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A Study of Forced Aeration Composting of Wastewater Sludges

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A STUDY OF FORCED AERATION COMPOSTING OF WASTEWATER SLUDGE

by

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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.

Wastewater sludge can be converted by composting into a soil conditioner as one method of recycling resources. Wastewater sludge has been composted on a regular schedule at Beltsville, Maryland, and Bangor, Maine, using forced aeration technology developed by the U.S. Department of Agriculture, Agricultural Research Service, Beltsville, Maryland. Both of these operations have received grant funds from the U.S. Environmental Protection Agency.

The results of an intensive study of these two operations are presented in this report.

Francis T. Mayo, Director
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ABSTRACT

This study was initiated with the overall objective of developing an independent assessment of the forced aeration wastewater sludge composting method as practiced at Beltsville, Maryland, and Bangor, Maine. A number of visits were made to both sites to observe operations under all weather conditions and to gather data. The analysis developed herein is based on information obtained during the site visits, information provided by various agencies and individuals, and independent observations and calculations.

Results of the study indicate that forced aeration wastewater sludge composting can be carried out in a satisfactory manner under nearly all weather conditions, including severe New England winters. A number of problems and potential problems are identified along with possible solutions. Costs per unit of sludge processed are very dependent on the size of the operation and the methods used. Several possibilities are explored for reducing costs by modifying operations.

This report was submitted in partial fulfillment of Contract No. 68-03-2186 by Culp/Wesner/Culp - Clean Water Consultants under the sponsorship of the U.S. Environmental Protection Agency. This report covers the period June 1, 1976 to July 1, 1977, and work was completed as of July 1, 1977.

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ACKNOWLEDGMENTS

Culp/Wesner/Culp - Clean Water Consultants gratefully acknowledge the cooperation of many agencies in providing information and data for this report.

The Maryland Environmental Service and United States Department of Agriculture, Agricultural Research Service, provided data related to the Beltsville operation and unlimited access to the site. The cities of Bangor, Maine, and Durham, New Hampshire, provided complete data related to their operations in addition to site visits.

The personnel of the Ultimate Disposal Section, Wastewater Research Division, US EPA, MERL, provided much of the coordination required between agencies and performed the technical review of the final report.

SECTION 1

INTRODUCTION

The objective of this study is to report on the major operational aspects of the forced-aeration wastewater sludge composting method as practiced at Beltsville, Maryland (Beltsville), and Bangor, Maine (Bangor). Beltsville has been supported from December, 1975, through December, 1977, as follows:

Blue Plains Participants	32%
EPA Region III	32%
U. S. Dept. of Agriculture	22%
EPA Office of Research and Deveopment	14%
Total	100%

Bangor has received grant funding from the EPA Office of Solid Waste Management Programs. The forced-aeration composting process is a development of the Agricultural Research Staff at Beltsville, Maryland.

The principal sources of information and data were the actual operations at Beltsville and Bangor with some support information from the operation at Durham, New Hampshire, and the windrow composting operation at the County Sanitation Districts of Los Angeles County Joint Wastewater Treatment Plant at Carson, California.

This report represents an independent assessment of the forced-aeration technique for composting raw wastewater sludge based on evaluation of available data and on-site observations.

SECTION 2

CONCLUSIONS AND RECOMMENDATIONS

CONCLUSIONS

The forced aeration method of wastewater sludge composting is a biological stabilization process, but in terms of actual work is basically a materials handling operation. All operations to date use mobile equipment with little demonstration of fixed materials handling equipment. The use of mobile equipment does provide for flexible and satisfactory materials handling, but use of fixed equipment might contribute to decreased operational costs for some parts of the operation. Presently, operation and maintenance costs vary from $86 to $150 per dry ton of wastewater solids processed and depend on the installation size. Removal of costs related to research and optimization of operations would reduce sludge composting costs to $50 to $80 per dry ton of wastewater solids.

Composting has been accomplished outdoors in all types of weather on a continuous basis at both Beltsville and Bangor. Heavy rain and extreme cold have been minor problems and require more careful operation, but have not interrupted composting operations.

Screening is greatly affected by weather. Screening cannot be accomplished outdoors in rainy or very cold weather. Therefore, screening must be accomplished during favorable weather or the operation must be weather proofed. Screening can be a limiting factor for a composting operation and careful consideration must be given to the type of equipment, the average daily screening capacity, the amount of material to be screened, moisture content of the material to be screened, and the number of days during which screening can take place.

Careful consideration must be given to the type and availability of bulking agent to be used. Bulking agents can be a major operational cost and may be difficult to obtain in certain areas of the country. There are several potential techniques for conservation and reuse of bulking agent. The most promising is to use compost from a pile being torn down as bulking agent for new sludge.

The operations at Beltsville and Bangor are carried out with minimal nuisances. Some odors are generated at both sites, but public complaints have been nil and operations are never shut down; in fact, it is impossible to "shut down" operations because composting and curing are continuous processes. Operations can be stopped by hauling the materials to a landfill or disposal site.

Waterproofing of some of the normal unit operations is desirable. Composting has been carried out at Beltsville for several years on an outdoor gravel base. The recent installation of hard surfacing at Beltsville has improved the operations and should be considered for all new installations. The installation of covered areas for mixing, curing, and screening should be considered for areas with heavy and prolonged rainfall.

Sufficient pathogen and indicator organisms data are available to develop some generalized conclusions. Based on these data and additional calculations, the risk of disease outbreak in adult humans from properly operated wastewater sludge composting appear to be very slight considering the tolerance level to pathogens exhibited by adult humans. Some risk may exist, however, because there is no way to assure complete kill of all pathogenic or parasitic organisms in outdoor composting unless the compost is sterilized. Generally, the use of wastewater sludge based compost will be subject to regulatory agency requirements in most states.

RECOMMENDATIONS

Operational methods should be investigated to minimize materials handling, use of bulking agent, and screening. Several methods which offer potential savings in these operations are suggested herein. One major method is reuse of unscreened compost as bulking agent through one or more cycles. Some of these methods have been tested on a limited scale, but should be tested and refined further. Use of these methods should reduce operation costs and also provide some operation benefits such as conservation of heat during cold weather operations.

Careful plans should be developed for marketing or disposing of the compost product. Some revenue may be realized from selling the compost, but the return will not cover the total costs of producing the compost. Methods are discussed for reducing compost production if desired, or necessary, because of disposal limitations.

It is difficult to make recommendations related to pathogenic organisms because any conclusions or illustrations developed herein are only opinions. Some pathogenic organisms will likely be present in the compost unless it is completely sterilized. Even with sterilization, reinfestation by certain pathogenic bacteria is possible. The possibility of disease outbreak related to the use of properly developed wastewater sludge compost is very small because humans do exhibit a tolerance to fairly high levels of pathogenic organism infection before actually exhibiting signs of the disease. It is recommended that composting operations be carried out to assure interior pile temperatures greater than 60°C for several days and that a 30 day curing period be utilized following composting. These steps will assure the highest possible pathogen kill. Other steps to minimize the ingestion of compost by humans such as use of compost on non food crop applications will reduce any potential of disease outbreak.

SECTION 3

OPERATIONS

GENERAL DESCRIPTION

The Beltsville composting site has been used for several years for the research and demonstration project. The composting operations are carried out by Maryland Environmental Service (MES) personnel. The research activities are carried out by the U.S. Department of Agriculture, Agriculture Research Service (ARS). Even though research activities are being carried out at Beltsville, the basic sludge composting operations are similar to what may be carried out by any municipality. In 1976, a total of 14,459 wet tons of undigested wastewater sludge conditioned with lime and ferric sulfate and dewatered (approximately 23% solids) from the Washington, D. C. Blue Plains plant was composted at Beltsville using the extended pile forced-aeration method. This method is described in Appendix A. Operations were carried out on a regular schedule as would be required by a municipal sludge processing facility. In the first part of 1976, sludge deliveries were made 7 days a week while, during the last part of 1976, deliveries were made 5 days a week with only partial staffing on weekends. Sludge deliveries averaged approximately 300 wet tons per week (approximately 60 wet tons per day on a 5 day per week basis). Sludge delivery was accepted every working day except when Blue Plains could not provide sludge or the delivery trucks could not operate. This delivery schedule represents operation typical for a municipality serving the equivalent of 140,000 to 160,000 persons. Sludge deliveries have been as high as 100 wet tons per day for several days at a time at Beltsville.

The analysis of operations at Beltsville provides guidance for planning a regular municipal wastewater sludge composting facility. This report will focus on the regular operations at Beltsville and will not emphasize the research operations except where specific data such as pathogen organisms densities provide applicable information. The Beltsville operations provide useful information for municipal sludge composting during various weather conditions including cold, snow, rain, inversion conditions, and fair weather.

Forced-aeration wastewater sludge composting also has been carried out by the municipality of Bangor for over two years, through two winters, outdoors and in very severe weather conditions. In 1976, the City composted approximately 1,944 cu yd (332 dry tons) of 23 percent solids, dewatered raw (primary) sludge at the City owned site at the Bangor International Airport. Total Bangor sludge production in 1976 was 3,033 cu yd (525 dry tons). The sludge not composted (1089 cu yd) was hauled to a landfill.

This report is based on observations of the Beltsville and Bangor municipal sludge composting operations with data input from several on-site visits and information provided by MES, ARS, the Town of Bangor, and USEPA.

SITE VISITS

To develop an independent and realistic assessment of the Beltsville and Bangor operations, considerable on-site observations were made at both sites under various weather conditions as shown in Table 1. Information was also obtained from discussions with operating, supervisory, and administrative personnel. Cooperation of all operating agency personnel was outstanding.

MATERIALS HANDLING ASPECTS

Optimization of materials handling is of primary importance for successful municipal sludge forced air composting operations. The volume of materials handled varies almost directly with the input sludge quantity. The type and characteristics of materials handled varies from site to site depending on type of sludge, type of bulking agent, and weather conditions. The optimum or most cost effective materials handling methods will vary significantly depending on the size and how the operation is carried out. Beltsville and Bangor provide information primarily on the use of mobile equipment for materials handling because neither operation was using fixed equipment at the time of this study.

Beltsville

An approximate scale layout of the Beltsville operations site is shown in Figure 1.

Undigested sludge cake (approximately 23 percent solids) from the Washington, D. C. Blue Plains wastewater treatment plant is delivered to Beltsville in 10 wet ton loads by conventional 3 axle dump trucks. Two trucks are used. Each truck makes 3 trips for 60 wet ton per day delivery. Delivery generally begins early in the morning and continues into early afternoon. Prior to the sludge delivery, pads of bulking agent are prepared in the mixing area. These pads are 9 to 10 feet wide, 1 to 2 ft deep and as long as required for the bulking agent to sludge ratio mix for one truckload of sludge. The sludge trucks arrive on site, are weighed, and then dump the sludge onto the bulking agent pad. A front loader is used to spread the sludge evenly over the top of the bulking agent. The Terex composter then moves along one side of the sludge - bulking agent pad and then along the other side, mixing the materials toward the middle to form a partially mixed windrow of triangular cross section. The Roto-Shredder then passes through the windrow, turns around, and passes back through the windrow. This operation mixes the sludge and bulking agent to form a relatively homogeneous mixture. The Terex composter and Roto-Shredder are both used because they are available at Beltsville. Satisfactory mixing can be accomplished using either machine alone. Mixing can also be accomplished

TABLE 1. SITE VISITS AND WEATHER

Site	Date	Weather	Range of temperature, °C
Beltsville	9-27-76	Fair	10 to 15
	9-28-76	Fair	10 to 15
	9-29-76	Fair	
Beltsville	1-26-77	Cold, Snow on ground,	-9 to 2
	1-27-77	some inversion, no	-9 to 4
	1-28-77	wind in early mornings	-9 to 7
Beltsville	4-4-77	Heavy rain, windy	4 to 13
	4-5-77	Rain	4 to 13
	4-6-77	Fair, windy	2 to 13
	4-7-77	Cloudy, windy	1 to 13
Beltsville	6-21-77	Fair	21 to 27
	6-22-77	Fair	21 to 27
Bangor	9-22-76	Fair	2 to 18
	9-23-76	Fair	2 to 18
Bangor	2-23-77	Fair	-9 to -1
	2-24-77	Cloudy	-9 to -2
	2-25-77	Freezing rain, snow	-4 to -1
Bangor	6-1-77	Clear	21 to 27

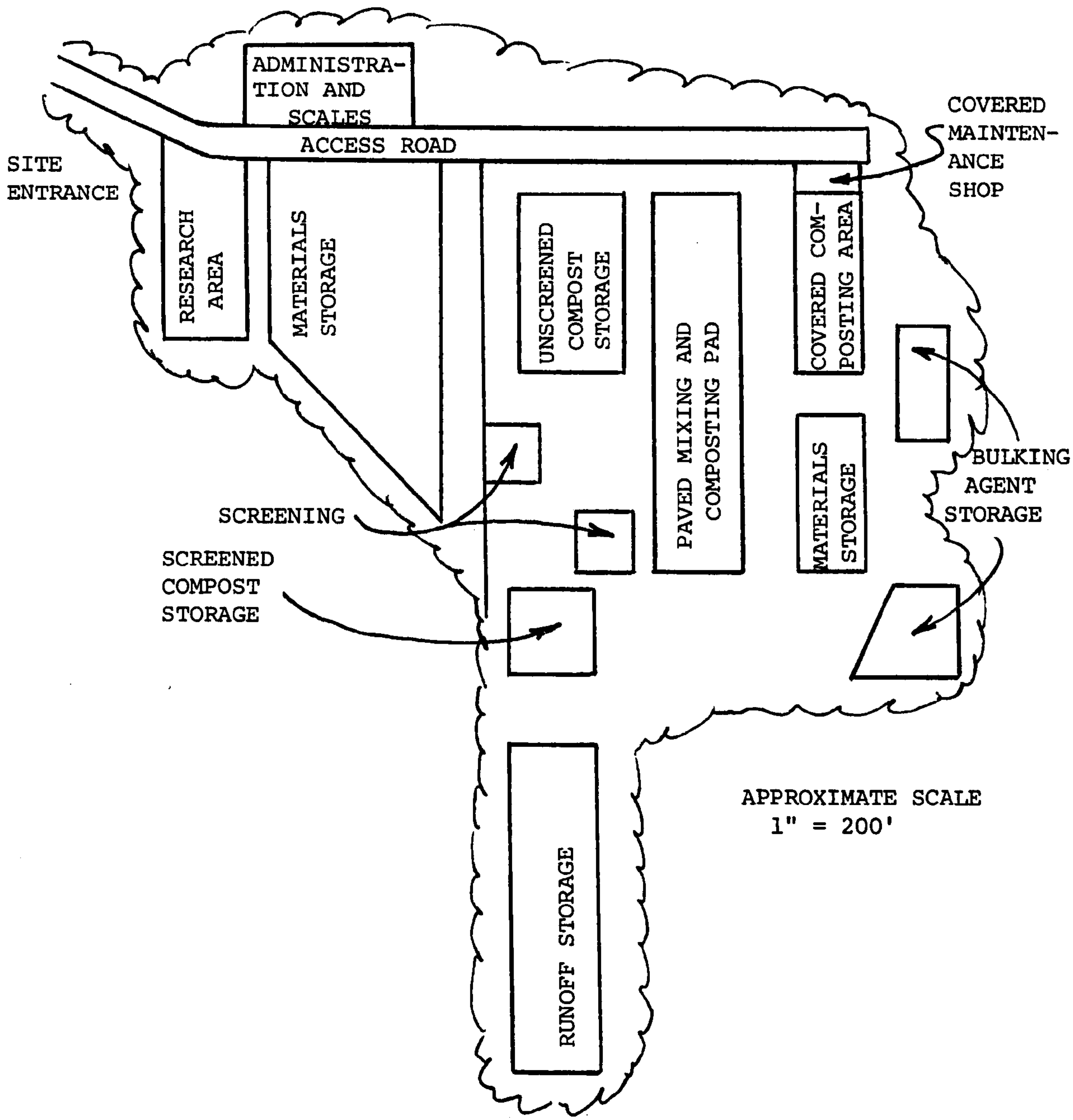

Figure 1. Beltsville composting site layout.

using only the front loader, but is more time consuming to produce a good mix. It is felt that a good mixture, free of large sludge balls, is important for good composting and producing a high quality product.

Beltsville has been using the extended forced-aeration pile composting configuration. Material is added to the pile each day and aeration pipes are spaced about every 8 feet on center. The composting pad for each days sludge-bulking agent mixture is prepared by laying out the aeration piping on the asphalt composting pad and covering this pipe with a 12 in. layer of wood chips using a front loader. The sludge-bulking agent mixture is then placed on the wood chip base using a front loader. The mixture is piled to a height of about 8 ft. The top and ends of the pile are then capped with an 18 in. layer of unscreened compost or a 12 in. layer of screened compost. At the end of each days operation the side of the pile (which will be added to the next day) is covered with a thin layer of compost. The blower is connected to the piping and a 5 cu yd pile of screened compost is placed over the end of the blower discharge piping for deodorizing the discharged air. The blower pulls air from the composting pile and discharges to the deodorizing pile. The blower is generally operated on an on-off cycle controlled by a timer. The duration of the on and off cycles is adjusted to suit the particular operating conditions.

Generally, compost is removed from the opposite end of the extended pile each day or every other day after 21 days of composting. This part of the pile is torn down using a front loader and is moved to the curing pile. At Beltsville, the aeration pipe is a light weight plastic considered expendable and therefore, is moved with the compost. The compost stays in the curing pile for at least 30 days, usually for a much longer period, awaiting screening or off-site use. The unscreened compost can be stored for long periods depending on the needs of the particular operation and the screening and compost distribution operations.

Processing of the dewatered raw sludge cake and formation of the compost pile must be carried out on a regular basis consistent with raw sludge delivery. Raw sludge is mixed with bulking agent and processed into a compost pile promptly as it is received on site to avoid odors and health hazards. Raw sludge is not stored on site. Should site conditions or weather shut down operations (there are practically no instances of this occurring at Beltsville) sludge would not be delivered but instead be either stored at the Blue Plains plant or diverted to other disposal sites.

Screening is used to separate the wood chips from the compost: (1) so that a portion of the chips can be reused, (2) to control the maximum particle size of the compost, and (3) to improve the carbon-nitrogen ratio of the finished compost. Most screening is performed using a 5/8-inch mesh rotary drum screen. The drum is 7 feet in diameter and about 14 feet long. The tilt of the drum is adjustable as is the feed rate. Screening can be scheduled independent of other operations because of unscreened compost storage availability. In practice, however, enough compost is screened to meet: (1) any on-site needs, (2) the demand from users, and (3) to provide room in the unscreened storage area for current production. At Beltsville, compost is screened at all times when the temperature is above freezing and rain is not falling. Peak hourly capability of the drum screen with fairly dry material is about 50 cu yd. However, under actual conditions of start-up, shutdown, cleanup, and typical breakdowns, the input drum screen capability is about 150 to 250 cu yd per day. The screen is mounted on wheels and can be moved with the front loader for cleanup. Moving the drum screen permits use of the front loader for cleanup rather than having to clean by hand.

Other site operations include regular cleanup of work areas, receipt and storage of bulking agent, loading and measurement of finished compost for users, and equipment maintenance.

The staff at Beltsville consists of 8 people; 2 administrative and 6 operating. This number is more than actually needed for normal operations. The additional personnel are used for special operations and to support the research demonstration program. The operating staff is highly trained, each member is qualified on each piece of equipment, and the staff is able to perform all preventative maintenance and much of the repair work. Personnel and equipment are available for the composting operation full time. A list of equipment is shown in Table 2.

The approximate materials quantities used in the Beltsville operation are shown in Table 3. These quantities are based on an annual undigested sludge cake (approximately 23 percent solids) input of 15,000 wet tons, a ratio of two and one half parts wood chip bulking agent to one part sludge cake by volume, and 5/8-inch screening of all compost for a wood chip recovery and recycle of 70 percent. Output or production quantities are shown for both a 12 in screened compost pile cover and an 18 in unscreened compost pile cover in Table 4. The unscreened compost production is based on 15 percent reduction in sludge volume during composting and curing. This example serves only to illustrate general concepts because the materials loss through composting and curing are estimated and have not been precisely documented at existing operations.

Bangor

A typical operations layout of the Bangor site is shown in Figure 2. The layout is to approximate scale.

Undigested raw lime conditioned sludge cake (approximately 25 percent solids) is delivered from the City of Bangor primary wastewater treatment plant in 5 to 7 cu yd containers by a single lift and carry type truck. The sludge is delivered to the composting site located at the Bangor International Airport approximately 3 miles from the treatment plant. Generally, the raw sludge is dewatered, delivered, and composted once a week; on occasions twice a week. Usually the dewatering operation is started the day before so that all available sludge containers are filled the morning composting is to commence. Sludge hauling to the site begins early on the morning of composting. An operator and 4 cu yd front loader is available early at the site on the day of composting. As the containers of sludge are delivered to the site they are dumped on a previously prepared bed of bulking agent in the mixing area, mixed immediately with the front loader,

TABLE 2. BELTSVILLE EQUIPMENT

2 Terex Rubber Tired Front Loaders, 4.5 cu yd
2 Dump Trucks, 10 Ton, 3 Axle
2 Flat Bed Trucks, 1.5 ton
2 Pickups
2 Rubber Tired Farm Tractors, one with loader
1 Rotary Screen with power unit
1 Sweco Screen, fixed (new)
1 Mobile Rotary screen, small (not used)
1 Terex Composter
1 Imco Roto-Shreader
1 Large conveyor with engine drive (not used)
1 Fixed Toledo Truck Scale
1 Mobile Office
1 Storage Building
1 Lot small equipment and hand tools

TABLE 3. BELTSVILLE MATERIALS REQUIREMENT FOR 15,000 WET TON ANNUAL SLUDGE INPUT

Limed raw sludge, wet tons	15,000
Solids, percent	23
cu yd	20,700
Density, lb/cu yd	1,450
dry tons	3,450
Extended pile construction	
Sludge, cu yd	20,700
Bulking agent	
mixing w/sludge, cu yd	51,750
pile base, cu yd	8,100
Pile cover	
screened compost, cu yd	12,000 (12 in. cover)
unscreened compost, cu yd	18,000 (18 in. cover)
Individual pile construction	
Sludge, cu yd	20,700
Bulking agent	
mixing w/sludge, cu yd	51,750
pile base, cu yd	17,000
Pile cover	
screened compost, cu yd	24,000 (12 in. cover)
unscreened compost, cu yd	36,000 (18 in. cover)

TABLE 4. APPROXIMATE MATERIALS OUTPUT, BELTSVILLE TYPE OPERATION

Case**	Net unscreened compost production, cu yd	Net screened compost production,* cu yd	Bulking agent, cu yd		
			Total required	Recycled	Net used* (new make-up)
Extended pile with:					
screened compost cover	82,260	39,170	59,850	43,100	16,750
unscreened compost cover	87,660	35,210	59,850	52,450	7,400
Individual piles with:					
screened compost cover	101,070	51,570	68,750	49,500	19,250
unscreened compost cover	111,355	43,351	68,750	68,000	750

* Does not reflect actual Beltsville operations because only a portion of the Beltsville compost is screened.

** Materials input shown in Table 3.

Assumptions:

1. 15 percent reduction in sludge volume during composting and curing.
2. 10 percent of the bulking agent lost in composting and curing cycle.
3. 20 percent of the bulking agent lost in screening (passing through screen into finished compost).
4. 15,000 wet ton annual sludge input.

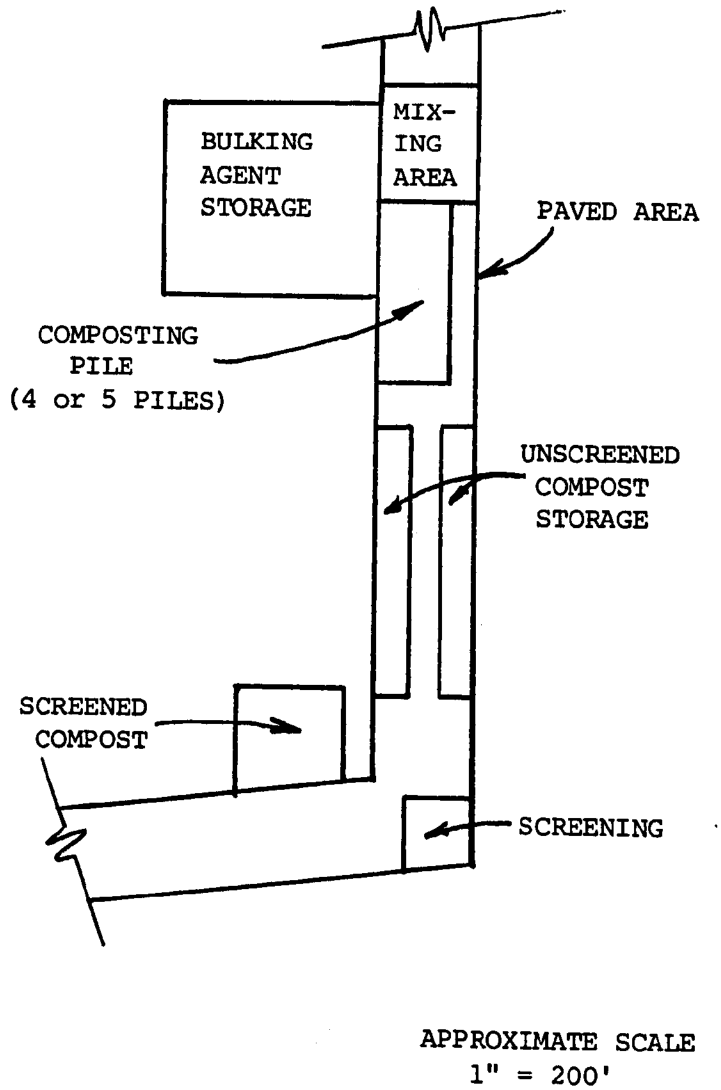

Figure 2. Bangor composting site layout.

and the compost pile is formed over a previously prepared base. Generally, one composting pile is constructed per week and typically consists of approximately 40 to 60 cu yd of raw digested sludge cake mixed in 1:3 ratio with about 120 to 180 cu yd of bulking agent. Approximately 6 to 8 trips must be made to the site to deliver the sludge cake. The mixing and pile construction requires a 10 hour day. Materials are measured by counting loader bucket loads.

Bark is currently used as a bulking agent. Most composting piles are mixed in a 3:1 ratio of bulking agent to sludge cake. The bark consists of a wide range of particle sizes from very fine to fireplace size logs. When the bark moisture content is less than 50 percent it is satisfactory for composting. Moisture is a problem during rainy weather because the bark is stored outside. During winter, there is little rain and the bark is quite satisfactory. A more uniform sized bulking agent, similar to chips, would probably help the composting operation.

The base for the compost pile is prepared using 7 ft lengths of perforated schedule 40 steel pipe joined together by short pieces of plastic pipe. The City found that the short lengths of steel pipe can be removed from the pile without significant damage and reused many times. Longer pipes were used previously, but were easily bent when pulled from the pile. The City has been experimenting with many different pile configurations. Currently, no base material is used; the sludge-bulking agent mixture is placed directly on the pad and aeration pipes. The City has also satisfactorily used unscreened compost as the bulking agent in a number of piles. Unscreened compost has been used up to three cycles as bulking agent with good results and thereby dramatically reduced requirements for new bulking material. The City plans further tests using unscreened compost as bulking agent. The reuse of unscreened compost may increase the nutrient content of the finished product; however, this needs to be confirmed.

The compost piles are constructed as high as the front loader can reach and capped with 1 to 2 ft of unscreened compost. The finished pile is 10 to 12 ft high. The blower is then hooked up and generally operated on an on-off cycle drawing air from the pile. During cold weather, the warm exhaust air from an older composting pile is piped into a new pile for a few days to rapidly increase the temperature of the new compost pile. The exhaust air from an older composting pile is very wet and will cause high moisture levels in the new pile receiving the air if used more than the first several days. The City has also purchased a ram air heater to provide initial heat to the piles.

The City found that during cold weather all available heat must be conserved to help the piles come up to temperature. Reuse of unscreened compost provides a warm bulking agent. The interiors of the bark storage piles are also sources of warm materials for mixing. Generally, if the sludge-bulking agent mixture can be kept about 4°C the pile will perform much better than if the mixture falls below 4°C. Recycle of warm exhaust air from an older composting pile into the new pile is also helpful for the first few days.

The piles are composted at least 21 days. Temperature and oxygen levels are monitored every 2 to 5 days during the composting cycle. The blower operating cycle is adjusted according to the performance of the pile. The aeration pipes, blowers, and moisture traps are checked for freezing during cold weather because of the large amount of moisture drawn through the aeration piping.

At the end of the composting cycle the pile is torn down, usually at the time another pile is constructed. The material removed from the pile is either used as the bulking agent for the new pile or is transferred to curing. As the pile is torn down the 7 ft lengths of aeration pipe are salvaged, cleaned out, and piled to the side for reuse.

Raw sludge is not stored at the compost site, but is stored at the plant. Generally, operations are scheduled so that sludge is dewatered and a compost pile constructed once a week. The exact day of pile construction is varied depending on weather conditions. The City has been able to compost nearly all of the sludge production simply by picking a good day each week for compost pile construction. During 1976, about 1,000 cu yd (700 wet tons) of dewatered sludge was hauled to landfill rather than composted, because composting at the time was being done by public works personnel, not treatment plant personnel. At times, public works personnel were unavailable to compost the sludge. Treatment plant personnel feel that they will seldom have to haul sludge to landfill. Liquid sludge is stored in the thickeners until dewatered. However, some additional liquid sludge storage capability would be helpful because of the cyclic nature of the dewatering operations. The plant is able to operate by storing sludge in the thickeners.

The City uses a Lindig rotary drum screen to screen compost prior to distribution. The drum is presently fitted with a 1-in. mesh screen. City personnel are planning to construct a 5/8-in. screen assembly so that either size material can be produced. Tests performed by the City indicate that the screen is capable of handling about 20 to 25 cu yd (900 lb per cu yd) of feed per hour under the best conditions. The screen is fed with a front loader. One loader operator and a laborer are required during operation. The City performed screening during late summer and fall of 1976, but has not been able to screen during winter 1976-77. Most of the unscreened compost production is stored in curing piles and about 3,000 cu yd is now on hand awaiting screening. It is estimated that the screen can process about 100 to 150 cu yd of feed per day based on typical operations and that 20 to 30 days of screening will be required to process the present 3,000 cu yd stock.

Currently, operations at Bangor are being carried out by treatment plant personnel under the direction of the treatment plant superintendent. There are no full time composting personnel because of the cyclical nature of the operations. Approximately 11 man-hours per week are required at the site, primarily for loader operation. In addition, approximately 9 man-hours per week are required for a truck driver to deliver sludge to the site. Sampling and monitoring for temperature and oxygen content requires 10 hours per week not including the pathogen and heavy metals monitoring which is performed under contract by the University of Maine. The supervision and administration requirements are about 15 man-hours per week. Annual equipment and labor requirements are shown in Table 5.

The equipment used for composting operations is shown in Table 6. This equipment is provided by the City motor pool and is available for composting when needed.

The approximate materials quantities based on 1976 sludge volume for the Bangor operation are shown in Table 7. These quantities are based on an annual sludge input of 2,170 wet tons and a mixture of 3 parts bulking agent to one part sludge. The calculated materials production is shown in Table 8 for three assumed cases. These production outputs assume a 15 percent reduction in sludge volume during composting and curing and one inch screening of compost before distribution. Recovery of bark is estimated at 70 percent by either screening an/or recycle of the unscreened compost as bulking agent. Table 8 serves only to provide an approximate indication of materials quantities.

MONITORING

Regular monitoring of operations can provide a good indication of composting effectiveness. The regular operations (not the research operations) at Beltsville are so routine and dependable that piles are monitored only occasionally.

The piles at Bangor are monitored regularly for interior temperatures and oxygen levels. Generally, this monitoring is performed every 2 to 5 days at several points in each pile. These data are used to judge the pile performance and to set the blower operating cycle. At the end of the composting period each pile is sampled and tested for moisture content and pathogens. In addition, random sampling and pathogen testing is performed on raw sludge, curing, and finished compost. Some heavy metals and nutrient testing is also performed.

Experiences at Durham and Bangor tend to indicate that regular monitoring of pile temperature can provide a direct indication of pile composting performance and can help to pinpoint problems. For instance, the initial rate of temperature increase is a good indicator of the composting efficiency to be expected. Generally, the temperature of a poorly constructed pile (too wet or not well mixed) will rise slowly and in many cases will not reach proper temperatures. At Durham, such piles have been torn down and rebuilt with vastly improved performance the second time. Durham also found it desirable to reverse air flow part way through the composting process and the time of reversal was determined from temperature monitoring.

Additional regular monitoring can be performed to include oxygen levels within the pile, pathogens, heavy metals and nutrients. For a small operation, at least regular temperature monitoring should be performed. It has been found useful to plot the composting temperatures on a regular basis (daily during the first few days as the pile comes up to temperature)

TABLE 5. ESTIMATED ANNUAL OPERATIONS REQUIREMENTS, BANGOR

Operation	Labor, hours	Equipment, hours
Composting, labor	572	
front loader		468
Sludge hauling, labor	468	
truck		468
Monitoring, labor	520	
pickup		520
Administration, labor	780	
Screening (8,000 cu yd), labor	1,040	
screen		520
front loader		520
Maintenance, labor	100	

This Table is based on information provided by the City of Bangor personnel.

TABLE 6. BANGOR EQUIPMENT

1	Case W24B Rubber Tired Front Loader, 4 cu yd
1	Rubber Tired Front Loader, 1.5 cu yd
1	Truck, Sludge container hauling
1	Mobile screen, Lindig
	Small tools as required
	Miscellaneous vehicles as needed from motor pool

TABLE 7. BANGOR MATERIALS REQUIREMENTS FOR 2,170 WET TON ANNUAL SLUDGE INPUT

Limed raw sludge, wet tons	2,170
solids, percent	23
cu yd	3,000
Density, lb/cu yd	1,450
dry tons	500
Static pile construction	
sludge, cu yd	3,000
bulking agent, cu yd	9,000
pile cover, cu yd	1,560

TABLE 8. APPROXIMATE MATERIALS OUTPUT, BANGOR TYPE OPERATION.

Case*	Net unscreened compost production, cu yd	Net screened compost production, cu yd	Bulking agent, cu yd		
			Total req'd	Recycled	Net used (new make-up)
New or recycled bulking agent used in pile construction	10,920	4,160	9,360	6,760	2,600
Unscreened compost from pile used as bulking agent for one cycle	6,240	3,198	4,680	3,042	1,638
Unscreened compost from pile used as bulking agent for two cycles	4,654	2,785	3,114	1,868	1,246

* Materials input shown in Table 7.

Assumptions:

1. 15 percent reduction in sludge volume during composting and curing.
2. 10 percent of the bulking agent lost in each composting and curing cycle.
3. 20 percent of the bulking agent lost in screening (passing through screen into finished compost).
4. 2,170 wet ton annual sludge input.

during the composting period along with daily precipitation and air temperature. This information provides a profile of each pile. It may also be desirable to monitor a temperature near the outside of the pile as a check on minimum temperatures and the effectiveness of the pile cover.

Bangor and Durham have been able to provide pathogen monitoring through a cooperative agreement with a local university.

SITE CONSIDERATIONS

The site location should be selected with great care considering transportation, adjacent land use, drainage, winds and similar factors. It is desirable to provide a buffer strip around the site, preferably one that will also block the view. Slight odors are generated at times and, although practically no complaints are received at operating facilities, this factor should be considered in site selection.

The basic requirement for almost any geographical location is to construct a site that is usable by heavy equipment on a year around basis. The site should be well drained and in most cases this drainage should be collected to a holding pond. Suitable facilities should be provided for administration, testing, equipment storage, and maintenance. Access should be provided to all working areas and this access should be suitable for heavy equipment. The minimum construction for this access should be gravel, but paving is better.

All working areas should be heavily gravelled as a minimum. It has been demonstrated at Beltsville that regular year around operations can be carried out on crushed stone, but drainage, cleanup, and other working conditions are less than optimum. Also, it is impossible to keep the gravel out of the materials and some heavy metals can be leached from some types of gravel. All working areas should be well drained because runoff from the composting process is significant. Removal of runoff will help to keep the materials as dry as possible and minimize odors and nuisance problems.

Properly designed hard surfaced work areas will provide more satisfactory operations, better drainage, and will facilitate cleanup. The composting area should have highest priority for paving, however, the screening area is also important. If necessary, the bulking agent and compost storage areas can be operated satisfactorily without paving. It is recommended that reinforced concrete surfaces be provided, however, asphaltic cement can be used. The asphaltic cement is more prone to damage from equipment because it tends to soften during hot weather and from heat under the composting piles.

WEATHER

Weather can have a significant effect on composting operations and must be taken into consideration both in design and in carrying out operations. It is possible to carry out composting operations under nearly all weather conditions as demonstrated at Beltsville, Bangor, and Durham, but experience has provided many useful observations. Significant adverse weather conditions are snow, rain, cold (below freezing), inversion conditions, and high winds. The effects of each of these conditions on composting will be discussed along with methods for mitigating the adverse effects.

Cold Weather Operations

Generally, cold weather above freezing has little effect on composting operations, therefore, this section will relate to locations with extended periods of subfreezing weather. Conditions where temperatures dip below freezing occasionally or at night, but return to above freezing during the day are of little concern.

While extremely cold temperatures do have some adverse effect on the compost pile process performance; Beltsville, Bangor, and Durham have demonstrated that the composting process can perform well in very cold climates. Extra care is needed in mixing, pile construction, and covering to assure optimum performance. Most cold weather problems relate to materials handling and equipment. Equipment will be harder to start in cold weather (especially diesel engines), but this can be mitigated by installing block heaters and storing equipment inside. Equipment operator stations should be enclosed and heated for cold weather operations. Equipment service and maintenance is more difficult and suitable arrangements should be made for carrying on regular and emergency maintenance.

Materials handling problems relate primarily to freezing of these materials. Generally, because of the heat generated, freezing of the composting piles, unscreened compost, or screened compost even in very cold weather has not been significant. Freezing of the bulking agent can be a problem. The wood chip bulking agent used at Beltsville does not freeze into large chunks because the moisture drains well from the material. Recycled wood chips do freeze to some extent because of the additional moisture and smaller particle size. Bulking agents which hold moisture will tend to freeze, however, the bark at Bangor only freezes on the outside, and heat is generated inside the piles.

Screening when temperatures are below freezing is a problem. The mechanical parts of the screen freeze and a residue freezes on the screen. Screening is not undertaken when it is below freezing at Beltsville and Bangor. In other cold locations it would be possible to stockpile unscreened compost during freezing weather and only screen when the temperature is above freezing. The other alternative would be to screen in a heated space or screen during freezing weather and try to overcome the problems. Adequate screening capacity must be available so that all required screening can be performed during the available suitable weather for a particular location.

The extremely cold weather in Bangor has a noticeable effect on the composting process. It is difficult to pinpoint the exact cause of the problems. City personnel report that if the sludge-bulking agent mixture can be kept above 4°C the pile has a much better chance of performing well than if the mixture temperature drops below 4°C. If wet bulking agent is used or if mixing takes place in rain the resulting compost pile may not perform well.

Bangor personnel are testing various methods of improving cold weather operation such as reusing unscreened compost as bulking agent (use of heat in the compost), piping the warm air discharge from an older composting pile into the new pile initially, and using a heater to warm the air blown into a new pile. It is too early to develop conclusions except that outdoor operations in very cold climates require attention to detail in mixing sludge and bulking agent, constructing piles, conservation of heat, and control of moisture in bulking agent and compost.

Rain

All present operations have been carried out without cover and rain has been more of a nuisance than a problem. The major effect of rain (assuming a properly drained site) is excessive moisture content in materials. Some bulking agents may require covered storage to maintain satisfactory moisture levels depending on the type of agent and the local rainfall characteristics. Bangor has experienced difficulty with excessive moisture in the bark bulking agent and has found that problems develop when bulking agent moisture levels are above 50 percent.

Bangor has experienced difficulties in constructing compost piles outdoors when it is raining because of excessive moisture pickup during mixing and pile formation. Piles are formed only once or twice a week at Bangor and they are able to schedule this work on days when rain is not expected. Beltsville has not had any problem with rain because they can mix and form piles very quickly, thus limiting exposure to moisture. In areas of heavy and frequent precipitation it may be necessary to consider a covered mixing area or an enclosed mixing system. Precipitation has little effect on the composting piles after formation and it is anticipated that individual piles will shed water better than the extended pile because of the large flat top of the extended pile. The unscreened compost in storage will pick up moisture from precipitation and this will make screening more difficult. A covered storage area would be helpful in minimizing moisture content, but outdoor operations will work except, possibly, in areas of very high precipitation.

Screening is difficult during precipitation and should generally be discontinued during these periods. In many parts of the country this procedure will not hinder total operations. If screening must be carried out during precipitation, a covered area should be provided. It is difficult to screen compost with a moisture content above 45 to 50 percent because the fine particles do not separate, but stick together.

Moisture has little effect on screened compost other than to change its density.

Snow

The effects of snow are much the same as rain because snowfall on top of compost will generally thaw rapidly due to the heat. The other considerations are visibility and site clearing for access. Snow could disrupt sludge deliveries to the site for short periods of time and this should be considered in planning plant operations and designing facilities for sludge storage at the plant. Generally, however, the effects of snow on the process are minimal.

Inversion Conditions

The composting operations do generate mild odors at times and may be most noticeable during inversion conditions with light winds. Careful operations will minimize odor generation. Slight odors were noticed at Beltsville under inversion conditions, but the problem was very minor and complaints are nil.

Odors were also noticeable at the Bangor composting site. These odors might be considered unacceptable to some people visiting the actual site. Apparently, these odors are dispersed rapidly away from the site because outside complaints have not been received. The site is about 2,000 feet from the Bangor International Airport terminal building and about a like distance from a major shopping center.

The normal operations at Beltsville and Bangor have never been shut down due to odor generation. There is no easy way to shut down a composting operation in any case because it is a continuing process involving large quantities of "active" materials. The best safeguard is to conduct careful operations, but odors will occasionally be generated. Beltsville does have both mobile and fixed deodorizing equipment which is used infrequently.

High Winds

It is possible that areas with significant prevailing winds may have problems with blowing of materials, especially with light bulking agents, and dust. The best mitigation would be careful site selection and masking of the site with wind barriers such as trees. In most areas, materials handling operations can be suspended during occasional periods of high wind. Dust can be controlled by careful site cleanup and the use of water.

Summary of Site Considerations

Operations downtime at Beltsville was minimal during 1976. Regular sludge deliveries have been accepted on schedule except when the Blue Plains Plant was unable to provide sludge or trucking was impossible. During the severe weather of January 1977 sludge was accepted five days a week on schedule. Downtime at Bangor in 1976 was slight and due mostly to scheduling of public works department personnel. Downtime should be reduced even more now that the treatment plant is providing the personnel. No on-site sludge storage is available at either composting site and it is recommended that such storage be limited to the wastewater treatment facility. As far as can be determined no nuisance complaints were received as a result of normal Beltsville and Bangor operations.

The essential function of compost pile formation has been performed on a regular schedule with little disruption. Other operations with more flexibility such as screening have been performed when conditions are favorable, but still have met the needs of the overall operation. Wastewater sludge composting has been demonstrated on a regular schedule for over two years at each site completely outside.

The hard surfaced composting pad at Beltsville will not reduce "downtime" or decrease the costs of operation. The primary advantages relate to more satisfactory and orderly working conditions. Drainage is much more satisfactory and cleanup is much easier and more complete. Water drainage from the composting pile is probably much more satisfactory, but the economic effect is almost impossible to calculate and probably quite small.

A portion of the new Beltsville covered area will be reserved for equipment maintenance. The balance of the covered area will be used for composting operations; primarily research and demonstration. The covered area will not reduce operational "downtime" but will provide additional data related to composting without the effects of precipitation. It is anticipated that the covered area will have little direct effect on normal operations. The cost of the Beltsville covered area is approximately $10 per sq ft including the concrete slab.

The primary adverse weather effects at operating installations are summarized as follows.

Cold
- equipment starting and operation are more difficult.
- equipment service and maintenance requires appropriate facilities.
- equipment cabs must be enclosed and heated.
- freezing of bulking agent may be a problem.
- screening is difficult to carry out.
- composting pile initial heat generation may be slow in extreme cold.

Rain
- site and working area drainage is important.
- runoff collection and treatment must be considered.
- moisture absorption during sludge-bulking agent mixing and pile formation must be minimized.
- moisture absorption by unscreened compost prior to screening can be a problem.
- screening is difficult to carry out.

Snow
- generally, similar to rain, but less severe.
- visibility problem.
- site clearing and access is necessary.

Inversion Conditions
- little documented problem under this condition.

High Winds
- blowing materials and dust can be problems.

NUISANCES

The potential nuisances of a raw sludge, forced aeration composting operation are:

1. Sludge hauling
2. Visual objections
3. Odor generation
4. Vermin propagation or attraction
5. Noise

No known nuisance complaints have been traceable to raw sludge cake hauling at Beltsville or Bangor. It is desirable to locate the composting site as close as possible to the treatment facility thus further reducing any potential for nuisance problems to develop.

A composting site is a potential visual nuisance because of the large piles of materials and heavy equipment. The Bangor site is in plain view to people using the Bangor International Airport, but complaints have not been received. A better approach is to mask the site from view by careful selection or landscaping if possible.

Odor generation is potentially of great concern because some mild odors are generated at composting sites; yet, no complaints have been received at Beltsville or Bangor. Odors have been noticeable at the Bangor site, but are not noticeable off the site. The best solution is to use care in selection of the site and, perhaps, have mobile deodorizing equipment available for use.

No rodent, fly, or other vermin problems have been reported at Beltsville. Bangor did report some fly problems in 1976 and 1977. During the 1976-1977 winter, mice have been nesting in the curing piles and it is not known if this will be a problem. To date, the reported and observed vermin problems seem to be minor to non-existent.

SECTION 4

CONSIDERATIONS FOR FUTURE OPERATIONS

GENERAL

Actual forced aeration composting operations to date have demonstrated the ability to process undigested wastewater sludge cake into a useful compost product with minimum on-site nuisance and essentially no public complaint. It is probable that further modifications and improvements to the process will provide additional operational advantages and reduction in cost.

A number of these possibilities are outlined in this section, but it is emphasized that process modifications should be tested under carefully controlled conditions to prevent the possibility of on-site and off-site nuisances and public complaints in the event that some are unsuccessful. The type of operation most advantageous in a given situation will depend on the goals of the operation, the market for compost, available bulking agents, climate, and similar considerations.

MATERIALS HANDLING

This is probably the most significant factor in the composting operation; it is a materials handling operation. A study at Durham, New Hampshire[(1)] investigated the use of fixed materials handling equipment as compared to the mobile equipment now used almost exclusively. The study concluded that certain steps in the operation could be mechanized to advantage, specifically, the sludge-bulking agent mixing and movement of some of the materials using conveyor belts. The design for Camden, New Jersey is reportedly based on extensive use of mechanized fixed materials handling equipment.

Mechanization using fixed equipment has not been demonstrated, except that conveyors are presently used to move materials within the screening process. The present practice of using mobile equipment provides greater operational flexibility, but may increase some other operational costs such as labor. The flexibility required for a composting operation should receive careful consideration, particularly when planning the materials handling operations.

There is a need to realistically evaluate various modes of operation and the effect on materials quantities to be handled in order to minimize the costs of materials handling.

BULKING AGENT

The bulking agent is a prime consideration in the composting process because it can be a major cost item and may be difficult to obtain in certain parts of the country. The exact considerations relating to bulking agent are site specific, but, it is possible to develop some general considerations.

It is important to plan for the bulking agent in the early stages of a wastewater sludge composting project to assure a supply of suitable material and for the materials handling equipment. Thereafter, in most cases, it is desireable to minimize the need for additional material because of the cost.

It is possible to recover approximately 70 to 80 percent of wood product bulking agent used in construction of a pile by screening after completion of the composting or curing process. This recovered bulking agent can be reused and removal of this material from the compost helps to increase the volumetric nutrient content of the final compost product.

It also may be possible to use the compost from a pile being torn down as the bulking agent for a new pile. This is illustrated in Table 8 and has been demonstrated in practice at Bangor with satisfactory results. In fact, Bangor has reused compost through two additional compost cycles (in addition to the original pile) as bulking agent with satisfactory results. As illustrated in Table 8, this procedure reduces both the bulking agent and screening requirements significantly along with other key process materials handling requirements. This can be significant for operations trying to minimize costs and illustrates the significant effect that can be obtained by varying operational procedures.

A number of other materials have been used as a bulking agent such as shredded tires, peanut hulls, cubed solid waste, and licorice root.

SCREENING

Screening is one of the more difficult and time consuming operations related to composting. Ideally, it would be desireable to eliminate screening if a market could be found for coarse compost and/or if an inexpensive bulking agent could be found that would essentially disintrigrate during composting and curing. Elimination of screening would, however, increase the requirement for new bulking agent. Practically, one solution is to develop a good balance in operations so that screening is limited to a manageable level of effort.

The best experience to date has been with horizontal, rotary type screens with a screen opening of 1/4 to 1 in. An effective drum screen should be about 10 to 15 ft long to provide adequate tumbling action to separate the fine and coarse particles. Shorter screens have been used, but particle separation is not complete and the recovered bulking agent contains fines. Feed rates must also be controlled to achieve good performance. Moisture content is a significant factor, but the horizontal screen has demonstrated an ability to operate even with relatively wet compost (up to 50 or 55 percent moisture). Vibratory screens have been satisfactory for moisture contents up to 45 percent.

With careful planning of operations it may be possible to reduce screening requirements significantly as illustrated in Table 8. Unless a covered area is available, screening can be carried out only in good weather and then the daily production must be carefully evaluated because of downtime, maintenance, and other factors. Screening capacity could be a limiting factor unless the capacity is carefully selected in relation to volume of materials to be screened. Screening typically requires one man plus a front loader and operator.

It is also possible to reduce screening by marketing some compost unscreened, but this will increase bulking agent requirements. It may also be necessary to market some compost unscreened if space is not adequate to store materials during times when screening cannot take place.

SITE WEATHERPROOFING

A permanent composting site should have certain basic amenities. The first would be a hard surfaced working area (preferably reinforced concrete) for mixing and composting. Other areas such as roads, materials storage and the screening area should be covered with a thick layer of crushed stone as a minimum though paving would be more satisfactory. Mixing, composting, and curing areas should be well drained to adequate runoff collection and storage facilities.

Beltsville and Bangor have demonstrated that covered areas are not necessary to carry out continuous operations. In some climates, covered areas would be helpful for: (1) protection of bulking agent, (2) protection of curing compost, and (3) protection of the screening area from rain.

Covered composting pads would possibly contribute to more satisfactory composting in very wet or cold climates, but there are no data available to give a quantitive comparison at this time.

SECTION 5

COMPOST DISTRIBUTION

GENERAL

Compost has been distributed from the Beltsville operation for several years. Reportedly, all of the production has been distributed in the past without satisfying the demand. Most of the compost is provided free of charge to various public agencies who pick the material up at the Beltsville site. Some compost has been sold for $1.00 per cu yd (approximate weight 850 lb per cu yd) to private companies (not individuals). Part of the compost is screened prior to distribution, and some compost is also distributed unscreened.

Compost from the Bangor operation has been stock piled. A marketing program began in Spring, 1977. The policy is to market the compost for approximately $1.00 per sack (approximately 60 to 80 lb), $5.00 per cu yd in bulk, or $10 per bulk pickup load. The compost is picked up at the site by the user and is loaded by City personnel. The City is also considering promotional efforts through other outlets such as supermarkets and nurseries in addition to sale to other City Departments such as Parks.

USES

There are a number of identified end use options for wastewater sludge compost:

1. Base for potting mixes.
2. Bedding mix for flowers.
3. Planting mix for trees and shrubs.
4. Base for producing "on-site" topsoil.
5. Surface mulch (although this is not recommended by all authorities).
6. Base for reclaiming mined or other unproductive areas or soils.
7. Land reclamation.
8. Landfill.

DEMAND

No formal studies have been undertaken in Bangor to determine potential demand for the compost. The City has nevertheless decided to sell the compost and has disposed of approximately 80 to 100 cu yd in 1977 through the month of May, compared to annual production in excess of 4,000 cu yd. It is very difficult to determine the total volume that can be disposed of in the Bangor area. The season is very short and there is very little potential demand in the winter. Adequate space is available for storage of large quantities of compost during the winter or from year to year. Until the market for compost can be developed in the Bangor area, the best strategy is to minimize compost production through appropriate operational strategies as illustrated in Table 8. It is likely that all of the Bangor compost could be landfilled at the present sludge disposal site, but this method of disposal does not meet the City goal of realizing some revenue from the disposal of the compost.

A comprehensive study[2] was recently completed which projected compost demand in the Washington, D. C. Standard Metropolitan Statistical Area (SMSA) and within a 100 mile radius of Washington, D. C. Estimates of demand, considering certain restrictions on use, ranged between 5,600 and 161,000 tons of compost per year within a 100 mile radius of Washington, D.C. Although this is a broad range, it indicates a potential market for the forseeable production from the Beltsville site. Production at Beltsville would be approximately 20,000 tons of compost per year if all the compost were screened, through actual production is somewhat higher because some compost is not screened.

Other wastewater agencies within the Washington, D. C. area are considering composting and this would increase the quantity of compost available for distribution.

SECTION 6

COSTS

Composting costs are documented for both Beltsville and Bangor. The Beltsville costs must be considered carefully because they include allowances for various research activities and the equipment and site may be capable of handling 2 to 3 times more sludge than is presently processed. Various financial aspects of the Beltsville operations are shown in Table 9. The 1976 actual and projected 1977-1978 costs were developed from information provided by MES for the total operation including research; but do not include the amortization of equipment or site costs. The off-site administrative cost item is basically unrelated to site operations. The on-site labor cost includes site supervision. Sludge hauling cost is for contract transport of sludge cake from the Blue Plains Plant to the composting site. These hauling costs are site specific for the Beltsville operation. Costs for bulking agent may not reflect actual usage because chips are purchased when prices are favorable and large quantities can be stockpiled. Screening in 1976 was performed by outside contract, however, all screening is now performed using on-site labor. The projected Beltsville costs for 1977-1978 were modified to show two different sludge input rates and research related costs were removed. Individual breakdown of costs for various processes such as mixing, pile construction, and screening are not available from Beltsville. However, cost estimates were prepared for an operation similar to Beltsville based on time and motion study at Beltsville[3]. This study estimated that total costs, including capital amortization, are approximately $51 per dry ton of sludge cake solids for an operation processing 10 dry tons of sludge solids per day. Total capital costs for site improvement and equipment were estimated at $376,000. Estimated costs for 50 dry tons of sludge solids per day were $36 per dry ton, including amortization of approximately $1,500,000 of capital costs. Costs from actual operations (Table 9) indicate that these estimated costs may be on the low side.

Bangor operation costs for 1975[4] are shown in Table 10. The capital investment was very low because only minor site work was required. Equipment is provided by the City Motor Pool. Amortization of equipment is included in the hourly equipment charge under "Operations". Cost information is not available for 1976. An estimated breakdown of labor and equipment requirements by operation is shown in Table 5.

Preliminary estimates at Durham indicate a cost of $16.00 per cu yd of sludge ($107 per dry ton solids for 20 percent solids sludge)[5] for composting an estimated 200 to 250 dry tons of sludge per year excluding

TABLE 9. BELTSVILLE ACTUAL AND PROJECTED COSTS

	Projected Oct. 1977-Sept. 1978	Actual 1976	Estimated Costs** 18,200 wet tons/yr****	Estimated Costs** 45,500 wet tons/yr
Off-site				
Admin., off-site	$ 60,000	$ 46,501	-	-
On site operations				
Telephone & travel	1,300	3,971	1,300	1,300
Utilities	2,211	426	2,211	3,000
Fuel & oil	10,500	13,036	10,500	25,000
Sludge hauling	132,000	120,000	-	-
Labor incl. fringes	125,750	152,919	80,000	125,750
Misc. contract services	27,540	112,942*	27,540	37,000
Wood chips	144,000	73,145	144,000***	350,000***
Supplies & materials	22,250	32,176	22,250	35,000
Equipment insurance	4,000	3,955	4,000	4,000
Total	$529,551	$559,071	-	-
Total excluding off-site	$469,551	$512,570	$291,801	$581,050
Dry tons sludge per year (23 percent solids)	3,450	3,450	4,200	10,500
Annual cost, $/dry ton sludge solids	$136	$149	$ 69	$ 55

* Includes screening performed by outside contract, screening now performed on site by MES personnel.

** Excluding requirements of research work.

*** Assume 50 percent of compost marketed unscreened and 70 percent recovery of bulking agent after screening finished compost.

**** Present rate of 350 wet tons of sludge per week. Reported capacity of site is 875 wet tons of sludge per week.

TABLE 10. BANGOR COMPOSTING COSTS, 1975-1976 (4)

Capital amortization 6 percent, 5 years	$ 3.00*
Operations	43.00
Bulking agent	37.00
Analysis	3.00
	$ 86.00

*Costs per dry ton of sludge for a total of 525 dry tons per year.

capital amortization.

The major cost items at present composting operations are labor and bulking agent which can each be 30 to 45 percent of the total annual cost of composting. Operation and maintenance of the mobile equipment at Beltsville, excluding capital amortization and direct labor, is 10 percent or less of the total annual cost. Amortization of the purchase cost of the equipment at Beltsville (approximately $400,000) over six years at 7 percent would be approximately $84,000 per year or about 13 to 23 percent of total annual costs shown in Table 9 depending on the case.

SECTION 7

PATHOGENS

Data are available from several sources (Table 11) that indicate pathogen and/or indicator organism density in composted wastewater sludge at various stages of the process. The total and fecal coliform, and salmonella data are summarized in Table 12.

Sufficient data are available from Bangor to plot cumulative probability curves of bacterial densities in sludge, compost, and compost stockpile. These curves (Figures 3, 4, and 5) are plotted to a lower density of one log (base 10) cells per gram which also include all densities below this level.

Although data vary widely, they are consistent in that some measureable level of salmonella, fecal coliform, and total coliform can be present in composted wastewater sludge. In most cases, especially in the static pile composting method, salmonella densities were below detectable levels, and when detected were less than one log cells per gram. No salmonella have been detected in compost samples at Bangor in over a year, although salmonella were detected in compost samples in early 1976. Total and fecal coliform densities up to 5 or 6 log cells per gram have been detected, but typically the levels are below 3 or 4 log cells per gram in the finished compost.

A study has reported on survival of virus through the windrow composting process, particularly the F_2 bacterial virus[7]. This work indicates reductions in densities to less than one or two log PFU per gram with windrow composting and stockpile curing. It is expected that greater reductions in virus concentrations would be observed using the static pile method because higher temperatures are developed.

Data indicate that maximum temperatures achieved by static pile composting even during very cold weather are generally greater than 60°C for at least a day and usually for several days. Exposure to temperatures of 60°C for a period of a day or two will inactivate most pathogens. Temperatures are not uniform throughout the pile and temperatures near the outside of the pile may be significantly below 60°C and not great enough to inactivate all pathogens. Tests have shown that indicator organism densities vary within the pile. It is possible to inactivate virus, bacteria, protozoa, and helminth by subjecting all parts of the composting mass to lethal temperatures. With present procedures it is not possible to assure total inactivation using outdoor composting methods because organisms may survive near the surface of the piles while total inactivation may be achieved

TABLE 11. SOURCES OF PATHOGEN DATA

Location	Type of composition	Reference
Beltsville, MD	Windrow and Static Pile	(6)
Bangor, ME	Static Pile	Plant Records
General	Windrow and Enclosed	(7)

TABLE 12. SUMMARY OF BACTERIA DATA

Location	Range of reported densities cells/gram of compost: Salmonella	Total coliform	Fecal coliform
Beltsville, MD (6)			
Highest	<10	$4x10^5$	$3x10^3$
Lowest	0.3	5	<.1
Bangor, ME (plant data)			
Highest	$2.4x10^3$	10^5	10^5
Lowest	0	1	0
Typical	0	10^2 to 10^3	10^1 to 10^3

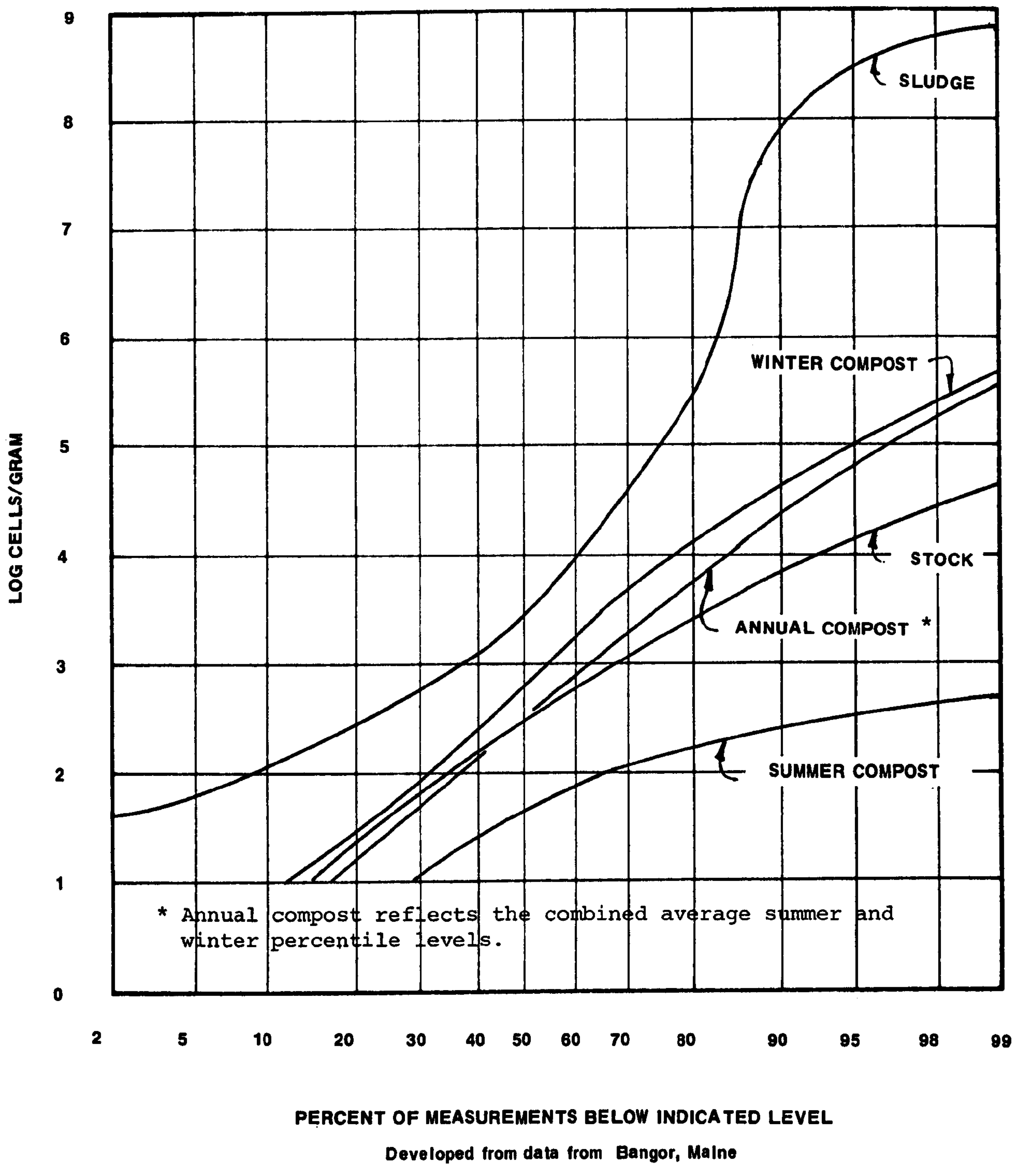

Figure 3. Total coliform densities.

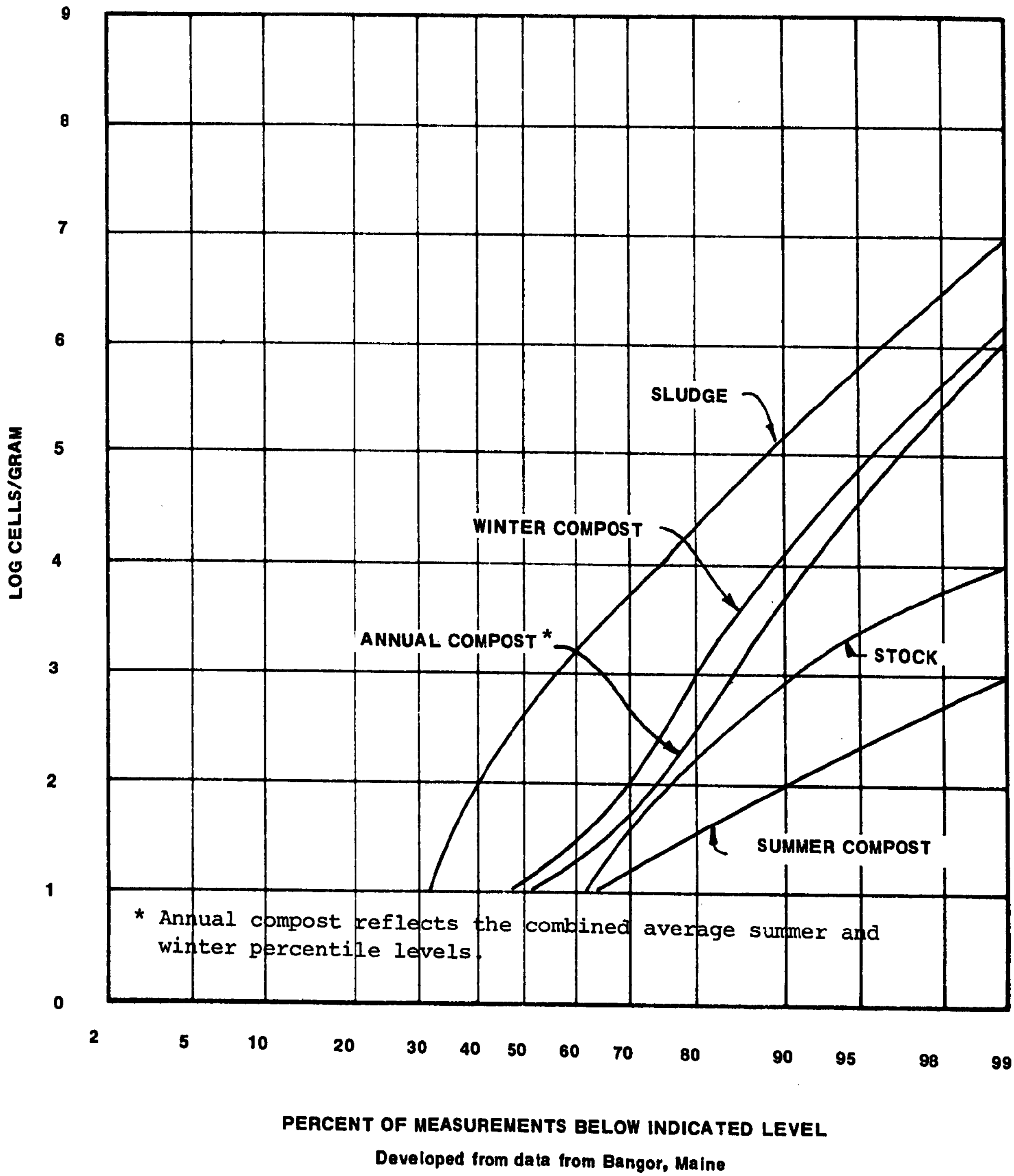

Figure 4. Fecal coliform densities.

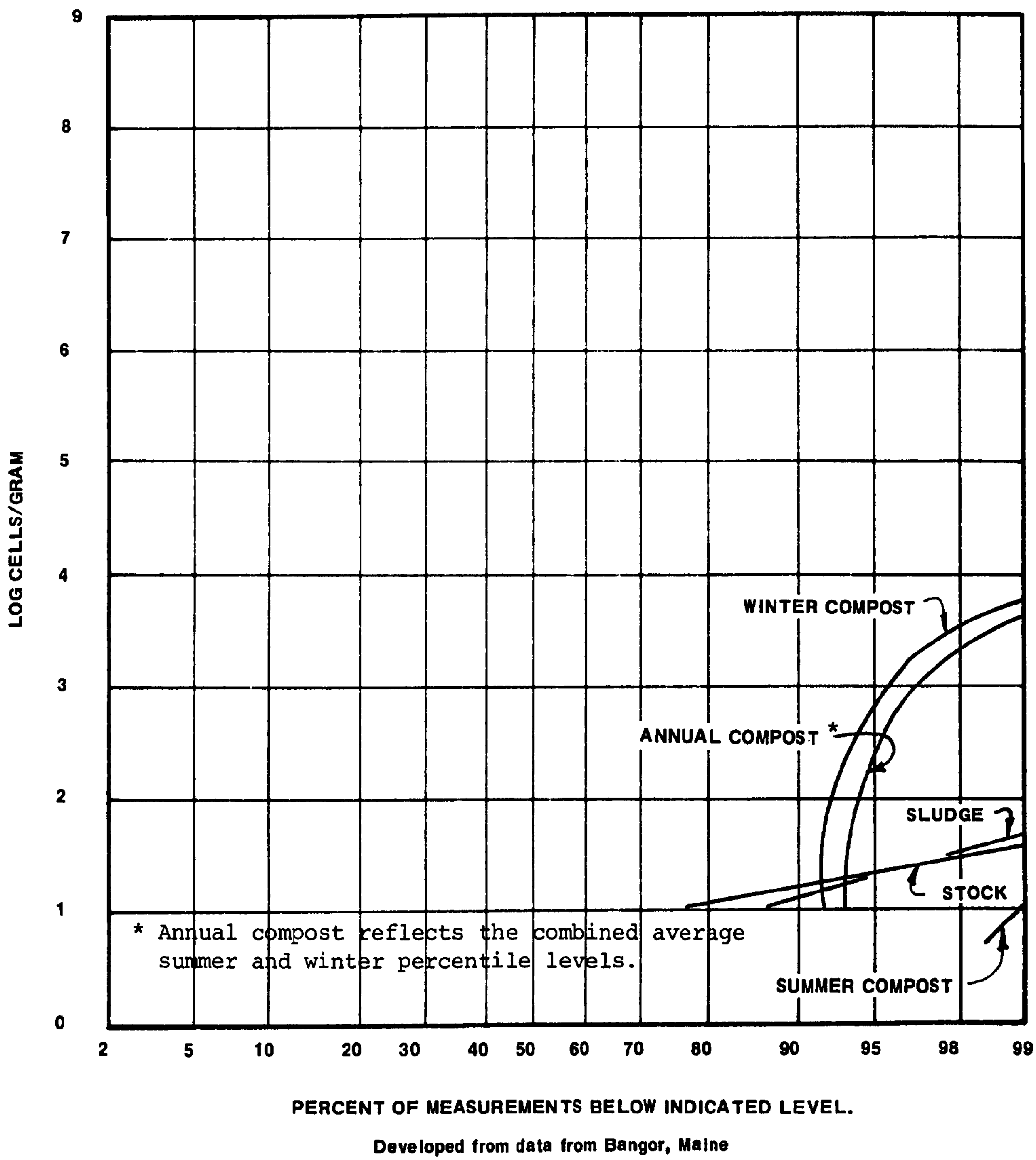

Figure 5. Salmonella densities.

within the pile. Therefore, it must be assumed that pathogenic organisms will survive the composting and curing processes unless some means of positive sterilization is used. Although the measurement of indicator organism density in the compost may not be a reliable method to determine actual levels of pathogenic organisms it is possible to apply historic ratios of pathogens to indicators to develop some generalizations of the risk of illness.

Hornick, et al[9] recently published dose - response data for _Salmonella typhi_ bacteria. These data indicate that the dose required to cause typhoid fever in humans was quite high (see Table 13). Earlier work[10][11][12] has also shown that large doses of other species of Salmonella are required to cause significant human disease (see Table 14).

Methods have been developed for estimating the disease risk based on the indicator organism density in drinking water[13][14][15]. While these methods have been developed for ingestion of drinking water, they can be applicable to ingestion of sludge. The major difference is that normally only small amounts of sludge or compost would be ingested as compared to water. Data from Mechalas, et al[15] is shown in Figure 6, and provides the basis for the illustration that follows. For purposes of illustration, assume that a compost marketed to the public contains a total coliform count of 10^3 organisms per gram of compost and that one gram of the compost is ingested by a human adult. The human would have ingested 10^3 indicator organisms. One gram of compost would be approximately 2.0 ml in volume at 850 lb/cu yd.

According to Figure 6 the risk of illness would be approximately one in 1,000,000 by extrapolation of the curve (approximately 5×10^4 MPN/100 ml total coliform). Based on earlier work by Kerr and Butterfield[13] in estimating relationships between numbers of indicator organisms and disease organisms in wastewater, a rate of, say, 100 salmonella of all types per 1,000,000 coliforms would be very high. Therefore, for the 10^3 coliforms ingested it is quite likely that less than one salmonella would be ingested. Typical coliform to virus ratios would be 50,000 to 100,000:1[8] and, therefore, for 10^3 coliforms less than one virus would be ingested. It has been shown for both virus and salmonella that significant numbers must be ingested to cause disease in humans; typically over 10^3 salmonella (of most types). Small doses of virus typically produce infection but not disease in humans.

This logic indicates a very low risk in using properly composted wastewater sludge even though it is not possible to assure complete kill of pathogenic organisms using outdoor composting techniques. At the level of coliform organisms found in typical wastewater sludge compost and assuming normal disease rates within the community, it is highly unlikely that enough of this compost would be ingested to produce disease in adult humans. Infants may be more susceptible. However, the danger of disease outbreak is very small considering the volume of compost that would normally be ingested. Also infants are less likely to be exposed than adults.

TABLE 13. RELATION OF DOSAGE OF *SALMONELLA TYPHI* TO DISEASE
(From Hornick et al.)[9]

No. of viable *Salmonella typhi*	Total volunteers challenged	Number with disease (percent)
10^9	42	40 (95)
10^8	9	8 (89)
10^7	32	16 (50)
10^5	116	32 (28)
10^3	14	0 (0)

Use of wastewater sludge compost does entail some disease risk, but for typical compost with total coliform counts of 10^1 to 10^3 cells per gram, the chance of disease outbreak in humans is probably less than 1 in 1,000,000. Should an area be subject to outbreak of a particular disease then the risk of infection from compost would be higher because of the presence of additional pathogenic organisms.

A potential problem recently observed at the Beltsville composting operation is the possible presence of secondry pathogens, specifically fungi. In the composting process fungal growths can proliferate, particularly at too low a composting temperature in some part of the pile, or by reinfection. In fact, much of the action of composting is probably due to fungal organisms. Some fungi, for example *Aspergillus fumigatus*, can produce toxic effects in susceptible individuals. Excessive concern is not warranted, but it is advisable that individuals with lung ailments or asthma not be exposed in the composting plant. Dusty conditions should be avoided, or dusk masks worn when dusty conditions cannot be avoided.

TABLE 14. DOSE OF VARIOUS SPECIES AND STRAINS OF SALMONELLA THAT CAUSED DISEASE IN HUMAN VOLUNTEERS (From McCullough and Eisele)[10][11][12]

Salmonella species/strain	Dose at which 50% or more develop clinical disease
S. meleagridis 1	50,000,000
S. meleagridis 11	41,000,000
S. meleagridis 111	10,000,000
S. anatum 1	860,000
S. anatum 11	67,000,000
S. anatum 111	4,700,000
S. newport	1,350,000
S. derby	15,000,000
S. bareilly	1,700,000
S. pullorum 1	1,795,000,000
S. pullorum 11	163,000,000
S. pullorum 111	1,295,000,000
S. pullorum IV	1,280,000,000

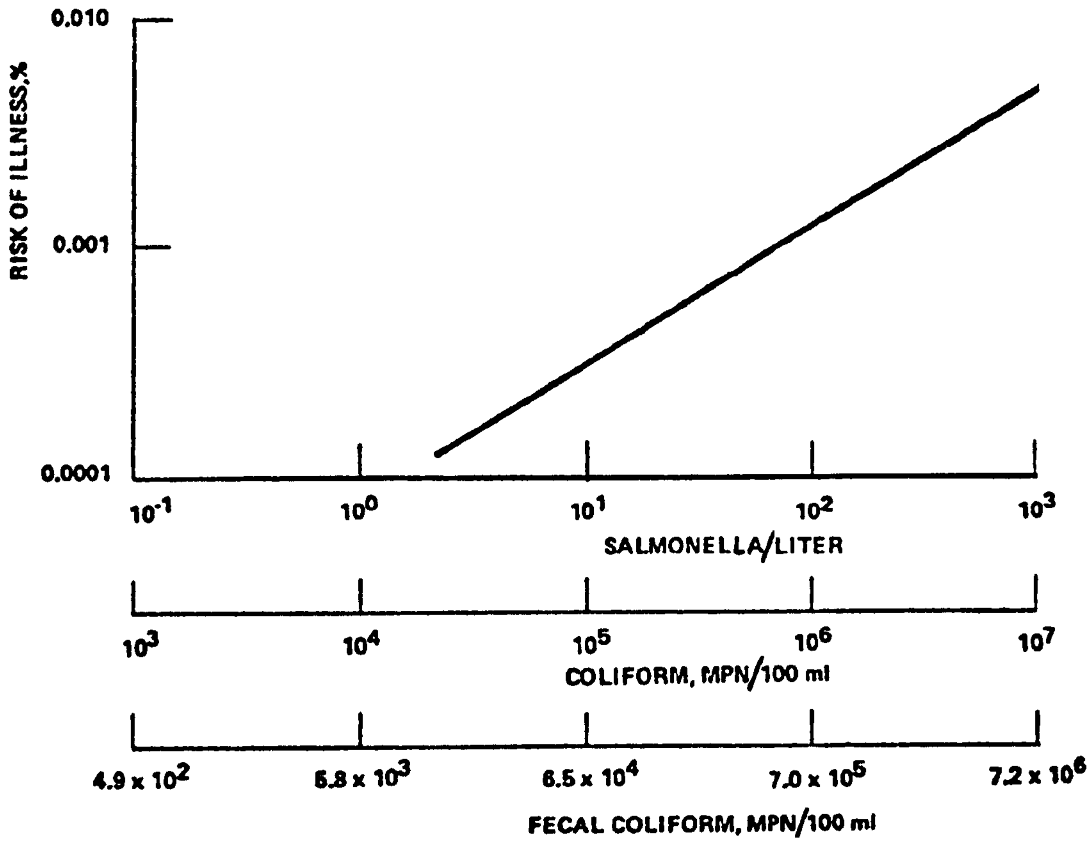

Figure 6. Relationship between disease risk and salmonella, coliforms, and fecal coliforms (after Mechalas et al.).[15]

SECTION 8

RESULTS AND DISCUSSION

Operations at both Beltsville and Bangor have demonstrated that composting operations can be conducted outdoors on a year around basis even in extremely cold climates. Both sites have been in use for static pile composting for over one year on a continuous basis. Operations were observed at both sites during all types of weather as shown in Table 1 for the purpose of analyzing various aspects of the operations under all weather conditions. The materials handling operations can be conducted outdoors using readily available mobile equipment under all weather conditions encountered at both sites by proper scheduling of work. It may be possible to use fixed materials handling equipment for portions of the materials handling operations, but this has not been demonstrated on a full scale operation.

Both operations are continuous on a year around basis; Beltsville receives limed sludge cake on a 5 day a week schedule and Bangor once a week and, occasionally, twice a week. Sludge is not stored at the composting sites, but is brought to the site when it can be handled and formed immediately into compost piles. The open operations are vulnerable to precipitation during the sludge-bulking agent mixing process, but once formed into piles the precipitation has little effect. Mixing can be accomplished in the rain at Beltsville because they have the equipment to accomplish the operation quickly. Bangor, on the other hand, can not mix during rain and, therefore, they schedule mixing on favorable days. Sludge can be stored at the plant to allow this flexibility in scheduling.

The major impacts of weather on outdoor composting operations are summarized as follows:

1. Rain
   - Screening can not be conducted in the rain without cover.
   - Moisture absorption by unscreened compost stored outdoors may make screening difficult or impossible during and following periods of rain.
   - It may not be possible to conduct sludge-bulking agent mixing during rainy weather unless the mixing can be accomplished rapidly.
   - Some bulking agents may absorb excessive moisture during rainy weather when stored outdoors.

2. Extreme Cold
   - It is necessary to conserve heat as much as possible in order to maintain optimum composting performance. Bangor has developed several procedures such as using warm compost from an active pile being torn down as bulking agent for mixing and construction of a new pile and/or piping hot exhaust air from an active pile into a new pile for the first few days and using relatively heavy covers of compost over the piles as insulation.
   - Equipment cabs must be heated and covered maintenance areas must be provided. It is advantageous to store equipment inside when not being used.

3. Snow
   - Snow has not been a serious problem except for impeded visibility and need for site clearing.

4. High Winds
   - High winds can cause materials to blow and can cause dust conditions.

5. Inversion Conditions
   - Inversion conditions have not caused problems at either site during operations.

Weather conditions have not caused "down time" at either site and, in fact it is not possible to "turn off" composting operations. Both sites schedule operations on a regular year-round-basis. Certain site improvements are necessary or can facilitate easier operations, but may not decrease costs significantly. The site improvements considered mandatory are heavy crushed stone cover so that heavy equipment can operate year around. A crushed stone surface has many limitations, but can be used as demonstrated at Beltsville. More desireable and almost in the mandatory category would be hard surfacing (preferably reinforced concrete) for access roads and the mixing and composting areas. Of lesser importance would be paving of screening and storage areas. Covered areas for mixing, screening, and unscreened compost storage would be helpful in areas with high precipitation. Covered composting areas may be helpful, but are not considered necessary in most climates.

A covered area under construction at Beltsville will be used for research studies. The normal work areas will not be covered. A paved mixing and composting pad was constructed and placed in service for regular operations. While this pad is a significant improvement over the crushed stone surface it was not installed because of expected operational cost savings. The advantages of the pad are less stone pickup in the compost, better drainage and easier cleanup.

There have been no significant nuisance complaints at either site. Some odors are noticeable at both sites. Beltsville has an odor control system, but is is seldom used. Paved work areas would help reduce odors on site because the compost and sludge can work down into the crushed stone. Operations have never been shut down at either site during static pile composting because of odor generation. Some fly problems have been noted at Bangor, but only around composting piles. Good site drainage and housekeeping will minimize fly problems. Both sites have occasional problems with blowing materials and dust, but just on the sites. Beltsville uses a water wagon to help reduce dust from equipment operations during dry weather. Paved work areas also would help reduce the dust problem.

Various weather conditions have had no documented effect on manpower or on the material quantities processed at either site. Some operations, such as screening, have to be curtailed during rain but equipment is sized so that screening can be accomplished during good weather. At Bangor, manpower is scheduled as needed, but at Beltsville the same level of manpower is available year around.

It is significant to note that savings can be made in manpower and materials handling by developing an optimum operation for a particular site and situation. This is illustrated in Table 8. By changing the bulking agent to unscreened compost the amount of screening and the volume of make-up bulking agent can be reduced significantly. This is only one example of possible savings for a cost conscious municipal operation. It is anticipated that other significant cost savings can be made by varying operations and, in fact, the potential savings are greater than those that may be realized by weatherproofing the site. Additional study is needed to find ways to reduce composting operation costs.

The product quality is affected very little by weather at a well run wastewater sludge compost operation. Available pathogen data do indicate some minor improved kills in summer above the high kills generally achieved. No data are available on seasonal volatile solids reduction. Color is a function of moisture content and is not a reliable indicator of process efficiency or performance. Odor is not affected by season or weather condition as best can be determined.

Pathogens and indicator organisms may be present in finished compost and there is no solution to this problem except complete sterilization. The outside of the piles may not reach lethal killing temperatures and therefore, some organisms can survive. A risk analysis based on data from Beltsville, Bangor, and published data indicates that the health hazard to adult humans is very slight. The methods used herein can be applied to specific situations for estimating risk to public health.

If the composting site is well laid out with specific separated areas for mixing, composting, screening and storage, and if proper procedures are used for mixing, composting, and curing, it is extremely unlikely that raw sludge or improperly composted sludge can become mixed with finished compost and delivered to users. It is possible to use pathogen or indicator organism analysis as a basis for quality control. However, it is felt that this type of sampling and testing is not convenient and can be costly for most smaller municipalities. This type of testing can be used for spot checks. Probably the most useful control is regular temperature monitoring of the piles. Temperature monitoring is simple, quick and provides a reliable indicator of day to day pile performance so that necessary process changes can be made quickly. Daily monitoring is desirable, but perhaps monitoring every few days will be more practical for most operations. Based on past operations at Beltsville and Bangor, if inside pile temperatures stay above 60°C for a period of several days, fecal and total coliform should be less than 10^4 cells per gram 90 percent of the time and below 10^6 cells per gram 100 percent of the time, and salmonella should be below detectable levels 90 percent of the time and below 10^4 cells per gram 100 percent of the time. Consistent readings of total and fecal coliform above 10^5 or 10^6 cells per gram probably indicates poor operations as would salmonella above 10^3 or 10^4 cells per gram.

References

1. Hoyle, Tanner & Associates, Inc. Report on Sludge Composting at the Proposed Wastewater Treatment Plant, Durham, New Hampshire. EPA/WS & PCC Project No. C330161-02 Amendment No. 1. August 25, 1976.

2. Urban Services Group, Final Report - Markets Study for Composted Sewage Sludge in the Metropolitan Washington Area, Metropolitan Washington Council of Governments. January 17, 1977.

3. Colacicco, D., Epstein, E., Willson, G. B., Parr, J. F., Christensen, L. A. Costs of Sludge Composting.

4. Joseph, J. T. Feasibility of Composting Raw Sewage Sludge by High Rate Suction Aeration Techniques. EPA Solid Waste Demonstration Grant S-803828-01, April 1976.

5. Crombie, George and Harter, Robert D. Application and Economics of Forced Aeration Composting of Sewage Sludge.

6. Epstein, E., Willson, G. B., Burge, W. D., Mullen, D. C., and Enkiri, N. K. A Forced Aeration System for Composting Wastewater Sludge. Jour. WPCF. Vol. 48, No. 4, April 1976. Page 688.

7. Kawata, Dr. K., Cramer, William N., Burge, W. D. Composting Destroys Pathogens. Water and Sewage Works, April 1977. Page 76.

8. Geldreich, E. E. and Clarke, N. A., "The Coliform Test: A Criterion for Viral Safety of Water." Proceedings of the 13th Water Quality Conference, Urbana, Ill., 103-113 (1971).

9. Hornick, R. B., et al., "Typhoid Fever: Pathogenesis and Immunologic Control." New Eng. J. of Med., 283, 686 (1970).

10. NcCullough, N. B., and Eisele, W., "Experimental Human Salmonellosis I. Pathogenicity of Strains of S. Meleagridis and S. Anatum Obtained from Spray-Dried Whole Egg." J. Infectious Disease, 88, 278 (1951).

11. McCullough, N. B., and Eisele, W., "Experimental Human Salmonellosis III. Pathogenicity of Strains of Salmonella Newport, S. Derby and S. Bareilly Obtained from Spray-Dried Whole Eggs." J. Infectious Disease, 89, 209 (1951).

12. McCullough, N. B., and Eisele, W., "Experimental Human Salmonellosis IV. Pathogenicity of Strains of Salmonella Pullorum Obtained from Spray-Dried Whole Eggs." J. Infectious Disease, 89, 259 (1951).

13. Kerr, R. W., and Butterfield, C. T., "Notes on the Relationship Between Coliforms and Enteric Pathogens." Pub. Health Rep., 58, 589 (1943).

14. Fair, G. M., Geyer, J. C. and Okun, D. A. Elements of Water Supply and Wastewater Disposal, 2nd Ed., John Wiley & Sons, New York, 1971, 512.

15. Mechelas, J. M., et al., "An Investigation into Recreational Water Quality." Water Quality Data Book, Vol. 4. EPA 18040 DAZ 04/72. U.S. Printing Office, Washington, D. C. (1972).

LIST OF METRIC CONVERSIONS

English Unit	Multiplier	Metric Unit
acre	0.405	ha
bushels	0.035	cu m
cu ft	28.32	l
cu yd	0.765	cu m
°F	0.555(°F-32)	°C
ft	0.3048	m
in	2.54	cm
lb	0.454	kg
mile	1.61	km
sq ft	0.0929	sq m
ton (short)	0.907	ton (metric)

APPENDIX

FORCED AERATION COMPOSTING AND APPLICATIONS

Composting is the biological oxidation of organic matter by aerobic thermophilic organisms, or anerobic, mesophilic organisms. The forced aeration method of composting is an aerobic, thermophilic process as presently practiced. Aerobic conditions are maintained in the pile by forced ventilation, compared to mechanical turning in the windrow process. The forced aeration method is significant because need for sludge digestion is eliminated and raw (undigested) sludge cake can be used without causing odor problems. In addition, the piles remain fixed during the composting period, higher and more uniform composting temperatures are developed and maintained, less land is required, and, generally, more conventional and less costly machinery is required as compared to windrow composting. The forced mechanical aeration allows operation personnel to effect some process control by adjusting the aeration operating cycle.

Raw limed dewatered wastewater sludge (approximately 20-25 percent solids) is mixed with a bulking agent prior to formation of the pile. The ratio is not necessarily fixed and, commonly, is two to three parts bulking agent to one part sludge cake by volume. The purpose of the bulking agent is to increase the porosity of the sludge cake to assure aerobic conditions during composting and to reduce the moisture content of the mix to an acceptable level (50 to 60 percent). Bark and wood chips have been used successfully as bulking agents, but other materials may also be suitable. Complete mixing of the bulking agent and sludge is essential.

A base is prepared for the pile consisting of a perforated aeration header and approximately 12 in of bulking agent or unscreened compost. The base plan dimensions are the same as the bottom of the finished pile, typically 15 to 24 ft wide and 40 to 50 ft long, although the dimensions can be changed to match the requirements of the specific situation. The base is important in providing proper air distribution in the pile.

The sludge-bulking agent mixture is piled on this base to a typical height of 10 ft forming a triangular cross section. The pile is capped on all exposed surfaces with a 12 to 18 in layer of screened or unscreened compost which insulates the active pile, limits the precipitation which penetrates into the pile, and absorbs odors. This pile configuration can be constructed using commercially available front loaders and contains approximately 50 cu yd of dewatered sludge and 150 cu yd of bulking agent in addition to the base and cap materials. Other size piles can be constructed.

Additional individual piles are normally constructed as sludge is available or the initial pile can be "extended" by placing a new pile immediately adjacent to one side of the last pile forming a wider continuous pile. These configurations are shown in Figure A.

The aeration header is attached to the suction side of a blower capable of producing an air flow of 200 to 300 cu ft per minute (for the size pile described). The blower discharge is piped into a smaller pile of unscreened compost which effectively deodorizes the gases drawn from the composting pile. Water condenses in the blower suction piping and some means must be provided to remove this water either by careful grading of the piping or installation of a moisture drain or trap.

A seven week cycle consisting of composting and curing has been used sucessfully. The pile is operated for the first three weeks (or more if necessary due to weather) with the blower providing the forced aeration. Interior pile temperatures and oxygen levels should be monitored regularly. Oxygen levels should be in the range of 5 to 15 percent and interior temperatures should rise to and remain above 60^{o} centrigrade during a major portion of the composting period. The lowest temperatures are generally near the outside of the pile. The blower can be operated continuously or on various on-off cycles during composting to maintain optimum conditions. Operating installations have demonstrated that pile temperatures can be maintained above 60^{o} centigrade for a week or more under severe New England winter weather conditions if proper composting techniques are used.

Upon completion of composting, the material in the pile is moved to a stockpile for curing and storage prior to distribution. The curing period is typically 4 weeks and is an added safety measure prior to distribution because elevated temperatures are maintained during curing. In most cases the compost is screened either prior to or after curing to control the maximum particle size of the compost product and to recover a portion of the bulking agent. The cost of the bulking agent can be substantial therefore, recovery and reuse may be very important to the overall economics. It has been shown that wood and bark chip bulking agents can be reused a number of times, however these materials do deteriorate and some passes through the screening becoming a part of the final compost product, so a portion is lost during each composting cycle. Reportedly, 20 to 30 percent is lost during each cycle, but this depends somewhat on the mesh size of the screening.

The foregoing is only a general description of the process. Continual modifications and improvements are being made and it is expected that this process of change will continue.

Two installations have been practicing forced aeration composting for two years or more and are described as illustrations of the process. The third location has practiced forced aeration composting for a year and is planning a new installation which should be under construction soon.

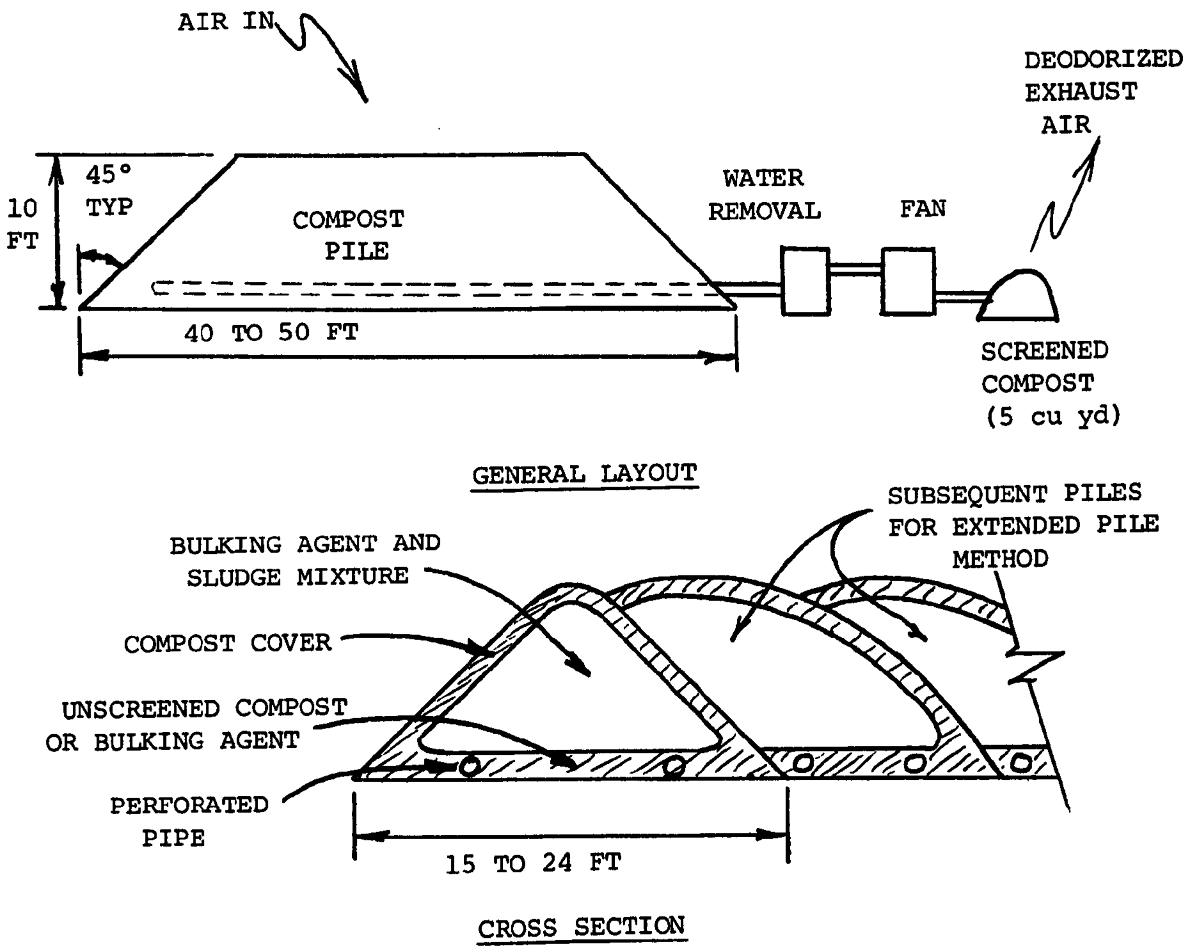

Figure A. Typical forced aeration compost pile for 50 cu yd of dewatered sludge.

BELTSVILLE, MARYLAND

The MES and ARS have jointly operated a demonstration and research wastewater sludge composting facility at Beltsville for several years. Initial work centered on windrow composting, but this process was found to be unsuitable for composting raw wastewater sludge because of odor problems. This led to the development of the forced aeration method in 1973. Subsequent demonstrations showed that raw wastewater sludge can be composted by this method without producing offensive odors in addition to producing higher composting temperatures. This method requires less space and eliminates the requirement for regular turning of the compost as compared to windrow composting. Work is continuing in an effort to further improve this method and develop additional performance data. Approximately 350 wet tons per week of raw dewatered wastewater sludge is composted at the 10 acre Beltsville site.

The site which was previously used for windrow composting, is being converted to an efficient layout for forced aeration composting. Paved composting pad areas, both covered and uncovered, are being constructed in addition to covered storage and working areas. It is estimated by ARS personnel that at least 150 wet tons per day of sludge could be composted on this site using the extended forced aeration method.

BANGOR, MAINE

The City of Bangor, Maine, population 38,000 has been composting limed raw primary sludge cake since mid 1975 using the forced aeration method as developed by USDA.

The City generates approximately 40 wet tons (50 cu yd) of sludge each week (approximately 20 to 25 percent solids). The sludge is dewatered and delivered to the compost site once a week from the wastewater treatment plant. A hydraulically operated, rear loading, lift and carry type vehicle is used to haul the dewatered sludge to the compost site in open top containers. The compost site is located 3 miles from the wastewater treatment plant and 2,000 ft from the Bangor International Airport terminal, on approximately 66,000 sq ft of abandoned concrete taxiway. Shreaded bark is used as a bulking agent. A front end loader is used to move the bulking agent, mix the materials, form the piles, and move the compost.

After composting is complete, the product is stored and it is planned for use by the City for applications such as land reclamation, ornamental plantings, parks, highway plantings, and similar soil conditioning applications.

DURHAM, NEW HAMPSHIRE

The Town of Durham composted approximately 40 to 50 wet tons per week of limed raw dewatered primary sewage sludge (approximately 20 percent solids) from early 1975 to mid 1976 using the forced aeration method as developed by USDA. The purpose of the work at Durham was to determine that adequate composting temperatures could be attained in a cold northern climate and to ascertain the costs of operation. The work was funded in part by the State of New Hampshire Department of Public Health.

As the result of a favorable test program, forced aeration composting is being incorporated into plans for expansion of the wastewater treatment facility to secondary treatment. Many of the labor intensive and critical operations such as sludge - bulking agent mixing will be mechanized to reduce operating costs and enhance process performance.

Durham officials concluded that forced aeration composting produced a safe and usable product in a cold northern climate and that the system design being developed is cost effective compared with other disposal methods. These conclusions are based on results of the actual full scale test program during 1975 and 1976 and an engineering predesign study.

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16. ABSTRACT

The overall study objective was to make an independent assessment of the forced aeration wastewater sludge composting method as practiced at Beltsville, Maryland and Bangor, Maine. A number of visits were made to both sites to observe operations under all weather conditions and to gather data. The analyses developed are based on information obtained during the site visits, information provided by various agencies and individuals, and independent observations and calculations.

Results of the study indicate that forced aeration sludge composting can be carried out in a satisfactory manner under nearly all weather conditions including severe New England winters. A number of problems and potential problems are identified along with possible solutions. Costs are very dependent on the size of the operation and the methods used. Several possibilities are explored for reducing costs.

17. KEY WORDS AND DOCUMENT ANALYSIS

a. DESCRIPTORS	b. IDENTIFIERS/OPEN ENDED TERMS	c. COSATI Field/Group
Composts, Sludge, Sludge disposal, Sludge drying, Sludge digestion, Microorganism control (sewage), Aerobic processes, Distribution, Cost estimates, Odor control, Aerobic bacteria, Sewage treatment	Wastewater sludge, Sludge forced aeration, Compost distribution	13B

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