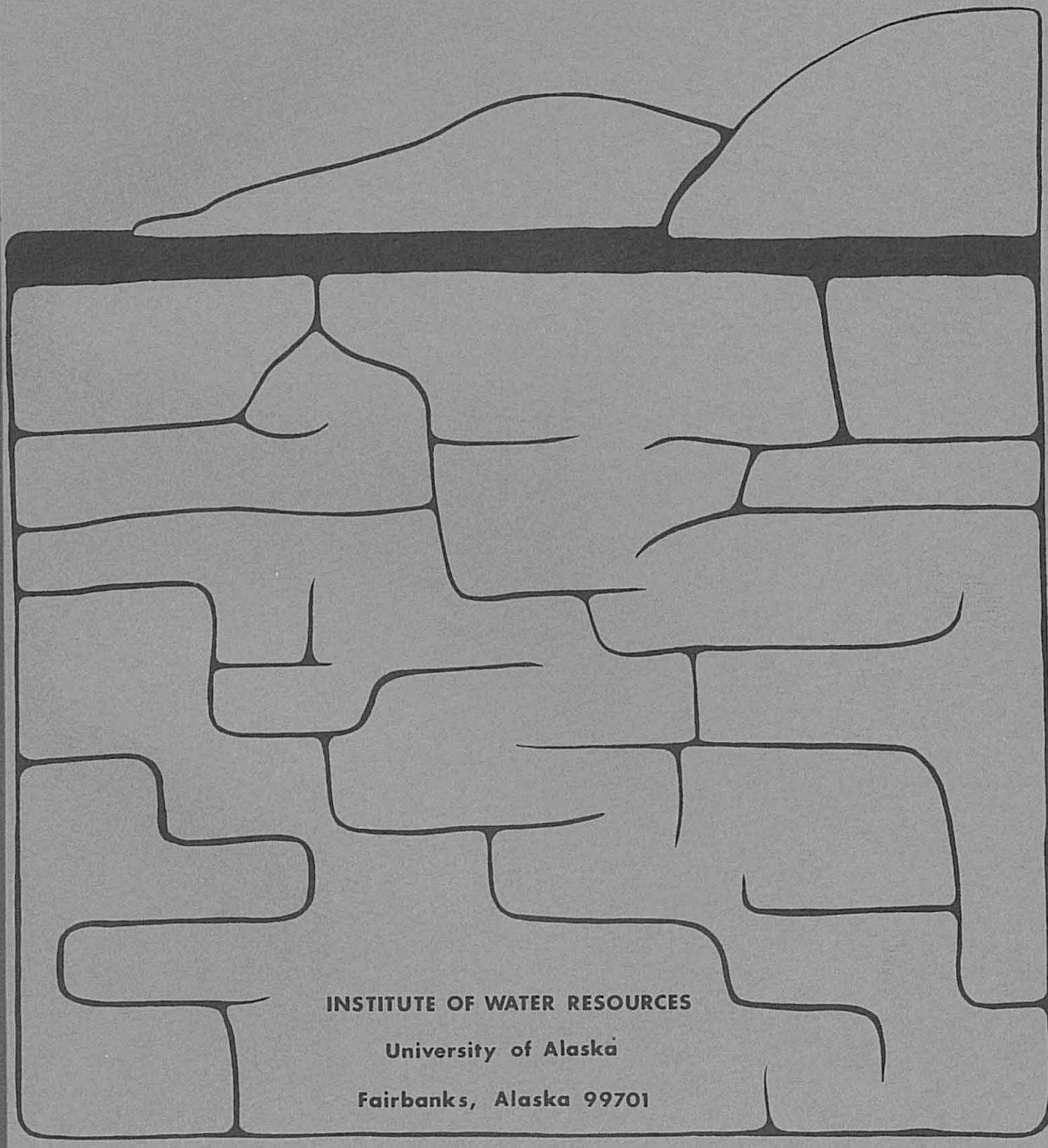
LAND APPLICATION OF DOMESTIC SLUDGE IN COLD CLIMATES



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LAND APPLICATION OF DOMESTIC SLUDGE IN COLD CLIMATES

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PREFACE

This study was performed for the U.S. Army Cold Regions Research and Engineering Laboratory (USA CRREL) and was funded under DA Project 4A762720A896, *Environmental Quality for Construction and Operation of Military Facilities*, Task 02, *Pollution Abatement Systems*.

Mr. Robert S. Shetten of USA CRREL served as technical monitor during the course of the study and he was instrumental in defining the final scope of work. Technical review of this report was performed by Messrs. Robert S. Shetten and Sherwood C. Reed of USA CRREL.

The author thanks graduate students Kerry Lindley and James Winslade for their long hours of field and laboratory work. Advice and laboratory space were provided by Ron Gordon and Charlotte Davenport of the U.S. Environmental Protection Agency's Arctic Environmental Research Laboratory. Other significant contributions were made by James O'Neil, Superintendent of Sanitation, City of Fairbanks, and Frank Wooding of the Agricultural Experiment Station, University of Alaska.

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ABSTRACT

Aerobically digested sludge from the Fairbanks sewage treatment plant was worked into the soil on several plots at the University of Alaska in the summer of 1978. Some of the sludge had been air dried for up to six months prior to application while some was taken directly from the thickener. Applications varied from 12 to 100 tons of solids/acre.

For sludge applied in July and August, the fecal coliform count decayed by several orders of magnitude by the middle of September. There was no significant movement of fecal coliform bacteria either vertically or laterally. Lime was used to raise the pH of one plot to 12, completely killing the fecal coliform bacteria within several days. The nutrient distribution demonstrated the potential for enriching soils by sludge addition.

The main purpose of the study was to investigate the feasibility of this concept for remote military sites. Air drying followed by land application may represent a viable means of sludge disposal.

INTRODUCTION

Land application of wastewater or sludges from wastewater has been practiced for centuries. One wastewater irrigation system in Germany operated for over 300 years beginning in 1559. As of 1972, between 570 and 950 municipalities as well as 1,300 industrial sites in the United States were using land treatment (U.S. Environmental Protection Agency, 1977). Septic systems, which are an infiltration mode of land treatment, are estimated to serve at least 50 million people in the United States (Thomas, 1973). Today, about 25 percent of the municipal sludge produced in the United States is applied to agricultural lands. In Illinois, at least 700 communities practice land application of sludge (Wassermann, 1978).

There are some localities in the United States where land disposal is precluded by a lack of available land or other environmental constraints. New York City is one notable example. Alaska, however, has an abundance of potential disposal sites. The long cold winters do not pose a problem since the sludge can readily be stored for summer application. In fact, the freeze-thaw cycle can be utilized to further dewater the sludge and thus reduce the weight of material to be transported. Important criteria for choosing a disposal site include topography, soil characteristics, flooding hazards, existing and future land uses, nearness to bodies of water, and health hazards.

Applicable data has already been generated in Alaska at Eielson Air Force Base. Wastewater was applied by spray irrigation during two summers of pilot testing. The soils for these tests varied from gravelly loam to silty loam. Effluent from an aerated lagoon was applied at a rate from 3 to 7 inches/week over a 2-month period. Biochemical oxygen demand (BOD) and suspended solids were each reduced to less than 30 mg/l after passage through 6 inches of soil. Fecal coliform bacterial counts were reduced to less than 20/100 ml after passing through only 4.5 feet of soil, representing a 10^4 reduction (Sletten and Uiga, 1976).

Several municipalities and military installations in Alaska have spread domestic sludge on land. The efficacy of this method depends critically on the local climate. In Juneau, where precipitation far

exceeds evaporation, this concept has not been successful (Johnson, 1978). In Fairbanks, the sludge resulting from treatment of municipal wastewaters from both the civilian community and Fort Wainwright is now being spread on sludge-drying beds. In the winter, the sludge freezes with subsequent thawing in the spring. A certain amount of drying is accomplished during the mild, dry summers. These phenomena aid the dewatering process. The sludge from an extended aeration package plant at Campion is placed on drying beds (Morris, 1978), while that from a package plant at Kotzebue is occasionally discharged to the surface of the ground. Eventually, it is transported to a final disposal site (Hargesheimer, 1978). From conversations with these two individuals and Jerry Dunn (1978), this author concluded that there is now no set policy for sludge disposal at remote military sites. These sites include several Army Nike Sites, Dew Line Stations, and Air Force Facilities at Cold Bay, Campion, Fort Yukon, Kotzebue, and Murphy Dome. Many small sites generate limited volumes of sludge. For instance, the total dry mass output from feces and urine is around 60 grams per capita per day (Metcalf and Eddy, 1972). Hence, the solids content from the human excretia of 10 people for one year would only be around 500 pounds mass (lbm), assuming no degradation.

The purpose of this study is to investigate the feasibility of sludge disposal by land application at remote military sites. Aerobically digested sludge from the Fairbanks sewage treatment plant was worked into the soil on several plots in the summer of 1978. Lime was added to one of the plots to aid in disinfection. The spatial and temporal distributions of nutrients and fecal coliforms were monitored until the end of September.

SITE DESCRIPTION

The test site consists of three acres of tilled farmland at the University of Alaska's Agricultural Experiment Station (Fig. 1). The test site and adjacent land are level. Several different treatments were established during July and August (Table 1). The primary plots

established for this project (labelled 0, 1, and 2) consisted of a control (no sludge applied), and dried sludge without and with lime addition respectively. The aerobically digested and thickened sludge had a moisture content of about 95 percent. After 6 months on an outside drying bed, this was reduced to about 30 percent. Moisture content is defined as mass of water divided by total mass.

On both plots 1 and 2, this dried sludge was roto-tilled into the soil to a depth of around 8 inches, after 2 inches were spread on the surface. The loading was 100 tons solids/acre. On plot 2, a lime dosage of 1 lbm of $Ca(OH)_2$ to 4.5 lbm of sludge solids was used. Lime was mixed with the sludge on the surface and the resultant mixture was worked into the soil a few hours later. The pH of this mixture was 12.

Plots 3 and 4 consisted of lesser dosages (40 and 20 tons/acre respectively) of a different dried sludge, which was also worked 8 inches into the soil. This sludge was mechanically dewatered using a polymer coagulant and air dried for about 4 months. This resulted in a moisture content of 70 percent. It will hereafter be referred to as dewatered sludge. The primary purpose of setting up these plots was to provide a nutrient source for planting crops in the summer of 1979. The plots will be used as part of a study by Dr. Frank Wooding of the Agricultural Experiment Station of the University of Alaska. In addition, some data was collected regarding pathogen die-off rates for these plots.

Plot 5 consisted of thickened sludge applied with a dosage of 12.5 tons solids/acre. Since this sludge had a moisture content of 96 percent, lysimeters were positioned at various locations to see the extent of pathogen and nutrient transport via percolating liquid. The application dates varied from July 17 for plots 1 and 2 to August 24 for plot 5.

Much of interior Alaska experiences the cold winters and mild dry summers such as those in Fairbanks. Yearly temperature characteristics for Fairbanks appear in Figure 2. The mean temperature is above freezing only 6 months per year. Breakup typically occurs near the end of April as the normal low climbs above freezing. More detailed climatological data for the research period appear in Table 2.

DESCRIPTION OF SLUDGES AND SOIL

The three-acre experimental site is in a permafrost region that was cleared 40 years ago. The permafrost zone has now retreated to a depth of over 30 feet. The top foot or so (the plowed layer) is Tanana silt loam without compaction. The permeability varies from .2 to .6 inches/hr. Typically, 80 percent of its particles are smaller than 50 microns (U.S. Department of Agriculture, 1963). After a long period of cultivation, this topsoil is quite different from the native soil and is much more consolidated below the plowed layer. Particle size distributions are similar for both layers. Each soil consists of about 7 percent clay, 50 percent silt, 20 percent very fine sand, 15 percent coarse, medium, and fine sand, and 8 percent very coarse sand.

Characteristics of all three sludges (obtained from the Fairbanks Sewage Treatment Plant) appear in Table 3. The air-dried sludge applied to plots 1 and 2 was essentially odorless, brownish-black in color, and consisted of rigid, fist-sized clumps (Fig. 3). A fecal coliform count of 7,900/gm was determined using a 5-tube most probable number (MPN) method.

The dewatered sludge applied to plots 3 and 4 was not quite as dry as that applied to 1 and 2, having a moisture content of around 70 percent. It appeared similar to sludge applied to plots 1 and 2. The fecal coliform count was greater than that for the sludge applied to plots 1 and 2, probably because it had been air-dried for a shorter time.

The thickened sludge applied to plot 5 had a solids content of only 4.4 percent. The relatively low fecal coliform count for the thickened sludge in Table 3 reflects the fact that chlorine is routinely added to the thickener to prevent septic conditions from developing. The higher count for the sludge after application probably reflects regrowth plus the fact that the thickened sludge applied was not from the same batch as that sampled for Table 3. It was applied to the surface in its liquid form to a depth of around 2 inches. Since the liquid readily percolated into the ground, this was the only plot where the sludge was not immediately worked into the soil. Some of this liquid was collected

using lysimeters (Fig. 4). Photographs of this sludge immediately after application and 6 weeks after application appear in Figures 4 and 5, respectively. Figure 5 reflects conditions after the sludge had been worked into the soil and the lysimeters had been removed.

TEST MATRIX

The primary objective of the field work was to obtain data on the fate of the pathogens following land disposal of sludge. Since identifying various individual pathogenic organisms is very time comsuming, it was decided to use fecal coliforms as indicator organisms. The test procedure involved initially using a presumptive test to indicate total coliforms. Then, some of the lauryl tryptose from the positive presumptive tubes was transferred to E.C. medium (Standard Methods, 1976) for a determination of the fecal coliform count at 44.5°C. In each case, a 5-tube MPN method was used. For the primary plots (0, 1, and 2), such data were collected at the time of application in mid-July and twice thereafter at four week intervals. Since the soils and sludge were very dry with no noticeable percolation of liquid except after a heavy rain, fecal coliform densities were monitored by taking grab samples of the soil at different locations. Samples were taken at the surface and depths of 1, 3, and 5 feet. A complete listing of all the sampling times and locations appears in Table 4. The surface samples on the plots were composites from several locations. The number of sampling sites per plot was decreased in September, because the results obtained in August indicated no lateral or vertical migration of fecal coliforms.

Additional monitoring of fecal coliforms was done at the other three sites (Table 4). Liquid samples were only obtained from plot 5. Since sludge was not applied to this site until late August, sampling was only done once more before freeze-up.

Other variables monitored include soil temperature, pH, chemical oxygen demand (COD), total nitrogen, total phosphorous, nitrate-nitrogen, and available phosphorous (Fig. 6, Tables 5 and 6). The first two were monitored at the surface of plots 1 and 2 at least bi-weekly. COD

values were initially obtained for the dried sludge and control plot as a measure of the applied organic loading. Nutrient data were obtained both at the time of application and at the end of the summer. The analyses were done on samples that had been frozen at the time of collection. The nutrient data is important in assessing the value of the sludge for agricultural uses. Nitrate-nitrogen is significant also as a water quality parameter. When consumed in excessive amounts, it can cause methemoglobinemia in infants. For this reason, the U.S. Environmental Protection Agency (EPA) has set a nitrate limit of 10 mg/l in drinking water.

The lysimeters consisted of porous ceramic cups molded to the ends of plastic tubes up to 6 feet long. By applying suction to the tubes after insertion to the desired depths, we obtained liquid samples from plot 5. Temperatures were measured using liquid-filled thermometers, while the pH was measured potentiometrically using a glass electrode. Phosphorous and total nitrogen were determined using the molybdenum blue and Kjeldahl methods respectively. The brucine method was used for nitrate-nitrogen. Potassium dichromate was used as the oxidizing agent for a determination of COD. See Black (1965) for the detailed procedures followed.

RESULTS AND DISCUSSION

All data suggested a rapid die-off of fecal coliforms (Table 4). Fecal coliforms were only found in the surface layer for plots 1 through 4. Essentially complete disinfection with respect to fecal coliforms was achieved within a few days for the lime-treated plot. The dosage of 1 lbm of $Ca(OH)_2$ per 4.5 lbm of sludge solids was sufficient to raise the pH to 12, where it remained for several weeks. This dosage is recommended for rapid disinfection and the resultant pH level has been found to be very effective in disinfecting wastewaters (Dean and Smith, 1973). In fact, Morrison et al. (1973) found even raw sewage could be disinfected to low levels of coliform bacteria in about an hour, by adding enough lime to raise the pH to 12. The fact that rapid disinfection was also

observed after the lime was mixed with dry sludge indicates adequate contact was achieved between the lime and the pathogens in the sludge.

For plots 1, 3, and 4, the fecal coliform counts decayed by several orders of magnitude over a 6-week period. The widely different initial fecal coliform counts for plots 1, 3, and 4 were mainly due to heterogeneity in the original sludge sample and to the different loadings on the two plots. Assuming Chick's Law applies, the decay rates (base e) were .34 and .17 $days^{-1}$ for plots 3 and 4 respectively. Even though there was scatter in the data, these values at least allow characteristic decay rates to be determined. Magnitudes of decay rates seem reasonable in light of similar data obtained by Miller (1973). The highest count initially recorded (49,000/gm) was observed in the dewatered sludge before it was applied to plots 3 and 4.

As noted in Table 4, results are obtained using 1 to 3 replications. Even though we have the most confidence in those values associated with 3 replications, the fact that even those replicated less than 3 times follow a general trend in time promotes confidence in their magnitudes. There is an unmistakable decay with time for all the data, regardless of the number of replicate samples.

The temperature at a 6-inch depth varied from 24°C to 13°C and the pH remained close to 7, except for plot 2, during the study (Fig. 6). Since the intestinal environment remains at about 40°C, the lower temperatures of the plots reduce the fecal populations. Lower temperatures, coupled with the competition from other organisms and the low moisture content of the soil and sludge, restrict the spread of pathogens. In fact, no fecal coliforms were found at depths greater than one foot for any of the plots or adjacent areas. According to Miller (1973), data from extensive studies suggest that pathogenic organisms do not move readily through the soil profile. This is certainly consistent with our observations. The survival time of *E. coli* (which comprises much of the fecal coliforms) is less in dry than moist soils (EPA, 1977). The soils at our test plots had moisture contents of less than 15 percent. The climatological data (Table 2) is consistent with the occurrence of dry soils, and helps one to understand why there is little transport of

pathogens through the soil. For comparable soils and topography, transport should be greater in a moist climate such as that found in southeast Alaska.

The main reason why no significant pathogen movement was observed is that there was negligible percolation of liquid through the soil. Even after the highest rainfall of about 6 inches, most of the soil was still unsaturated. Hence, it is highly unlikely that pathogen transport occurred even after a rainstorm. Even if it did, our data indicate the decay rates must have been very high to reduce the fecal coliform count to zero several days after a rainstorm. The fact that no fecal coliforms were found on the surface soil outside the plot boundary indicates airborne transport to be negligible also. On plot 5 where liquid did percolate through the soil, the fecal coliform count was reduced from 115,000/gm in the raw sludge before application to only 1/gm at a 1-foot depth 2 weeks after application. This shows the potential for rapid decay coupled with limited pathogen mobility.

The effect of the lime on vegetation can be seen by comparing Figures 7 and 8. The lime-treated plot experienced essentially no plant growth because of the high pH. The surface pH decreased from 12 to 8.2 over a 2-month period (Table 6).

The decay rates for fecal coliforms in the dried sludge-soil mixtures were at least .17 day^{-1} in the summer. With initial fecal coliform concentrations of about 50,000/gm, the fecal count should fall below 1/gm after about 60 days. This dried sludge, in turn, undoubtedly had its fecal count drop by several orders of magnitude during the drying period. Hence, if the dewatered sludge were applied to land before drying, more time would be required to reach a count below 1/gm. If the initial fecal coliform density in the dewatered sludge were 500,000/gm, about 80 days would be required, given summer temperatures. Even if some pathogen transport occurred in other soils after a heavy rainstorm, these decay data suggest that net transport will be kept to a minimum.

Data on virus survival was not obtained. Other evidence (Miller, 1973) indicates the movement and survival of viruses differ from fecal coliforms. Therefore, one must be careful about extending this data to

viruses. The fact that coliform densities are used as one measure of drinking water quality suggests that a substance with a low concentration of fecal coliforms should also have a low concentration of viruses. In fact, the enteric virus to coliform ratio in domestic sewage is typically less than 10^{-5} (Hammer, 1975). However, in assessing potential danger from pathogens, one should realize that the infective dose of viruses ranges from 1 to 100. This is orders of magnitude lower than the infective dose for most bacterial and protozoan pathogens (EPA, 1977). Infective dose is defined as the number of organisms necessary to cause disease in healthy humans or animals.

Although some of the samples extracted from the lysimeter tubes had higher than ambient nitrate readings, none had detectable levels of fecal coliforms. Subsequent laboratory tests suggested the porous ceramic cups did not allow fecal coliform bacteria to pass through. This is consistent with a characteristic pore size of 1 to 2 microns, since the rod-shaped *E. coli* is a organism with dimensions of .5 by 1.0-3.0 microns. Hence, the fact that no fecal coliforms were detected did not conclusively prove none were in the infiltrating liquid. It is likely, however, that the concentrations of *E. coli* in the infiltrating liquid were greatly reduced by entrapment of bacteria by the soil particles.

Nutrient data (Tables 3 and 5) indicate large amounts of nitrogen and phosphorus can be applied to agricultural lands using dried domestic sludge. Since typical crop uptake of nitrogen is about 100 lbm/acre/yr, the sludge loadings can be applied to at least this level. In fact, removal of 35 to 60 percent of the applied nitrogen can be expected because of crop uptake if input nitrogen does not greatly exceed crop requirements (EPA, 1977). Of course, for the lime-treated plot, the pH would have to first attain suitable levels before plants could grow. To be usable by the plants, it must eventually be in the form of NH_4^+ or NO_3^-. Similarly, only certain forms of phosphorous are usable by plants. Another project referred to earlier will study the details of nutrient uptake by crops.

Data in Table 5 indicate nitrate levels are higher in the treated plots than in the control. Since NO_3^- readily moves with subsurface water, it is not surprising that elevated levels were found in the

lysimeters buried in plot 5. These levels dropped appreciably in samples outside the plot boundary. With allowable nitrate levels up to 10 mg/l for drinking water, it is obvious that the liquid percolating down from the thickened sludge would violate these standards. Of course, for other reasons, one would not use this liquid directly for drinking water. Since nitrate will move with groundwater, it would be appropriate to monitor this variable for any drinking water collected near land used for sludge disposal. Naturally, the actual nitrate levels occurring would depend on many factors such as oxidation levels, plant uptake, and geohydrological conditions.

By subjecting aerobically digested and thickened sludge to a freeze-thaw cycle followed by a summer drying period, the moisture content was reduced from 95 percent to around 30 percent. Hence, its total mass was reduced by a factor of 14. This finding is consistent with results obtained in Philadelphia (Senske and Lavletta, 1978) where air-dried sludge had a moisture content of 40 percent. If such sludge had to be hauled to a final disposal site, the reduction in transportation costs would be tremendous. This shows the potential for utilizing the climate of even interior Alaska to reduce costs associated with sludge disposal.

By achieving this low moisture content, one year's worth of human excreta from a 10-person facility should weigh less than 1000 pounds. Disposal of such a mass annually should not pose much of a problem for a remote military facility. It could easily be destabilized further by using waste heat and/or hauled to a safe disposal site. With the latter, the transportation cost per capita would be that associated with hauling away 100 lbm/yr. Any military facility that has a nearby site similar to that used for this study and a climate similar to Fairbanks could certainly apply their domestic sludge to land.

If the sludge is initially placed on drying beds, the percolate may still represent a potential disposal problem. It is likely to be of high strength with respect to BOD and other water quality parameters. If climatic conditions permit, the liquid portion of the sludge may be able to be evaporated sufficiently to require disposal of only the relatively

dry residue. Otherwise, it can be recycled to the head end of the plant providing this is done judiciously. In Fairbanks, minimal percolation of the leachate into the siol was observed.

The extra expense involved in building sludge drying beds may be justified if either hauling distances are long, groundwater tables are close to the surface, or the soils are unstable at the disposal site. The latter would certainly be true in permafrost areas. Then, the environmental problems or high costs with adding liquid sludge may be excessive. Of course the detailed economics and environmental problems would have to be studied at each site. For instance, even though pathogens are likely to be transported further in saturated that unsaturated soils, application of sludges may still be justified at some sites at some times.

For dry soils similar to those used for this study and nearby disposal sites, application of liquid sludges is probably acceptable. For loading of 10 tons/acre/year, pathogen transport in dry soils appears minimal. Sludges dredged from the bottom of lagoons could probably be disposed on such sites.

CONCLUSIONS

1. The climate of interior Alaska can be productively utilized to reduce the moisture content of aerobically digested sludge by more than an order of magnitude. This can be accomplished by subjecting the sludge to a freeze-thaw cycle and then allowing it to air-dry in the summer. Such a reduction in total sludge mass will greatly reduce transportation costs if the sludge must be hauled to a final disposal site. Moreover, the same natural processes also will reduce the pathogen count. If any percolate remains, it could be further evaporated or recycled to the head end of the plant.

2. Such sludge was worked into the soil at a solids loading of 100 tons/acre, producing an odorless mixture. Over the course of six weeks, the fecal coliform count was reduced by three orders of magnitude and no

significant movement into the soil column was observed. Lateral movement was not observed either. This was for relatively dry soils. There does not appear to be a health hazard linked to the spread of pathogens, if land application on such soils is practiced. Additional monitoring for viruses should be performed before standardizing such practices. For soils saturated with water, additional field data should be collected.

3. Rapid disinfection results if slaked lime is mixed with such sludge at a dosage of about one pound of lime per four pounds of sludge solids. For the tests discussed in this report, the resultant pH was 12 and no fecal coliforms were detected after several days.

4. Since the camp populations at remote military installations may range from a dozen to several hundred, it doesn't seem wise to install elaborate sludge treatment facilities where suitable land disposal sites exist. This is especially true if the site populations are decreasing. Drying followed by land disposal may represent a simple but workable solution for non-permafrost sites.

5. If sludge from the thickener is applied to land without dewatering, nitrate levels should be monitored because this ion easily moves in the liquid phase.

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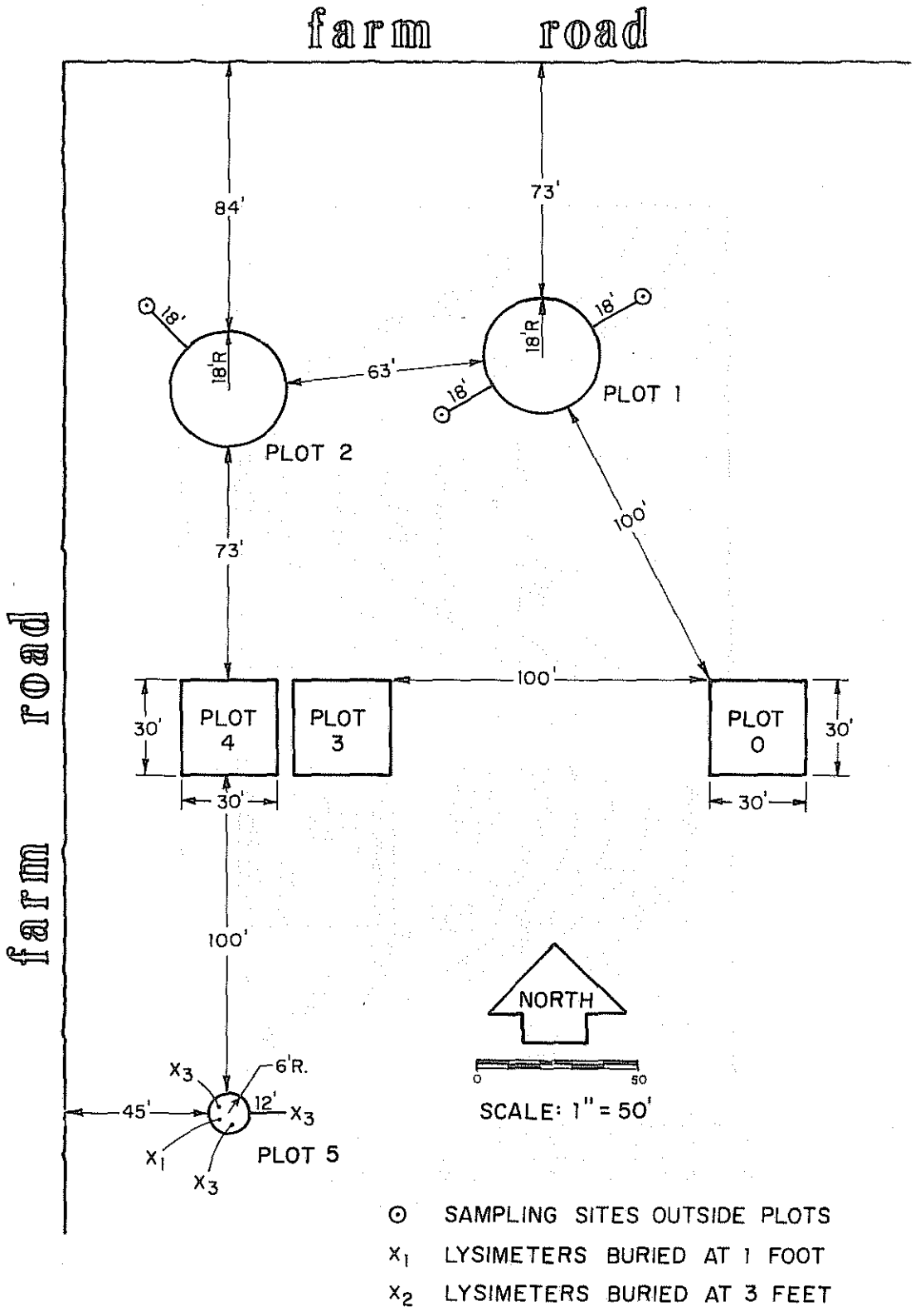

Fig. 1. Plot locations.

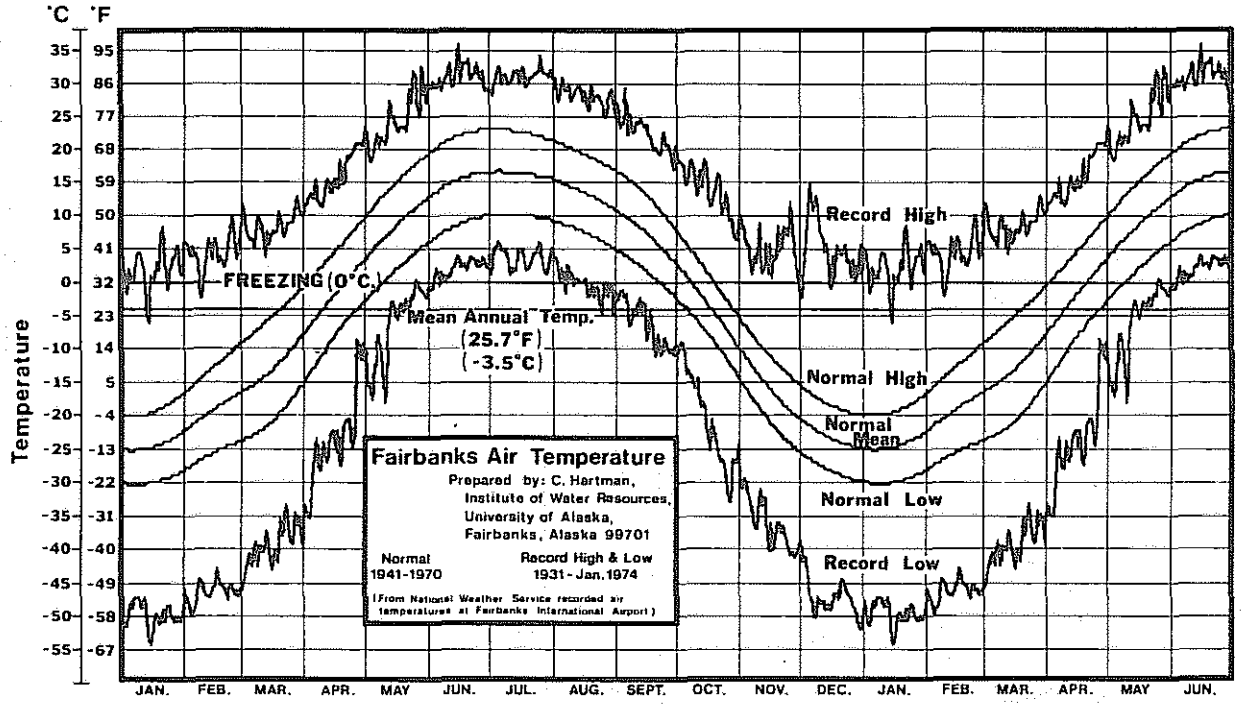

Fig. 2. Fairbanks temperature variation.

Fig. 3. Dried sludge before incorporation into soil.

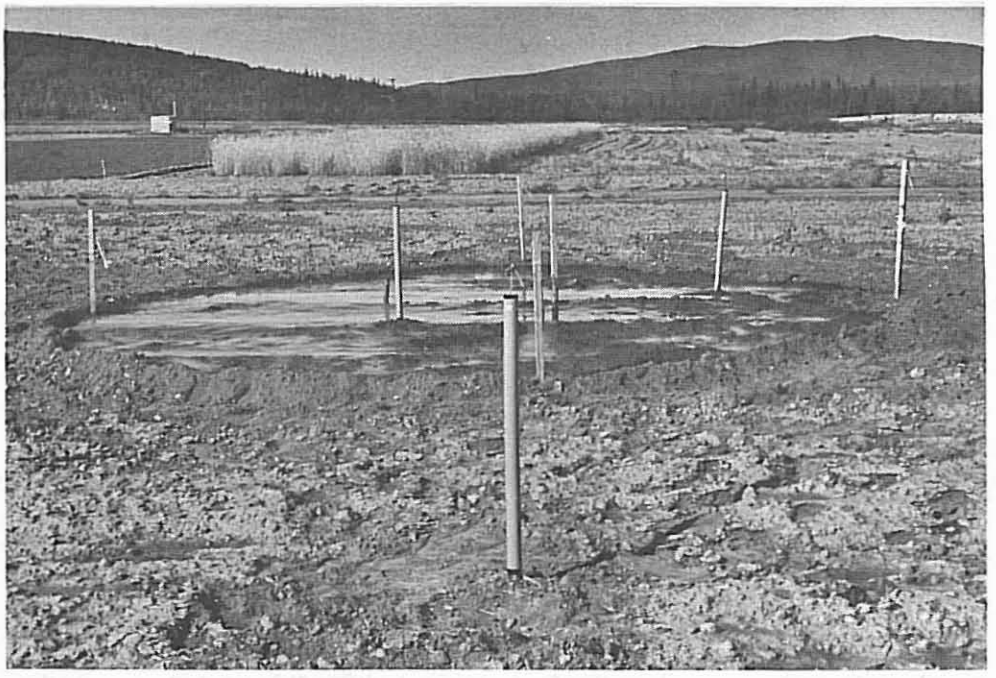

Fig. 4. Plot 5 immediately after application.

Fig 5. Plot 5 five weeks after application.

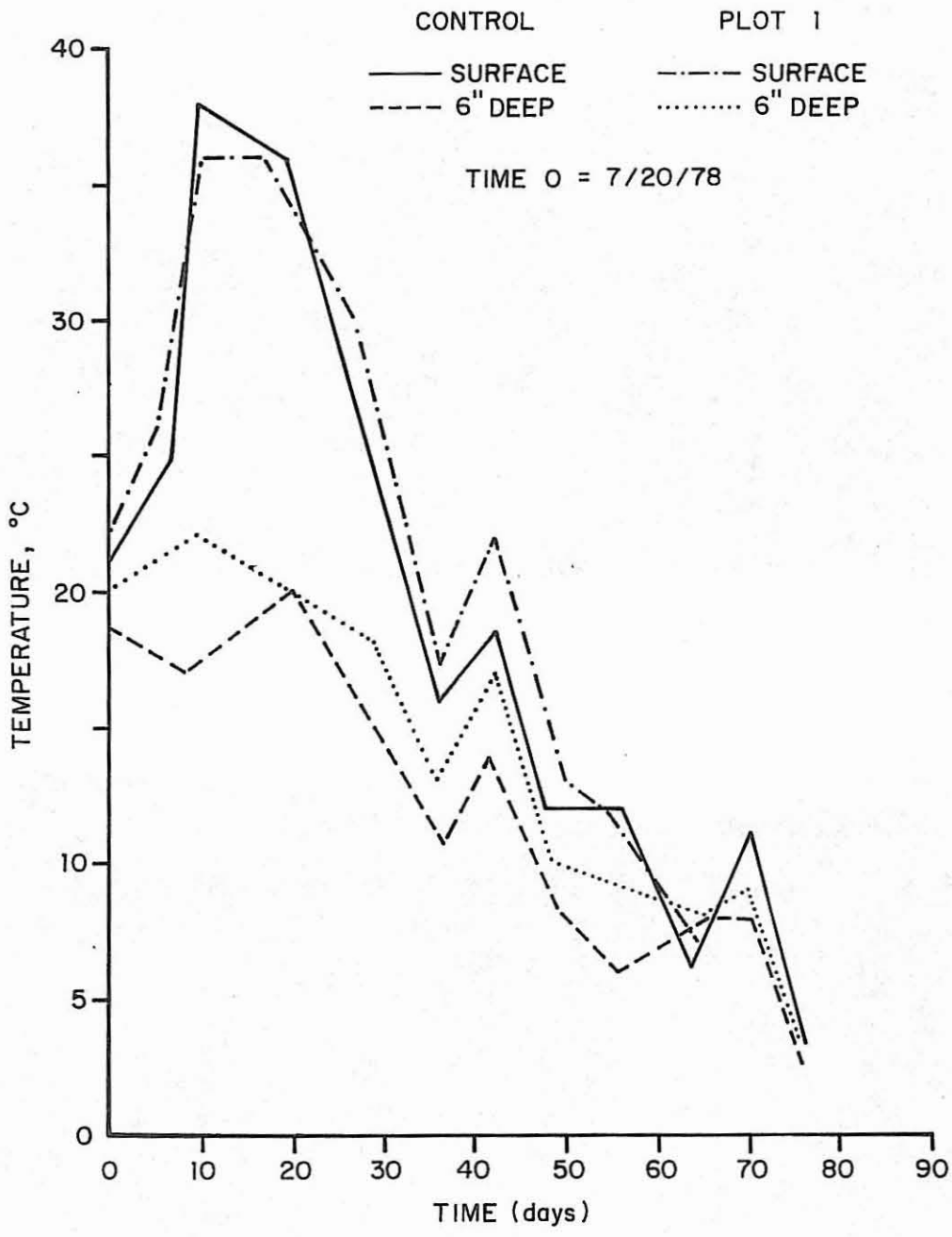

Fig. 6. Soil temperature variation.

Fig 7. Plot 1 six weeks after application.

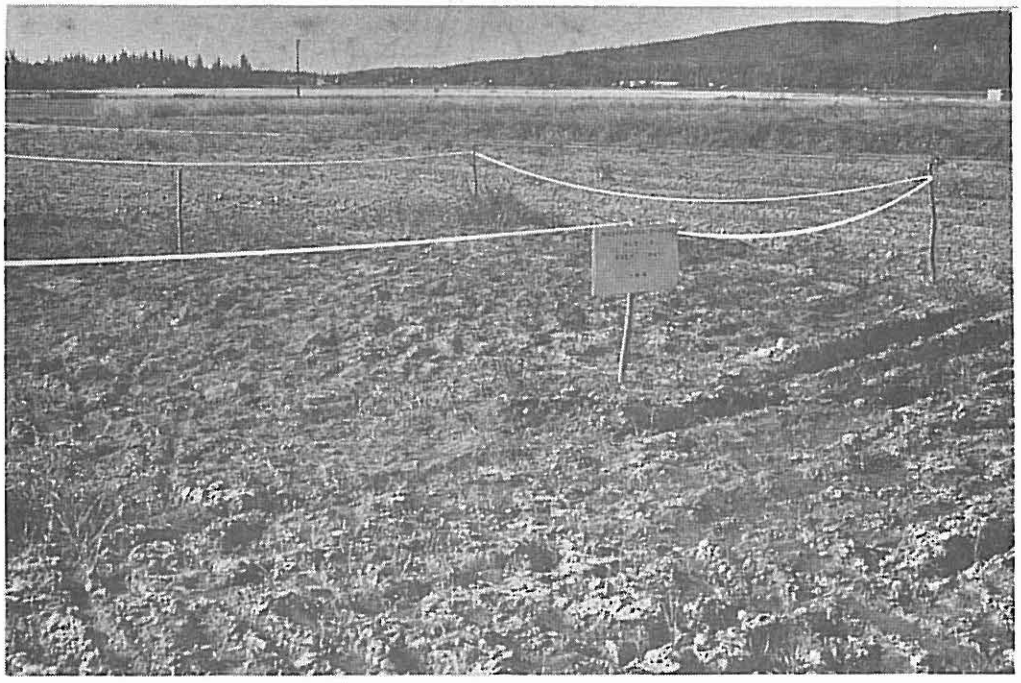

Fig. 8. Plot 2 six weeks after application.

Table 1: Summary of Treatments

Plot No.	Area ft^2	Type Sludge Applied	C.O.D. Load tons/acre	Solids Load tons/acre	Nitrogen Load tons/acre	Moisture content-%	Application Date
0	-	None	0	-	0	14.3	-
1	1000	Air-dried	83	100	3.2	30.0	July 19, 1978
2	1000	Air-dried	83	100 (not including lime)	3.2	30.0	July 19, 1978
3	900	Dewatered Air-dried	-	40	-	70.0	August 24, 1978
4	900	Dewatered Air-dried	-	20	-	70.0	August 24, 1978
5	450	Thickened	-	12.5	-	95.6	August 26, 1978

Table 2: Climatological Data (at Agricultural Experiment Station)

Date	Air Temperature °F Max	Min	Mean	Precipitation (24 hrs.) Inches	Evaporation Rate in/day	Wind Speed mi/hr[1]
7/19*	79	46	69		-.215	1.42
7/20	70	51	60		-.250	2.21
7/21	75	46	58		-.157	1.17
7/22	67	44	55	.23	-.056	1.71
7/23	75	46	62		-.326	1.00
7/24	77	44	66	.61	-.923	3.63
7/25	69	43	56		-.006	7.92
7/26	76	45	60		-.107	-
7/27	75	42	68	.18	-.139	1.25
7/28	78	46	71		-.366	1.96
7/29	83	46	63		-.170	2.21
7/30	86	50	68		-.288	2.04
7/31	83	46	67		-.179	1.71
8/1	79	51	56	.09	-.213	2.58
8/2	73	51	61	.10	-.161	0.75
8/3	78	50	64		-.259	2.08
8/4	82	45	65		-.156	2.46
8/5	75	54	60	.34	-.114	1.42
8/6	70	56	60		-.125	1.25
8/7	72	44	62		-.112	1.00
8/8	81	50	68		-.200	1.38
8/9	78	47	65	.26	-.094	2.21
8/10	75	43	64		-.171	0.54
8/11	79	46	65		-.138	0.71
8/12	75	47	67		-.149	1.21
8/13	78	45	60	.14	-.207	1.21
8/14	70	47	58	.05	-	1.29
8/15	69	49	55		-.113	.96
8/16	72	45	59		-.131	1.00
8/17	74	44	60		-.108	.83
8/18	72	59	37	.03	-.250	1.25
8/19	77	36	40		-.110	1.54
8/20	59	41	50	.06	-.148	3.00
8/21	52	42	50	.44	-.061	2.88
8/22	56	42	51	.02	-.041	1.58
8/23	56	46	49	.07	-.103	.63
8/24	No Data Available					
8/25	No Data Available					
8/26	70	40	65		-.190	1.46
8/27	73	33	69		-.140	.67
8/28	74	40	70		-.044	1.04
8/29	72	41	70		-.202	2.08
8/30	73	39	64		-.086	.83
8/31	72	43	68		-.089	.25

Date	Air Temperature °F Max	Min	Mean	Precipitation (24 hrs.) Inches	Evaporation Rate in/day	Wind Speed mi/hr[1]
9/1	73	41	65		-.117	3.25
9/2	71	42	67		-.117	.92
9/3	75	44	56		-.083	1.54
9/4	70	36	56		-.085	1.50
9/5	70	41	53		-.107	.75
9/6	61	42	49	.40	+.04	.96
9/7	64	38	56		-.075	1.00
9/8	68	31	56		-.071	2.67
9/9	72	38	63		-.072	1.96
9/10	64	43	47	.09	-.019	1.00
9/11	63	41	57		-.055	.88
9/12	68	38	60		-.053	1.96
9/13	65	36	59		-.041	1.46
9/14	66	30	48	.02	-.072	1.88
9/15	62	31	50		End of	.79
9/16	63	34	58		observation	1.58
9/17	59	37	50	.03		1.21
9/18	64	35	55			2.08
9/19	56	34	44			1.63
9/20	59	31	46			End of
9/21	50	31	47			observation
9/22	49	29	43			
9/23	49	20	41			
9/24	52	28	40			
9/25	52	26	49	.65		
9/26	51	30	47			
9/27	53	33	49			
9/28	52	29	43			
9/30	48	23	34			

[1]Mean daily wind speed divided by 24 hrs/day to yield mean value in mi/hr.
Source: Agricultural Experiment Station, University of Alaska, Fairbanks.
*Date of sludge application to plots 1 and 2.

Table 3: Characteristics of Sludge and Soil

Variable	Soil			Sludge		
	Control Plot	Plot 1	Plot 2	Thickened	Dewatered	Dried
Moisture[c]	14.3	13.9	19.6	95.6	70	30
Volatile Solids[c]	6.3	8.5	10.3	50.8	41	43
Fixed Solids[c]	93.7	91.5	89.7	49.2	59	57
C.O.D.[a], mg/gm	359	453	358	-	-	832
Fecal Coliforms, count/gm	-	-	-	8,800[b]	49,000	7,900
pH[a]	7.5	7.4	12.1	5.7	6.0	7.4

[a]pH and C.O.D. of plots 1 and 2 after incorporation of sludge and sludge-lime amendment respectively.
[b]Geometric Mean
[c]Values represent percent by mass.

Table 4: Fecal Coliform Data

	Dried Sludge	Plot 1	Plot 2	Control Plot	Dewatered Sludge	Plot 3	Plot 4	Thickened Sludge	Plot 5
7/4	7900								
7/21[a]		7900	0	0					
8/16[b]		14	0	0					
8/22					49,000	3500	200		
8/28						426[f]	90[f]	8800[f]	
9/5						11[c]	10[c]		
9/12[d]		14[c]	0	0		14[c]	8[c]		115,000[e]

All numbers shown above represent values at surface, measured as count/gram.
For data obtained on or before 8/22, only 1 composite sample was taken for 5 tube MPN.

[a]Dried sludge applied to plots 1 and 2 on 7/19; lime added to plot 2 and both plots cultivated to incorporate amendments.

[b]Samples taken from surface, 1', 3', and 5' depths from plots 1 and 2. Samples taken from surface and 1' depth, 18' away from plots 1 and 2. Fecal coliforms were only detected at surface.

[c]Average value - 5 tube MPN. 3 replicates.

[d]Samples taken at 1' depth on plot 1, and 18' away from plot 1 on surface showed no fecal coloforms.

[e]Samples taken at 1' depth on plot 5 showed values of 0, 0, and 2 fecals/gm on the 3 replications.

[f]Values represent geometric mean.

Table 5: Nutrient Data

Date	Sample From	Nitrate-Nitrogen[a] (mg/kg wet wt.)	Total[b] Nitrogen (% dry wt.)	Total[c] Phosphorous (% dry wt.)	Available[c] Phosphorous (mg/kg dry wt.)
7/4/78	Plot 0	70	.22	.075	359
	Air-Dried Sludge	134	3.3	2.3	4200
7/27/78	Plot 0	-	-	.15	-
	Plot 1	118	.30	.30	912
	Plot 2	-	-	.13	-
9/12/78	Plot 0	68	.200	.09	429
	Plot 1	263	.41	.39	2102
9/22/78	Plot 1 1' Depth	124	.20	.12	440
	Plot 1 3' Depth	103	.10	.08	172
9/5/78	Plot 5 Lysimeter Sample-1' Depth-Inside	84 mg/l[a]	-	-	-
	Lysimeter Sample 3' Depth Inside	30 mg/l[a]	-	-	-
	Lysimeter Sample 3' Depth Outside	24 mg/l[a]	-	-	-

All samples taken from surface unless otherwise noted.

[a]Values obtained via Brucine Method at Environmental Services Limited, Fairbanks.

[b]Kjeldahl Method via Forest Soils Lab at University of Alaska, Fairbanks.

[c]Molybdenum Blue Method via Forest Soils Lab at University of Alaska, Fairbanks.

Table 6: pH Data

Date	Sample Tested	pH Reading
7/19/78	Plot 0	7.4
	Plot 1	7.4
	Plot 2	12.1
7/17/78	Plot 0	7.5
	Plot 1	7.3
	Plot 2	11.9
8/8/78	Plot 0	7.5
	Plot 1	7.3
	Plot 2	11.9
8/25/78	Plot 0	7.6
	Plot 1	7.2
	Plot 2	8.8
9/1/78	Plot 0	7.6
	Plot 1	7.2
	Plot 2	8.6
9/12/78	Plot 0	7.6
	Plot 1	7.2
	Plot 2	8.6
9/22/78	Plot 0	7.6
	Plot 1	7.2
	Plot 2	8.6
9/26/78	Plot 0	7.0
	Plot 1	6.4
	Plot 2	8.2