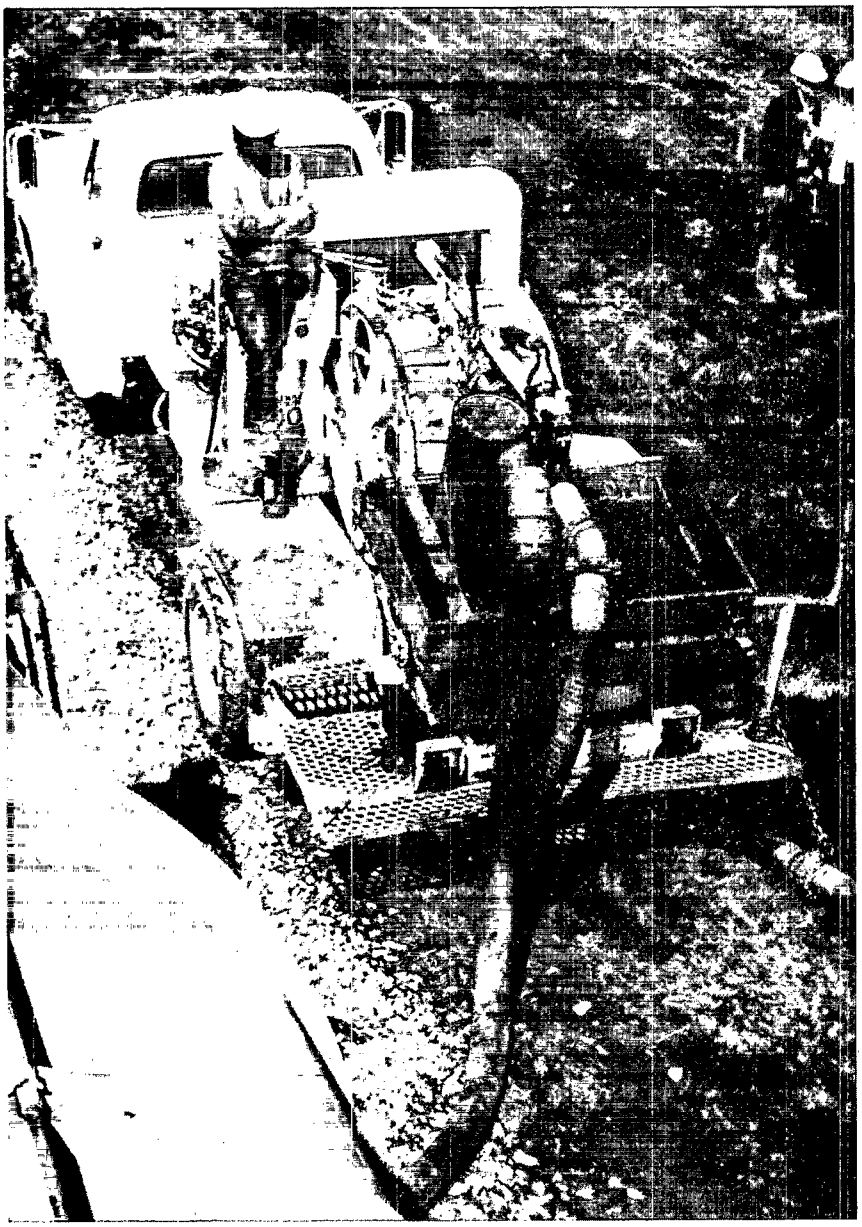

Figure 8. Peristaltic-type pump (Challenge 900) being used for pumping dewatered sludge through a hose from tank truck to trenches at Maryland Environmental Service entrenchment site.

other methods of improving the ability to trench sludge in wet soil conditions are described in the next section.

SOIL CONDITIONS, WEATHER AND SITE DRAINAGE

Sludge could be entrenched in the sandy area throughout most seasons and weather conditions. Most of the sandy area was entrenched with sludge in February and March, often on days following heavy rains. Sludge was even entrenched in the sandy soil during a snow storm and general maneuverability of the trucks and the TLB was possible.

On the other hand, maneuvering was difficult on a clay soil with a high water table. Only the TLB could be used on this soil during the winter. Hence, the clay area was drained in a preliminary fashion with open trenches running through the plots as shown in Figure 9A. After some of the water had drained out (Figure 9B), tile drains were installed perpendicular to the direction of the open ditches as shown in Figure 9C. This change in direction was made to provide for collection and carrying away of water perpendicular to the direction of its normal subsurface flow. A flexible plastic 10 cm drain line was installed. This corrugated slotted line was fabricated with a fiberglas mesh cover which permitted its installation in the clay soil without a gravel envelope (Figure 9D). This covered drainage tile was obtained from Advanced Drainage Systems. The average depth of the tile was approximately 1 meter below the soil surface. The tile has functioned well in carrying off excess water. The area became drier after drainage lines were installed during the winter, both because of the drainage system and because of increased evaporation during the spring. Tile installation was completed in early February. Sludge was entrenched in the area without difficulty by the end of May.

This experience shows the importance of picking sites with different soil properties for use during different weather conditions and seasons. If only heavy wet soils with high water tables are available, then installation of tile drainage systems will probably be necessary. Tile drainage may also be necessary in high water table sandy soils. Provision for overland flow of the drainage water over grassed areas and impoundment and/or irrigation of the drainage water may be necessary to reduce nitrogen levels prior to its discharge into surface drainage streams. In most situations, however, tile drainage is not desirable or necessary. Advice on drainage of soils and impoundment of drainage water can be obtained from the Soil Conservation Service located in each county and state.

Beltsville, in the metropolitan Washington, D.C. area, has a moderate climate. The average annual precipitation is 105 cm including 57 cm of snow. Snows generally are not persistent. January is the coldest month and July the warmest. The respective mean monthly temperatures are 1°C and 25°C. There is an average of 194 frost-free days each year.

In colder climates, soils should be covered if they are likely to become frozen to appreciable depths. If the treatment facility is in a very cold climate, sludges possibly could be lagooned or stockpiled for entrenchment later in the spring, provided surface runoff and infiltration are controlled.

SEEDING

The test areas, entrenched with sludge between December 1974 and May 1975, were leveled and cultivated with a tractor-mounted rotovator in early June. Rotovating of the different test areas was followed by application of fertilizer and lime. Finally, the different test areas were seeded by hand with Kentucky-31 tall fescue grass seed. The applied rates of lime, fertilizer and seed are given in Table 5.

Recommendations for seed, fertilizer and lime requirements for your particular soil and area may be obtained from your local Office of the Cooperative Extension Service, Soil Conservation Service or State Agricultural University.

Figure 9. Drainage of clay soil with high water table.
A. Digging trench for preliminary drainage.

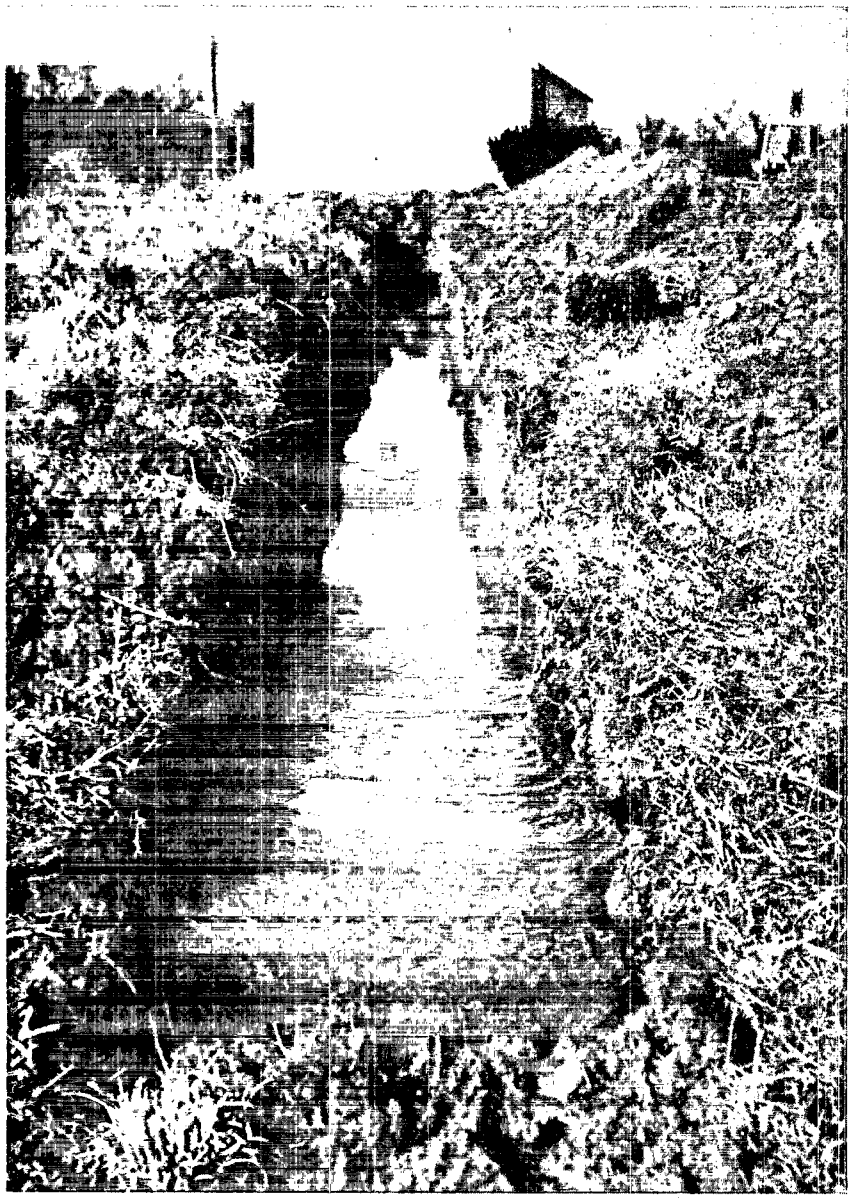

Figure 9. Drainage of clay soil with high water table.
B. Water draining out of trench.

Figure 9. Drainage of clay soil with high water table.
C. Installation of fiberglas-covered slotted flexible 10 cm-diameter plastic drain tile, prior to covering with soil.

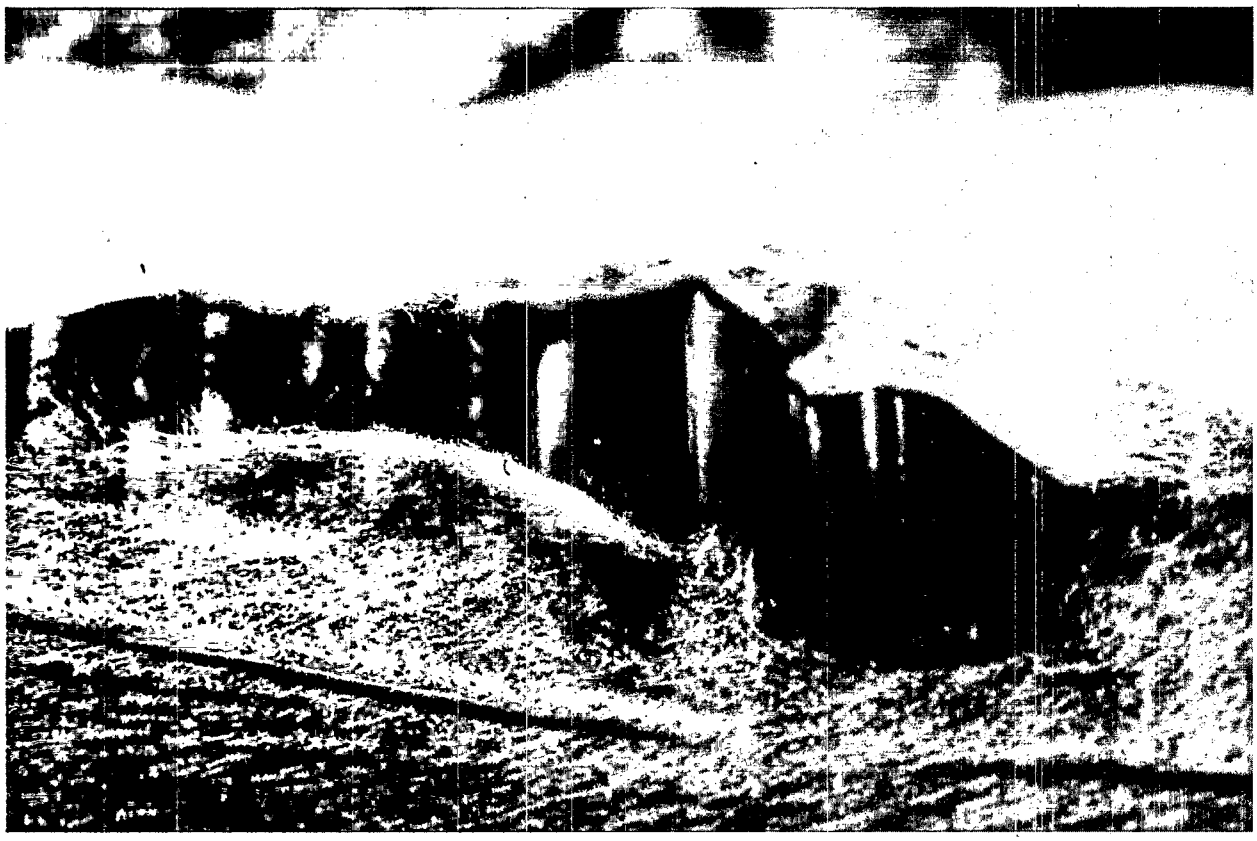

Figure 9. Drainage of clay soil with high water table.
D. Fiberglas wrapping over flexible slotted plastic drain tile by Advanced Drainage Systems (ADS).

TABLE 5. APPLICATIONS OF FERTILIZER, LIME AND GRASS SEED

Material	Application rate Kg/ha
10-10-10* fertilizer	1100
Dolomite lime	4400 (to pH 6)
Kentucky 31-tall fescue	165

*Equivalent to 110, 48 and 91 kg/ha N, P and K on an elemental basis.

SECTION 6

ENVIRONMENTAL RISK, ITS MANAGEMENT AND SUGGESTED MONITORING

INTRODUCTION

Monitoring of a sludge entrenchment site should be the minimum necessary to detect potential harmful effects in the environment. Monitoring data should be available and acted upon when it shows that additional steps must be taken to minimize environmental degradation.

Monitoring is discussed for sites receiving sludges from municipalities at rates from 3 to 48 dewatered, filter-cake tons (15-25% solids) per day in this report. This monitoring is sludge and site specific, resulting in a specific local environmental risk.

ENVIRONMENTAL RISKS OF TRENCHING AND THEIR MANAGEMENT

Potential environmentally harmful materials in sludge include nitrogen, heavy metals, pathogens and certain organic compounds. Potential risks are greater when larger amounts of sludge are entrenched on the same land area.

Nitrogen

The most probable environmental risk from entrenching dewatered sludge is possible pollution of groundwater with nitrogen. It is difficult to predict the extent of this nitrogen risk. The large amount of immobile organic nitrogen in entrenched sludge can undergo many fates. Under aerobic conditions, microorganisms transform the organic nitrogen into the inorganic forms of ammonium, nitrite and nitrate. Some of these mineralized forms of nitrogen can move into groundwater via water infiltrating through the soil. They also can be temporarily absorbed by the soil cation exchange complex or taken up by crops (100 to 300 kg/ha/yr). Finally, nitrogen can be denitrified (transformed microbially from nitrate to nitrogen gas) and lost harmlessly into the atmosphere under anaerobic conditions and with a suitable carbon source.

Entrenchment of sludge promotes anaerobic conditions, essentially prevents water percolation through the sludge for at least a year or longer, slows nitrogen mineralization, promotes denitrification and contains and allows microbial destruction of malodorous materials and pathogens (8).

In an earlier study (8), sludge was placed in trenches 60 cm wide x 60 cm deep x 60 cm edge spacing which added over 300 dry tons of sludge per hectare (over 1500 dewatered, filter-cake tons per hectare). Dewatered undigested sludges in this study contained about 3% nitrogen. This amounted to 20,000 total kilograms of organic nitrogen being added per hectare, which is about 100 times more nitrogen than is needed by a grass crop during one year. If the sludge were mixed throughly with soil instead of being entrenched, 20 to 50% of the nitrogen could be released into the soil in mobile form. The studies (8) showed that release and movement of nitrogen from entrenched sludge into groundwater was minimal during the first two years after entrenchment. The sludge, however, did become more aerobic during that period and some increased nitrogen movement through the soil was observed. In subsequent studies of this and of large-scale areas trenched by the Maryland Environmental Service, movements of excessive amounts of nitrogen have not yet been detected (Unpublished, personal communication, Larry Sikora, USDA, ARS, Beltsville, MD).

If excessive amounts of nitrogen are mineralized and begin to move to groundwater, mineralization and movement can be reduced by promoting anaerobic conditions. This can be accomplished by increasing the soil water content. In a field with the water table at considerable depth, the soil water content can be increased by installing an asphalt barrier in the soil uniformly under the entrenched sludge with a special machine at an estimated cost of between $700 to $1000 per acre (1,5). In a tile-drained entrenched field (shallow water table), drains could be plugged to increase the soil water content. If plugging was not desired, drainage water with excessively high nitrogen content could be impounded and/or irrigated onto a cropped field. A third procedure would be to pump out excessively contaminated groundwater from wells and irrigate onto cropped land.

Heavy Metals

A second potential problem is movement of heavy metals through soil from entrenched sludge to groundwater. However, this risk is not thought to be very great with most sludges in most soils. Additions of lime (CaO) to sludges prior to dewatering, to induce pH's of 10 to 11, have been recommended (8) to maintain pH's of sludges near neutral, thereby minimizing chances for metal movement.

In the studies previously mentioned (8), metals did not move out of entrenched sludges into soils as long as pH's remained near neutral. In entrenched unlimed sludges, in which the pH became acid, slight metal movement was observed. The sludges became acidic as nitrates and sulfates formed. Formations of these compounds were accelerated by increasingly aerobic conditions in the sludge and more rapid microbial sludge decomposition. It was not possible to tell in the studies how effective the lime additions were in neutralizing acid formation in entrenched sludge during rapid aerobic decomposition. Such studies are a continuing part of sludge entrenchment research at Beltsville.

Pathogens

Pathogens in entrenched sludges are not thought to pose a hazard. The pollution indicators - fecal coliforms and pathogenic salmonella bacteria - were not detected more than a few cm into soils outside of entrenched sludges any time during a two-year period following entrenchment (8). Furthermore, concentrations of these organisms dropped to nearly non-detectible levels during this two-year period. Total coliform bacteria, measured in the same study, were detected in soil no more than 30 cm outside the entrenched sludge.

In a recent study, the model polio virus (bacteriophage F-2) was seeded into sludge at a treatment plant prior to dewatering. The seeded sludge was then entrenched. The virus was not detected moving from entrenched sludge into surrounding soil. The F-2 virus decreased in numbers within the entrenched sludge from 10^7 plaque-forming units per gram to non-detectible levels within one month after entrenchment (Unpublished, personal communication, Wylie Burge, USDA, ARS, Beltsville, MD). Virus studies are continuing at Beltsville. There will be an attempt to follow the fate of endogenous enteroviruses in entrenched sludge.

Organics

The fate of chlorinated hydrocarbons, PCB's and other similar organics has not been studied in entrenched sludges. In studies on specific organic compounds, some movement of trace organics through soils has been observed, particularly of water soluble trace organic compounds. Furthermore, polar trace organics in the form of acids can be absorbed by plants (Personal communication, Ralph Nash, USDA, ARS, Beltsville, MD.). During the process of dewatering, most of these more soluble trace organics should move out of the sludge into the liquid filtrate. Therefore, it is not believed that the less soluble, nonpolar trace organics, probably remaining in the sludge after dewatering, would move appreciably through soil from entrenched sludge under normal circumstances; and little uptake by plants would be expected. Nonetheless, the fate of trace organics in entrenched sludges needs study.

MONITORING

The specific monitoring requirements will depend upon the risks previously discussed and be up to the applicable federal, state and local authorities and statutes. Minimal monitoring is suggested for small entrenchment sites, providing sound entrenchment procedures are followed.

The sludge should be adequately characterized at the treatment plant (Table 6) so that potential for future environmental risk can be determined. There also will be some requirements for monitoring ground and surface water at the entrenchment site. Monitoring suggestions are given in Table 6. Assistance in determining where monitoring wells should be located, with crops to be grown, with drainage, etc., can be obtained through the local County Cooperative Extension Service, Soil Conservation Service, Health Department and/or State Geological Survey.

Proper use of the recommended entrenchment procedures and maintenance of grass in waterways should minimize problems with surface water contamination and need for its monitoring. If crops are grown that will enter the human food chain, and if the sludge metal levels are high, it may be necessary to monitor the crops (Table 6) at harvest to determine their safety.

TABLE 6. SUGGESTED MONITORING FOR SLUDGE ENTRENCHMENT

Component	Determination	Frequency
sludge	total & volatile solids; total, NH_4 and NO_3-N, P, K, Cl, soluble salts, lime, Zn, Cu, Cd, Pb, Hg, Ni	twice yearly of one representative composited weekly sample
sludge	pH	daily or weekly
groundwater	NH_4 and NO_3-N, Zn, Cl, total and fecal coliforms	one or two background from several strategically located wells
groundwater	*NH_4 and NO_3-N, *Cl	once every three to six months during and for five years after entrenchment
tile drainage	NH_4 and NO_3-N, total and fecal coliforms	unnecessary if provision for impoundment or crop irrigation
surface water	NH_4 and NO_3-N, P, total and fecal coliforms	unnecessary if sludge is properly entrenched
crops	Cd, Pb, Hg, Ni	probably necessary at harvest if metals high in sludge and if crops will enter human food chain

*If a significant increase of these ions is detected over time, they can be analyzed more frequently and/or for more components. Appropriate methods should be utilized to prevent water degradation.

SECTION 7

COSTS

SLUDGE HAULING AND ENTRENCHMENT

Costs were estimated for entrenchment in 1975 based upon actual experiences during the Beltsville pilot studies. The costs are estimated for hauling and entrenchment of 3, 12 and 48 dewatered tons of sludge per day, both on a rental and an ownership-self-operation basis. Assuming a hauling distance of 32 km each way between the treatment plant and the sludge entrenchment site, the loading and two-way travel took less than three hours for dump and concrete mixer trucks and the unloading at the site took less than one hour. Reasonable working times at the entrenchment site for all operations of the TLB, including trenching, unloading the dump truck and covering the sludge with soil were one-half hour per small truck (up to 3.8 m^3 in size) and one hour per large truck (up to 9.2 m^3 in size) (Table 7).

Estimated rental costs for entrenchment are given in Table 8. These estimates were based upon the minimum fraction of a day it was possible to rent the equipment rather than upon actual working times. For any given haul distance, cost savings can obviously accrue, particularly for 3 to 12 ton per day operations, as a result of any procedure that increases the effective utilization of the trenching machine and reduces truck transport, e.g., stockpiling sludge for several days at the treatment plant before hauling to the site. Considerable savings could also occur if a TLB were available both for entrenchment and for other municipal operations, thereby enabling cost-sharing. A third possibility for a small daily operation would be to use the same operator for the TLB and the dump truck.

There also would be a cost for supervision at the site. This cost would probably be minimal. Such site supervision for the smaller operations (3 to 12 dewatered tons of sludge per day) would probably amount to no more than a weekly visit after an initial orientation given to the TLB operator. For a 48 ton per day operation, however, it may be desirable to have an additional person on the site to guide trench spacing and filling and truck unloading operations of the TLB operator. This individual could also collect any necessary samples for monitoring. If this individual earned $4.00 per hour per eight-hour day, this would add less than $1.00 per ton of dewatered sludge entrenched to the cost for a 48 ton-per-day operation.

Estimated entrenchment costs, assuming equipment ownership and self-operation by the wastewater treatment authority, are given in Table 9. These costs are estimated for hauling 32 km each way and entrenchment of 3, 12 and 48 tons of dewatered sludge per day, five days per week over a 3-year period.

TABLE 7. ACTUAL TIMES REQUIRED FOR SLUDGE HAULING AND ENTRENCHMENT

Equipment			Times, hrs		
Type	Size m^3	Dewatered tons sludge	Loading at treatment plant	Travel, 64 km total	Unloading and entrenchment at treatment site
Dump truck	3.8	3	0.25	1.5	0.5*
Dump truck	9.2	12	0.75	1.5	1*
Concrete truck	8.4	11	1	1.5	1**

* Time includes trenching as well as dump truck unloading because the TLB performs both operations sequentially.

** Includes trenching with TLB and self-unloading of concrete mixer truck. Unloading and maneuvering of concrete truck takes essentially the same time as unloading a dump truck with the TLB.

TABLE 8. ESTIMATED SLUDGE ENTRENCHMENT COSTS - RENTAL (1975)

HAULING (32 km each way)

Size of Operation	Dump trucks No.	Dump trucks Size	Actual time for loading, 2-way hauling and unloading	Rental time	Costs* per hr	Costs* per day	Costs* per dewatered ton
Dewatered tons/day		m^3	hrs.	hrs.	$	$	$
3	1	2.3	2.25	4	20	80	26.65
12	1	9.2	3.25	4	24**	88	7.35
48	2	9.2	13.00	8 each	24	352	7.35

TRENCHING

Size of Operation	TLB'S	Actual time for TLB	Rental time	Costs* per hr.	Costs* per day	Costs* per dewatered ton
tons/day		hrs.	hrs.	$	$	$
3	1	0.5	2-4	25	50-100	16.65-33.35
12	1	1	2-4	25	50-100	4.15-8.35
48	1	4	8	25	200	4.15

(continued)

TABLE 8. (continued)

TOTAL RENTAL COSTS FOR HAULING AND ENTRENCHMENT*

Size of Operation	per day	per dewatered ton
tons/day	$	$
3	130-180	43-60
12	138-188	11.50-15.70
48	552	11.50

* includes operator

**concrete truck rental including operator would be $25.00/hr.

TABLE 9. ESTIMATED SLUDGE ENTRENCHMENT COSTS - PURCHASE AND SELF-OPERATION (1975)

CAPITAL

Size of operation, dewatered tons		Dump trucks					Trencher			Total Capital	
per day	per 3 yrs*	No.	Size, m^3	New	Value after 3 yrs	3 yr cost	New	Value after 3 yrs	3 yr cost	Total	per ton sludge per 3 yrs
			$	$	$	$	$	$	$	$	$
3	780	1	4	9K+	5K	4K	24K	15K	9K	13K	16.65
12	3,120	1	10**	23K	11K	12K	24K	15K	9K	21K	6.75
48	12,480	2	10	23K	11K	12K	24K	12K	12K	23K	1.85

EQUIPMENT OPERATORS

Size, tons/day	Trencher Operator			Truck driver (32 km each way)			Total Operator	
	hrs/day	cost/hr	cost/day	hrs/day	cost/hr	cost/day	cost/day	cost/ton sludge
		$	$		$	$	$	$
3	1-8	8	8-64	4-8	6	24-48	32-112	10.65-37.35
12	2-8	8	16-64	4-8	6	24-48	40-112	3.35-9.35
48	8	8	64	16	6	96	160	3.35

(continued)

TABLE 9. (continued)

MAINTENANCE++

Size, tons/day	Dump trucks		Trencher		Total maintenance	
	cost/hr	cost/day	cost/hr	cost/day	cost/day	cost/dewatered ton sludge
	$	$	$	$	$	$
3	8	32	5	5	37	12.35
12	8	32	5	10	42	3.50
48	8	128	5	40	168	3.50

* 5 days per week, 260 days per year

** A concrete mixer truck would cost $40,000.

\+ K = thousands of dollars

++ All maintenance costs are estimated from state and rental operator estimates (includes fuel, oil antifreeze, materials, parts, all labor repair costs, storage repair facilities, insurance, overhead, etc.)

It is cheaper to rent equipment for small operations if all costs, based upon purchase of the equipment and self-operation, must be borne by the wastewater treatment facility for sludge entrenchment only (Table 10). If costs can be shared with other phases of wastewater treatment or other municipal functions, equipment ownership becomes more attractive.

DRAINAGE

Drainage was necessary in only one of the half-dozen test sites due to a high water table. The actual time and costs for installing drainage of the 0.24 hectare test plot with a TLB and inexperienced labor are given in Table 11. The total cost was $484 for the 0.24 hectare plot ($2,000/hectare or $800/acre). In some states drainage can be installed by professional specialists who use laser-guided trenching machines. Their charge for installing perforated plastic drainage tile in a 16 hectare field (40 acres) would be $750/hectare ($300/acre). These charges include land survey and engineering, labor, materials and equipment. Drainage costs may vary, therefore, between $750 and $2,000/hectare ($300 to $800/acre). The drainage costs per dewatered ton of entrenched sludge are between $0.30 and $0.80 figuring entrenching of 2,500 dewatered tons of sludge per hectare (if drainage is necessary).

LAND

No costs for land rental or purchase are included. Land can be farmed within a few weeks after sludge entrenchment. Estimated costs for cultivating, fertilizing, liming and seeding are given in Table 12. These estimated revegetation costs for equipment rental, labor and materials amount to less than $0.50 per dewatered ton of sludge assuming entrenchment of 2,500 tons of dewatered sludge per hectare.

MONITORING

The total estimated analytical costs for sludge, groundwater and surface water monitoring were not over $0.55 per ton of dewatered sludge (Table 13). These cost estimates were based upon equipment purchase and self-operation for pH analysis and contract analyses by some university or service laboratory for the other analyses (Table 14).

TOTAL

Costs for entrenching 12 to 48 dewatered tons of sludge per day with 32 km haul distance each way were estimated to be under $15 per ton and not too different whether on a rental or purchase-self-operation basis (Table 10 and 15). These costs would obviously have to be figured by each municipality. Estimated costs for a 3 ton-per-day operation are considerably higher because allowances were made for minimum rental times and times of employment. If arrangements could be made for use of equipment and personnel more nearly based upon the actual operation time required, 3 to 48 dewatered tons of sludge per day could be hauled 32 km each way and entrenched for less than $15.00 per dewatered ton.

TABLE 10. ESTIMATED SLUDGE ENTRENCHMENT COSTS - TOTALS FOR PURCHASE AND SELF-OPERATION vs RENTAL*(1975)

Size of operation, dewatered tons/day	Dollars/dewatered ton			
	Low**		High**	
	Rental	Purchase-Self-operate	Rental	Purchase-Self-operate
3	43.00	40.00	60.00	66.00
12	11.50	13.50	15.50	19.50
48	11.50	9.00	11.50	9.00

* Totals from Tables 8 and 9.

** Low and high estimates for rentals based on shorter and longer rental periods and for purchase-self-operation based upon shorter and longer labor periods.

TABLE 11. ESTIMATED DRAINAGE COSTS (1975)

Mode	Time	Cost/hr	Total cost 0.24 ha	Total cost 1 ha	Total cost dewatered ton**	Characteristic 10 cm tile spacing	Characteristic 10 cm tile length/ha	Characteristic 7.5 cm tile spacing	Characteristic 7.5 cm tile length/ha
	hours/each		--------$-----				----------m--------		
TLB*									
Labor & Equipment									
surveying, 2 men	4	5	40						
TLB + operator	8	8	200						
Other labor, 3 men	8	5	120						
Materials									
Tile (190 m/0.24 ha)			124+						
			$484	$2,000	$0.80	12	315		
TRENCHER++, Professional contractor									
Labor, Equipment, & Materials				$ 750	$0.30	20	230	12	480

* Method used on 0.24 hectare test plot

* Assuming entrenchment of 2,500 dewatered tons of sludge/hectare

\+ Cost for 10 cm flexible perforated tile is approximately $0.65/meter

++ Cost estimates for tiling in Michigan

TABLE 12. LAND FINISHING COSTS (1975)

Costed Items	Process	Unit cost $/hr	Time reqr. hours*	Total Cost $
LABOR & EQUIPMENT				
Tractor & operator	Rotovating	20.00	4	80
	spreading fertilizer & lime and working in		6	120
Other labor	hand seeding	5.00	4	20
Total				$220
MATERIALS	Total amt reqr, (kg)	$/bag**	No. bags	
10-10-10 fertilizer	450	3.10	23	77.50
Ground dolomitic limestone	1800	0.95	80	76.00
Kentucky 31 tall fescue	69	35.00	3	105.00
Total				$258.50
TOTAL LABOR, EQUIPMENT & MATERIALS, for 0.4 hectare				$478.50
LAND FINISHING COSTS/dewatered ton (20% solids), assuming 2,500 tons sludge/hectare				$ 0.50

* For all test plots spread out in 40 hectare area, about 0.4 hectare total area cultivated in our trials, about 450 total tons of dewatered sludge was entrenched.

** Single bag rate.

TABLE 13. ESTIMATED MONITORING (ANALYTICAL) COSTS (1975)

Size of operation	Land needed per yr[1]	Monitoring element, frequency[2] and cost												
		Sludge[3]					Well Water					Surface Water		
		pH		Other[4]		Total cost sludge/ ton	No. wells	Background[6]		Subsequent[7]		Streams[8]		Total water cost/ton
		times/ day	cost/ yr	times/ yr	cost/ yr[5]			times	cost/ yr	times/ yr	cost/ yr	times/ yr	cost/ yr	
tons/day	ha		$		$	$			$		$		$	$
3	0.3	0.3	364	1	100	0.47	2	2	36	2	12	4	28	0.10
12	1.2	1	460	2	200	0.21	3	2	54	3	27	6	42	0.04
48	4.8	4	1240	3	300	0.12	6	2	108	4	72	12	84	0.02

[1]Assuming 5 day week, 260 days/yr, 1 m^3 = 1 ton dewatered sludge with 20% solids content, 2500 m^3/ha.

[2]Frequencies may be greater or less. Sampling and analyses should be made only often enough to allow good management and control of ground and surface water pollution. Some monitoring should probably continue for 5 years after last sludge is entrenched.

[3]Normally charged to sludge processing operations.

[4]Volatile solids, N, P, K, Zn, Cd, Cu, Pb, Hg, Ni, soluble salts, Cl, lime. The samples should be a good composite taken over a several week period.

[5]Estimated contract cost.

[6]Total and fecal coliforms, Zn, Cl, NO_3, NH_4.

[7]NO_3, NH_4, Cl.

[8]NO_3, NH_4, total and fecal coliforms.

TABLE 14. COSTS FOR ANALYTICAL DETERMINATIONS (1975)

Material	Analysis	Per sample	Capital/yr/2yrs
		$	$
Dewatered sludge	pH	1.00	200.00
	Other*	100.00	
Ground and surface water	NO_3	1.00	
	NH_4	1.00	
	Cl	1.00	
	Zn	1.00	
	Total and fecal coliform	5.00	

* Other - Volatile solids, N, P, K, Zn, Cd, Cu, Pb, Hg, Ni, soluble salts, Cl, lime.

TABLE 15. ESTIMATED TOTAL ENTRENCHMENT COSTS INCLUDING SITE PREPARATION HAULING, TRENCHING, REVEGETATION AND MONITORING* (1975)

Size of operation	Hauling & Trenching rental cost/ton**	Drainage cost/ton**	Seeding cost/ton**	Monitoring cost/ton**
tons/day	$	$	$	$
3	50.00+	0.80	0.50	0.55
12	13.50	0.80	0.50	0.25
48	11.50	0.50	0.50	0.15

* From Tables 6-13.

** Per ton dewatered sludge - assuming 20% solids, 5 day week, 260 days/yr, 1 m^3 = 1 ton dewatered sludge, applying 2500 m^3/ha.

\+ These costs can be reduced nearly equal to costs for a 12 ton/day operation if sludge is held and entrenched only once or twice per week and/or other steps are taken to reduce hauling and trenching costs.

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*U.S. GOVERNMENT PRINTING OFFICE:1978 260-880/31 1-3

TECHNICAL REPORT DATA
(Please read Instructions on the reverse before completing)

1. REPORT NO. EPA-600/2-78-018	2.	3. RECIPIENT'S ACCESSION NO.
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16. ABSTRACT

A method of disposing of dewatered sewage sludge by entrenching it into soil was developed for small communities. Readily available and relatively inexpensive equipment was used. Included were a tractor equipped with a loader and backhoe, and dump truck or concrete mixer truck. A tractor operator and a truck driver were required. Trenches, dug with the backhoe, were 60 cm wide, 60 cm deep, and 60 cm apart. The time required to entrench 12 tons of dewatered sludge was one hour. The estimated cost of sludge incorporation was less than $15.00 per ton of dewatered sludge. Cost items included equipment, personnel, hauling (64 km round trip), land, drainage monitoring, and cultivation. Reuse of a previously trenched site indicated that about 2 years is the minimum satisfactory time lapse between the first and second entrenchment.

Trenching of limed sludge cake can be done without odor or surface water runoff problems. Trenching is most appropriate on low quality land where surface application is not feasible.

17. KEY WORDS AND DOCUMENT ANALYSIS

a. DESCRIPTORS	b. IDENTIFIERS/OPEN ENDED TERMS	c. COSATI Field/Group
Sludge disposal Land reclamation Trenching Salmonella Lime Metals	Limed sludge Digested sludge	13B

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