SLUDGE COMPOSTING AND UTILIZATION:

Statewide Applicability For New Jersey

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Preface

The intent of this study is to develop an approach to the analysis of composting as a sludge management alternative for New Jersey. This study, a part of New Jersey Agricultural Experiment Station Project #03543, is one of twelve projects organized under the Camden Composting Project, coordinated by Professor Mark Singley and Dr. Joel Kaplovsky, Cook College, Rutgers University. They involved sixteen principal investigators and six departments at the college. The results of each project are reported under separate titles in this series.

In the original formulation of this project the intent was simply to quantify and qualify sewage sludge output and its potential for utilization as compost. In the development of the conceptual approach to these issues, however, it became apparent that other questions demanded attention. This led to an expansion of the scope of work to include the topics of bulking agent needs and composting site selection. The following report presents an analysis of each of these issues, including summaries of quantitative information developed in this project and elsewhere.

Acknowledgments

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Other investigators on the Camden Composting Project who provided valuable advice include Drs. Joel Kaplovsky, Joseph Hunter, Melvin Finstein, John Cirello, and Emil Genetelli of the Department of Environmental Sciences; Drs. Steve Toth, Robert Duell, and Harry Motto of the Department of Soils and Crops; Dr. Donn Derr and Victor Kasper of the Department of Agricultural Economics and Marketing; and Drs. James Macmillan and Ted Chase of the Department of Biochemistry and Microbiology. All departments listed are part of the New Jersey Agricultural Experiment Station and Rutgers University.

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Background on Sludge Management and Composting

The impetus to develop a program to evaluate the statewide applicability of sewage sludge is traceable ultimately to two pieces of federal legislation of the early 1970's. The first, the Federal Water Pollution Control Act Amendments of 1972 (PL 92-500), requires the secondary treatment of all public wastewater, thereby increasing by two-fold the amount of residual solids, or sludge, removed from the wastewater. The national goal of pollution discharge elimination, coupled with increased federal funding for the construction of sewage treatment plants, has resulted in an extension of sewers to a much larger population. The combined impact of these factors is an approximately quadrupling of the quantity of sludge. It is an irony, common to many resource management issues, that in the effort to improve the management of one resource, the nation's navigable waters, a new problem has arisen in the form of sludge disposal.

The second piece of legislation, the Marine Protection, Research, and Sanctuaries Act of 1972 (PL 92-532), relates to the maintenance and improvement of the nation's oceanic waters. While the 1972 version of the act mandates the Environmental Protection Agency (E.P.A.) ". . . to prevent or strictly regulate" ocean dumping, it was not until the 1977 amendments that ocean dumping of sludge was banned, effective December 31, 1981. Nationwide, the oceans account for 15 percent of the total sludge disposal (Bastian, 1977), but in New Jersey, where approximately 50 percent of municipal sludge is dumped in the ocean, the impact is considerably more severe. It means that new disposal options must be found for the approximately 200,000 dry tons of municipal sludge produced manually in New Jersey, which had previously been dumped in the ocean. While there is some evidence of retrenchment on this position, as of this writing the 1981 ban on ocean dumping remains in effect.

With the navigable and oceanic waters effectively precluded as sludge disposal areas, the focus of attention has shifted to land-based alternatives. It is axiomatic in environmental matters that there are only three media for disposal, water, land, and air, and that the foreclosing of one necessitates a concomitant shift to the others. Disposal to the air is generally accomplished by thermal reduction, either through incineration or an energy recovery system, with the ash residue disposed in landfills. Thermal reduction technologies are required to meet ambient air quality standards and the more stringent source emission performance standards as mandated by the Clean Air Act Amendments of 1970. In areas where the primary standards are not attained, as in New Jersey, it is increasingly difficult and costly to gain approval for new emission sources.

The common land disposal practice in New Jersey is landfilling of sludge in approved sanitary landfills. Both state and federal regulations require monitoring wells at landfills accepting sewage sludge, and recent evidence of groundwater contamination at landfills is causing the state to curtail approvals for sludge disposal. Direct land application, which combines disposal with utilization of the nutrient or soil ameliorating (organic matter) potential in the material, is an alternative practice. Concern over groundwater contamination and other public health risks has impaired the acceptance of land application until regulatory programs are in effect.

This brief discussion of sludge disposal alternatives is abstracted from a background paper prepared in the early stages of this study. It is not meant to be an exhaustive review, but is merely intended to demonstrate the context in which the composting of sewage sludge is being examined. Since the goal of sludge management is ultimate disposal in an environmentally compatible manner, with maximum use of the resource, the preceding comments have focused on the medium of disposal to the exclusion of the various available processes. To understand thoroughly any of the options it is necessary to examine not only the disposal mode and its impact on resource use but also the means of preparing the material, or the process. From this perspective sludge composting is a process, the product of which, compost, is suitable for land disposal. Sludge is also suitable for land disposal, but composted sludge may be utilized more widely than sludge. This may be a small distinction, but it is essential to understanding this approach to the applicability of sludge composting for New Jersey. The emphasis in this report is on the link between process and product and the ramifications of each.

When composting is mentioned as a process it is frequently preceded by the modifier "age old." While this appellation is probably intended to signify that the process occurs naturally and is known through history, it tends to obscure the distinction between different composting materials and processes. In all probability composting has been used to stabilize human fecal matter throughout the ages; but when dealing with sewage sludge composting, it must be remembered that the material is a processed waste, not a naturally occurring one. With this distinction in mind, it is possible to view sludge composting as a technological innovation, not in principle, but rather in its application to a specific material and in its manipulation by man to suit his purpose. If the composting of sewage sludge is viewed in this manner, then the apparent novelty of the process is more understandable. The approach taken in this report reflects the idea that the novel application of the process requires basic analysis and understanding.

Despite the apparent novelty of composting sewage sludge, there is a considerable historical record of successes in composting human fecal matter, either unprocessed wastes (night soil) or processed wastes (sludge). In the early part of the twentieth century the principles of composting night soil and agricultural wastes in windrows were systematized in the Indore process developed in India (Howard, 1935). At about the same time, research in Europe concentrated on the mechanization of the process, including the development of the Beccari process for composting municipal wastes and sewage sludges in aerated cells (Hyde, 1932). Throughout the 1930's and 1940's, much attention was given to the development of more suitable mechanized systems to provide greater environmental control (Golueke, 1972). The success of these efforts can be measured in the spate of studies which indicated the absence of a health hazard from composting (Van Vuren, 1949; Agricultural Research Council, 1948).

The 1950's saw further development in the science of composting, both in the United States and abroad. The work in the United States concentrated on municipal refuse as the material, and the emphasis shifted to systematizing the process around scientific principles (McGauhey and Goleuke, 1953). At the same time, the U.S. Government began to show an interest in the potential of composting for solid waste management. Work at the U.S. Public Health Service was aimed at the development of suitable large scale technologies and the shortening of the duration of composting through better handling and environmental control (Wiley, 1957).

Because of the cultural differences between the U.S. and Europe in population density, land utilization, land tenure, and waste utilization, the Europeans have generally advanced more rapidly in developing agricultural uses of municipal wastes. A brief review of European activity in composting in the 1950's and 1960's provides an illuminating comparison. This period was characterized by an international effort to systematize and standardize the methods of analysis and evaluations of composting, and a concerted effort to develop new processes and uses for the material.

While much of this work was devoted to the composting of municipal refuse, sewage sludge certainly was not overlooked. The Germans Steigerwald and Spring reported (1953) on the advantages, a better product and better process, of composting refuse with digested sludge in experiments from 1949 to 1952, and on later experiments which ran until 1956 (Steigerwald, 1957). The development of the Dano Biostabilizer for composting refuse and sludge, a mechanical system involving a rotating, aerated drum, was reported by Stahlschmidt (1957). A recurring theme in the literature is the effort to provide better environmental conditions for microorganisms through mechanical aeration of the composting material.

An article by the Swiss workers Braun and Allenspach (1958) on windrow composting of sludge and refuse referred to "a perforated concrete slab with air ducts beneath which gave poor results." A paper by Gothard (1959) given at the First International Congress on Disposal and Utilization reported on the process advantages of combining dewatered sludge with refuse in an aerated, mechanical system of the silo type. A review section at the same meeting noted that "the discussions emphasized that the problem of concomitant processing of refuse and sludge constantly becomes more urgent in all countries" (Jaag, 1959). This report also noted the success of German, Dutch, and Swiss researchers in composting dewatered sewage sludge with equal amounts of refuse.

A particularly interesting contribution by Rohde (1959) concerns successful composting of dewatered sludge with no additional material, in which the material is dewatered on drying beds, plowed, harrowed, and rototilled, before stacking in "windrows which are provided with aeration channels to better provide oxygen." This manner of dewatering and handling, which was originally demonstrated by Imhoff and Muller in 1938, was further developed by Bohme (1966) in experiments in 1957 and 1958. Using the same technique, Bohme demonstrated that with correct handling, processing, and pile geometry, pore space in the pile and therefore, aerobic conditions, can be maintained without need for mechanical aeration, aeration channels, or turning (Bohme, 1965).

Research on "sludge only" composting is relatively rare, but the theme of forced aeration recurs, as noted in the following articles. A paper by Tietjen and Banse (1960), on the analysis of pore space in compost piles, noted that "sorted refuse frequently requires aeration initially as by means of a blower or natural aeration through perforated pipes beneath the windrows." In the French biotank system the use of "semicircular, perforated pipes (manifold) which make possible mechanical aeration of the compost heaps" is mentioned, and an editorial comment notes, "the 'biotank system' is more aptly described as sheltered, forced-air windrow composting" (Dobrouchkess, 1960). A 1960 article from Southern Rhodesia which introduces the Tollemache system for composting refuse and sludge in windrows makes reference to "a perforated concrete floor which permits forced aeration" (Anonymous, 1960). An Israeli patent was granted covering a process of grinding and windrow composting of refuse with forced aeration in which "windrows are placed over pipes with air discharge holes connected to a blower from which air is supplied" (Coleman, 1961).

With this foundation the Europeans continued to refine technical factors in the composting process. A great deal of work was devoted to matching suitable composts with available markets, standardizing methods of analysis, developing materials handling processes, and controlling process parameters. Two American reviews of the late 1960's (Jensen, 1969; Hart, 1968) noted that the apparent success of composting in Europe was not possible without a great deal of experimentation and failure. They warned against transferring the experience in Europe directly to the United States without considering the different circumstances encountered.

Unfortunately for the development of composting in the United States, their cautions were not always heeded. Clarence Coleuke, one of the few Americans active in compost research throughout the last quarter century, suggests "over-mechanization and overpromotion" as leading to the difficulties encountered in the United States. He also cites the "excessive optimism in regarding composting as a panacea," and the tendency to apply a double standard to composting which requires commercial profitability. Breidenbach (1971) cited the latter reason as a partial explanation for the closing or intermittent operation of fourteen of the eighteen composting plants founded between 1951 and 1969. At the same time approximately 125 composting facilities were operating in Europe.

The overpromotion noted by Golueke seemed to stifle American activity in process development throughout the 1960's. Research on utilizing compost produced by operating plants was carried out at the Alabama Experiment Station (Scarsbrook, et al., 1970) and the Tennessee Valley Authority, the latter in conjunction with the federally funded research project at Johnson City, Tennessee (Clemons, 1975). This was a large scale, intensively studied project undertaken cooperatively with many contributors. A noteworthy contribution to sludge composting was the demonstration of a small vessel mechanical composter with air supply and paddle mixers, which was capable of processing dewatered sludge with recycled sludge compost (Shell and Boyd, 1969).

Available information on European experience in the 1970's with sludge composting indicates further refinement of the operating parameters and required quantities for composting sludge with other organic wastes. A Dutch article noted that dewatered sludge and refuse mixed at a 1:1 ratio by weight produced optimum composting conditions (Teeuwen, 1973). Two German articles note the success of windrow composting of combined sludge and solid waste (Rogartz, 1973), and the reduced cost of waste disposal and agricultural fertilization when mixtures of sludge and solid waste are composted (Anonymous, 1973). A French patent was issued in 1974 for a variable aeration process in a reactor composting sludge with sawdust and straw, with the addition of bentonite to remove heavy metals (Kneer, 1974). A similar process developed in Germany is also in use (Hessian Environmental Institute, 1975). A 1977 article describes the windrow composting of sludge and sawdust in Canada (Heaman, 1977).

The early 1970's in the United States provided a period of reassessment of composting applicability. The interest in composting of solid waste continued in a reduced state, and was superceded by the pressing need for a sludge management alternative. The legislative mandates mentioned earlier provided both the carrot and the stick for this effort. The County of Los Angeles, which had sold heat-dried sludge to the home market for fifty years, began the windrow composting of dewatered sewage sludge with recycled compost in 1972 (LA/OMA, 1976). The New Jersey Agricultural Experiment Station studied the windrow composting of swine waste and solid waste, with a later experiment substituting dewatered sewage sludge for swine waste (Besley, et al., 1973). The Biological Waste Management Laboratory at Beltsville, Maryland, with experience in handling manures and solid wastes, began investigating composting as one of several sludge management alternatives (Walker and Willson, 1973). Their work led to the adoption of the forced aeration, static pile method as the most suitable method for composting dewatered sewage sludge (Epstein and Willson, 1975; Epstein, et al., 1976).

Forced aeration systems are also in use at Bangor, Me. (Anderson, 1977), Durham, N. H. (Leighton, et al., 1978), and Camden, N. J. (Bolan, et al., 1978). Basic principles affecting the composting process (Haug and Haug, 1978) and materials handling operations (Shea, 1978) are under investigation at these locations and elsewhere.

Scope and Development of Investigation

The preceding section provides the reader with some background information essential to understanding the context for considering sludge composting in New Jersey, and also provides some points of reference for what is to follow.

The first point to note in reference to sludge management issues is the rapid course of events which led to the consideration of sludge composting in New Jersey. The shift from water to land disposal alternatives should have been anticipated so that suitable technologies could be developed. That it was not can be partially attributed to the failure "to recognize the multimedia nature of environmental impacts from municipal sludge" (NAS, 1978). The failure is characteristic of that form of decision-making in environmental regulation which proceeds on an incremental, stopgap basis, as opposed to the more reasonable approach of unified policy formulation based on scientific information.

The review of the recent history of composting indicates a second point of reference: the use of sludge composting, while relatively new in the United States, is not unusual when viewed from an international perspective on resource management. What is unusual about the American case is the past predilection to view potential resources which emanate from the land as wastes which must be disposed elsewhere. As this attitude changes, the acceptance of proven technologies, such as composting, must increase. The viewpoint taken here is that sludge composting is a proven technology, and that the statewide applicability of the technology is dependent on other issues and broader questions.

The preceding section is a product of background papers and conceptual models developed in the early stages of this effort. Besides the models on sludge management and composting alternatives, additional papers include work on compost uses and utilization sites. Pertinent parts of this work are included in the Appendix. Coincident with this work the same research group developed a systems approach to the analysis of the Camden, N. J. composting operation, which is reported under a separate title. All of this work at the New Jersey Agricultural Experiment Station is funded under a large, multidisciplinary demonstration program called the Camden Composting Project.

With the preliminary work completed the next step was to develop an approach to the identification and analysis of factors fundamental to the understanding of the applicability of sludge composting in New Jersey. Working with the models formulated under both the statewide applicability study and the systems approach, the salient points of the required research program became apparent. The systems approach identified two basic resources, sludge and bulking agents, as necessary components of the work, and they are so included. This same model (reprinted in Appendix A) made clear the essential nature of land utilization as a component of statewide importance, for it is through land utilization that the goals of sludge disposal and resource recycling are realized. The fourth and final component is the composting site, the essential link to which are brought the raw materials and from which the finished compost emanates. Figure 1 is a graphic rendition of this organization. With the four-component model it is possible to define the scope of the study.

The complex interrelationships which exist among the four components in a sludge composting operation are little appreciated or understood, because of the relative novelty of composting as a sludge management alternative in the United States. Those wishing to adopt sludge composting have little experience with the process or the material, and yet the information requirements are extensive. The basis for sound decision-making must be a clear understanding of the range of applicable factors and their implications; by identifying these factors and developing practical criteria for their evaluation, a determination of the statewide applicability can be made.

The investigation focused on two areas simultaneously: the factors which affect each component were developed and evaluated, and the availability of the necessary information and the interaction of the components were examined. The evaluative criteria which were developed are reported in a previous progress report, and are included in Appendix B. The criteria for each component are listed as to their effect on the quantity, quality, and availability of the component in question; this tripartite division is a useful framework for examining resource issues.

In evaluating each component there are four basic concerns: the major resource factors associated with that component which can affect the design or operation of the system or the potential for using the compost; the kind of information available relative to each factor; how the information, or lack of it, can be incorporated into the approach; and how each of the factors might affect the decision to compost. The objective of the research is to provide the information, in quantitative and qualitative terms, that is needed to decide if composting is applicable to the circumstances under consideration.

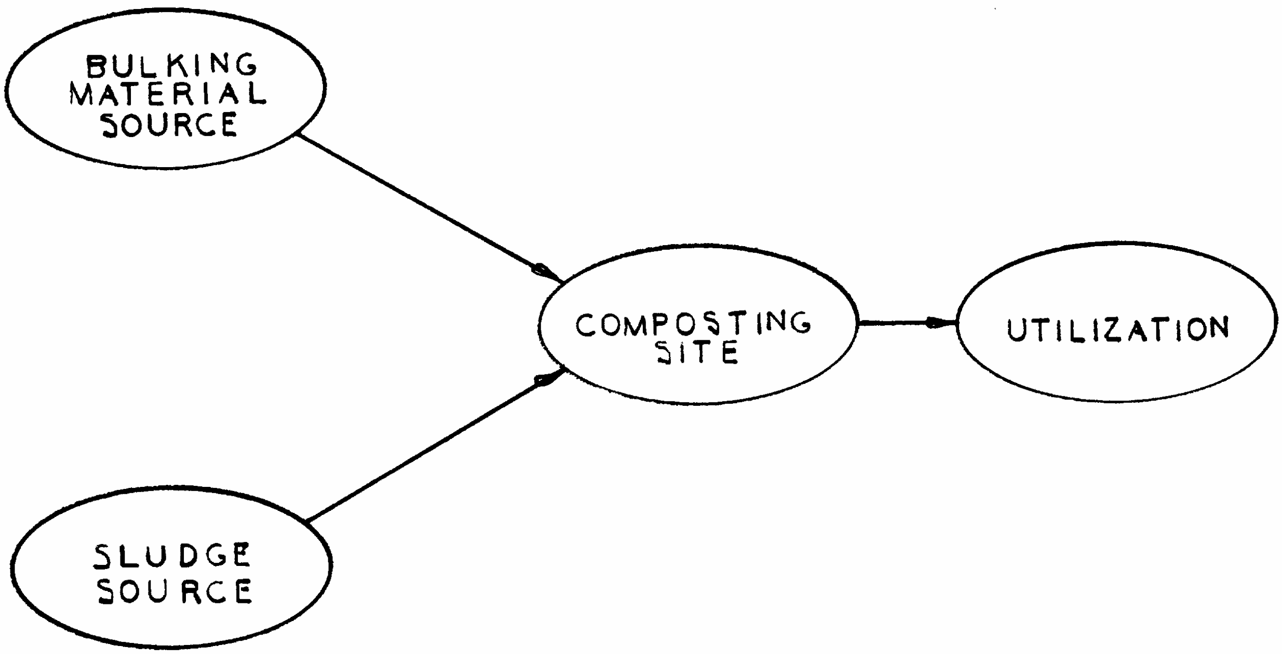


Figure 1:
Statewide Applicability

Report Format

One chapter is devoted to each of the components, with the information similarly organized. Each chapter begins with a basic description of the approach which should be followed in analyzing the component. The basic outline is:

1. Define the relevant factors and their parameters for evaluating each component.
2. Identify suitable materials, sites, or uses.
3. Quantify supplies of material based on available information.
4. Define and discuss issues affecting applicability.

The definition of relevant factors and parameters is essential to the assessment. The aim of this section is to identify the particular properties which affect the capability to compost. The identification of suitable materials, sites, or uses is in the nature of a preliminary planning guide. The quantification of available supplies is a broad inventory of the suitability factors, including an assessment of information availability and utility. The final section defines and discusses the major issues related to that component which might affect either the specific availability or general applicability of the component. Included in this section is a discussion of the state, regional, and local implications of using the component.

While the state is the basic unit of application for this report, in a state with the diversity of New Jersey it is unreasonable to aggregate the information without commenting on local conditions. On the other hand, when working with limited manpower and resources it is impossible and unproductive to attempt a case by case enumeration of alternatives. This report gives basic information so that responsible authorities can carry out the necessary enumeration. However, to ignore local conditions is unrealistic. As a compromise, a demonstration study was initiated using a county as the basic unit. Counties are large enough units to demonstrate the complex interrelationships which exist; they have been designated as the basic units for solid waste management planning in New Jersey, which includes planning for sludge management; and much of the regionalization of sewage treatment plants is done on the scale of county or multicounty areas. The inventory part of this demonstration has been reported in the third progress report on this project; pertinent sections from that report are abstracted and included in the text and Appendix.

Chapter II: Sludge and Its Source

Introduction and Suggested Approach

The first component of the statewide program is sewage sludge and its source, the sewage treatment plant. Sludge is the basic raw material under consideration, and the treatment plant is the planning unit for most sludge management decisions. The following approach to the sludge component of a composting plan is considered generally applicable no matter what the level of planning:

1. Determine the anticipated quantity of sludge produced based on treatment plant characteristics and material characteristics.
2. Analyze current and anticipated quality of sludge for feasibility of composting and compost use.
3. Develop estimates of sludge quantities for planning unit under consideration.
4. Define issues and arrangements which affect the decision.

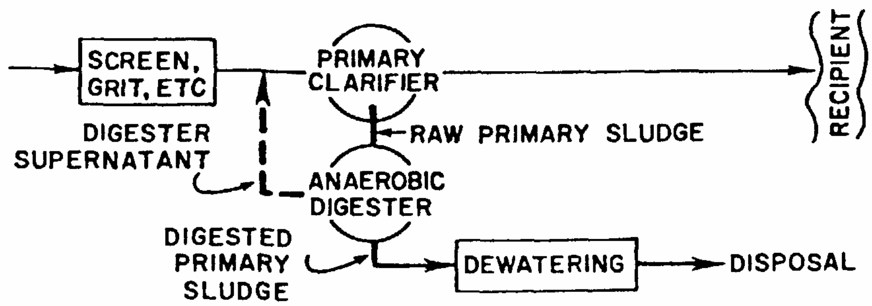
Determination of Sludge Quantity

Treatment Plant Characteristics

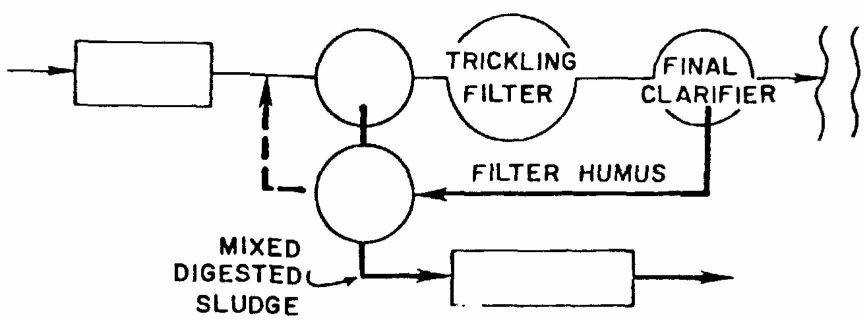
Sewage treatment plants practice physical, biological, and chemical treatment, depending on the composition of the wastewater and the required treatment level. Physical (primary) treatment, by settling, is common to most plants and was the major treatment process in the past, but it has since been supplemented by biological (secondary) treatment, which uses microbial activity to remove the solids. Figure 2

Figure 2:
Typical Wastewater Treatment Systems

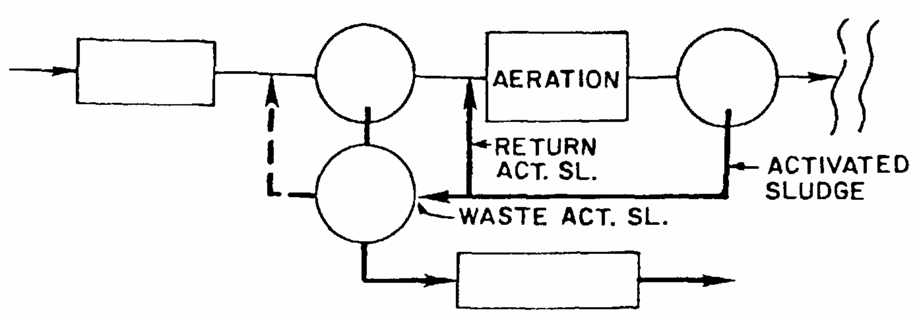
Primary sedimentation



Trickling Filter



Activated Sludge



Source: Adapted from Vesiland, 1977

(from Vesiland, 1977) shows illustrations of primary treatment and the two most common types of secondary treatment, trickling filters and activated sludge. Although trickling filters may be ideal for small and medium sized plants, the activated sludge process is considered more versatile and more efficient.

Since the Clean Water Act of 1972, all treatment plants have been required to implement secondary treatment. The result is a mixed primary and secondary sludge as the plant output, generally in a 60:40 or 50:50 ratio. All plants should have secondary treatment by 1984, missing the legislated goal of 1977.

Chemical treatment is used with wastewater that is high in difficult-to-remove solids or exotic industrial contributions, or where especially thorough treatment is needed to meet water quality standards. Chemical treatment, usually with alum, lime, ferric chloride, polymers, or combinations of these, can produce a highly inert sludge or one that is difficult to dewater, two aspects which may hinder their handling by composting. There is some reported experience with composting chemical sludges (Willson, 1977), but the resulting product may also have limited use due to its low organic matter content.

Table 1 shows the normal quantities of sludge produced for various treatment processes. These values are useful for broad estimates, but it should be noted that their calculation includes several assumptions about the "average" wastewater. Due to the complex nature of wastewaters, the only ways to determine the sludge yield from treatment processes accurately is by laboratory or pilot studies on the specific wastewater. Typical equations for calculating sludge yields are given in the Appendix.

Most treatment plants also have one or more sludge treatment processes, including digestion, other stabilization techniques, thickening, conditioning, and dewatering. Of these, digestion and dewatering have special relevance to composting. Because digestion reduces the amount of solids in sludge, it can have three potentially adverse impacts on composting: it may leave the sludge with too low a content of volatile solids to achieve thermophilic temperatures; it may cause the compost produced from this sludge to have too high a content of inert materials to be useful; and it increases the overall cost for sludge management. For these reasons it does not appear advisable to digest sludge before composting.

Because the composting of sludge generally requires a semi-solid material, dewatering is of major importance to composting. Usual dewatering methods are drying beds, vacuum filters, centrifuges, belt filter presses, and pressure filters. All of these options except drying beds require sludge treatment by organic or inorganic chemicals to aid in solidification. These chemical additions can have an impact on the compost process or product. Any of the dewatering methods appear compatible with composting, although each may require a different mode of materials handling due to the different physical and chemical properties of the output from each.

Table 1:
Average Quantities of Sludge from Sewage Treatment

Treatment Process	Code	Pounds/ Million Gallons of Sewage	Tons/ Million Gallons of Sewage
Primary sedimentation	PS	1,250	.625
Primary sedimentation with digestion	PS w/D	750	.375
Activated sludge	AS	2,250	1.125
Activated sludge with digestion	AS w/D	1,350[2]	.675
Chemical precipitation	CP	3,300	1.650
Chemical precipitation with digestion	CP w/D	1,980[2]	.990
Trickling filter	TF	475	.237
Primary sedimentation and activated sludge	PS + AS	2,340	1.170
Primary sedimentation and activated sludge with digestion	PS + AS w/D	1,400	.700
Primary sedimentation and trickling filter	PS + TF	1,725	.862
Primary sedimentation and trickling filter with digestion	PS + TF w/D	1,225	.612

Notes: 1. Metcalf and Eddy, Inc., Wastewater Engineering, McGraw-Hill Book Co., New York, N. Y., 1972.

2. Digested quantities based on a 40 percent reduction.

Material Characteristics

This section treats only those characteristics applicable to a determination of sludge quantity; characteristics depicting sludge quality are discussed later.

Wet Measurement

Sludges in a liquid form are usually measured in gallons. The solids fraction of the slurry is described by its specific gravity, calculated as follows:

$$1/S_s = \sum_{i=1}^{n} \left(\frac{W_i}{S_i}\right)$$

where S_s = specific gravity of the sludge
W_i = weight fraction of the i^{th} component in the sludge
S_i = specific gravity of the i^{th} component

Solids' Concentration

The most common way of reporting solids in sludge is by percentages, calculated as follows:

$$\text{Concentration (\%)} = \frac{\text{weight of dry sludge soils}}{\text{weight of wet sludge}} \times 100$$

Solids concentration in dewatered sludge can differ widely depending on the type of input sludge, the mode of dewatering, and the type and amount of chemicals added. Some typical solids concentrations with different sludges and dewaterers are given in Table 2.

Dry Tons/Wet Tons

In the literature on sludge and composting, reference is often made to "dry tons" and "wet tons" of sludge. Although sludge is never entirely dry, a dry ton is a theoretical measurement which assumes the total absence of water. Referring to Table 1, primary sedimentation produces 1,250 pounds of dry solids per million gallons of sewage, or .625 dry tons per million gallons. The dry ton provides a convenient and useful method of comparing sludge outputs and capacities because it is a standardized value.

A wet ton is an expression of the total weight of the sludge, including water, and is often used to describe the quantity of sludge to be disposed of. For the conversion of wet tons to dry tons, the solids content of the wet sludge must be known and is calculated by the following equation:

$$\text{Wet tons} = \frac{\text{dry tons of sludge}}{\text{\% solids content of sludge}}$$

Table 2:
Typical Solids Concentrations with Different Sludges and Dewaterers

Dewatering Mode	Type of Sludge	Solids Concentration %
Drying bed	Digested primary	40
	Digested activated	20
Vacuum filter	Digested primary and activated	18-22
	Raw primary	25-38
	Primary and trickling filter	20-30
Belt filter press	Raw primary	24-27
	Primary and activated	20-35
Pressure filtration	Primary and activated	34-37
Centrifuge	Digested primary and activated	20-28
	Digested primary and activated	16-19

Source: J. R. Harrison, 1978, "Review of Developments in Dewatering Wastewater Sludges," U.S.E.P.A. Seminar on Sludge Treatment and Disposal, Cincinnati, Ohio.

The failure to include the solids content when speaking of wet tons of sludge is a cause of considerable confusion in the interpretation of sludge quantity estimates. That is why the expression in dry tons is usually preferable, although the quantity of wet tons is important in the transportation of dewatered sludge.

Bulk Weight/Bulk Density

These two terms are often used interchangeably in the expression of total weight per unit volume; they are actually two separate and distinct terms. Because cubic yards are a common expression of volume in composting, the bulk weight and bulk density of sludge or compost are defined herein as:

$$\text{Bulk weight} = \frac{\text{total wet weight (lbs.)}}{\text{unit volume (cubic yards)}}$$

$$\text{Bulk density} = \frac{\text{total dry weight (lbs.)}}{\text{unit volume (cubic yards)}}$$

With knowledge of the solids content the conversion of bulk weight to bulk density is possible, as follows:

$$\text{Bulk weight} = \frac{\text{bulk density}}{\text{solids content}}$$

Because bulk weight refers to the entire mass and volume, both solids and water, it is the more useful term in the quantification of sludge composting, although bulk density has its application in describing the compost product. The bulk weight of dewatered sludge is highly variable, depending on the proportion and total amount of fixed (inert) and volatile solids, the chemicals used for flocculation, and the porosity of the dewatered sludge mass. This relationship is complex and of considerable importance to the composting process, but rather exotic for this level of analysis; its implications are assessed in other reports issued by this research group.

Table 3 shows the bulk weight of various sludges by type of sewage treatment and type of dewatering. It is impossible to predict these quantities without a careful analysis of porosity, as well as the usual analysis of mixed solids and chemical flocculants. (Determination of pore space is essential for the analysis and planning of the composting process, but is not necessary here. Other projects of the Department of Biological and Agricultural Engineering are treating these issues in greater detail.)

Analysis of Sludge Quality

For this analysis sludge quality is defined as those chemical characteristics of the sludge which can affect either the composting process or the use of the compost product. The quality of sludge is determined by two factors: the wastewater input and the sewage and

Table 3:
Reported Bulk Weight of Dewatered Sludges by Sewage Treatment and Dewatering Mode

Sewage Treatment	Dewatering Mode	Bulk Weight (lbs./yd.)^3
Primary	Vacuum filter	1,700[1]
Primary	Belt filter press	1,100-1,200[1]
Digested primary and activated	Vacuum filter	1,650[2]
Digested primary	Centrifuge	1,900[3]

Sources: 1. Experimental data from Department of Biological and Agricultural Engineering, New Jersey Agricultural Experimental Station, Rutgers University.

2. Freese and Halley, 1978.

3. Horvath, 1978.

sludge treatment process. The relative effects of these factors produce sludges with considerable variation in constituents, particularly in metal content and macronutrient composition, the principal factors of importance to composting. Although sludge composting can dilute or concentrate mineral elements, for the most part whatever is in the original sludge is carried over to the compost product. Sludge quality is here discussed broadly, while in the chapter on utilization the specific aspects affecting compost use are discussed.

Treatment Plant Characteristics

The treatment plant characteristics which can affect the quality of sludge are: the source of the incoming wastewater, the type of sewage treatment process used, and the treatment processes to which the sludge is subjected. The incoming wastewater can be of domestic (homes and offices) origin, or it can be contributed by industries tied into the municipal sewerage system. Where the sewage is a mixture of domestic and industrial sources, as in much of metropolitan New Jersey, the characteristics reflect the diversity of the inputs.

Because primary, biological (secondary), and chemical (tertiary) sewage treatment processes act on different fractions of the total solids in sewage, these processes produce sludges with considerable variation in quality characteristics. Primary sedimentation generally removes dense, inorganic grit in one stage and large, suspended, or settleable solids in the second stage. This raw primary sludge is generally high in organic matter (60-80 percent) and contains a moderate amount of nitrogen (2-3 percent). Biological processes extract organic material and inorganic nutrients from sewage through bacterial action, with the organic material converted in part to oxidized end products. Biological sludges generally are also high in organic matter and organic nitrogen in the raw state, although much of the organic matter is in an unstable form. Chemical treatment processes are often used to remove nitrogen and phosphorous from plant effluents, and are therefore high in these constituents. Because chemicals such as alum and iron are added to affect the reaction, these sludges have a high mineral content and a correspondingly low content of organic matter.

As mentioned previously, the treatment processes of particular importance to sludge composting are digestion and dewatering. Since digestion destroys the unstable organic material in raw sludges, it has the effect of raising the concentrations of macronutrients and trace elements, while reducing the volatile solids (generally 30-60 percent) available for energy use by composting. Dewatering the liquid sludge (generally 1-8 percent solids) to a semi-solid (20-30 percent solids) can result in the reduction of inorganic nitrogen and potassium contents. Some dewatering processes also favor the capture of organic solids over inorganic, thereby raising the volatile solids content of the dewatered sludge.

In summary, sewage sludge contains in some proportion whatever is found in the incoming wastewater. The use of any of the above processes in combination or alone on a similar incoming wastewater produces significantly different concentrations of those constituents in the sludge solids. It is clear that the only way to assess the quality of the sludge accurately is by frequent and complete analyses.

Material Characteristics

The following section introduces the full range of important chemical characteristics for sludge composting. Since the eventual depository for the compost is the land, and all materials have some impact on the land, it can be said that each chemical characteristic is relevant. However, only the major characteristics are identified and ranges quantified.

Macronutrients

The macronutrients for plant growth, all of which are in sludge, include nitrogen (N), phosphorous (P), potassium (K), chlorine (CI), calcium (Ca), magnesium (Mg), and sulfur (S), the last three of which are secondary elements. Of these, the major macronutrients are N, P, and K, which can vary widely in sludge depending on the factors noted earlier. Chaney (1974) and Sommers and Nelson (1976) have published normal ranges of these constituents based on extensive analyses, summarized in Table 4.

Table 4:
Normal Range of Primary Macronutrients

Constituent	Range	Typical	Source
Total N	1-6%	2-4%	Chaney (1974)
Organic N	1-5%		Sommers and Nelson (1976)
Ammonium N	1-3%		Sommers and Nelson (1976)
Ammonium N	12-55% of total N		Chaney (1974)
Total P	.8-6%	1	Chaney (1974)
Total P	1.5-5%		Sommers and Nelson (1976)
Total K	0.1-0.5%	.2	Chaney (1974)
Total K	0.2-0.8%		Sommers and Nelson (1976)

To assess the extreme range that might be expected, the following data from Sommers (1977), reporting on over 250 sludge samples, is included: a range of total N of 0.1-17.6 percent, median of 3.3 percent, mean of 3.9 percent; a range of total P of 0.5-14.3 percent, median of 2.3 percent, mean of 2.5 percent; and a range of total K of 0.02-2.64 percent, median of 0.3 percent, mean of 0.4 percent.

The variation produced by different sewage treatment has been noted by Vesiland (1977), and is adapted in Table 5.

The variation over time within a treatment plant is not often considered, but may be significant for composting. To illustrate this variance, the data in Table 6 were compiled from thirty-five analyses of Camden liquid and dewatered sludge by the Department of Soils and Crops at Rutgers University. This range of values should not affect the compost process, and would produce minor changes in the compost product.

In an area with the diversity of industrial and municipal development of New Jersey, a wide variation in the N, P, and K content of sludges can be anticipated. McCalla, et al. (1978) reported on thirteen sludge analyses from New Jersey communities, summarized in Table 7. These values are within the ranges reported by other investigations except for the low ammonium nitrogen content.

Table 5:
Variation in Micronutrient Content by Sewage Treatment Process

Sludge	% Nitrogen N	% Phosphorous P_2O_5	% Potassium K_2O
Raw Primary	2.4	1.1	-
Raw Primary	2.9	1.6	-
Trickling filter	2.9	2.8	-
Activated	5.6	7.0	0.56
Activated	3.5	2.8	-
Activated	3.0	3.6	-
Mixed Digested	5.9	3.5	
Mixed Digested	2.0	1.4	0.14
Mixed Digested	2.5	1.2	0.20
Mixed Digested	4.6	1.4	0.38
Mixed Digested	2.5	3.3	0.40

Table 6:
Within Plant Variation in Macronutrient Concentrations (Camden, N.J., Primary Treatment)

Weekly Samples		N	P	K
Liquid sludge				
Range	%	1.8-3.2	.87-1.89	.08-.16
Mean	%	2.6	1.22	.12
Dewatered sludge				
Range	%	1.2-2.6	.4-2.6	.04-.15
Mean	%	1.9	.9	.09

Table 7:
Statewide Variation in Macronutrient Constituents

Constituent	Range (%)	Median (%)	Mean (%)
Total N	0.8-7.5	2.6	2.9
Ammonium N	0.01-0.45	0.06	0.15
Total P	0.5-3.2	1.7	1.7
Total K	0.02-0.54	0.16	0.17

Source: McCalla, et al., 1978

Of the other elements present in sludges, organic carbon is in abundance, generally on the order of 20-40 percent of total weight. Calcium, which is a secondary element and a contributor to higher pH, is found in sludges at concentrations of approximately 1-4 percent. Magnesium and sulfur can contribute in ways similar to calcium, but are less abundant, with normal concentrations of .5 percent and 1.0 percent, respectively.

An overlooked factor in sludge composting is the ratio of carbon to nitrogen in the dewatered sludge. This relationship is the fundamental expression of the nutrient balance in composting, for the microorganisms in composting require these elements for protein synthesis and energy. Because microorganisms generally use about thirty parts of carbon to one part of nitrogen, a C/N ratio of 30:1 is considered optimum for composting. The Camden sludge has varied from a low C/N ratio of 10:1 to a high of 22:1. Other analyzed sludges showed a range of from 7:1 to 24:1. The implication for sludge composting is clear: with sludges of a high C/N ratio there is less need for a bulking agent to provide carbon, while at low ratios carbon must be added for efficient composting.

Micronutrients (Trace Elements)

Micronutrients are required by plants for growth but can be toxic at high levels. Among the micronutrients found in sludges are iron, manganese, boron, chlorine, zinc, copper, and molybdenum. Of these, the last three have been identified as posing a potential hazard, and will therefore be discussed with the heavy metals. The first group is not only considered vital for plant growth and a normal component of soils, but is also believed to pose little hazard, for a variety of reasons: iron is an ordinary component of soil; manganese is usually converted to inert forms not taken up by plants; and boron and chlorine are rarely present at hazardous concentrations. Because these elements are currently not considered dangerous they cannot be ignored, however;

any long term land use of sludge should require periodic monitoring of these elements.

Heavy Metals

Among the heavy metals are arsenic, chromium, mercury, cobalt, cadmium, nickel, and lead. Because they can be found in high concentrations in some sludges, the last three, when included with the trace elements of zinc, copper, and molybdenum, make up the class of hazardous metals in sludge.

Some information as to why these metals may be considered hazardous is appropriate as an introduction to their quantification. Zinc and copper are essential micronutrients, and may actually be deficient in human nutrition, but are considered hazardous because excessive concentrations found in some sludges can cause toxicity to plants. Molybdenum, too, is an essential micronutrient, but is considered hazardous at high levels because it competes with other nutrients that plants require. Nickel is nonessential and at elevated levels can cause phytotoxicity, while lead is included in the list of hazardous heavy metals not because it is phytotoxic but because of concern for the direct ingestion of lead by animals or humans. Cadmium, like lead, is not phytotoxic, but can be concentrated in plants to levels which are hazardous to animals and humans when ingested. Of the six heavy metals listed in this paragraph, all but molybdenum have the potential of occurring in sufficiently high concentrations in sludge to represent a health hazard and, therefore, to warrant limits on the amounts applied to land.

To illustrate the extreme variation in heavy metal content, Table 8 is adapted from Chaney and Hornick (1977). The values under "Observed Maximum" are 10 to 40 times greater than those listed under "Maximum Domestic." The large discrepancy indicates the contribution from industrial or older municipal sources. It should be noted that the values under "Maximum Domestic" are often used as guidelines to measure the suitability of sludge for land application.

As an indication of the documented variation within New Jersey, data for thirteen sludges are abstracted from McCalla, et al. (1977) in Table 9. For all metals listed the median values are below the "guideline values" (Maximum Domestic) from Table 8. They exceed these guideline values only in copper and cadmium. When Salotto, et al. (1974) compared the metal analyses of thirty-three plants in eight states to an earlier, more restrictive tabulation of the guideline values, they found a close coincidence between the guidelines and the twenty-fifth percentile concentrations. The topic of metal content in New Jersey sludges and its effect on compost utilization is given more complete treatment in a later section.

To illustrate the variation within a single treatment plant, thirty-five analyses of Camden liquid and dewatered sludges are summarized in Table 10. Although the variation is less than the between-plant variation, it is sufficiently wide to warrant a regulated

Table 8:
Metal Contents of Digested Sewage Sludges

Constituent	Reachable Levels[2] mg/kg	Maximum Domestic[3] mg/kg	Observed Maximum mg/kg
Lead (Pb)	-	1,000	10,000
Zinc (Zn)	750	2,500	50,000
Copper (Cu)	250	1,000	17,000
Nickel (Ni)	25	200	8,000
Cadmium (Cd)	5	25	3,400

Notes: 1. From Chaney and Hornick, 1977.

2. Observed in sludges generated from wastewater of newer suburban communities.

3. Typical of sludges from communities without excessive industrial waste sources or with adequate source abatement.

Table 9:
Metal Contents of Thirteen New Jersey Sludges

Constituent	Range mg/kg	Median mg/kg	Mean mg/kg
Pb	115-1,354	181	327
Zn	735-6,775	1,850	2,205
Cu	480-2,643	1,200	1,400
Ni	20-860	89	156
Cd	5-82	11	29

Source: McCalla, et al., 1977.

Table 10:
Variation of Metal Content in Sludges from Camden, N.J.

Constituent	Liquid Sludge[2]		Dewatered Sludge[2]	
	Range mg/kg	Mean mg/kg	Range mg/kg	Mean mg/kg
Pb	34-629	343	250-588	390
Zn	107-1,315	918	324-1,088	582
Cu	149-1,100	421	152-286	221
Ni	21-77	40	12-69	38
Cd	15-70	42	15-46	31

Notes: 1. Experimental data from Department of Soils and Crops, N.J.A.E.S.

2. The liquid and dewatered sludge samples were not from the same days.

monitoring program. The distribution of values for an element is approximately normal. Cadmium is the only heavy metal in the Camden sludge which even approaches the guideline limit, and, therefore, is the limiting element for land application.

Sludge Quantity Estimates

A preceding section and Appendix C outline several procedures for estimating the quantity of sludge produced in a given plant or jurisdiction. In this section the issue of statewide, regional, and county estimates of current conditions is addressed, with the statewide estimate extended to the year 2000. These issues are discussed relative to the availability and utility of information and their impact on sludge composting for the various planning jurisdictions discussed. Counties are used as a basis for aggregation and disaggregation for the following reasons: counties are distinct units; they have been designated as the basic units for solid waste management planning in New Jersey, with sludge included; much of the regionalization of sewage treatment plants is done on the scale of county or multicounty areas; and population projections, water supply estimates, and wastewater estimates use county data.

Current Statewide and County Estimates

The initial attempt at estimating sludge quantity produced only a single source of information compiled on a statewide basis. A Land Oriented Reference Data System (Bureau of Geology, 1975) was developed to provide a uniform resource information system for New Jersey, and included map overlays showing the location and size (mgd) of sewage treatment plants. The information was compiled from a mixture of county planning board reports, local facilities' plans, and utility authority reports of various vintage, and was therefore somewhat erratic in identification. From this source an initial estimate of 570 treatment plants of all types producing 230,000-300,000 dry tons of sludge annually was developed.

Subsequently, the Office of Sludge Management and Industrial Pretreatment (OSMIP), New Jersey Department of Environmental Protection, planned and implemented the development of a data base for statewide sludge management through the Wastewater Management Information System (WMIS). The information includes physical data on the plant, the receiving stream and classification, and effluent and sludge quality. The data were gathered through mail and telephone questionnaires, and involved considerable checking and rechecking. The system is continually under revision as new data become available.

OSMIP provided this study with a printout from December, 1978 containing the following information: National Pollution Discharge Elimination System number, name of plant, discharge stream and basin code, county and municipal code, design capacity and average flow reported, and type of plant, categorized as commercial, federal, industrial, municipal, or state according to ownership. These data are presumed to be a precise quantification of treatment plants currently operating in New Jersey. The total number of treatment plants in the state is 710, broken down as follows:

Category	Number of Plants
Commercial	82
Federal	13
Industrial	155
Municipal	424
State	36

For the purposes of aggregating the sludge totals on a statewide basis, OSMIP included commercial, federal, and state plants with municipal under the single category of domestic plants, a convention which is followed here.

The input data from OSMIP is analyzed in the following manner. The treatment plants are initially aggregated into county sub-totals by county and municipal code. The total design capacity and total average flow for each county is then calculated; where information on capacity and flow is missing, but is a significant factor, the data are updated by more recent reference. The total average flow by county is then multiplied by the appropriate sludge estimator (from Table 1), depending on type of sewage treatment, and a total county sludge production is calculated.

The use of counties as the planning units presents one major methodological problem in attempting to aggregate the information. Because the franchised areas of the large sewage authorities are not coterminous with county borders, there are significant intercounty transfers of sewage. In order for the sewage flow and sludge production data by county to reflect accurately the total population served and not just the population residing in the county where the sludge is produced, adjustments were made to allocate population to the county where the sewage is treated. These adjustments were made by comparing the New Jersey 201 Facility Planning Areas Map to county boundaries, determining which municipalities sent sewage to another county, calculating the population in those municipalities (Series II for county projections; Greenberg and Newman, 1978, for municipal projections), allocating the population to the receiving county, and subtracting the population in the county not served by sewers (approximate population using septic tanks supplied by OSMIP). The population projections are for 1980, the nearest base year to the present.

The results of this analysis are displayed in Table 11. All counties, with the exception of Bergen, Burlington, and Gloucester, have sewage flows well within design capacities. The total domestic (municipal, state, federal, and commercial) treatment capacity is 1528 mgd, with an average reported flow of 1088 mgd. The state is well within its capacity, but aggregation of data masks the documented local shortages in a number of areas.

The total sludge production in the state is 1040 dry tons per day (380,000 dry tons per year), compared to the state estimate of 1240 dry tons per day (450,000 dry tons per year). Both estimates show a large increase over estimates in previous years. The discrepancy between the two appears large but is readily explained by different assumptions concerning current sludge yields. The state used secondary treatment estimators for Essex and Hudson counties, in anticipation of the upgrading in sewage treatment, while this study used primary treatment estimators; this variation accounts for 60 percent of the discrepancy. The remainder of the variation, primarily attributable to Middlesex and Monmouth counties, is explained by variation in the secondary treatment estimators. The state used estimators of 1.3-1.6 dry tons per mgd, while this study used a consistent 1.12 dry tons per mgd for secondary treatment; the difference in estimators probably lies in the use of advanced treatment in these areas. Based on the analysis of these assumptions, it would appear that the statewide sludge production is within the limits of the two estimates (380,000-450,000 dry tons per year), with the upper figure being approached in two to three years.

The comparison of total county populations and sewered

Table 11:
Statewide Sludge Production of 1980, by County

	Wastewater and Sludge Production Characteristics					Population Characteristics			
	Number of Plants[1]	Total Design Capacity (MGD)[2]	Total Average Flow (MGD)[2]	Sludge Production (tons/day)	States Estimate (tons/day)[1]	1980 Projected Population[3]	Sewered Population	Population on Septic	Sewered Population -Septic Population
Atlantic	19	70.7	31.2	35.0	35.0	187,860	187,860	6,400	181,460
Bergen	25	99.0	90.8	101.7	104.2	927,760	759,770	15,700	744,070
Burlington	47	39.7	40.4	45.2	38.8	355,180	355,180	60,700	294,480
Camden	49	111.8	87.0	85.1	80.7	515,315	515,315	-	515,315
Cape May	18	27.0	13.0	14.6	12.6	69,105	69,105	10,200	58,905
Cumberland	9	26.3	15.3	17.1	17.7	138,360	138,360	3,700	134,660
Essex	11	330.3	270.8	175.9	278.3	938,670	1,259,255	-	1,259,255
Gloucester	8	17.9	16.2	18.1	16.2	196,070	196,070	70,700	125,370
Hudson	19	148.0	80.4	58.2	78.6	615,175	577,455	-	377,455
Hunterdon	21	5.5	4.0	4.5	5.2	79,865	70,865	42,500	37,365
Mercer	25	65.0	50.0	56.0	59.1	342,360	342,360	24,300	318,060
Middlesex	25	188.6	138.0	154.6	180.8	639,970	891,820	-	891,820
Monmouth	55	96.2	60.3	67.5	96.0	503,345	503,345	52,400	450,945
Morris	61	64.2	37.8	42.3	55.2	430,580	430,580	59,500	371,080
Ocean	32	66.8	30.6	34.3	27.9	333,840	333,840	76,900	256,940
Passaic	35	11.8	9.1	10.2	13.1	485,245	174,810	24,200	150,610
Salem	12	4.7	3.7	4.1	4.1	68,280	68,280	31,900	36,380
Somerset	37	17.3	12.9	14.5	16.6	215,385	186,315	90,000	96,315
Sussex	28	4.0	2.8	3.1	3.9	96,230	96,230	75,800	20,430
Union	6	124.5	89.5	93.9	109.5	560,145	532,430	-	532,430
Warren	13	8.8	4.2	4.7	4.8	81,510	81,510	45,700	35,810
Totals	555	1,528.1	1,088.0	1,040.6	1,240.4	7,780,250	7,080,650	699,600	7,080,650

Notes: 1. From WMIS, Office of Sludge Management and Industrial Pretreatment, 1978.

2. From WMIS and individual checks.

3. From Office of Business Economics, 1975; and Greenberg and Newman, 1977.

populations contributing to each county's sludge production, is included to demonstrate the intercounty transfers of sewage and sludge. The major intercounty transfers are from Bergen (200,000) and Passaic (300,000) to Essex, Essex (195,000) to Union, and Union (220,000) to Middlesex. Essex and Middlesex are large net receivers of sewage, and Bergen and Passaic net senders. Four rural counties (Hunterdon, Salem, Sussex, Warren) have 45-75 percent of their population on septic systems and not contributing to sewers, while Gloucester and Ocean have 35 percent and 23 percent, respectively, on septic. The use of population figures is included as a prelude to the year 2000 projections.

Statewide and County Estimates for the Year 2,000

To make an estimate of sludge production more than twenty years in advance is, at best, a difficult task. For a ten-year planning horizon, it is reasonable to base the estimate on anticipated improvement in sewage treatment yielding more sludge, and population increases producing more wastewater. Applying this method to the previous estimates produces the following changes:

	1980 Annual Production (tons)	1990 Annual Production (tons)	1980-1990 Change (tons)
Essex	64,250	111,000	+46,750
Hudson	21,000	33,100	+12,100
Middlesex	56,000	66,000	+10,000
Monmouth	24,500	35,500	+11,000
Union	34,000	40,000	+6,000
			85,850
	Other counties		10,000
	Population increase (500,000)		20,000
			115,850

These figures would raise the 1980 estimate to 495,000 dry tons per year, and the state estimate to 560,000 dry tons per year. To extrapolate to 2000 without considering the implications of changing patterns of municipal and industrial water use and population changes would be an inadvisable step, since these factors are the major contributors to wastewater estimates, no matter how water quality parameters may change.

The use of water demand and population projections for a sludge production estimate is made feasible by the availability of information for these factors. The Statewide Water Supply Master Plan (Division of

Water Resources, 1977) is the first attempt to project water supply demand accurately into the future. The plan was developed using a relatively sophisticated forecasting technique based on a component model which projects individual water demand rates for disaggregated use categories. The plan concluded that a moderate estimate based on "current trend" assumptions (Series II of the Office of Business Economics, 1975) for population growth and a "shift-share" technique for employment forecasts is most likely to occur. By examining the water intake and water consumption values, two categories of water supply demand, it is possible to determine the amount of water which should be going into sewage or septic systems. The water demand figures in this study include this adjustment.

Because the focus of this report is always on where sludge is produced, and not on where water supply or wastewater emanates, it is necessary to alter the water demand figures by county to account for intercounty transfers of wastewater in order to accurately locate sludge production. This alteration is accomplished by distributing population and its associated water demand from the county where water is consumed to the county where sludge is produced. The local population projections used in the allocation are from the Minor Civil Division Model 1 (Greenberg and Newman, 1977), which is considered the best model for minimizing extreme projections; the county population projections are Series 2, the same as were used in the Water Supply Master Plan projections.

To arrive at a multiplier for the percentage of water demand which will be discharged to sewers in 2000, the 1980 water demand and sewage flows were consulted. Because industrial water demand in 1980 is included in the total figure, it is necessary to add the sewage flow from industrial treatment plants to the domestic sewage flow for a total flow figure. Of the 155 industrial treatment plants in the state, 25 percent did not report a design capacity, and 30 percent did not report an average flow; therefore it was necessary to develop an estimate of the range of industrial STP flow. The mid-point of this range, approximately 200 mgd, is added to the domestic sewage flow to produce a total sewage flow of 1290 mgd in 1980. When this is compared to the water demand of 1400 mgd, a multiplier of .925 for the ratio of sewage to water demand is developed. Before calculating this value, the water demand going to septic systems (approximately 40 mgd) was subtracted from total demand to normalize the data. The convention of removing the population on septage and their associated water demand is carried throughout.

The results of this analysis are shown in Table 12. A word of clarification on the meaning of the two population columns is appropriate. As noted, the population on septic systems is removed from each. The first column, "County Population on Sewers," is the total population in that county served by sewers, whether the treatment plant is in the county or not. The second population column, "Disposal Population," is the total population which sends sewage to be treated and disposed of in that county. Therefore Bergen, Hudson, Passaic, Somerset, and Union are net exporters of wastewater, while Essex and Middlesex are net importers

Table 12: Statewide Sewage Flow Estimate for 2000, by County

	1980 Total Water Demand[1] (mgd)	2000 Water Demand (mgd)			Projected 2000 Population on Sewers[2]	2000 Population Disposing in County	Current Flow Industrial Wastewater (mgd)	Current Sewage Flow Total (mgd)	Expected Sewage Flow Total-2000
		Resi-dential	Indus-trial	Total					
Atlantic	20.5	14.2	9.6	23.8	205,860	205,860	1-2	32-33	22.0
Bergen	178.5	75.3	132.7	208.0	968,940	795,098	4-7	95-98	157.6
Burlington	32.7	21.3	19.8	41.1	403,200	403,200	10-20	50-60	38.0
Camden	61.1	37.4	31.6	69.0	630,355	630,355	1	88	63.8
Cape May	5.3	5.3	1.4	6.7	77,925	77,925	0	13	6.2
Cumberland	19.4	8.9	12.4	21.3	167,840	167,840	.5	16	19.7
Essex	177.1	73.5	108.4	181.9	948,090	1,264,887	.5	271	230.4
Gloucester	61.9	9.3	48.7	58.0	170,830	170,830	38-48	54-64	53.7
Hudson	124.5	48.4	71.9	120.3	627,155	564,206	15-35	95-115	100.1
Hunterdon	8.8	2.8	7.0	9.8	57,305	57,305	9	13	9.1
Mercer	52.3	23.8	33.9	57.7	392,540	392,540	1-3	51-53	53.4
Middlesex	173.9	46.9	159.0	205.9	748,590	1,016,356	15-18	153-156	255.0
Monmouth	50.4	31.8	29.6	61.4	529,085	529,085	1-2	61-62	56.8
Morris	78.8	28.9	72.4	101.3	461,700	461,700	3-9	41-47	93.7
Ocean	22.5	17.3	10.8	28.1	310,460	310,460	5-7	36-38	26.0
Passaic	92.8	38.7	63.6	102.3	507,425	223,572	1	10	41.8
Salem	23.1	2.8	22.7	25.5	52,060	52,060	15-30	19-34	23.6
Somerset	38.2	9.4	34.9	44.3	157,945	122,899	20	33	31.9
Sussex	4.4	2.1	3.9	6.0	37,050	37,050	.1	3.1	5.6
Union	156.6	45.5	106.9	152.4	591,885	563,012	18-24	108-114	121.9
Warren	14.1	2.7	16.2	18.9	50,690	50,690	6	10	17.5
	1,396.9	546.3	997.4	1,543.7	8,097,930	8,096,930	164.1-264.1	1,252.1-1,353.1	1,428.0

Notes: 1. From Division of Water Resources, 1977.

2. Statewide population on septic systems (699,000) is excluded from county totals in these adjustments.

of sewage.

A comparison of current total wastewater flow with expected wastewater disposal in 2000 shows some interesting discrepancies. Most notable are the counties such as Atlantic, Burlington, and Camden which, although they have enclosed water-wastewater systems with all wastewater retained in the county, have current wastewater flows larger than predicted. There are three possible explanations for this discrepancy: the current sewage flow total may be greater than water demand because of excessive infiltration-inflow or excessive stormwater flow in old systems; the current sewage flow total may be inaccurately reported and not a true reflection of current flow; or the water supply demand figures for 2000, because they are projected so far into the future and involve sophisticated accounting, may result in bias. In particular two areas of the water supply demand projections may introduce an error: recirculation of industrial water may not be as great as assumed, which would result in more discharge to sewers than expected; and, because employment data on which industrial water use is based is allocated to counties from national projections, a bias could be introduced in the allocation procedures.

The counties involved in intercounty transfers of wastewater are a noteworthy class because they account for approximately 60 percent of the wastewater in New Jersey. Two of these counties, Union and Hudson, show a close correspondence between current and predicted levels, which would seem to indicate that the adjustment procedures adapted for this study are reasonable. Since these two counties are also the only ones which remain static in water consumption for the twenty-year period, the suspicion on employment data and industrial water projections is partially confirmed. The transfer counties which show major changes in current and future figures are Bergen, Essex, Middlesex, and Passaic. The decrease in Essex is again primarily a result of the underlying assumptions concerning water demand by industries and the relocation of employment; in the year 2000 Essex is projected to demand 190 gallons of water per capita, while Middlesex is projected at 275 gallons per capita, Union 257 gallons per capita, and Bergen 215 gallons per capita. The large increases in Bergen and Middlesex are the result of employment relocation of large water-demanding industries; these data indicate a need for added sewage treatment capacity for these counties by 2000.

To derive a statewide estimate of sludge production for 2000, the total sewage flow is multiplied by the sludge production estimator of 1.12 dry tons of sludge per mgd of wastewater. This results in a statewide estimate of 584,000 dry tons per year. If treatment levels are increased, and sludge production per unit of wastewater goes up by 25 percent, the resulting total could be 730,000 dry tons per year. Before leaving this topic, it is important to note the large contribution of industrial wastewater to domestic (municipal, state, federal, and commercial) treatment plants. If the wastewater being treated by industrial treatment plants (200 mgd) is subtracted from total water demand and the sewage estimator applied, 740 mgd of the 1245 mgd of wastewater going to domestic plants, or 60 percent, is of industrial origin. This topic will be taken up later in the discussion of the impacts of sludge quality on compost utilization.

Current County Characterization

The twenty-one counties in New Jersey represent a diverse assortment different in population distribution, type and stage of development, and land characteristics. This diversity is carried over into the areas of wastewater and sludge management. Treatment plants in the past generally were retrofitted to accommodate existing population conditions, in contrast to the situation in counties now experiencing development, in which treatment plants are a major determinant of where development occurs. The alternating view of regionalization also affects this distribution. The early history of wastewater management and the period since the Clean Water Act of 1972 have favored centralized, regionalized systems, while in the 1950's and 1960's the trend was towards decentralized, individual treatment systems.

Figure 3 illustrates this diversity among counties. For this table only the 424 strictly municipal plants are included; the 131 state, federal, and commercial plants, which were counted in the domestic sewage total earlier, are excluded here because their small size tends to distort the picture. The graph plots the total number of municipal plants in the county against the total population disposing of sewage in that county. The dotted lines indicate the average number of plants and the average population served per county, and provide a convenient frame of reference for the discussion of county differences.

Quadrant I identifies counties with a low average population and a low number of sludge production facilities, generally a result of dispersed population growth. This category can be further subdivided into two groups, based on centralization of sludge production: one, including Cape May, Hunterdon, and Salem, which have less than 33 percent of the sludge produced at the two largest municipal plants; and the second, including Atlantic, Cumberland, Gloucester, Mercer, and Warren, which produce 55-90 percent of total sludge at the one or two largest plants in the county. Quadrant II includes counties with low sewered populations and moderately high numbers of plants, indicative of a pattern in which plants are built to serve individual subdivisions and villages. It is interesting to note, however, that even in these relatively dispersed counties, all but Burlington have 60-80 percent of sludge production at two county plants.

Quadrant III includes only Camden, Morris, and Monmouth counties, relatively heavily populated counties with a large number of plants. All of these counties experienced dispersed growth in the 1960's, when decentralized systems were the norm. Of the three, only Morris currently shows some centralization of sludge production, with 55 percent of the county's sludge produced at two plants. Quadrant IV includes the urbanized, industrialized, densely populated counties in the state, with the five counties accounting for about 60 percent of the statewide sewered population. Due to the density of development when the systems were developed, these counties are dominated by large,

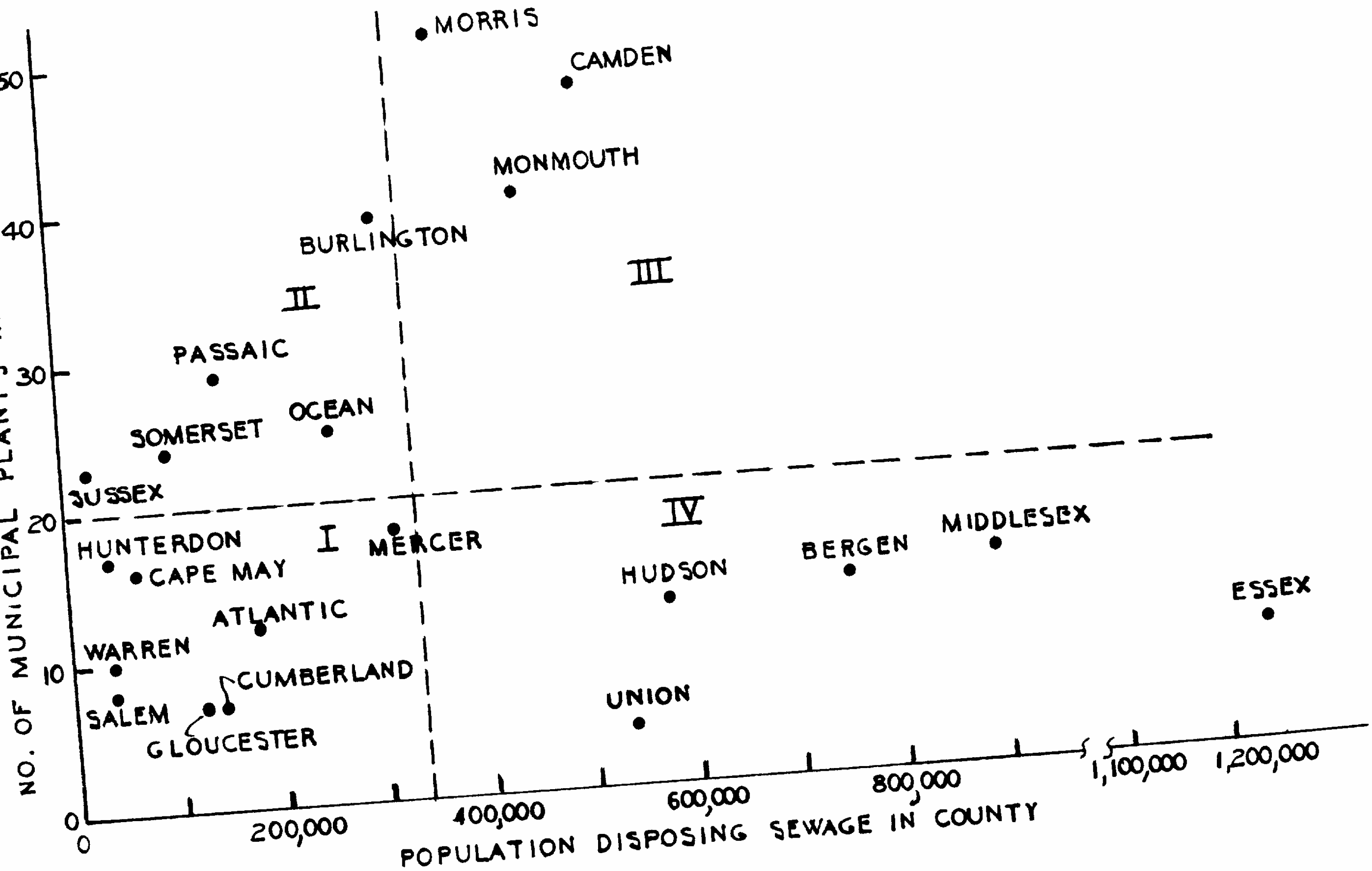


Figure 3:
Total Municipal Plants in County vs. Population Disposing Sewage in County

regional plants which produce a sludge of mixed content.

Table 13 confirms the relationship suggested above and shows the wide variation among counties by average flow of plant. The five counties with the greatest flow per plant correspond to the five counties in Quadrant IV, while the next four are all in Quadrant I, and the next three are those in Quadrant III.

Implications for Statewide Applicability

The evaluation of the sludge component demonstrates the multiple planning levels which are relevant to the applicability of sludge composting on a statewide basis. Local issues of importance are directly linked to the evaluative and decision criteria mentioned earlier, while the regional issues are related to the availability and arrangement of information.

Local Considerations

The most important local consideration is a thorough understanding of the resource involved and the effect this has on succeeding decisions. When sludge is viewed simply as a waste for disposal there is less need for precise information on the material; when, however, it is realized that disposal to any medium does not eliminate the material, but merely changes its state, the need for careful analysis is clear. In the initial step in sludge management, composting is evaluated *vis à vis* all other available options, an assessment primarily dependent on economics and technological feasibility. Technological feasibility sometimes is not given the attention it deserves, because the characteristics evaluated are general and not specific to the considered technology. Specific characterization of material for each technological alternative is required, together with suitable pilot studies.

Specific quantification of sludge production volume is a routine procedure in sludge management investigations, but too often the goal is simply to determine the steady state condition. This may be suitable for a general assessment, but for composting it is more important to understand the variability through time. Short-term variability can affect the productive operation of a composting facility, while long-term variability can result in a mistaken estimate of design parameters. Specific knowledge of variability by day, week, and month should be a routine evaluative parameter.

Analyses of sludge quality for macronutrients, micronutrients, heavy metals, organics, and physical characteristics are essential to two phases of composting: the analysis of process performance and the utilization of compost. With regard to process, sludge characterization

Table 13:
Rank Order of Counties by Average Flow of all Municipal Plants

Rank	County	Average Flow (mgd)
1	Essex	33.7
2	Union	22.4
3	Middlesex	9.8
4	Bergen	7.0
5	Hudson	6.7
6	Mercer	2.7
7	Atlantic	2.6
8	Gloucester	2.3
9	Cumberland	2.2
10	Camden	1.8
11	Monmouth	1.5
12	Ocean	1.2
13	Burlington	1.0
14	Cape May	.8
15	Morris	.7
16	Somerset	.5
17	Salem	.5
18	Warren	.4
19	Passaic	.3
20	Hunterdon	.2
21	Sussex	.1

is needed to estimate required bulking materials, handling operations, and expected impacts on biological and thermodynamic performance. These topics require specific research to evaluate various combinations. In compost utilization, sludge characterization is needed to develop initial estimates of expected compost quality and anticipated uses. Knowing the current state of sludge quality should not be the final goal of the analysis, however; with problem areas related to heavy metals and organics defined, every effort should be made to minimize these problems in order to reduce potential adverse impacts of land disposal.

State and Regional Considerations

At the state level sludge composting is aided by a pair of tools relating to sludge quantity and quality, the Wastewater Management Information System (WMIS) and the Sludge Quality Assurance Regulations (presently in draft). The WMIS is an operational data collection system for sewage treatment plants developing information on physical and locational parameters. The Sludge Quality Assurance reporting schedules, which will have the force of regulations when adopted, require periodic analyses of a wide range of sludge characteristics, particularly heavy metals, toxic organics, and pesticides.

The need for an accurate reporting schedule should be obvious from the extreme variability in sludge quality. This is a significant step in the development of assessment information, but for optimum land utilization the analyses should be compared to a mandated standard of acceptability. This standard should result from an analysis of the capability of industrial pretreatment standards to produce an acceptable sludge for land utilization. No state can be expected to establish standards which may result in economic dislocation. The need for industrial pretreatment standards, which have not been promulgated by the U.S.E.P.A. seven years after the mandated enactment date, is clear. To assure the accuracy of sludge quality reports the state should be provided with a monitoring capability.

The WMIS provides a major effort in the development of an accurate data base, but, as with any information system, a great deal of refinement is required to make it operable. Any information system is only as good as the input data, and in a situation as changeable as wastewater and sludge management the information is in a constant state of flux. Given this variability the WMIS should be so formulated as to require a regular update of information, possibly including a monitoring capability to check the accuracy of information.

When this project was initiated, Somerset County was chosen as a demonstration area to test the availability of information for the four components of applicability. The inventory of treatment plants and sludge began with five sources of information at the state, regional, and county levels, including the WMIS; these five sources listed between twenty-seven and fifty-five treatment facilities in the county. Through telephone questionnaires, aerial photo interpretation, and field checks this inventory identified forty-two treatment facilities in the county; a later update of the WMIS identified forty-five plants. Forty of the plants appeared on both inventories, while our inventory identified two plants which the WMIS lacked. Of the five extra plants which the WMIS identified, our inventory found that three were recently tied into other systems, one was miscoded by county, and the other was recently built. The agreement between the two inventories is about 93 percent.

When the average reported flows for the plants were compared, minor discrepancies were found in 45 percent of the figures, revealing the variability in flows at small plants when reported at different times. However, there were significant differences in only 14 percent of the reported flows, and in only 7 percent of the reported design capacities. For the whole county the WMIS reported 13.8 mgd of domestic flow, while our inventory reported 13.2 mgd. These comparisons reveal the essential accuracy of the WMIS, although the need for refinement is evident.

As a computer-based data collection system, the WMIS joins several other data inventories dealing with water resources in New Jersey. The attempt to use this information has raised two major problems: the use of varying regional designations to aggregate the data makes it difficult to sort out the information, and the information is not easily related to specific points on the earth's surface. These problems are interrelated in that a solution to the latter would also accommodate the former.

A few examples of some regional designations should illustrate the point. The WMIS codes information by twenty-one counties, the 567 municipalities, approximately forty-five stream classes, and four basins. An attempt in this system to use latitude and longitude as point locators proved unsatisfactory due to the inaccuracy of reported values. The New Jersey Water Supply Master Plan generally uses six water supply planning regions and the counties for regional aggregation, with the information in a form to be adapted to smaller watersheds. Water supply demand estimates are given for the county of use, not for the supply area.

There are three distinct regions defined for wastewater quality management planning. Basin planning (Section 303) has six regions, coincident with Water Supply Planning Regions, three which follow county borders and three which cross county lines to follow drainage basins. Areawide wastewater planning regions (Section 208) number twelve, whose boundaries follow a mixed assortment of drainage basins, political boundaries, and enfranchised sewage treatment areas. Facilities' planning areas (Section 201) include ninety-eight designated regions, following planned or actual sewage enfranchised areas, usually on a watershed or sub-watershed basis.

With this diversity in regional designations, two primary areas for data collection are suggested: as a physiographic region the sub-watershed appears most useful, and as a political region counties can serve as clearinghouses for information. In order to increase the accessibility and utility of the data developed for the various planning areas, and to make the information immediately translatable to specific point locations, all of the data should be coded with a uniform system on a statewide basis. The most suitable location systems for this application are the State Plan Coordinate System, used by the Bureau of Geology with the Land Oriented Reference Data System (LORDS), or the Universal Transverse Mercator (UTM) system. The degree of precision demanded for implementation would also require the use of exact methods of location, especially aerial photographs, LANDSAT and other remote sensing sources, and fieldwork.

Besides serving as political centers for planning information, counties can have an active role in the organization and arrangement of sludge management. Counties are the planning agencies for solid waste management in New Jersey, including sludge, and as such are in a position to consider waste management with a unified approach. Because sludge represents a small percentage of the total waste management problem, the opportunity to combine its disposal with solid waste in composting is given little consideration. This is an unfortunate omission. Waste management demands fresh institutional arrangements, as well as substantial coordination among the small units involved in sludge disposal. Organization of these activities at a county level would appear desirable.

Chapter III: Bulking Materials and Sources

Introduction and Suggested Approach

Bulking agents provide three characteristics which promote the composting of dewatered sewage sludge: they provide a means of controlling moisture content within the composting matrix; they provide porosity and structure to allow air flow and maintain aerobic conditions; and, depending on their composition, they may provide an additional carbon or energy source to enhance biodegradation. The suitability and availability of bulking materials is an integral component of applicability, since these materials are needed in great quantity for composting.

The format followed is similar to that in the preceding chapter. The basic idea is to suggest an approach suitable for any level of planning activity:

1. Investigate the full range of potential materials.
2. Analyze material properties for composting applicability.
3. Determine available materials and their impact.
4. Develop estimates of available quantities and sources.

Range of Potential Materials

Given the preceding criteria, the range of bulking agents can include many organic and inorganic materials. Because decomposition affects most organic materials, they will compost, although at widely differing rates and conditions. Many inorganic materials can also provide an adequate composting substrate. This fundamental fact can affect significantly the overall operation of a sludge composting facility, not only in the active composting process but also in the auxiliary functions which determine the overall performance. Therefore bulking agents must be evaluated with regard to their impact on the total composting system, and the relative merits of a material should be specific to the situation encountered.

The most common choice of bulking agent in static piles with forced aeration for sludge composting is wood chips produced from large scale land clearing operations. The advantages of this grade of chip lie in its uniformity, structural suitability for sludge composting, relative ubiquity in most areas, slow rate of breakdown under composting conditions, and relative ease in handling. It has also been considered moderately priced, although subsequent analyses have demonstrated changing market conditions. Other wood wastes act similarly within the active composting process but differ in other evaluative characteristics. Wood wastes from tree trimming activities, such as that done by municipal tree commissions and private tree experts, are less uniform and inconsistent in supply, and present additional difficulties in materials handling and institutional arrangements, although they are less costly. Wood wastes are also produced by the 1,500 wood manufacturing companies in New Jersey, known as secondary processors, which use dimensional lumber to produce furniture, boats, pallets, cabinets etc. (Pierson and Lempicki, 1975). Much of the waste produced by these sources is currently landfilled, at a considerable cost to the producer, and is located near population centers. This waste requires processing for uniformity and presents some difficulties in materials handling and market arrangements.

Municipal solid waste, defined as residential or commercial waste, is a heterogeneous mix occurring in large concentrated volumes, and is currently a disposal problem. It can be composted with sewage sludge, with sorting and processing optional, in various types of composting systems. The use of this bulking agent probably requires substantially different materials handling and operational arrangements. There is a large group of specific industrial wastes which have been successfully composted with sludge, although their relative impacts on a composting operation have not been fully explored. These include auto salvage materials and paper cubes (Epstein, 1978), and shredded rubber tires (Higgins, et al., 1978).

A further organic class of bulking agents is vegetative wastes, either directly from agricultural, horticultural operations or from food and materials processing. The latter category includes such relatively exotic materials as licorice root, peanut shells, rice hulls, and fruit pits; the local availability and impact on a composting operation limits the utility of these sources. Certain materials from the field, such as leaves, are ubiquitous in supply but have not been adequately demonstrated as suitable for large scale composting of sludge. Some agricultural wastes, such as straw or bedding, are directly usable but of limited and dispersed availability, while others, like corn stover, do not appear compatible in composting with sludge.

Because of its constant availability in a composting operation, screened compost could be used for bulking purposes, as currently practiced in windrow composting in Los Angeles (Horvath, 1978). The performance of this material is dependent on its ability to maintain the necessary structure to promote air flow in static pile operations. This limitation is one of the reasons why sludge is not often composted alone. Compost particle size is determined by type of screening and handling.

Material Characteristics

As one might expect, the material characteristics of the bulking agent which require evaluation are similar to those of sludge, although the relative importance of a characteristic is considerably different for the two materials. Since the specific goals of a bulking agent are addition of structure and carbon, reduction of moisture, and general compatibility with composting operations, these characteristics take precedence over the material's chemical characteristics. The chemical analysis cannot be ignored, however, as it can have some impact on the composting process and a considerable effect on the final compost product. The data on physical characteristics summarized below are derived from experiments at the Department of Biological and Agricultural Engineering.

Bulk Weight/Bulk Density

These terms are defined in the same manner as for sludge. For bulking agents the importance of these factors lies in their impact on equipment selection. All of the bulking agents identified in Table 14 are of low bulk weight, generally one-half to one-third of that of sludge, and therefore require no special modifications. Because these bulk weights are so low, much handling equipment can be oversized relative to normal power requirements of operating machinery.

Moisture Content

The bulking agent should allow for some moisture reduction by its absorptive capacity, thereby reducing the moisture content of the input sludge from the usual 70-80 percent, to 60-65 percent. Since moisture content can also be controlled by air flow in a static pile operation, however, some absorptive capacity can be sacrificed if the bulking agent is otherwise suitable.

Porosity (Free Air Space)

Porosity is a measure of the interstitial void space of a material. Because this void space could be occupied by air or water, it is better to speak of free air space, the actual volume not occupied by solids or water. The experimental method used for the measurements reported in Table 14 is actually a measure of free air space. This factor is one of the primary determinants of the capability to mix and aerate a bulking agent with sludge.

Table 14:
Physical Characteristics of Bulking Agents

Material	Bulk Weight (lbs./cubic yd.)	Moisture Content %	Porosity %
New wood chips	420-720	24-43	61-65
Recovered wood chip	425-630	33-46	53-67
Shredded tires	600-700	0-10	63
Hogged wood waste	500	11	66
Corn stover	675	68	-
Tree trimmings	725	24	-
Leaves	250	57	-
Unscreened compost	400-650	29-46	67
Screened compost	675-900	35-50	65

Source: Experimental data from the Department of Biological and Agricultural Engineering.

From the data in Table 14 it is apparent that many of the available bulking agents have similar, low bulk weights, with only compacted leaves significantly lighter. Moisture contents are all within a similar range, with the exception of relatively dry shredded tires and hogged wood wastes and the wet materials of leaves and corn stover, which are too moist to serve as effective bulking agents. The data on leaves may be misleading, as moisture content can vary greatly with season of the year, storage, and handling.

Porosity determinations for the materials tested show the large available air space in each of the potential bulking agents. It is important to note here that when bulking agents are mixed with sludge at various ratios, the pore space of the mix is considerably different. Therefore pore space is not adequate as a single measure of the mixing and aerating capability of a bulking agent. Experiments have shown that materials with a similar pore space mixed at similar ratios with sludge result in considerably different measurements of air conductivity through a composting mass. It is therefore likely that the structure of the material is more important than initial porosity. Experiments are continuing to refine these relationships among pore space, structure, air resistance/conductivity, and pressure drop through a composting pile.

Chemical Analyses

As mentioned earlier, the chemical composition of a bulking agent can affect the process performance and the quality of the compost produced. The magnitude of the effect is related to the range in values of the measured parameters. For this reason Table 15 is included to demonstrate the variation of the chemical analysis of bulking agents. The choice of elements is the same as the major elements for sludge and is not meant to be exhaustive but indicative.

It is interesting to note the increase in all elements from fresh wood chip to recovered wood chip, indicating physical or chemical bonding of sludge to the bulking agent during composting; the reduction in volatile solids content indicates the wood chip also composts in this environment. The high Zn concentration in the shredded tires and paper resulted in elevated levels of zinc in the final compost; the paper used is computer paper, with the high level of Zn coming from printer's ink, and should not be considered indicative of other paper bulking agents. The high N content of corn stover indicates that it would decompose fairly rapidly alone, although its high moisture and fiber content and its tendency to clump when mixed are not compatible with sludge composting. However, if chopped and dried, it should be satisfactory. The similarity in volatile solids content of the various materials is striking.

Estimate of Available Quantities

This analysis of bulking agent quantity is intended to identify the gross volume of materials which are compatible for use with sewage sludge. Because of the diversity of potential materials, some of which are considered wastes and some resources, this inventory concentrates on the broadest level of identification, the state as a whole. As the use of any of these materials in sludge composting realizes their partial resource potential, demand/supply relationships are certain to change as a function of technical factors, cost relationships, local goals, local institutional arrangements, and changing patterns of environmental regulations. This section deals only with the questions of what and how much material is available, with some of the other issues discussed in the succeeding section.

Table 15:
Chemical Constituents of Bulking Agents

Con-stit-uents	Units	Wood Chips	Tree Trim-mings	Shredded Tires	Recovered Chips	Leaves	Paper	Corn Stover
N	%	.12	.49	.37	.65	.74	.11	1.32
P	%	.05	.05	.33	.2	.02	.01	.15
K	%	.04	.35	.02	.1	.06	.01	1.39
Cu	ppm	30	103	7	55	24	38	27
Zn	ppm	18	83	9700	163	18	14150	75
Ni	ppm	TR[3]	10	5	19	19	9	6
Cd	ppm	TR	TR	1	9	1	2	TR
Pb	ppm	5	108	48	70	343	60	85
vola-tile solids	%	98	88	64	93	93	93	92

Notes:
1. Experimental data from Department of Soils and Crops, N.J.A.E.A.
2. All analyses on dry basis; ppm = parts per million.
3. TR = trace, but not measurable at ppm.

Because potential bulking agents represent a varied assortment of materials, information on their total quantity is inconsistent. For certain materials relatively precise enumerations are available, while for others estimates must be developed from the ground up. Each of the materials therefore requires a unique procedure for the estimate. The methodology and underlying assumptions for each estimate are given, together with the estimated quantity.

Wood Chips

The wood chips generally used in sludge composting originate from land clearing operations which employ "total tree chippers" such as the Morbark Chiparvestor. These total tree chips are of superior quality compared with chips produced by tree maintenance chipping machines, and in fact are almost equal in quality to chips produced at sawmills. The New Jersey Bureau of Forestry defines these chips as one class of wood residues for their Wood Residue Recycling Program.

Since cubic yards is the common volumetric measure in sludge composting, a method is needed to convert timber stands to cubic yards of wood chips. Ferguson and Mayer (1974) indicate that in the northern counties of New Jersey, the average volume of growing stock is thirty-six cubic yards per acre, while in the nine southern counties the average volume is twenty-five cubic yards per acre. If the assumption is made that the pore space of wood chips (64 percent) is a result of the change in structure and volume expansion, then the growing stock volumes can be converted to wood chip volumes in the following manner:

$$\text{Chip volume (yards}^3\text{/acre)} = \frac{\text{growing stock volume}}{\text{\% solid space in chips}}$$

$$\text{For northern counties: } \frac{36 \text{ yds.}^3\text{/acre}}{.36} = 100 \text{ yds.}^3\text{/acre}$$

$$\text{For southern counties: } \frac{25 \text{ yds.}^3\text{/acre}}{.36} = 70 \text{ yds.}^3\text{/acre}$$

Since the volume of growing stock is about equally divided between the northern and southern halves of New Jersey, a statewide average of eighty-five cubic yards per acre of wood chips for forest land is reasonable. Some mature, dense stands may have twice this volume.

Studies by Ferguson and Mayer (1974) and Bones and Pierson (1974) indicate that in the period 1955-1971 the average loss of forest land to land clearing operations was 15,000 acres annually. Using the conversion factor of eighty-five cubic yards per acre, the average annual generation of wood chips from land clearing for the 16-year period was 1,275,000 cubic yards.

To compare this to the volume of chips used in sludge composting, a twenty-dry-ton-per-day facility (5000 dry tons per year) needs approximately 25,000 cubic yards of chips annually. This is equal to the chip volume from 300 acres of forest land, or approximately 2 percent of the land cleared annually. A compost facility of 100 dry tons per day (25,000 dry ton/year) requires approximately 125,000 cubic yards annually, the quantity from 1500 acres of forest land or 10 percent of the land cleared annually.

To expand this to the state as a whole, the 380,000 dry tons of domestic sludge produced annually would require composting facilities of 1400 dry tons per day capacity. The annual need for wood chips therefore would be approximately 1,750,000 cubic yards.

The Wood Residue Recovery Program has surveyed wood chip dealers in New Jersey and three nearby states to determine their capability to supply a 20,000-cubic-yard-per year composting facility. Seventeen suppliers met this criterion, four in New Jersey, eight in Maryland, four in Pennsylvania, and one in New York. Several of these are wood brokers who have access to national markets and supplies. Several other suppliers can produce large amounts of sawdust and wood shavings, which may not be suitable to composting use alone but could provide an additive material.

Tree Trimming Wastes

Tree trimming wastes are defined as chips produced by tree maintenance chippers, a chip of slightly inferior grade containing more foliage and twigs but highly suitable for combination with sludge. This chip is routinely produced by local shade tree commissions, county park commissions, and tree removal companies.

Local shade tree commissions are a difficult source to quantify as their production is variable and much of the material produced is used internally by local citizens or other municipal operations, although there are disposal problems in some areas. Local commissions probably produce from several hundred to a thousand yards annually, which may be a viable source for small operations.

County park and shade tree commissions also produce tree trimming wastes from internal operations, but the material is also frequently used internally. In a survey of the Monmouth County Park Commission (Bonnell, 1979) and the Somerset County Park Commission, the quantities produced ranged between 1,000 and 2,000 cubic yards annually.

As part of the demonstration study in Somerset County, the wood processing industries within the county were inventoried, including tree removal companies. Of the 224 wood-waste producing establishments, fifteen were tree removal companies, four of which were contacted by telephone in a random sample survey. Of the four, two produced no significant accumulation of chip, but the other two produced an annual total of 3,300 cubic yards. If this pattern persists throughout the state, small tree removal companies may present an adequate source of wood chips for small operations.

Wood Residues

Wood residues can be broadly defined as the materials which remain after wood in a processed form is utilized. This definition excludes wood chips from land clearing and tree removal, which, of course, are also residues, but since they are in a natural state they are considered in the preceding section. The residues considered here are those originating from processed wood products, which are considered wastes. These materials are highly variable in quantity, but the quantity available is such that they must be considered.

The Wood Residue Utilization Program of the New Jersey Bureau of Forest Management has developed a substantial body of information in their effort to identify and coordinate wood residue supplies and uses (Pierson, 1973; Pierson and Lempicki, 1975). Using surveys and published information, they developed a list of sources and annual volumes for a wide range of residues. Some of the major categories are included in Table 16.

Table 16:
Areas of Potential Wood Recovery

Sources	Volume Generated (cubic yds.)	Volume Available (cubic yds.)[2]
Logging residues	410,000	370,000
Secondary industry residues	785,000	370,000
Harbor debris	925,000	780,000

Notes: 1. Adapted from Pierson, 1973.

2. This represents an "in place" volume. When chipped the volume will expand to twice these figures.

From this table it is apparent that a vast amount of wood residue is generated on an annual basis, although the figure for harbor debris is for total volume. The logging residues represent the amount left in the field or requiring disposal. The secondary industry figures represent a compilation of 1400 wood product manufacturers producing an approximate average of one ton per day of wood residue. The large volume of secondary residues in use are primarily handled by seven companies utilizing an average of 32,000 cubic yards annually.

For the Somerset County study the Secondary Directory of Wood Processing Industries (New Jersey Bureau of Forestry, 1976) was used to identify twenty potential sources in Somerset County. These sources produced an annual volume of 8,000 cubic yards of residue, with the two largest sources handling 5,800 cubic yards.

Solid Waste

The volume of solid waste generated in New Jersey is rapidly becoming a major disposal problem. The sheer quantity and its suitability for composting with sludge demand that it be considered as a bulking agent. The New Jersey Solid Waste Administration requires that all wastes disposed in landfills be recorded and reports submitted quantifying these materials. The Administration collects these reports for both waste origin and disposal and summarizes the data annually. The 1976 data show the following quantities for some selected categories:

Table 17:
Solid Wastes Originating in New Jersey

Type of Waste	Cubic Yards
Municipal waste	27,946,961
Bulky waste	5,327,324
Vegetative waste	572,941

Source: N. J. Solid Waste Administration, 1977, Waste Origin Report.

Municipal wastes include wastes originating in households, businesses, and institutions. It is generally composed of 67-70 percent paper and other organic wastes, with a moisture content of approximately 30 percent. The category of bulky wastes includes appliances, furniture, whole trees, branches, tree trunks, stumps, demolition materials, and automotive wastes; it is impossible to determine the percentage that is organic or compostable. Vegetative wastes are composed of materials which go to landfills and which originate at farms, nurseries, greenhouses, and tree wastes. Some of the materials from this category are already counted under wood residues.

Shredded Tires

Shredded rubber tires are an exotic bulking agent but the material satisfies many of the requirements for incorporation with sludge. Tires present an extremely difficult waste disposal problem. Each of the approximately five million automobiles in New Jersey disposes of an average of two tires annually, for a total of ten million tires, with a weight of 24 pounds per tire, 16 pounds of which are passed through in shredding. At a bulk weight of 700 pounds per cubic yard, shredded tires provide a potential supply of 230,000 cubic yards of bulking agent annually.

Issues Affecting Bulking Agent Choice

A wide range of issues can affect the specific selection of a bulking agent. Among these are cost, recovery, uniformity, regularity of collection/supply, impact on compost output, and availability.

Cost

The gross cost of bulking agents, which includes transportation and any necessary processing, can vary widely. Total tree chips, originally thought to be an inexpensive material at about $4 a yard (Colacicco, 1976), have steadily increased to $6, $7, and now even $9-10 a yard. Part of this increase is related to insurance and performance bonds, and part to the need for dump body delivery trucks. Pulp mills are still able to get chips at $5-6 a yard because they provide unloading services for the material. Tree trimming wastes are less expensive than total tree chips, but are unquantified at present. Solid waste and corn stover each cost approximately $3 a yard for collection, with the cost of solid waste increasing if processing is required. Shredded rubber tires cost approximately $30 a yard for a haul distance of 100 miles, with two-thirds of the cost for transportation; the use of mobile shredders, a feasible option, could halve this cost. Wood residues are generally landfilled at a cost to the producer, but the processing and collection would impose a cost on the compost facility, although it should at least be competitive with wood chip. The use of recycled compost produced by the composting facility would incur only the opportunity cost of not marketing it, which should be minor.

Recovery

Potential bulking agents vary considerably in their capability of recovery by screening. Total tree chips are generally 70-80 percent recoverable, with the loss due to biological and mechanical breakdown. Tree trimming wastes would generally be 50-60 percent recoverable, reduced in comparison to total tree chips due to more foliage and smaller pieces. Processed wood residues currently available are similar to tree trimming wastes due to the presence of small particles, although an alteration in processing could make their recoverability similar to that of the total tree chip. Shredded rubber tires represent the extreme case, in that they are virtually 100 percent recoverable when relatively uniform in size. Recycled compost represents the other extreme, in that it is totally incorporated, thereby obviating the need for screening. The recoverability of solid waste is highly dependent on how the material is processed: as sorted or classified matter it is totally incorporated into the compost; as unprocessed waste, screening recovers some material unsuitable for composting; as a pelletized or cubed material, it is partially recoverable.

Cost/Recovery Relationship

The comparison of bulking agents on the basis of annual variable cost discloses the advantage of a recoverable material. An analysis by the Department of Agricultural Economics at Rutgers University for a 26-dry-ton-per-day facility, with identical assumptions, showed the following relationship:

Table 18:
Estimated Annual Variable Costs for Three Alternative Bulking Agents with Different Prices and Recovery Rates

Bulking Agent	Price per Cubic Yd.	Recovery Rate	Annual Variable Cost	
			Total	Per Dry Ton
	($)	(%)	($)	(%)
Corn stover	3	0	198,900	28.98
Wood chips	7	75	110,200	16.29
Shredded tires	27	97.7	5,400	.79

While it involves a greater initial investment, the shredded tires result in a reduced annual cost. This analysis did not include solid waste, which as a current waste disposal problem has a minimum cost, or recycled compost, which is an internal product of the composting facility.

Constancy of Source

Most of the potential bulking agents are available throughout the year, although some may be seasonally intermittent. Total tree chips and tree trimming wastes are probably unavailable for much of the winter, requiring considerable on-site storage capacity and advance planning. Solid waste is available throughout the year, although its characteristics change by season. Recycled compost should be available throughout the year at a composting facility, provided that a means to protect the material from inclement weather is available. Because an inert material such as shredded tires is virtually 100 percent recoverable, it is available internally at a composting facility so long as recovery (screening) is able to operate.

Compost Output

The output of compost per unit input of sludge is directly related to the choice of bulking agent, and is the other side of the recoverability coin. Shredded tires and other highly recoverable materials result in a low output compared to total tree chips, tree trimming wastes, or hogged wood residues, which contribute biologically and physically to the final compost. The use of solid waste should increase output over wood chips because part of the solid waste also decomposes at a fairly rapid rate. Recycled compost would also increase output over wood chips, but because much would be used at the composting site the compost available for distribution would be less than with solid waste. Where ready markets are available, an auxiliary goal may be the maximization of output. The major determinant of which bulking agent is selected is probably the cost/recovery relationship. Gross cost includes the cost of required processing and the cost of transport based on local and regional availability; these factors are therefore accounted for in the cost/recovery relationship. Based on this criterion, an inert material such as shredded tires, or an internal product such as recycled compost, would have to be favored. However, there may be other goals which supersede this criterion. If the goal is to manage the total waste disposal problem with a unified approach, then municipal solid waste and wood residues may be more appropriate.

The selection of a bulking agent should be given careful consideration in planning and design stages. Whatever material is chosen will require a unique approach to materials handling in the composting operations. Perhaps the real goal should be sludge composting without a bulking agent, thereby obviating the need for auxiliary materials and operations.

Chapter IV: Composting Site

Introduction and Suggested Approach to Site Selection

The selection of a suitable site for composting is of vital importance to the overall applicability of sludge composting. As the production center for compost, it is the vital link in the transformation of a waste into a valuable resource. Because the site is the most visible component of a composting program, it is most often the focus of public attention and, therefore, a vital factor in the development of public support. Careful site selection demonstrates a concern for the public's opinion while at the same time promoting the effective functioning of the composting operation. The siting of composting facilities should be given the same careful consideration as the location of any production facility.

The format for this chapter is similar to the others in that the main consideration is the development of a rational approach to the analysis of the component. The format is as follows:

1. Analysis of the technical factors relating to land requirements and accessibility.
2. Development of criteria for the physical feature assessment of the site.
3. Development of criteria for minimizing the impact of the site on the affected population.
4. Examination of major issues and tradeoffs and selection of suitable land.

The level and method of analysis employed here differs from that used elsewhere. Because of the impracticality of demonstrating site selection on a statewide basis, this section relies entirely on data developed in the Somerset County demonstration study. By isolating a specific geographical area, it is possible to explore more fully the relevant factors and their interaction in compost site selection. All references to the study area in the following text signify Somerset County.

In carrying out the inventory of sewage treatment plants in the study area it became apparent that their location described a network of sludge production. Each of these locations can be described based on site selection criteria relating to the technical, physical, and public suitability of the site. These criteria can therefore be viewed as decision variables which will direct where and in what quantity composting facilities will be required.

To analyze this problem a linear programming application called the Transportation Problem is used. This particular analysis permits an evaluation of the interaction of the various decision criteria and a relative ranking of the desirability of any potential composting site in comparison to all others.

In order to produce a desirability rating for a site each decision criterion must be internally ranked on a quantitative basis in order to discriminate relative site desirability for that criterion. Then a modified Delphi technique is applied to give each decision criterion a weighting in reference to all other criteria. The internal rankings provide each site with a suitability index, while the weightings among variables provide coefficients to test the importance of a given variable in the overall site selection process.

This method of analysis can, of course, be expanded to include any geographical region or the whole state, and decision variables can be expanded or reduced as the availability of information or the specific application requires. This report represents an interim guide to the evaluation of composting sites, as the complete analysis of Somerset County is not yet available; the thesis work pertaining to the application in Somerset County will include the final results of this analysis, and will be issued as an addendum to this report when available.

Technical Factors Relating to Site Evaluation

The group of technical factors includes land availability for composting, proximity to a sludge source, and site accessibility within the local transportation network. These factors are a comprehensive set of measures designed to discriminate among alternative locations, and to establish the capacity at a specific location.

Land Requirements and Availability

In developing a measure for land availability in the evaluation, it is necessary to establish a land requirement for the composting facility. The facility must be large enough to accommodate the required composting operations, which include at a minimum mixing, active composting, drying, screening, curing, and the associated work and storage spaces.

Because each of these operations will have a different spatial requirement depending on the scale of operation, the land requirement is not a consistent function.

In association with the Department of Agricultural Economics and its research work on economies of scale in composting, site designs for several scales of operation were developed. Table 19 shows the variation in the land requirement as the design capacity of a facility changes:

Table 19:
Acres Required at Various Design Capacities

Design Capacity (dry tons/day)	Acres/Dry Ton (acres)
3	.66
13	.35
26	.22
50	.17
100	.15

These land requirements include the entire used area, both occupied and work areas, but do not include any requirement for a buffer from surrounding land uses.

In the Somerset study area, data on land availability at sewage treatment plants were obtained through a telephone questionnaire. The undeveloped land at the sites was then compared to the land requirement needed to compost sludge generated in the county. Of the forty-two treatment plants in Somerset, twenty have sufficient land to accommodate a facility composting all of the domestic sludge in the county, with five others capable of handling 50 percent of the output. Of the twenty plants with four or more available acres, nine are publicly owned and eleven are private. Of the twenty-five with two or more acres, all but two are capable of accommodating their own output. In the study county at least, it appears that the opportunity to build either individual or regional facilities is good. Of the seven currently active sanitary landfills in Somerset, the four which are publicly owned have more than seven unused acres and a 10-50 total acres.

For the quantitative analysis of composting site location, it is necessary to rank the relative desirability of potential composting site locations within each decision variable. For the measure of land availability, the ranking is established by the capability of the site to accommodate a facility of a certain size. For this demonstration, the categories from most to least desirable are: greater than five acres (capacity for all county sludge); two to five acres (50 percent of sludge); one-third acre to two acres (capacity for individual plant production at least); and less than one-third acre (insufficient land for composting). These categories can, of course, be adjusted to suit the specific area under study. Potential sites other than waste treatment facilities are included in the analysis.

Accessibility of the Site to Road Transportation

To minimize the difficulty of moving material into and away from a site, and as a measure of proximity for sludge transport in regional composting, a necessary variable is the relative accessibility of a location within the transportation network. In this application it is preferable that transportation avoid residential streets, so the preference order for road type is: interstate highways, expressways, major arterials, minor arterials, collector streets, and local streets.

The accessibility of the site is defined by the accessibility index A_i, calculated as follows:

$$A_i = \sum_{j=1}^{n} d_{ij} \qquad d_{ij} = \text{shortest route from point i to point j}$$

This index is a measure developed for use in network analysis, which converts linear spatial patterns into links and nodes on the basis of graph theory. The A_i is a concept describing the relative position of individual points and the road pattern. The distance from each site to every other is measured, weighted by highway type, and summed to give each site an accessibility index. The smaller the index value, the more accessible the site within the transportation network. For some applications, rail or barge transport can be included and given a factor weighting.

Sewage Treatment Plant on Site

A factor identifying whether the site is coincident with a sewage treatment plant is included. The existence of a treatment plant means that some problems related to public acceptance and site suitability are answered, the plant provides a convenient means of treating water generated by composting, and the need to transport that plant's sludge is obviated. For this factor the measure of desirability is a simple binary value denoting whether a treatment plant exists at the site or not.

Distance of Composting from Sludge Source

It is advisable to avoid the transport of sludge over considerable distances because of the high cost involved and because it is undesirable to move the material through populated areas. Therefore, a factor is included to measure the relative proximity of a sewage treatment plant to a composting facility. The most desirable choice is to keep a composting site at the treatment plant, with the desirability decreasing as a function of distance from the treatment plant. The distance intervals selected to characterize the categories of decreasing desirability can be based on the economics of sludge transport, or on the density of treatment plants located in the study area. The latter approach is used in the Somerset demonstration.

Analysis of Physical Features for Site Evaluation

The physical features in site evaluation are defined as those natural factors pertaining to the potential site which contribute to its physical suitability for a composting operation. These factors include physiographic, hydrologic, vegetative, soil, and meterologic considerations. As a group, these factors probably rank below technical and public acceptance factors, but their importance in operation and in the minimization of public and physical disturbance cannot be ignored.

Hydrologic Limitations

To avoid potential surface and ground water pollution, the evaluation of a composting site should consider the hydrologic limitations of soils. The primary information is available from soil survey interpretations and includes the categories of ground water pollution hazard, seasonal flooding by a high water table, and frequent stream overflow. For this decision variable the most desirable site has no limitations, with desirability decreasing as one or more categories becomes limiting.

In the Somerset study area, the hydrological limitations of the forty-two treatment plants have been analyzed, with the Soil Survey of Somerset County of New Jersey (Soil Conservation Service, 1976) as the source. Of the forty-two treatment plants, twenty-two have no limitations for this criterion. Of the twenty plants with some limitations, two are limited only by the category of ground water pollution hazard, three are limited only by seasonal flooding by a high water table, fifteen are limited by the two categories of seasonal flooding and frequent stream overflow hazard, and two sites are limited by all three categories. These data show that 40 percent of the sites are limited by two or more categories, indicating that this criterion is not considered in locating sewage treatment plants, and therefore may not be a primary consideration in locating composting sites.

Type of Vegetative Cover Surrounding the Site

Vegetative cover serves two related purposes at the site environs: trees provide a wind barrier to the dispersion of odor, pathogens, and material particles, and shrubs and trees serve as a visual break for surrounding land uses and as a view enhancer for the public. For this criteria, the taller the vegetation the more desirable is the site for composting. The categories are established on the basis of common growth forms in order of decreasing desirability as follows:

Growth Forms	Height Class (meters)
Woody--tall trees	>5
Woody--low trees and shrubs	2-5
Herbaceous--forbs and grasses	.1-2
Barren land	<.1
No vegetation due to presence of buildings	

For this analysis, and for many of the site suitability factors, the use of large scale (1:9600 or larger) stereographic aerial photographs is essential. In the study area, aerial photographs were used to calculate percentage of vegetative cover by growth form for a 2,000-foot radius around the site. Nine of the forty-two plant sites had tall trees surrounding 45-90 percent of the site, with fifteen sites containing 20-40 percent low trees and shrubs; eight of these sites had 60-90 percent of vegetative cover in the two most desirable categories. The herbaceous class (.1-2m.) is the most common growth form, occurring at twenty-five sites as 45-80 percent of total vegetative cover. Where sites are not well shielded by vegetation, the development of necessary barriers should be included in design work.

Terrain Conditions At and Around the Site

To reduce the problem of site preparation, it is probably preferable to have a relatively even terrain, although sloping sites can be used. The area is best suited if it has natural barriers between the site and surrounding, occupied land uses. Of course, the impact on surrounding areas can be mitigated by the factor of vegetative cover.

For terrain conditions at the site, the most desirable category is flat (0-6 percent slope), followed by medium slopes (6-12 percent), and steep slopes (>12 percent). For surrounding terrain conditions, the more desirable site has rolling hills and natural barriers, with a flat landscape less preferable. Both of these factors were examined with stereoscopic aerial photograph interpretation and soil survey interpretations. Thirty-eight of the forty-two treatment plant sites had flat conditions on site, while eighteen had a rolling landscape around the site. Fourteen sites met the double criteria of flat site conditions and rolling terrain surrounding the site.

Prevailing Winds and Direction

Because some of the material particles, pathogens, and odors could become airborne from a composting site, the speed and direction of the dominant wind should be a siting consideration. To develop this criterion, it is necessary to consider not only the speed and cardinal direction of the wind but also the land uses surrounding a site which may be affected. For this criterion, residential areas, hospitals, and schools are considered the critical land uses to protect, and the wind direction is evaluated relative to its effect on these areas.

Because it is so vital to this evaluation of composting sites, the nature of the stereographic aerial photointerpretation requires explanation. Using large scale (1" = 800') stereo photographs, which provide the third dimension, and field checks, the land uses surrounding each site were analyzed for a search radius of 2,000 feet, or approximately 275 acres. The area was divided by a hexagonal grid into fifty-five five-acre plots, and the land use and vegetative cover for each plot was identified; hexagons were used because they provide the best fit for a circular search radius. This technique provides a reliable and accurate characterization of the surrounding environment. The search radius is ample to demonstrate the need for or impact of a buffer zone, and is eight to ten times more than the 200- to 250-foot radius for zoning and variance applications.

According to available data on winds in New Jersey, the prevailing wind is from the west for over 70 percent of the year. In the winter the origin is generally the northwest quadrant at an average speed of eleven knots, and in summer the southwest wind predominates at a speed of eight knots. Therefore, the quadrants to the southeast and northeast are subject to the greatest impact from winds near a composting site. The desirability ranking for this factor incorporates wind direction, critical land use, and a two-zone division of the 2000-foot search radius to identify those sites where the impact of wind can be minimized. The most favorable site has no critical land use within 2000 feet to either the southeast or northeast, the next best site has no critical land use to the southeast and none within 1000 feet to the northeast, and so on through the nine possible combinations.

In the Somerset study area, eleven of the forty-two analyzed sites had no critical land use in either quadrant within 2000 feet, and another ten had no critical land use in either quadrant within 1000 feet. Fourteen sites had a critical land use located in the southeast quadrant within 100 feet of the site.

Public Interaction Factors

The decision variables in siting which relate to public interaction include land uses surrounding the composting site, zoning at the site, visibility of the site, and the concept of distance to a critical land use. This group of factors provides a means of analyzing the manner in which negative public reaction can be minimized. Public acceptance is a prerequisite to widespread adoption and appreciation of a sludge management technology, and the best way to gain acceptance is to demonstrate that the public's wishes have been attended to. Much of the adverse public reaction to a composting site can be largely mitigated if proper attention is given these factors in the process of site selection.

Land Uses Surrounding the Composting Site

Public concern is greatest in the area immediately surrounding a composting site. The methodology developed for the land use analysis is explained in the preceding section. For the desirability ranking of this factor it is also necessary to categorize land uses as to their potential for causing a negative public reaction; unoccupied, shielded land uses are therefore more preferable than occupied, open ones. Based on this idea, the ranking of land uses for this variable is as follows, with the most desirable rated first:

Rank	Land Use	Rank	Land Use
1	Forest and wooded parks	6	Industry
2	Disturbed land	7	Golf courses and open parks
3	Open land	8	Commercial and mixed use
4	Farmland	9	Residential low density (1-3 acres)
5	Wildlife preserves	10	Residential high density, hospitals, nursing homes and schools

The latter two categories are, of course, the two most critical in terms of protecting public health and welfare.

In the analysis of the forty-two sites in the Somerset study area, the most common surrounding land uses are open land, farmland, commercial and mixed uses, and low density residential. Half of the sites are surrounded by 40-80 percent open land or farmland, with an additional thirteen having 20-40 percent of surrounding acreage in those uses. Ten of the forty-two sites had 17-22 percent of the acreage in the two residential categories, with an additional six sites containing 24-50 percent of acreage in the restrictive categories. Half of the forty sites had less than 10 percent of surrounding land in critical uses. It would appear that an ample number of sites exist which can minimize contact with human populations.

Critical Distance to Occupied Area

The concept of critical distance relates to a site selection procedure which considers the relationship between a composting site and the nearest occupied land use, with the land uses ranked as to their potential for permitting a critical impact. The rank order is approximately the reverse of the surrounding land use analysis. Hospitals and nursing homes are ranked first in the order of critical land use, followed by schools and high density residences, low density residences, commercial and mixed uses, and so on through open land and forests. The distance to the first critical category encountered, and the relative position of that category in the order, are combined to produce the critical distance rating for a site.

In the preliminary analysis of the forty-two sites in the study area, for 67 percent of the sites the first critical land use encountered is a residence. The distance from the site border to the structure ranged between 160 feet and 1500 feet, with an average of approximately 850 feet. At three sites the most critical use, hospitals, is encountered at distances between 800 feet and 1200 feet. At six sites schools are encountered at distances from 160 feet to 1100 feet, with an average of 500 feet. Five sites have no occupied land uses within 2000 feet of their borders.

Visibility of the Site

For this factor the consideration is whether a site is visible from residential areas, other places of population concentration, or heavily traveled roads. There are three characteristics on which the ranking is based, each with a dual discrimination: proximity of an occupied area, rated as far or close; the height of surrounding vegetation, rated as high or low; the surrounding terrain, rated as a barrier or flat. This ranking system produces eight possible combinations, with the most desirable site far from population, with high surrounding vegetation and terrain as a barrier, while the least desirable combination is close to population, with low vegetation and flat terrain.

In the study area, ten of the forty-two sites fall into the least desirable category, close to population with low vegetation and flat terrain. Another seven plants are close to population with low vegetation, but terrain forms a barrier. Four plants are in the most desirable category, far from population with high vegetation and terrain as a barrier. Thirteen other plants are far from population, but ten have low vegetation and ten have flat terrain (seven are coincident).

Zoning at the Site

For practical reasons a composting site should be away from residentially zoned areas, although the frequency with which zoning can change may reduce the impact of this factor. A composting site could probably be located in any zoning class if a public body condemned the land, but it is preferable to keep the site somewhat removed from areas anticipating heavy population concentrations. Therefore, industrial and restricted use zones are the most desirable.

In the Somerset study area, the forty-two sites so far analyzed, which are all coincident with sewage treatment plants, include twenty-six located in residential zones, twenty-four of which are in low density (one-three acres per unit) zones. These statistics reflect the existence in Somerset of many small treatment plants serving isolated residential developments. Fourteen of the sites are in industrial zones, and two in commercial/business zones.

Other Issues Affecting Composting Site Selection

The factors identified in the preceding sections are the major site-specific issues relevant to site selection, but they do not include some of the broader issues which may affect the selection of a site. Among these are the cost comparison of transporting sludge to a remote, inexpensive site or purchasing nearby, high-priced land, the cost of transporting sludge in different forms as it affects the selection of a regional site, and the effect on the land requirement of including required buffer areas.

Sludge Transport and Adjacent or Remote Sites

Colacicco (1977) has analyzed the economic tradeoff between buying land adjacent to a treatment plant and transporting the sludge to a remote but less expensive composting site. The analysis plotted the land price differential between adjacent and remote sites against the cost of transporting 50 dry tons of dewatered sludge daily. The linear relationship developed represents the "land price differential in transport charge combinations which cost the sludge authority the same to transport sludge to a remote site or process it at an adjacent site";

this differential is also referred to as the "breakeven line." In this analysis, Colacicco found it cheaper to purchase nearby land at $80,000 an acre more than remote land, than it is to transport the sludge five miles. This is a compelling argument for avoiding long distance transport of sludge.

It should be noted that since sludge transport is subject to economies of size, daily tonnages more than 50 dry ton/day would cost less. This led Colacicco to conclude that "There will be very few circumstances where it is cheaper to transport the dewatered sludge."

Cost of Transport for Liquid and Dewatered Sludges

Sludge can be transported in liquid form (5 percent solids) by tank truck, railroad, or pipeline, and in a semi-solid form (30 percent solids) by dump truck or railroad. Derr, et al. (1974) summarized the costs as follows:

	Cost per Dry Ton ($ per mile)	
Method	At 5% Solids	At 30% Solids
Tank truck	3.02	-
Dump truck	-	.65
Railroad	.25	.25
Pipeline	1.55	-

From this analysis it is apparent that railroads offer the cheapest method, but they are limited in practicality.

Examining the difference between truck transport of liquid and dewatered sludge, it is obvious that dewatering the sludge greatly reduces the unit cost of transport, because less water is moved. This cost differential is offset somewhat by the high cost of dewatering, which can run from $30 to 60 per dry ton. However, since all sludges require dewatering for composting, and there do not appear to be major economies of size, the dewatering cost is still a factor whether it is done at the sludge production site or the composting site. Therefore, the goal should be to reduce the cost of dewatering wherever possible. For small treatment plants, this probably means the use of drying beds.

An argument often put forth against regionalized composting sites is the high cost of sludge transport. This argument loses some of its impact when one realizes that much of the sludge in the study area is transported 30-35 miles to landfill sites. It would appear that if institutional arrangements can be worked out to transport sludge this far for disposal, then they certainly can be developed to collect sludge for composting at a regional site.

Land Areas and Buffer Requirements

Buffer areas around a composting site are intended to shield the area from the surrounding environment. The motivation behind this is the prevention of public nuisance and public health hazard, although little is known about the specific effect distance has as a mitigating factor. To show the effect that a buffer requirement has on the land area needed for composting, the following comparison is offered:

Design Capacity (dry tons/day)	Total Used Area (acres)	Acres Needed for Buffer	
		100' Wide	200' Wide
3	1.98	3.64	12.78
13	4.64	5.08	15.67
26	5.55	5.44	16.39
50	8.70	6.74	19.00
100	15.67	8.30	30.43

Source: Interim Report of the Camden Composting Project.

The 100-foot-wide buffer represents a minimum required by the state (Sadat, 1979); the 200-foot-wide buffer is included to show how rapidly required land areas can escalate with the imposition of large buffers. At the three-dry-ton-per day capacity, the 100-foot-wide buffer occupies 65 percent of the total land area, and the 200-foot-wide buffer occupies 87 percent of the total land area; for 100 dry tons per day, the values are 35 percent and 66 percent, respectively. Because of the manner in which land costs are calculated in cost-effectiveness regulations for waste management systems, land is a minor cost factor; but the requirement for large buffers can have an important impact on the search for available land.

Probably the most effective way to reduce buffer requirements is by careful site planning. Because winds rarely originate from the east, the west side of a small composting facility needs only a tree break as a buffer. To provide a more substantial buffer on the east side, the site selection procedure should include the examination of sites which already have natural, permanent buffers in the form of forests or parklands. In this way, the respect for the public is maximized and costs minimized.

Chapter V: Utilization of Sludge Compost

Introduction and Suggested Approach

The utilization of the compost product is the final step in composting as a sludge management option. It represents the realization of the resource potential of the materials, while at the same time accomplishing the goals of sludge disposal. Success in these dual, and sometimes conflicting, purposes is the final measure of sludge composting performance. It involves the integration of a thorough assessment of the range of available uses and a comprehensive analysis of the material's content and its impacts. Only through a concerted attempt to develop these factors can composting realize its full potential.

The format for this component parallels that developed in the other chapters. The following approach is recommended as suitable for any planning level:

1. Examine the full range of available uses.
2. Determine necessary compost characteristics.
3. Classify compost with regard to acceptable uses.
4. Distribute compost to appropriate users.

Compost utilization represents possibly the most complex component of a sludge composting operation. The process of utilizing the material involves many actors, each of which has separate, and sometimes conflicting, goals. The goal of the composting authority is to develop year-round, productive uses which allow for maximum flexibility in meeting production schedules, while at the same time minimizing disruptions at the facility. The user groups desire a consistent, beneficial material of known impacts, so that their use schedules can be adapted to suit the material and its supply regime. Regulatory authorities are charged with sludge disposal in an environmentally safe manner, while at the same time realizing the full resource potential of the material.

Finally there is the public, which has perhaps the most important role in utilization: it is the public health and welfare which regulatory authorities are charged to protect by restricting compost use; and it is the public which must accept compost if the true potential of sludge composting as a management alternative is to be realized. The special burden on all involved in sludge composting, educational, regulatory, and utility authorities, is to meld these two areas of public participation successfully. In the long term it is the only measure of performance with meaning.

Range of Potential Uses

Compost represents a uniquely suitable material for a wide range of use categories. The primary value of compost is for soil conditioning purposes, benefitting both physical and chemical properties, but it can also be used for more specific applications. Sludge compost has been used for agricultural fertilization purposes (Chaney, et al., 1978; Epstein, et al., 1976) and tested for fertilizer response (Taylor, et al., 1978; Tester, et al., 1979; Epstein, et al., 1978); for nursery seed beds (Gouin and Walker, 1977; Gouin, 1977); for potting soil mixes (Gouin, 1978); for land reclamation (Patterson, 1975; Carstenson, 1974); and for a wide range of specialty markets, including retail and wholesale nurseries, landscape contactors, golf courses, cemeteries, schools, parks, and other recreational areas (Kellogg, 1978).

Solid waste compost, a material similar in overall characteristics, has been used in the United States for many different applications. Vlamis and Williams (1972) tested the fertilizing capabilities of compost for agricultural production, and others tested the effect on crop yields and soil properties (Mays, et al., 1973). Solid waste compost has been used in floriculture (Conover and Joiner, 1966; Gogue and Sanderson, 1975; Shanks, 1976), and for growing woody ornamentals (Sanderson and Martin, 1974). Other horticultural applications include greenhouse pot experiments (Terman, et al., 1972) and testing of container-grown plants (Sawhney, 1976). In land reclamation, solid waste compost has been used to establish grasses on strip-mined areas (Scanlon, et al., 1973).

In the long history of compost use in Europe, the trend has been to use most compost for specialties such as floriculture, nurseries, greenhouses, and the home market, not because the material is unsuitable for use elsewhere but because the demand from specialty use has created a lucrative market.

The research program on sludge composting at Rutgers University includes a thorough examination of sludge compost applications. Included in the work is research on turfgrass germination, establishment, and maintenance, land reclamation and soil property improvement, mineralization rates and heavy metal uptake, and agricultural and horticultural applications.

From this discussion it is apparent that the range of potential uses is quite extensive. It is not suggested here that each use is appropriate for every type of compost, nor that all compost producers will avail themselves of the full range of uses, but rather that each compost producer must be knowledgeable of the full range and the specific implications of each use. Sludge compost utilization is a relatively new field, with little practical experience outside of Southern California in the distribution and utilization of the material. It is precisely this fact that places a heavy demand on compost producers and users to explore thoroughly the full range of potential uses.

Table 20 identifies the range of available uses, the general form of distribution, and the user group, excluding exotic uses such as livestock litter or energy production. This typology of uses is arranged in a hierarchy, based on considerations of public health and quality of product demanded with the uses requiring the highest quality material listed first. The use categories included represent applications which are currently practiced or for which compost is suitable. This hierarchy serves as the basis for later discussions of recommended utilization programs and estimates of quantities, and is discussed in more detail in that context.

The form of distribution identifies whether the use requires material in bulk or as a bagged product, and whether the users consume the compost internally or distribute to another group. Most of the uses require material in bulk form. Bagged products can be provided in fifty-pound quantities, either directly from the compost producer or through a retailer, or as specialized mixes in one- to five-pound bags. Bagged products realize higher market prices but incur additional costs for packaging and, possibly, processing.

The category of final user group identifies the ultimate recipients of the compost, without regard to the distribution channel. There are five potential user groups which are readily distinguishable: general public, food growers, nonfood growers, private institutions, and public institutions. The group of private institutions represents a diverse assortment of operations including golf courses, landscape contractors, sod growers, industries, cemeteries, mining companies, and landfills. In some cases a single use category may include distribution channels to more than one user group. The concept of user groups is also developed further in the section on recommended utilization programs.

Compost Quality

Compost quality is directly related to the quality of the sludge input. Broadly speaking, whatever is in sludge is in the compost made from that sludge. The operation of the composting process, however, can exert an influence on the relative reduction or

Table 20:
Range of Uses, Form of Distribution, and Final User Group

Range of Uses	Form of Distribution	Final User Group
Private Residential		
Food applications	Bulk or bagged	
Nonfood applications	Bulk or bagged	
Private Food		
Grains for food and feed	Bulk for soil conditioning and nutrients	Class 5
Vegetables for food and feed	Bulk for soil conditioning and nutrients	Class 5, 3
Forages for feed	Bulk for soil conditioning and nutrients	Class 4
Fruit trees	Bulk for soil conditioning and nutrients	Class 4
Private Nonfood		
Forages for horses	Bulk for topdressing and fertilization	Class 3
Greenhouses	Bulk to greenhouse for own use	Class 3
Nurseries	Bulk for mulching	Class 3
Garden centers	Bagged for retail sales	Class 5, 3
Golf courses	Bulk for topdressing and fertilizing	Class 2
Landscape contractors	Bulk for beds and lawns	Class 5, 3
Turfgrass farmers	Bulk for soil conditioning and beds	Class 2
Industrial park grounds	Bulk for lawns and beds	Class 2
Cemeteries	Bulk for lawns	Class 2
Public Agencies		
Public parks	Bulk for soil conditioning and topdressing	Class 1
Playgrounds	Bulk for soil conditioning and topdressing	Class 1
Roadsides and medians	Bulk for cover establishment and maintenance	Class 1
Military installations	Bulk for soil conditioning on grounds	Class 1
Public grounds	Bulk or bagged for lawns and beds	Class 1
Land Reclamation		
Landfill cover	Bulk for intermediate and final cover	Class 2, 1
Strip mined lands	Bulk for vegetation establishment or maintenance	Class 2
Sand and gravel pits	Bulk for vegetation establishment or maintenance	Class 2
Landfill		
Compost disposal	Bulk disposal	Class 2

Key for Final User Group: Class 5--General Public
Class 4--Food Grower
Class 3--Nonfood Grower
Class 2--Private Institutional
Class 1--Public Institutional

concentration of the various compost components. The primary mechanisms by which these effects occur are process performance and choice of bulking agent. If an inert bulking agent is used or sludge is composted alone, and process performance is good, then organic matter content is reduced through decomposition, nitrogen is preserved, and elements are concentrated. Poor process performance, in which anaerobic zones occur, would result in a greater loss of nitrogen and less organic matter reduction.

Most bulking agents are not inert, however, and therefore contribute matter to the final compost. The specific contribution of organic bulking agents is dependent on the extent to which the agent is removed or incorporated through screening or processing, but the general effects can be described. Since most organic bulking agents are low in nitrogen relative to sludge, there is usually a reduction of nitrogen in relative and absolute amounts. If the organic matter concentration of the bulking agent is greater than the final compost, then its incorporation into the finished product will increase organic matter content. Mineral elements may be diluted relative to their concentrations in sludge with the addition of large amounts of bulking agent, although addition of less than the amount of sludge solids volatilized should result in concentrations.

Far more significant than the variations caused by composting operations are the variations which result from differences in the quality of incoming sludge. As detailed in an earlier section, these variations are a result of differences in both incoming wastewater and the sewage and sludge treatment processes. For a given sludge it was shown that content of many elements can vary by 50-100 percent, but for different sludges the variation can be as great as 600 percent. In terms of trace elements and metals, the sludge from a given treatment plant can vary by 500-1,000 percent and variations among treatment plants can be as much as 5,000-10,000 percent. Obviously, such wide variations will have a large impact on the specific utilization program for a facility.

Chemical Components

The chemical components of importance in compost are naturally the characteristics which occur in sludge, including macronutrients, secondary elements, trace elements, heavy metals, and the quantity and quality of organic matter.

Macronutrients

The macronutrients are nitrogen, phosphorous, and potassium; the secondary elements of importance are calcium, sulfur, and magnesium. In samples of compost produced by the Camden operators, the analyses are listed in Table 21. Comparing these analyses to the analyses of Camden dewatered sludge (Table 6), nitrogen concentrations are reduced by 30 percent, and phosphorous by 20 percent; potassium increases by

Table 21:
Macronutrients and Secondary Elements

Element	Mean	Range
Total nitrogen	1.31	1.10-1.55
Total phosphorous	.72	.40- .90
Potassium	.18	.13- .21
Calcium	1.28	.80-1.75
Sulfur	.28	.31- .37
Magnesium	.16	.09- .21

100 percent; carbon, calcium, and magnesium are reduced by 10 percent, and sulfur remains constant. It should be noted that in Rutgers experimental composts made with the same sludge, N concentrations are reduced by 15 percent, P concentrations are increased by 20 percent, and K concentrations increased by 120 percent, possibly indicating more effective separation or process performance.

Since Camden's primary sludge is on the low side in terms of macronutrient concentrations (N, P, K, of 2 percent, 1 percent, and .1 percent, respectively, compared to statewide N, P, K ranges of 1-8 percent, 1-6 percent, and .1-.8 percent, respectively), it can be anticipated that composts made from secondary sludges will have higher macronutrient concentrations. If the reduction/concentration effects observed here hold true, then a typical compost of secondary sludge might have N, P, K concentrations of 2.5 percent, 1.5 percent, and .5 percent, respectively.

Micronutrients (Trace Elements)

Micronutrients are elements which are required by plants for growth in micro-quantities; as with any nutrient, they can be toxic at excessive levels. Among the more common micronutrients found in sludge are iron, manganese, boron, chlorine, zinc, copper, and molybdenum. As discussed in Chapter II, only the latter three are considered a potential hazard; the others pose little or no problem because they are either in low concentration in compost or not hazardous to plants. The concentration of microelements in compost will generally increase in comparison to sludge concentration under effective composting conditions, although the addition of a bulking agent sometimes acts to reduce concentrations.

Heavy Metals

Heavy metals in compost can be taken up by plants and can have beneficial or detrimental effects. Among the important ones are arsenic, chromium, mercury, cobalt, cadmium, nickel, and lead. As detailed in Chapter II, the metals which present a hazard because of their possible phyto- or animal toxicity and their concentration in sludge, are cadmium, nickel, and lead. Along with the micronutrients of zinc, copper, and molybdenum, they make up the class of elements in compost currently identified as posing a potential hazard. All but molybdenum are considered to be in sufficient concentration in sludge compost to warrant limits on their application to lands on which food is grown.

The heavy metal content of Camden compost is listed in Table 22.

Table 22:
Heavy Metals in Camden Compost

Element	Mean (mg/kg)	Range (mg/kg)
Lead	325	200- 400
Zinc	1004	280-4025
Copper	169	94- 257
Nickel	39	30- 56
Cadmium	30	17- 38

For most of the elements, the concentration in the compost is very similar to the concentration in the incoming sludge. For most composts it might be expected that concentrations should be less than the sludge concentration, but it is very difficult to predict or measure because of the bulking agent contribution and the inevitable sampling discrepancies when working with material of such low concentration.

The heavy metal content of sludges has become one of the major issues among regulatory and scientific bodies affecting land application as a sludge management alternative. Because the content of these metals is a consideration in developing application rates and utilization programs for sludge compost, it is given full treatment in later sections.

Physical Characteristics

Organic Matter (Volatile Solids)

Volatile solids content is used as the measure of organic matter in compost. Organic matter represents the full array of residual organic materials from plants and animals that is not consumed. Organic matter in the soil is decomposed by microbiological processes, resulting in a recycling of the elements essential to organic synthesis by plants, and thus to plant life. The term humus is applied to the complex of organic matter residues which are decomposed slowly, thereby serving as a reservoir for essential elements. In addition, in the words of the author of the seminal work on humus, Selman Waksman (1938), "Humus also plays a prominent, if not predominant, role in the formation of most soils. It exerts a variety of physical, chemical, and biochemical influences upon the soil, making the soil a favorable substrate for plant growth."

Because humus in soil is constantly being decomposed and formed, a steady replenishment of humus is required to maintain soil fertility and stability. The organic matter in compost must therefore be viewed as a vital supply of humus, a fundamental resource. For this reason, the compost organic matter is a primary characteristic when evaluating utilization options. This characteristic defines compost as a soil conditioner and represents the reason why compost fulfills a basic need in the maintenance of agricultural productivity and soil fertility. The continuous loss of organic matter in cultivated soils and the role compost has in replenishment are major factors in utilization programs and estimates, discussed in succeeding sections.

The organic matter of composts can vary widely, depending on the initial content in sludge, the bulking agent used, and the process performance in decomposition. In the Camden situation, the organic matter content of sludge has ranged from 55-85 percent, and the organic content of various compost samples from 50-70 percent. If sludge were composted, the difference in dry weight of sludge and compost would represent the solids volatilized during decomposition. Composts of any organic matter content can be utilized, but as a general rule composts of 60-80% organic matter are preferred (Toth, 1972).

pH

Composts can have a pH ranging between 5 and 11, depending on the initial pH of the sludge, the chemical added during sewage and sludge treatment, and the process performance. With a sludge having a pH range of 6.5-7.0 the pH will initially rise during active composting, and then drop to neutrality. The pH of compost is an important characteristic because of its buffering capacity, and because a neutral or basic pH tends to make heavy metals less available to plants. The pH of soil should be maintained above 6.5 when compost containing large quantities of heavy metals is applied.

Moisture Content

Moisture content is an operational parameter for sludge composting as it indicates when a compost is suitable for separation from a bulking agent. For utilization purposes the U.S.E.P.A. has tentatively suggested that a control on the moisture content of sludge products permits the use of products with higher metal concentrations, e.g., if there is more than 15 percent moisture, the product must have less than 25 ppm cadmium, 600 ppm lead, and 10 ppm PCBs, but if there is less than 15 percent moisture, it may have up to 75 ppm cadmium, 1,000 ppm lead, and 10 ppm PCBs (Business Publishers, 1978). The particular rationale behind this suggestion is not explained.

Particle Size

The particle size of the compost depends upon type of sludge, type of bulking agent, handling before and after composting, and screening in the case of recoverable bulking agents. The effect of fractionating a sample of wood chip-bulked compost that passed through a three-eighths inch screen into smaller sizes to examine variations in compost quality is displayed in Table 23.

Table 23:
Fractionation and Analysis of Screened Camden Compost

Size Fraction (mm)	Dry Weight of Sample (%)	Dry Bulk Density (g/cc)	N (%)	C (%)	C/N
> 6.4	8.4	.20	1.54	38.6	25.1
5-6.4	10.8	.20	1.63	35.9	22.0
3-5	21.3	.25	1.79	33.9	18.9
2-3	22.2	.25	1.95	31.8	16.3
1-2	22.4	.24	1.85	31.1	16.8
< 1	15.0	.30	1.72	25.4	14.8
Whole sample		.28	1.79	32.1	17.9

Source: Interim Report from Dr. H. Motto, Department of Soils and Crops.

The C/N ratio decreased and bulk density increased as particle size decreased. A C/N ratio of less than 15:1 in compost will generally release nitrogen when added to soil (Waksman, 1938); therefore most of this compost would not affect plant growth. Tester, et al. (1979) reported the increase in N release from smaller compost fractions. A bulk density of .3 g/cc dry matter corresponds to 500 pounds/yard^3 dry matter. In a companion experiment at Rutgers, the 2-5 millimeter fractions (5 millimeters = one-fifth inch) were also found to contain the highest concentrations of cadmium, lead, and nickel, with the 1 millimeter fraction the lowest. Screening below 1 millimeter would appear to improve the agronomic value of the product, but may be impractical in most cases because of the lack of a technique for fine screening of chips on a large scale.

Degree of Decomposition

The degree of decomposition is a measure of the compost's stabilization and is an important factor in determining how a compost will act when applied to different uses and soil conditions. Degree of decomposition is a function of process performance and bulking agent used. Many techniques for measuring stabilization have been suggested and tested, including temperature drop, redox potential, reheating capacity, onset of nitrification, bioassay techniques, moisture content, and pH, but none has gained universal approval. In recent European literature (Hofmann, 1974), four classes of compost are identified based on increasing levels of decomposition: raw compost, mulch compost, fresh compost, and mature compost

Pathogens

Pathogens are essentially an operational consideration and should not affect utilization. Composting has been shown to be effective in destroying viruses, pathogenic bacteria, protozoal parasites and Ascaris eggs. The pile should be well insulated in order to achieve a complete pathogen kill (a temperature of 60^0 C for two to five days is considered sufficient by regulatory agencies). However, it is important to realize that pathogenic bacteria can grow up again in regions of the curing pile where temperatures are usually not high. Salmonella has been isolated from the surface and other cool regions of curing piles, indicating regrowth resulting from contamination from uncomposted sludge and other sources. Regrowth is generally not substantial, and can be minimized by turning the curing pile so that all the material is reheated to killing temperatures. Use of cured compost as insulating material on the primary composting pile will also lead to appearance of Salmonella in cool regions.

Composting temperatures favor growth of thermotolerant fungi and actinomycetes. Some of these are known allergens and pathogens. Ingestion of substantial numbers of spores of Aspergillus fumigatus can cause bronchopulmonary hypersensitivity, marked by asthmatic spasm, fever, malaise, and prostration, particularly in sensitized individuals.

In addition, ingestion of germinated spores or fragments of mycelia can result in invasive infection of the lungs in individuals weakened by age, other diseases, or deficient immunological response, particularly related to corticosteroid therapy. Other thermotolerant fungi in compost which can cause disease are Rhizopus arrhizus and Absidia corymbifera. Similar diseases are caused in persons handling decomposing plant material (e.g., moldy hay) by the actinomycetes Thermopolyspora polyspora, Micromonospora vulgaris, and Thermoactinomyces sacchari. These organisms do pose possible hazards to workers at composting plants; sensitive individuals should wear masks or transfer to work more distant from the compost. They have also been cited by opponents of proposed compost plants, and may be a consideration in siting plants away from hospitals, old age homes, etc.

Application Rates

Loading rates for compost are generally a function of the intended use, the compost quality, and any regulatory limitations imposed. They are usually developed so as to protect public health and land and water resources, while at the same time permitting sludge compost to be successfully utilized. The process of developing loading rates begins with research institutions, where the fundamental properties of the material are examined and quantified and its effect on soil and plant responses measured. This information is then evaluated and discussed, and ultimately conveyed to the regulatory agencies to assist in their formulation of guidelines and regulations. The regulatory agencies play the key role in balancing public health concerns with maximum utilization of the resource potential of the material. Often they are required to strike a compromise between divergent views on the best way to regulate utilization, and the only way they can realize the proper balance is by constant support from the research community, together with a concern for public health and the public's wishes.

To examine the specific limitations relative to developing application rates, an extensive literature review was carried out as a part of this research. This review sought information not only on application rates but also on the specific properties of the compost which will either encourage or limit its use. The review included a search of approximately twenty journals in the soil science, agricultural science, and environmental quality areas. Each was searched for at least six previous years, and in cases where useful information was found the search period extended up to fifteen years.

Initially, the search concentrated on information pertinent to the application and utilization of sludge, sludge compost, and solid waste compost. As information was generated it became apparent that liquid and dewatered sludge acted in a considerably different manner in the soil than compost, while the characteristics of solid waste composts, other than heavy metal concentrations, closely approximated those of sludge composts reported in the literature. Therefore references to liquid sludge applications were dropped from consideration, and pertinent references to solid waste composts were retained.

The results of this search are displayed in Appendix E, which includes the bibliography of cited references; the bibliographic references appear as parenthetic numbers in the text. The organization of the information follows the same order as the hierarchy developed for the Range of Uses (Table 20). For each utilization option the information includes the following: mode of distribution, beneficial properties, detrimental properties, mineralization rates, loading rates, tentative federal government limits, and proposed New Jersey regulations. For certain uses additional information, such as salt tolerance, phytotoxic levels, material standards, and specific applications, is also included. Where no research information existed for a particular utilization option but the option is similar in nature to other researched uses, the reader is directed to consult the relevant categories.

This review is not meant to be entirely exhaustive but is intended to serve as a guide to the range of relevant considerations in developing compost uses and applications. This information provides a means of assessing the applicability of many uses in relation to the specific conditions encountered when dealing with a variable material produced under changing circumstances. It is hoped that the information in Appendix E will stimulate imaginative approaches to the utilization of sludge compost. Even a cursory examination of the information should demonstrate that arguments denigrating the value of sludge compost are not valid; the challenge confronting both compost producers and users is to fully realize the vast resource potential of sludge compost. This guide may perhaps contribute to that realization.

There are several excellent guides on calculating application rates which the reader should consult. Among these are Municipal Sludge Management: Environmental Factors (U.S.E.P.A., 1977); the draft copy of Guidelines for the Preparation of Sludge Management Plans (N.J.D.E.P., 1979); and Application of Sludges and Wastewaters on Agricultural Land: A Planning and Educational Guide (Knezek and Miller, 1976). For a cogent review of the impact of heavy metals on agricultural utilization, the reader is referred to Application of Sewage Sludge to Cropland: Appraisal of Potential Hazards of the Heavy Metals to Plants and Animals (Council for Agricultural Science and Technology, 1976).

There are four bases for calculating application rates which deserve special mention due to their universal importance. These are: nitrogen availability and requirement; annual cadmium loading; cumulative heavy metals loading; and organic matter replacement. A short review of each follows.

Nitrogen Availability and Requirement

Formulae for calculating application rates on this basis are given in Appendix E, Sec. II.A. Because compost contains a minimal amount of inorganic nitrogen, this factor can be ignored and a simplified equation developed, as follows:

N available (lbs./ton) = organic N content x mineralization rate x ton

For a compost containing 1.5 percent N with a mineralization rate of 5 percent the calculation is:

N available (lbs./ton) = .015 x .05 x 2000
= 1.5 lbs. of N available per ton of compost

To calculate the amount of compost needed to fertilize a specific crop, it is also necessary to know the expected yield of the crop, the productivity index of the soil, and the crop N requirement.

For example, the expected yield of grain corn from a soil with a productivity index of eight is 120 bushels per acre, which in turn requires 145 pounds of nitrogen to produce. To illustrate how the mineralization rate affects the compost application rate, Table 24 is developed using the assumptions previously stated.

Table 24:
Compost Applications as Function of Mineralization Rate

Nitrogen Mineralization Rate %	Lbs. of Available N/ton	Application Rate (ton/acre)
5	1.5	97
8	2.4	60
11	3.3	44

At the 5 percent mineralization rate, ninety-seven tons per acre of compost are required to fertilize a crop of grain corn. Since on a dry volume basis 32 tons per acre corresponds to a one inch layer of compost, three inches are required at the low mineralization rate with the material plowed in prior to planting; it is doubtful that farmers would apply such a high rate. Only if mineralization rates approach the higher values is total crop fertilization feasible.

Annual Cadmium Loadings

The limit on the annual application of cadmium is designed to protect public health by regulating the accumulation of cadmium in the soil so that toxic levels in plants are avoided. The current limit for cadmium is two pounds per acre per year, a value which may be reduced to one pound per acre per year in 1984, and 0.4 pound per acre per year in 1987 as industrial pretreatment becomes more effective. Therefore, a high cadmium concentration reduces the amount of compost that can be applied. It should be noted that these limits are tentative and subject to change by the Environmental Protection Agency.

Table 25 relates cadmium concentrations and annual cadmium limits to the levels of compost applications to reach those limits. Comparing these data to the data on nitrogen availability, a compost would need 10 ppm cadmium or less to be used for cropland fertilization with a mineralization rate of 5 percent.

Table 25:
Annual Cadmium Limits and Application Rates

Cadmium Concentration	Annual Cadmium Limits		
	2 Lb./A./Yr.	1 Lb./A./Yr.	0.4 Lb./A./Yr.
	(Tons of compost applied to reach limit)		
10 ppm (.02 lb./ton)	100	50	20
25 ppm (.05 lb./ton)	40	20	8
50 ppm (.1 lb./ton)	20	10	4
100 ppm (.2 lb./ton)	10	5	2
200 ppm (.4 lb./ton)	5	2.5	1

Cumulative Heavy Metal Loadings

Cumulative heavy metal loadings are developed to protect the long-term capability of a site for food production, and are therefore applicable to any land on which food crops may be grown. The limitation is explicitly based on the cation exchange capacity of the soil, a measure of the soil's capability to retain and immobilize elemental cations. The cations, or heavy metals, for which draft recommendations exist are lead, zinc, copper, nickel, and cadmium; the specific recommended limitations are given in Appendix E, Section II.A.

Using the Appendix E limits, Table 26 shows the maximum cumulative compost applications for the Camden compost, assuming a soil of medium range (5-15 meq/100 g) cation exchange capacity.

Table 26:
Maximum Comulative Applications of Camdem Compost

Metal	Concentration (ppm)	Lbs./Ton	Limit (lbs./acre)	Cumulative Amount (tons/acre)
Pb	325	.65	1,000	1,540
Zn	1,004	2.01	500	250
Cu	169	.34	250	735
Ni	39	.08	100	1,250
Cd	30	.06	10	170

The cumulative amount is arrived at by simple multiplication. From these data it is apparent that cadmium and zinc are the most limiting metals in Camden compost. Since the cumulative cadmium limit is five times the annual limit, the 170-ton per acre total could be applied in annual increments of 34 tons per acre.

Organic Matter Changes and Replacement

Organic matter (humus) in the soil is in a dynamic state, continuously decomposing and changing in physical and chemical properties as it is acted upon by microorganisms. Since organic matter is continually being lost through the conversion of organic solids to carbon dioxide, there is a critical need to replace the lost organic matter to maintain favorable soil properties under cultivated conditions. Compost represents one of the most valuable materials for replacing soil organic matter because it is already partially stabilized, and therefore more usable, after being subjected to controlled composting conditions.

In estimating decomposition of organic matter in nature, Waksman (1938) states that "in general, the amount of CO_2 evolved in twenty-four hours from one square meter of soil ranges from two to twenty grams, measured as carbon." If these values are converted to tons per acre per year, the common measure used throughout for application rates, the resulting figures are 3.3 to 33 tons per acre per year. However, these figures represent a gross carbon loss, and must therefore be adjusted to reflect the dynamic conditions under which soil systems operate. The following examples are provided by Dr. H. Motto of the Department of Soils and Crops to illustrate the manner by which sludge compost can benefit soil organic matter content.

The organic matter level in soils approaches an equilibrium dependent on the conditions under which that soil exists. When a virgin soil is placed under cultivation, the organic matter level begins to decrease to a new equilibrium level dependent on the system of cultivation. Similarly, when a cultivated soil is returned to permanent vegetation the soil organic matter level will increase towards a new equilibrium level.

The change in soil organic matter with time follows first order kinetics which may be expressed as

$$\frac{dc}{dt} = a - bc$$

where: c is the organic carbon content of the soil;
t is the time in years;
a is the carbon addition per year; and
b is the fraction of the carbon decomposed per year.

Various workers have calculated losses in soil organic matter from cultivated soils. The values range from 2 to 10 percent of the organic matter present lost per year, with an average of about 4 percent; this average value is used in the following calculations. However, compost decomposes more rapidly during the year of application. For the organic matter content of common soils the following values are used: 1 percent organic matter content, representing sandy coastal plain soils; 2.5 percent organic matter content, the average value in New Jersey soils; and 5 percent organic matter content, representing a desirable level for maintenance. It is assumed that an acre of land has 1,000 tons of soil at plow depth (upper seven inches).

Example 1

Objective: To maintain soil organic matter at an initial value.

Assumptions:
a. Soil organic matter is lost at a rate of 4 percent per year.
b. Sewage sludge compost contains 60 percent organic matter.
c. Sewage sludge compost decomposes at a rate of 16 percent the first year of application and at the same rate as soil organic matter in later years.

Calculations:

Tons/acre of organic matter needed = initial soil organic matter (%) x .04 x 1,000 tons/acre

Tons/acre of compost organic matter needed =

$$\frac{\text{Tons/acre organic matter}}{0.84}$$

$$\text{Tons/acre of compost needed} = \frac{\text{Tons/acre compost organic matter}}{0.6}$$

When comparing an initial soil organic matter content to the quantity of sludge compost required to maintain that level, the above calculations produce the following results:

Initial Soil Organic Matter Content (%)	Sludge Compost Required to Maintain Initial Level (tons/acre/year)
1	0.8
2.5	2.0
5	4.0
7	5.6

Example 2

Objective: To increase soil organic matter from 2.5 percent to 5 percent over a five-year period by addition of sludge compost to the soil.

Assumptions: Same as those in Example 1.

Calculations:

Required increase in organic matter per year = .05%

0.5% x 1,000 Tons/acre = 5 Tons/acre/year of organic matter

Needed organic matter = 5 Tons/acre/year + amount decomposed
= 5 Tons/acre/year + (Initial soil organic matter x 4%)
Year 1 = 5 Tons/acre + (2.5% x 4% x 1,000 Tons/acre)
= 6 Tons/acre

Needed compost organic matter = needed organic matter + amount of compost decomposed

$$= \frac{6.0 \text{ Tons/acre}}{0.84} = 7.1 \text{ Tons/acre}$$

$$\text{Needed compost} = \frac{\text{Compost organic matter}}{0.6}$$

$$= 11.8 \text{ Tons/acre}$$

For the five-year period the amounts required are:

Year	Initial Soil Organic Matter (%)	Composed Required/Year (tons/acre)
1	2.5	11.8
2	3.0	12.3
3	3.5	12.7
4	4.0	13.1
5	4.5	13.5

Example 3

Objective: To increase soil organic matter level from 2.5 percent to 5 percent in one year.

Assumptions: Same as in previous examples.

Calculations:

Loss of soil organic matter/year = 2.5% x 4% x 1,000 Tons/acre
= 1 Ton/acre

Organic matter needed = 2.5% or 25 Tons/acre + 1 Ton/acre
= 26 Tons/acre

To correct for decomposition of compost:

$$\frac{26}{.84} = 30.1 \text{ Tons/acre of compost organic matter needed}$$

At 60 percent organic matter content in sludge compost, an amount of 30.1/.6 = 50.2 Tons/acre of compost would be needed to raise the soil organic matter level from 2.5 percent to 5 percent in one year.

Example 4

Objective: To increase soil organic matter level from 1 percent to 5 percent in one year.

Assumptions: Same as in previous examples.

Calculations:

Following the same order of calculations as in Example 3, an amount of 80 Tons/acre of sludge compost would be needed to raise the soil organic matter level from 1 percent to 5 percent in one year.

These examples show the magnitude of amounts of sewage sludge compost required to maintain or increase the organic matter levels in soils. On a well-maintained soil of 5 percent organic matter, four tons per acre per year of compost is sufficient. On an average New Jersey soil of 2.5 percent organic matter, a five-year program to increase organic matter requires rates of approximately thirteen tons per acre per year, with a continued maintenance application of four tons per acre per year after that. A one-year program to increase organic matter contents on poor to average soils requires 50-80 tons per acre.

These rates of organic matter additions do not include the even greater soil loss resulting from natural and accelerated erosion, merely the loss resulting from natural processes of decomposition. Under these conditions sludge compost is a resource that should not be wasted.

In reporting results investigating the specific effects of sludge compost on soil physical and chemical properties, applied at twenty-100 tons per acre per year, Epstein, et al. (1976) noted the following beneficial effects: increased water content, increased water retention, enhanced friability, increased cation exchange capacity and pH, and increases in micronutrient levels.

Synthesis of Uses and Compost Quality

The range of uses, form of distribution, and final user groups are identified and discussed earlier in this chapter (see Table 20). In the preceding sections the various characteristics which contribute to compost quality are discussed in some detail. At the core of successful utilization is an understanding of how the two elements are merged to produce a program which meets the needs of compost producers and users. The link thus forged is essential to the overall performance of composting as a sludge management alternative. Only through a careful analysis of uses and characteristics can sludge composting realize the objective of a long-term sludge disposal option; this appears to be the key element in making composting, often referred to as merely an interim alternative, an ongoing alternative of wide applicability.

The major complicating factor which must be satisfied in utilizing compost is the accommodation of the diverse objectives of the involved groups, not only compost producers and users but also regulatory agencies and the general public. As mentioned earlier, the goal of the compost producer is to have consistent outlets for the material while at the same time minimizing the cost of distribution. Although the producer is somewhat less concerned with finding the most suitable use for a given compost, if it can be demonstrated that it will benefit his operation and the operation can be manipulated to satisfy certain utilization criteria, then it is obviously in the producer's interest to pursue this goal. Much of the current research in utilizing compost is indirectly related to this aspect, but a comprehensive approach is still needed.

Compost users, on the other hand, have a somewhat different orientation. Their primary goal is to have a material that will give similar performance at a reduced cost in comparison to currently used materials, or will give better performance for a similar cost. Users are not interested in the fact that someone wants to sell or dispose of a material. They are instead concerned with the quality and results of the product, its availability, its price, and the service provided. It is in these areas that the concerns of producers and users interface.

Decisions taken by regulatory agencies influence both groups, and therefore represent the crucial importance of the regulatory role. The duality of the regulatory role is further exemplified by legislative goals which require that sludge be disposed in an environmentally acceptable manner which protects public health, while at the same time realizes the maximum utilization of the material's resource potential. Because sludge is ultimately a product of plant and animal residues which originate from the soil, the agronomic utilization of sludge, or sludge compost, must be encouraged by regulatory agencies as the optimum use of the material. On the other hand, the consideration of public health forces regulatory bodies to take a somewhat conservative approach which sometimes places the two goals at odds.

The final concerned group is the general public. In many ways regulatory agencies are surrogates for the general public, but this fact does not lessen the public's importance. Regulatory bodies are public servants, and should therefore be responsive to public demands. The public, through legislative representatives, has determined that sludge should be utilized, a clear indication that the goal of resource conservation be given equal standing with environmental regulation. To realize this end, regulatory bodies must take positive steps to promote land utilization. This is the basis for industrial pretreatment of wastewater for heavy metals and organics, a topic which is discussed in more detail later in this section.

This section presents two potential mechanisms for synthesizing the information on uses and compost quality. The first, a classification system for compost, is developed from a historical review of compost use in Europe, and from an examination of the compost properties which affect different uses. This system presents a rational way to direct compost into appropriate uses. The second mechanism, a certification program, has as its basis the regulatory concerns for public health and welfare and the recognition that variations of heavy metals in sludge will produce variations of those elements in compost, and therefore possibly alter its quality. The certification program is a logical outgrowth of the classification system and current thinking on regulatory approaches.

Classification System for Sludge Compost

Earlier in this chapter, in the tabulation of the range of uses, the category of final user group was introduced (see Table 20, p. 70). The five groups identified are:

General Public - Class 5

Food Grower - Class 4

Nonfood Grower - Class 3

Private Institutional - Class 2

Public Institutional - Class 1

Each group is paired with a numerical designation indicating the classification for that group. These five classes serve as the basis for the suggested classification system. These classes can be expanded or contracted as need arises, but for the time being they appear satisfactory to demonstrate the approach.

The second part of this chapter discussed the important characteristics of sludge compost. To complete the classification it is necessary to identify the distinguishing characteristics and then develop a means of ranking each characteristic internally. For this demonstration an attempt is made to rank each characteristic on the basis of a range scale, which in turn is identified by a descriptive adjective for the classification system (Table 27). The range scale for macronutrients, micronutrients, and metals is derived from analyses of New Jersey sludge (McCalla, et al., 1977). The other characteristics are reasonable recommendations based on current knowledge.

By combining the five user groups of compost with the ranking of distinguishing characteristics, it is possible to produce a classification system for sludge compost (Table 28). The primary feature of this system is that it recognizes that sludge compost has variable characteristics which make it more or less desirable for particular user groups. The attempt to match characteristics and composts is intended to stimulate full consideration of compost's properties, while at the same time providing a general guide to direct materials to the appropriate users.

This classification scheme provides a certain amount of flexibility in interpretation. Although the classes are developed around the idea of user groups, this system does not mean to imply that a particular class of compost is confined to a single user group. Any class of compost could be used in any lower class, i.e., a Class 5 or 4 is used to satisfy demands in Class 3 or 2, although to do so is to realize less than the full benefit of the material; Classes 5 and 4 are

Table 27:
Distinguishing Characteristics for Compost Classification

		Low	Medium	High
Macronutrients (%)	N	.5-1.5	1.5-3	>3
	P	.5-1	1-2	>2
	K	.02-.15	.15-.3	>.3
Secondary elements (%)	Ca	.6-1.5	1.5-3.5	>3.5
	Mg	.1-.25	.25-.4	>.4
	S	.5-1.0	1-1.5	>1.5
Micronutrients (mg/kg)	Fe	1,000-8,000	8,000-15,000	>15,000
	Mn	20-150	150-400	>400
Metals (mg/kg)	Pb	100-400	400-1,000	>1,000
	Zn	100-1,200	1,200-2,000	>2,000
	Cu	100-600	600-1,200	>1,200
	Ni	20-100	100-200	>200
	Cd	1-15	15-35	>35
Salt content (mmhos)		0-1	1-2	>2
Moisture content (%)		0-25	25-50	>50
Organic matter content (%)		35-50	50-65	65-80
Texture (particle size)		100% < 1/4" (fine)	60% < 1/4% (medium)	more than 40% > 1/4" (coarse)
Degree of decomposition		Partial (fresh compost)	Thorough (mature compost)	
Redox potential		Low	High	
Moisture holding capacity		Low	High	

Table 28:
Classification System for Sludge Compost

Class 5--General Public	Class 4--Food Grower
Medium-high macro- and micronutrients	Medium-high macro- and micronutrients
Low metals	Low metals
Low salt content	Low-medium salt content
Low-medium moisture	Medium moisture content
Medium-high organic matter	Medium-high organic matter
Fine texture	Fine-medium texture
Mature compost	Mature compost
Low redox potential	Low-medium redox potential
High moisture holding capacity	High moisture holding capacity
Class 3--Nonfood Grower	**Class 2--Private Institutional**
Medium-high macro- and micronutrients	Low-medium macro- and micronutrients
Medium metals	Medium-high metals
Low salt content	Medium salt content
Medium moisture	Medium-high moisture content
Medium-high organic matter	Low-medium organic matter
Fine texture	Medium texture
Mature compost	Fresh compost
Low redox potential	Low-high redox potential
High moisture holding capacity	Low-high moisture holding capacity

Class 1--Public Institutional
Low-medium macro- and micronutrients
Medium-high metals
Medium-high salt content
Medium-high moisture content
Low-medium organic matter
Medium-coarse texture
Fresh compost
Low-high redox potential
Low-high moisture holding capacity

generally the most restrictive, and therefore need the highest quality material. Class 5 is the material intended for general distribution to the public, but a Class 3 or 2 material could supply certain demands of the public, provided that the form of distribution limited the amount available and utilization guidelines were observed.

This classification system is limited by incomplete information and the lack of standardized testing procedures for some of the most important compost physical and chemical properties, particularly degree of decomposition, moisture holding capacity, and redox potential. There are undoubtedly omitted characteristics which should be included and certain characteristics which may not be relevant to each use, but partitioning quantitative analytical information into descriptive categories is inexact at best, as it entails certain value judgments to interpret the factual premises. Its feasibility is questionable given the current state of knowledge, but inexact knowledge cannot be held as an excuse to ignore decision-making. Value premises, while lacking the precision of factual premises, are necessary even when scientific information is available.

It is hoped that this proposed classification system stimulates further consideration of its implications and that it results in other, more sophisticated appraisals at a future date. Ideally, classification of compost should stress the positive properties of the material, with a small set of factors listed which may reduce compost value. This is not the case, however, because contamination by heavy metals and certain undesirable organics makes sludge compost, which would otherwise present little hazard for any of the many uses listed, a material that may find limited use in agriculture. There are, however, two ameliorating practices: stemming the source of heavy metals, and judicious management of compost, crops, and soils.

Certification Program

In the early stages of this project, considerable attention was given to the impact of sludge quality on compost utilization. Examination of this issue produced one inescapable conclusion: much of the sludge from urban New Jersey contained sufficient quantities of metals to limit its application to land on which food is grown. This means that not only are uses unrelated to food production required for successful compost utilization, but also that utilization practices in food production must be carefully scrutinized to prevent a public health problem.

There are several reasons for the existence of metals in sludge, but in New Jersey one predominates: over 60 percent of the sludge produced by municipal treatment plants originates from industrial wastewater. This wastewater contains an exotic assortment of discharges typical of New Jersey petrochemical, chemical, and manufacturing industries. While municipal authorities generally have the right to require that these discharges be treated before entry into municipal sewers, they are loathe to enforce such rights for fear of economic dislocation.

Because of the unwillingness of local bodies to act in this regard, the federal E.P.A. is required, under Sec. 307 (b) of the 1972 Clean Water Act, to publish proposed regulations establishing pretreatment standards for introduction of pollutants into publicly owned treatment works. Almost seven years after the mandated date, the first of these pretreatment regulations is only now being developed. The need for implementation of industrial pretreatment requirements on a national level is clear. Without them the cessation of ocean dumping of sludge might only result in the risk of greater environmental damage on land.

Confronted with this situation, the authors suggested that an appropriate resolution is a certification program for sludge compost (Bolan, et al., 1978). Recognizing that many composts may have limited use in growing food crops, this approach suggested that only the best composts, i.e., those lowest in heavy metals and undesirable organic compounds such as PCB's, should be directed to food crop uses. The method for accomplishing this program is to establish parallel hierarchies: the first is a hierarchy of uses (see Table 20), with the most restrictive uses at the top; the second is a hierarchy of compost quality, with the least contaminated materials occupying the highest position. When a compost is produced, it is then subjected to a chemical analysis, particularly for metals and organics, and assigned a position corresponding to a particular use in the hierarchy of uses. This "certified compost" could then be used in the category to which it was assigned or any less restrictive category, but it could not be utilized in a more restrictive use.

A certification program of this type appears to have a number of distinct advantages in public protection and use assessment, by guaranteeing that only the best materials go to food production and by permitting an easier evaluation of appropriate uses for a given product. The idea of the certification program ultimately gave rise to the consideration of a classification system, discussed earlier, as a rational way to direct compost materials. The original intent of the certification program, to serve as a regulatory basis for compost distribution, is complicated, however, by the many unresolved issues in current regulatory approaches. Included among these are heavy metal concentrations, annual metal limits, lifetime metal limits, crop fertilization requirements, and appropriate uses for certification.

Because potential plant or animal toxicity is the primary hazard of sludge compost use, the appropriate users of certification are private food growers, either homeowners or farmers. To give an indication of the current status of metal content in New Jersey sludges, Table 29 is included. The seven treatment plants represented in Table 29 account for approximately 55 percent of the sludge protection in New Jersey. They include six facilities located in urbanized and industrialized New Jersey, and a seventh (Middletown) indicative of a primarily domestic facility with some light industrial input. For each of the seven metals listed there are two concentrations given, the average

Table 29:
Heavy Metal Contents in New Jersey Sludges

	Elements and Concentrations (ppm)													
	Cd		Cr		Cu		Hg		Ni		Pb		Zn	
	1974-75 Avg.	78-79 Avg.	74-75 Avg.	78-79 Avg.	74-75 Avg.	78-79 Avg.	74-75 Avg.	78-79 Avg.	74-75 Avg.	78-79 Avg.	74-75 Avg.	78-79 Avg.	74-75 Avg.	78-79 Avg.
Passaic Valley Sewage Commission	111	48	1030	767	610	533	9	4	180	167	1670	1854	3500	2733
Middlesex County Sewage Commission	170	43	475	416	830	1516	2	1	150	78	1160	722	3230	10214
Elizabeth Joint Meeting	70	50	625	519	1125	2123	7	3	86	101	444	702	1330	2263
Bergen County	149	185	2820	873	1450	1106	11	2	285	467	695	766	2290	2365
Linden-Roselle-Rahway Valley	70	35	720	679	1680	1081	10	2	195	233	595	520	4950	3279
Camden County Municipal Utilities Authority	-	37	-	-	-	321	-	-	-	39	-	370	-	750
Middletown Township	10	20	270	173	665	1431	4	5	32	152	204	798	1530	2365
"Maximum Domestic"	25		1000		1000		10		200		1000		2500	

Source: Sludge analyses submitted to the U.S. Environmental Protection Agency, Analysis and Surveillance Division, Edison, N. J.

concentrations for 1974-1975 and for 1978-1979. Also given are the "Maximum Domestic" concentrations from Chaney (1974), defined as "Typical of sludges from communities without industrial metal waste sources or with adequate source abatement."

As discussed in an earlier section on loading rates (Section D, and Appendix E), regulatory limitations on rates for food chain lands are related to the nitrogen requirements of the crop, the annual limits of cadmium applied, the lifetime of site limits of lead, zinc, copper, nickel, and cadmium applied, and the concentrations of the seven metals in Table 29. All of these factors are criteria for a certification program; the following discussion examines the utility of each approach.

The nitrogen in compost is in organic combinations, and must be converted to inorganic forms prior to plant use. Compost releases nitrogen at a slow rate. For a typical compost of 1.5 percent N, to satisfy the nitrogen requirements of a moderately productive corn crop, approximately 48 tons of compost per acre is needed. Figure 4 shows the relationship among cadmium content of compost, compost application rates, and cadmium application; the horizontal line at two pounds per acre shows the recommended maximum annual cadmium application. At the 48-ton-per-acre rate, the compost must have slightly less than 25 ppm cadmium to remain within the annual cadmium limit. From the data it appears that loading rates based on nitrogen requirements require sludges of low metal contents. Therefore it seems that compost should be applied at less than nitrogen requirement rates, and this rate calculation method does not provide a sound basis for certification.

Figure 4 is a graphic representation of a second regulatory method for food chain compost applications, the limitation on maximum annual cadmium application. Under this regulation no more than two pounds per acre of cadmium (the horizontal line) can be applied to cropland annually. For a compost of 200 ppm Cd, the annual application limit is five tons, for a compost of fifty ppm Cd it is twenty tons, and for a compost of twenty-five ppm Cd the limit is forty tons. Limiting annual applications of metals appears to be a sound basis for certifying compost use in agriculture but it would have to be combined with cumulative limits on metals' application. Currently it is applicable only where cadmium is the most limiting metal.

Under proposed New Jersey regulations governing compost use, one application option permits twenty tons per acre of compost to be applied provided the metal concentrations are within the "Maximum Domestic" limits of Table 29. This simplified approach would protect croplands from overloading with toxic heavy metals; as such it shares many elements with a certification program. Because it is based on metal concentrations, however, and not on total amounts added, it does not provide an entirely accurate representation of the metal hazard. A further constraint on using this option for certification is that if one metal exceeds the limit by a small amount, then the compost could be excluded from agricultural use, which may not be justified on a scientific basis.

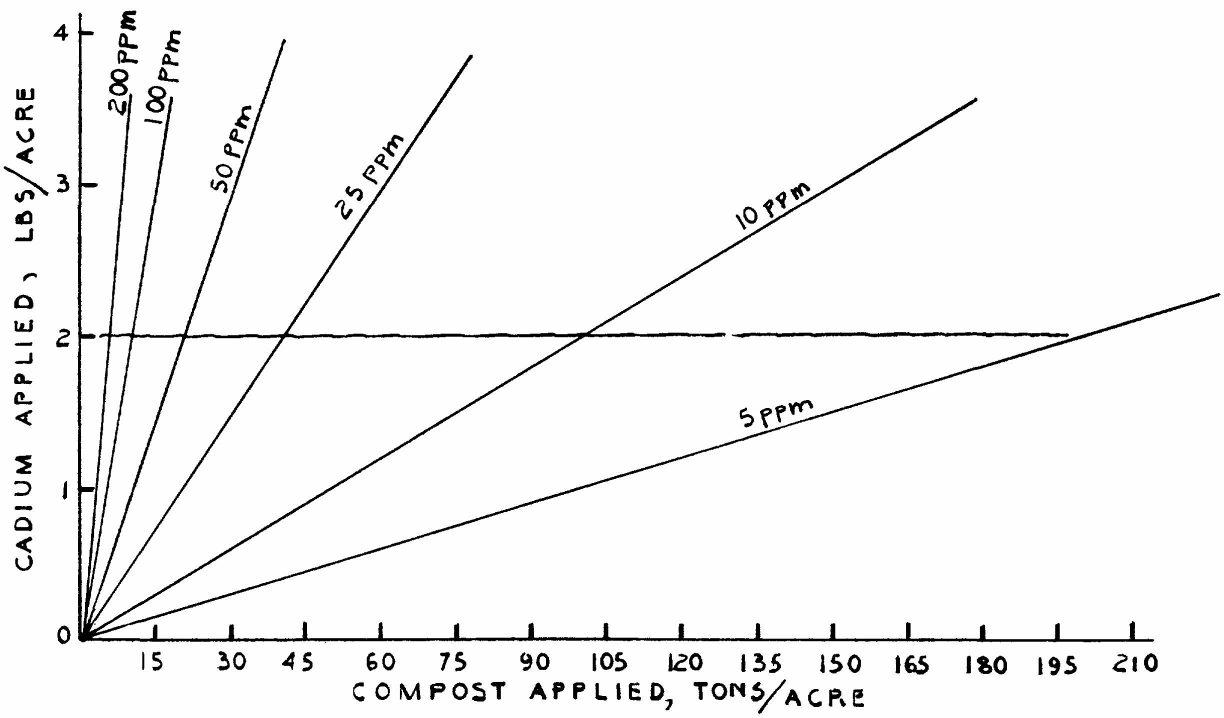


Figure 4:
Relationships among Cadmium Content, Cadmium Application, and Compost Application Rates

Proposed New Jersey regulations also limited the maximum cumulative metal addition over the lifetime of a site, with limits established for lead, zinc, copper, nickel, and cadmium (see Appendix E). Table 30 is introduced to show the current status of sludge quality for the large urban treatment plants in New Jersey, and to suggest another possible method for certification. From these data it is evident that little progress has been made in reducing metal contents of sludges; each of the seven plants exceeds the "Maximum Domestic" limits for one to four of the metals.

Table 30:
Metals Which Limit Land Applications of New Jersey Sludge

	Number of Metals Which Exceed "Maximum Domestic" 1974-75	1978-79	Metals Exceeded in 1979	"Most Limiting" Metal
Passaic Valley	4	3	Cd, Pb, Zn	Zn
Middlesex County	3	3	Cd, Cu, Zn	Zn
Elizabeth Joint Meeting	2	2	Cd, Cu	Cu
Bergen County	5	3	Cd, Cu, Ni	Cd
Linden-Roselle, Rahway Valley	4	4	Cd, Cu, Ni, Zn	Cu
Camden County	-	1	Cd	Cd
Middletown Township	0	1	Cu	Cu

This table also introduces the concept of "most limiting" metal. The "most limiting" metal is defined as that metal which will cause maximum cumulative limits of application to be exceeded first; it is therefore the metal which is most out of proportion in the compost. The last column in Table 30 lists the "most limiting" metal for that treatment plant. Using zinc, which is most limiting for Passaic and Middlesex, as an example, Figure 5 plots the relationship among zinc content of compost, compost application rate, and zinc application; the horizontal line at 500 pounds per acre of zinc applied is the maximum zinc application for medium-textured soils. For Passaic compost the cumulative zinc limit is reached at approximately 100 tons per acre of compost applied, and for Middlesex compost the limit is reached at twenty-five tons per acre. These figures are therefore the maximum

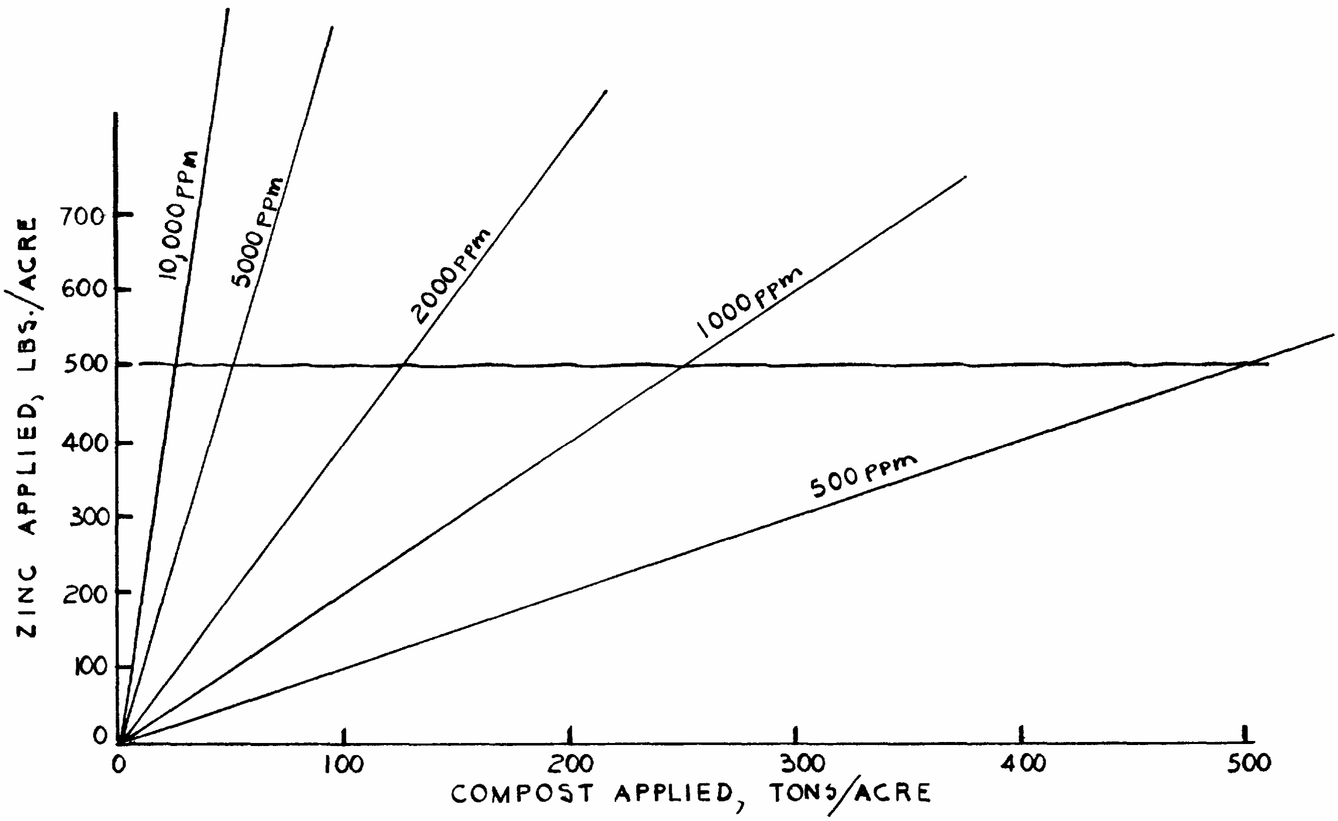


Figure 5:
Relationship among Zinc Content of Compost, Zinc Application, and Compost Application Rates

applications for this compost, and since they represent lifetime of site totals, the applications could be staggered over a five-year period, at an annual rate of twenty tons per acre, for Passaic compost, and five tons per acre for Middlesex compost.

These situations are, of course, extreme cases, representing as they do the most highly metal-contaminated sludges in New Jersey. In all probability neither of these sludge composts would be considered for land application to cropland. They are merely presented here to demonstrate one of the potential ways to develop a certification program. If annual limits could be established for each of the potentially hazardous metals, as cumulative limits now exist, then the concept of most limiting metal could be effectively implemented for both annual and cumulative applications. When pretreatment regulations are enforced, as they must be if land application of sludges is to succeed, the program could be altered to provide greater protection and flexibility in land utilization.

The idea of a certification program is an attempt to provide public protection and to insure that appropriate compost is used on cropland, while allowing a better evaluation of the applicability of composting by making the limits on a given product easier to assess. As it now stands the proposed New Jersey regulations on compost use contain many of the elements needed to implement certification, which would in turn simplify the regulatory approach. The burden now falls in two places: with regulatory agencies to implement pretreatment and sludge testing standards, and with the research community to provide the definitive information that is currently lacking. If these two institutions can succeed in their tasks, the implementation of such a program appears feasible.

Estimates of Potential Compost Use

The possible utilization options for sludge compost are numerous and diverse, and the specific conditions under which the compost may be utilized vary widely. When developing estimates for total compost use, it is therefore necessary to construct a unique approach for each category of potential utilization. Since local geographic and land use patterns play a significant role in deciding which option is selected, it is necessary to account for these factors in the quantification of material use. The aggregation of this information to a statewide level requires certain generalizations to make the procedure feasible.

Many of the specific factors which are used to develop the estimates have been discussed previously. The organic matter replacement rate is used throughout the estimates for each utilization category, as it is the truest measure of the need for and benefits of compost. The application rates recommended by researchers, from Appendix

E, are also relevant to each of the utilization categories. Loading rates based on nitrogen requirements, annual cadmium limits, and cumulative heavy metal additions are specifically applicable to food chain uses, but are also mentioned relative to other uses in which long-term food production capability may be desired.

A final basis for estimation is the idea of material substitution, an attempt to quantify the materials currently used for which compost is a suitable substitute, and estimates of where material should be used but is not. Figure 6 shows the utilization categories and the bases for estimation which apply to each.

To provide a context in which to understand the quantitative estimates discussed, it is necessary to have some idea of how much sludge compost might be produced in New Jersey. Since there are approximately 380,000 dry tons of sludge produced annually in New Jersey, and as a general rule of thumb one dry ton of sludge results in one dry ton of compost, the maximum productive capability from domestic sludge is 380,000 dry tons annually. If only the sludge which meets the "Maximum Domestic" limits identified earlier were composted, and this limit is coincident with the twenty-fifth percentile of sludge analyses as suggested by some researchers (Salotto, 1974), then the annual production would be approximately 90,000 dry tons. Sadat (1978) estimated a daily production of 200 dry tons (70,000 dry tons annually) if the treatment plants for which composting appeared the only cost effective sludge solution were to adopt the technology. If certain large treatment plants considering composting were to select it, the compost output could increase by another 60,000 dry tons. Current output is only 5,000 dry tons per year, but should increase in the coming year to approximately 20,000 dry tons. The general range of potential output lies between 20,000 and 130,000 dry tons annually.

In the following estimates, dry tons are generally used as the unit of measure, but the reader should be familiar with other measurements when they occur. The measurements used in these estimates include:

1 dry ton of compost = 4.2 cubic yards of compost
1 air or heat dry ton of sludge = 2.8 cubic yards of sludge
1 inch layer of compost per acre = 32 dry tons per acre

Private Residential

The private residential category includes food uses for home vegetable gardens, and nonfood uses for lawns, flower beds, and for possible use in potting soil mixes. Regulatory concerns over heavy metals in compost and continual use to produce garden crops consumed regularly by the same family have resulted in tentative guidelines limiting the distribution of compost to the general public to those materials with less than 25 ppm cadmium. A 25 ppm Cd concentration limits applications to forty dry tons per acre. It should also be noted that the U.S.D.A.

Figure 6:
Factors in Utilization Estimates

Utilization Categories	Bases for Estimates					
	Organic Matter Replacement Rate	Researcher's Recommenda-tions	Nitrogen Regulations	Cadmium Limits	Cumulative Heavy Metals	Material Sub-stitutions
Private residential	√	√	√	√	√	√
Private food	√	√	√	√	√	
Private nonfood	√	√				√
Public agencies	√	√				√
Land reclamation	√	√	√		√	√

Figure 6. Factors in Utilization Estimates

does not currently recommend any sludge for use on home gardens, although sludge products are still marketed and distributed generally. The organic matter replacement rate for home lawns is at most four tons per acre, while up to fifty tons per acre in one application, or thirteen tons per acre per year in a five-year program, could be used on beds and in gardens with poor soils. If the 25 ppm Cd concentration limit were increased to 50 ppm, which is the concentration of most of the urban domestic sludge in New Jersey, then the annual cadmium limit would result in maximum applications of twenty dry tons per acre.

The quantity of compost used in the private residential category is subject to considerable variability, depending on local and regional geographic and economic conditions, institutional arrangements, and user and producer education. In addition, there is little current information on the amount of organic materials used in this category. For these reasons, the quantification of this category on a statewide basis is somewhat speculative, and should be amplified by studies of the full range of local conditions and markets. Some generalizations are possible, however, based on the consideration of loading rates and land availability.

At a loading rate of thirty dry tons per acre (one inch deep layer), a ten-foot-by-twenty-foot home garden would accommodate .15 dry tons of compost. With the small quantities involved, even a program involving 50,000 home gardeners would utilize only 7,500 dry tons, but this is a high market value use and may be significant in certain locations. At the four tons per acre rate, a home lawn of forty feet by 100 feet could use 0.40 tons. Although there is no precise information on the extent of home lawns in New Jersey, a conservative estimate of 115,000 acres was made in 1959, and it is a ubiquitous outlet occurring primarily in urban and suburban areas. At a rate of four tons per acre, which would be protective of public health with all but the most metal-laden composts, the potential exists for using 460,000 tons annually in this category.

There are several areas in the United States where sludge compost or sludge is marketed or offered free to the general public. In Chicago, 76,000 dry tons of air-dried sludge are given away annually to private citizens within a thirty-male radius of the city. In Southern California, 45,000 dry tons of sludge compost are marketed annually, at $1.79 for a fifty-pound bag, within a 200-mile radius of Los Angeles, and the vendor intends to expand to 110,000 tons annually. While these two cases are strikingly different in geographic conditions and economic approach, with Chicago's output distributed free by a public agency and California's sold by a private vendor, the large quantities involved are striking.

Private Food

Private food uses include growing of field and garden crops and fruit trees, and animal agriculture (dairy and beef production).

Ironically, this category is generally subject to considerable regulatory constraint while it is the use in which the resource potential of compost could realize its greatest benefit. Basing the estimate on the nitrogen requirements of the crop, with a 10 percent nitrogen mineralization rate applications for field crops on moderately productive soils (Productivity Index = 6) would range between twenty and forty tons per acre, and for grasses between ten and thirty tons per acre. With a nitrogen mineralization rate of 5 percent these applications would be doubled. With Cd concentrations for compost applied to food crops limited to 25 ppm, unless extensive crop monitoring is practiced the annual cadmium limit results in a maximum application of forty tons per acre. The organic matter replacement rate for cropland on an average New Jersey soil, is forty to fifty tons per acre for a single application, and thirteen tons per acre per year in a five-year program. With these various limitations it appears that forty tons per acre is the approximate maximum application, with ten tons per acre a reasonable minimum.

The total land devoted to agricultural and horticultural use in New Jersey is 1.1 million acres, or 23 percent of the state's land area. The breakdown by county is shown in Table 31, together with the county compost production and the acreage required to utilize the compost at two separate loading rates. Comparing the cropland harvested to the two values for acres required reveals some striking relationships. Even at the minimum replacement rate of ten tons per acre, all but four counties--Bergen, Essex, Hudson, and Union--have ample land to utilize the annual compost output on harvested cropland. Thirteen of the counties would need 10 percent or less of the total cropland harvested for annual compost utilization, and nine would require less than 2 percent of cropland. In the Somerset County demonstration area, 1 percent of harvested cropland is needed. All of these values are for the minimum organic matter replacement rate of ten tons per acre; at higher replacement rates, nitrogen requirement levels, or annual cadmium limit levels, more compost could be utilized per acre, thereby reducing the land requirement. There is clearly no lack of available cropland for compost utilization.

When compost is used for food production an effort should be made to select specific soils and crops which will promote utilization and minimize hazards. For food crop utilization the principal soil factors are: cation exchange capacity as a measure of the soil's ability to tie up the cations of heavy metals; productivity index, which indicates the productive capacity of the soil and is a surrogate measure for the nitrogen requirement of the crop; and soil pH, which must be maintained at 6.5 or higher with compost applications. In selecting agricultural land, it is therefore desirable to select those soils which combine a high cation exchange capacity with a high productivity index. Table 32 identifies the soils in three counties which best combine the properties of productivity, wide extent, and high C.E.C. This is not to say that other soils are in any way unsuitable, but rather that these soils utilize the most material and produce the highest yields.

Table 31:
Qualified Farmland in New Jersey

County	Cropland Harvested	Cropland Pastured	Permanent Pasture	Woodland	Total Devoted to Agricultural and Horticultural Use	Annual Compost Production[2]	Acres Required at 40 T/A	Acres Required at 10 T/A	% of Cropland Harvested Required at 10 T/A
Atlantic	15,275	582	764	9,093	25,715	12,775	320	1,280	8
Bergen	1,546	190	302	2,420	4,459	37,230	930	3,720	-
Burlington	82,470	6,480	13,770	59,624	162,344	16,425	410	1,640	2
Camden	9,824	363	698	3,118	14,004	31,025	775	3,100	30
Cape May	5,817	247	260	2,715	9,039	5,475	137	548	10
Cumberland	42,760	1,150	2,903	14,893	61,705	6,205	155	620	1
Essex	325	4	35	130	494	64,240	1,606	6,424	-
Gloucester	60,516	3,080	3,828	12,059	79,484	6,570	164	656	1
Hudson	0	0	0	0	0	21,170	530	2,120	-
Hunterdon	82,981	9,419	22,774	37,243	152,418	1,640	41	164	<1
Mercer	34,353	2,194	5,119	12,286	53,952	20,440	511	2,044	6
Middlesex	30,249	1,509	1,519	9,645	42,921	56,575	1,415	5,660	16
Monmouth	56,157	4,738	9,180	20,768	90,843	24,820	620	2,480	2
Morris	14,050	2,406	5,259	11,143	32,857	15,330	383	1,532	10
Ocean	5,669	617	811	3,881	10,978	12,410	310	1,240	20
Passaic	414	76	145	1,592	2,227	3,650	91	364	85
Salem	75,900	4,388	11,505	16,983	108,777	1,440	36	144	<1
Somerset	36,268	4,826	11,903	14,984	67,981	5,290	132	528	1
Sussex	33,982	10,022	26,750	40,814	111,568	1,095	27	108	<1
Union	362	76	13	59	511	34,310	858	3,431	-
Warren	51,719	8,000	17,309	24,236	101,263	1,825	46	184	<1
Totals	640,639	60,366	134,848	297,687	1,133,540	380,000	9,500	38,000	

Notes: 1. Eighth Report on the Farmland Assessment Act of 1964, New Jersey Division of Taxation, 1976.

2. Assuming all domestic sludge is composted.

Table 32:
Extent and Properties of Desirable Soils for Compost Utilization in Camden, Middlesex, and Somerset Counties

County	Soil Series	% of All Soils in County	Acres	C.E.C. meq/100 g.	Productivity
Camden	Freehold	15	21,000	5-10	8
	Aura	7	10,000	5-10	7
Middlesex	Sassafras	13	22,800	5-10	9
	Woodstown	9	15,500	5-10	9
	Keyport	5	9,300	5-10	7
Somerset	Penn	20	40,200	15-20	5
	Neshaminy	12	23,000	15-20	9
	Mt. Lucas	5	9,400	10-15	7
	Norton	5	7,200	10-15	8

[1]Unpublished information provided by Dr. H. Motto, Department of Soils and Crops, New Jersey Agricultural Experiment Station, Rutgers University.

Proper crop selection can also greatly enhance the productive utilization of compost on cropland, either because the crop excludes metals or because it does not directly affect the human food chain. Of the field crops, corn excludes cadmium from the grain to the greatest degree (Bingham, et al., 1975), while clover and alfalfa for feedstuffs are also low accumulators of cadmium (Bingham, et al., 1976). Very little (0-20 percent) of the field crop production in New Jersey goes directly to humans. Most is used as feedstuffs for cows, and cattle and fowl. Since only 7 percent of human cadmium intake is supplied by dairy products (Breude, et al., 1975), and since dairy farming is an important agricultural enterprise in an urbanized environment, possibly the best foodcrop utilization is in dairy farming. For this specific application loading rates on hay and pasture lands should be limited to twenty-thirty tons per acre to avoid smothering grass and direct lead ingestion, and rates on forages should be limited to twenty tons per acre.

Agricultural utilization of compost is a promising and productive category, but in some cases it may be necessary to subsidize the food grower for its use. Spreading compost on agricultural lands may cost as high as $4 a ton, which would be a prohibitive cost for a farmer at the loading rates discussed but is only 3-4 percent of the cost of compost production. These costs should rightfully be internalized by the compost producer. In this way the general public would benefit in two ways from agricultural utilization: on the one hand, the resource cycle is completed and a potential waste problem is made into a resource; on the other hand, the farmer may be able to reduce fertilizer costs, thereby lowering the public's food costs. The logic is too compelling to be ignored.

Private Nonfood

This category includes a wide range of specialty and general uses, including greenhouses, nurseries, golf courses, landscape contractors, turfgrass farmers, industrial park grounds, and cemeteries. It has been proposed by the E.P.A. that these uses be subject to similar constraints on heavy metal and toxic organic concentrations, with a cadmium limit of twenty-five ppm, a lead limit of 600 ppm, and a PCB limit of ten ppm for most composts; if dry compost is produced, then the Cd and Pb limits are increased to seventy-five and 1,000 ppm, respectively. These suggested guidelines would generally limit application rates to forty tons per acre, although fifty to 100 tons per acre may be feasible for dry material. The organic matter replacement rate varies between four and thirty tones per acre within this category depending on specific use.

The specific uses involve considerably different modes of distribution and application, with some uses in bagged or potted form, others as a light topdressing on limited areas, and still others with a more general application and distribution. Therefore, each use demands a unique approach for a qualitative estimate; the approach, units, and assumptions are discussed in the text. Reference should be made to Appendix E for more complete references on the basic assumptions.

Specific information on use of organic materials in greenhouses is not readily available, nor is the annual acreage devoted to greenhouse production, due to the existence of many small operations. Some partial estimates can be derived from data in the 1977 N. J. Agricultural Statistics. Table 33 lists acreages and estimates of potential compost use for the categories given in the statistics, which include cut flowers (chrysanthemums, gladioli, roses, snapdragons), potted plants (poinsettias, geraniums, lilies, hydrangeas), and bedding plants. The various forms of production make a material usage estimate difficult, but the general rule is a one inch layer of compost (thirty-two tons per acre) as a one-third component of a mix (see Appendix E).

New Jersey has a thriving nursery business situated throughout the state. As of 1976 there were 955 certified nurseries in New Jersey with a total of 10,862 acres in nursery stock. Table 34 shows the number of nurseries, stock acres, and potential compost usage, with the state divided into four districts: Northeast (Bergen, Essex, Hudson, Passaic, Union); Northwest (Hunterdon, Morris, Somerset, Sussex, Warren); Central (Burlington, Mercer, Middlesex, Monmouth, Ocean); and South (Atlantic, Camden, Cape May, Cumberland, Gloucester, Salem). The estimate is based on a minimum organic matter replacement rate of ten tons per acre; it is likely that for certain applications up to forty tons

Table 33:
Area and Compost Estimates in Plant Production

Category	Production Area (acres)		Estimate (tons)
Cut flowers	51		1,632
Potted plants	52		1,664
Bedding plants	23		736
		Total	4,032

Source: Derived from New Jersey Crop Reporting Service, 1977.

Table 34:
Nurseries, Acres in Stock, and Potential Compost Use

District	Certified Nurseries	Average Acreage	Total In-Stock Acreage	Compost Estimate (tons)
Northeast	192	3	565	5,650
Northwest	208	6	1,273	12,730
Central	311	18	5,421	54,210
South	244	15	3,603	36,030
Total	955	11	10,862	108,620

Source: From New Jersey Crop Reporting Service, 1977.

per acre could be utilized. The statewide estimate of 108,620 tons is concentrated in the central and south districts.

The New Jersey Agricultural Statistics for 1977-1978 lists categories for organic materials marketed in the state, including manures and sludges, other organics, and soil conditions. The annual averages for the three categories are 2,200 tons, 5,800 tons, and 3,800 tons, respectively. Other estimates extrapolated from survey information place nursery usage of common potting soil amendments such as peat and vermiculite at 11,000 tons annually.

Golf course use of compost may be somewhat constrained by the texture of the product, but fine screening should produce a satisfactory material. Application rates for this category can be calculated on the basis of current maintenance programs and usage, organic matter replacement, and soil improvement. Maintenance on fairways, currently done predominantly with Milorganite, could utilize compost at a rate of two tons per acre, and topdressing of tees and greens, generally done with a mix of original materials, could be done with 50 percent compost, resulting in annual use of ten yards^3 of compost per golf hole. At the organic matter replacement rate, four tons per acre could be readily utilized on fairways, and for some areas of courses, particularly since many have thin or light soils, applications of thirty tons per acre would improve soil conditions and grass growth. Golf courses have a locational attraction for compost use because they are usually coincident with developed areas.

New Jersey has approximately 150 eighteen-hole golf courses and seventy shorter courses, averaging 200 and fifty acres, respectively; the total golf course acreage is 33,500 acres. Generally a little less than 25 percent of this acreage or 8,000 acres on a statewide basis, requires a maintenance program. At the two tons per acre maintenance rate this land would utilize 16,000 tons of compost annually, or 32,000 tons at the organic matter replacement rate. Converting the cubic yards per hole to tons per course for topdressing, the estimate is forty-three tons annually per course, or 8,000 tons of topdressing for greens and tees on a statewide basis.

Turfgrass-sod production occupies considerable acreage in New Jersey, predominantly confined to fertile soils of the central region. Sod production currently relies on heavy fertilization programs, applications which could be matched by compost at rates of forty-five tons per acre; since sod acreage is occasionally rotated with field crops, applications should not exceed a forty-ton-per-acre limit. Because sod harvesting involves the removal of some soil, a replacement rate of thirteen tons per acre appears reasonable.

Most sod operations are large, with thirty-five growers involved in the 5,500 acres of sod production. Since sod production requires a two-three-year growth period, the annual turnover is 2,000 acres, which could result in compost use of 26,000 tons at the organic matter replacement rate. There are indications from some researchers that compost applications can reduce the turnover period to less than one year. Sod production may require a finer material than is currently produced, and, as with other large volume and large acreage users, transportation of material to the site is needed.

Other categories of private nonfood uses are somewhat impractical to estimate due to the lack of quantitative information. Landscape contractors are in constant need of organic materials, and may serve as the link between the producer and the home grounds market. In the Somerset County demonstration, forty landscape contractors were identified. If each utilized twenty-five tons annually, the 1,000-ton total would consume 20 percent of the county's output. The material may serve as a partial component of topsoil, so that a topsoil dealer of 100,000 cubic yards, of which there are a few in the metropolitan areas, could annually utilize 8,000 tons. Other sources for private compost use include industrial park grounds, which commonly have well-maintained grounds but are impossible to estimate and may involve double counting, and other maintained areas such as cemeteries.

Public Uses

The range of potential public compost uses includes maintenance of developed parts and development of new parklands, recreation areas, public grounds, roadsides and median strips, and military installations. Application rates will, of course, vary depending on the specific use and on the degree of development of the site. For use as topdressing on developed public areas, the ten-tons-per-acre replacement rate is a minimum value; for use on undeveloped areas or areas requiring special maintenance a thirty-tons-per-acre rate is suitable. Mulching rates on planting beds and around woody specimens such as young trees could approach 100 tons per acre.

The quantification of all parkland in New Jersey is a task beyond the scope of this work. Instead, an effort was made to develop a thorough listing of park uses for a smaller unit, the Somerset County demonstration area. From these data it is possible to extrapolate general indications of utilization on a statewide basis (Somerset County has 3 percent of the state's population and 4.5 percent of its land area). Compost use on parklands appears particularly favorable because of the widespread occurrence of parks, the need for an inexpensive maintenance material, and public ownership.

The Somerset County Park Commission provided an extensive survey from which Table 35 is compiled. Total undeveloped acres indicates the area that has no current use or facilities of any kind, with open acres the unwooded area. This categorization therefore ignores the greater quantity of parkland that is open but is on sites with some public facilities. Basing the estimate only on open, undeveloped parkland, and applying the minimum maintenance rate of ten tons per acre, the nearly 7,000 tons utilized is 140 percent of the total county compost output if all domestic sludge were composted. In actual cases of parkland establishment, loading rates of seventy-100 tons per acre were used (see Appendix E, Section 4). Extrapolating to the state level on the basis of population or land area demonstrates the large potential of this use.

Compost application to highway roadsides to establish and maintain vegetation is a potential public use. Application rates of twenty-five - thirty tons per acre provide sufficient material to stabilize and fertilize roadside vegetation. The annual acreage along new highway construction has been estimated at 255 acres for 1980; at twenty-five tons per acre, the potential utilization is 6,400 tons, disregarding maintenance applications to existing roadside strips. One

Table 35:
Public Park Acreage and Compost Estimate in Somerset County

Ownership	Total Acres	Total Undeveloped Acres	Total Open Undeveloped Acres	Compost Estimate (tons)
Municipal	1,566	905	547	5,470
County	3,424	265	64	640
State	380	347	73	730
Total	5,370	1,517	684	6,840

[1]Derived from Somerset County Park Commission, 1979.

of the primary users of Camden compost is the Atlantic City Expressway, for vegetation establishment and maintenance.

Military installations hold extensive acreages throughout the state. If other utilization options are limited, there is a potential to utilize the material on these land holdings. Application at a minimum organic replacement rate of four-thirteen tons per acre appears reasonable.

Land Reclamation

Compost utilization for land reclamation includes use on sand and gravel pits, strip mined lands, and intermediate or final landfill cover. Application rates for reclamation of extraction areas can range from a minimum of ten tons per acre, applied as topdressing or cover, to fifty-100 tons per acre, incorporated into the soil and planted for stabilization. The latter rates could result in productive lands established from wasteland. Daily cover for landfills should be applied in a six inch layer at the end of a day's operation; if compost were used to satisfy this entire requirement, the loading rate would be 190 tons per acre, while as a one-third component of cover, the rate would be sixty-five tons per acre. Final cover for closed landfills is applied in a twelve inch layer, which would utilize 385 tons per acre if compost alone were used, and 130 tons per acre if compost were a one-third component of a mixed cover material.

There are more than 10,000 acres of sand and gravel pits in New Jersey requiring reclamation, predominantly in the central and southern portions of the state. There are also several thousand acres of quarry land in the northern portion of the state. If compost were applied at the minimum replacement rate of ten tons per acre to the 10,000 mined acres, the resulting utilization would be 100,000 tons annually; if applied at the reclamation rate of fifty-100 tons per acre, the annual utilization would be 500,000-1,000,000 tons, although application of this amount each year is inappropriate.

With the anticipated closing of many landfills as the E.P.A. enforces the strict criteria mandated by the Resource Conservation and Recovery Act, and with stricter enforcement of operating procedures governing the use of daily cover on landfills, there will be a critical need for suitable materials to meet this demand. If only 1,000 acres of landfill space require final cover, and if compost makes up only one-third of the cover material, the resulting consumption is 130,000 tons of compost. The opportunity for using compost as intermediate, daily cover is even more impressive. If 500 acres of landfills require daily cover, and compost is applied as one-third of the cover mix, the resulting utilization is 32,500 tons daily. This use may be especially attractive where compost is too high in metal or toxic organic content to permit general distribution or food chain use.

Other Utilization Issues

This discussion of compost utilization has been concerned with analyzing the potential applicability of compost for a variety of uses, with the emphasis on matching uses and compost characteristics so as to maximize the benefits and opportunities for sludge composting. No attempt has been made to exhaust the range of issues affecting compost utilization. Other issues are pertinent either to successful utilization in a safe manner or to the selection of a particular utilization strategy.

Management Issues

The primary management issues are related to proper site selection on the basis of soil and vegetative properties. Specific soil and site limitations for the application of biodegradable solids have been identified by the U.S.D.A. (1974), and include permeability, soil drainage class, runoff class, flooding potential, and available water holding capacity. These factors are classified on the basis of slight, moderate, and severe limitations. When severe limitations are encountered, specific mitigating measures may be required. Other factors which may limit a site's utilization potential are slope (Fast, 1979) and occurrence of a seasonal high water table. If soil survey information is consulted, it should not be difficult to select utilization areas which avoid these limitations.

A factor of considerable importance in managing compost containing heavy metals is the maintenance of soil pH. Applying compost to a soil with an initial pH of 6.5 greatly reduces the assimilation of metals by plants, and maintaining the soil at pH 6.2 provides further protection. Because most New Jersey soils are somewhat acidic, liming materials should be applied to raise pH to a near neutral value.

Other management issues relate to proper site selection in relation to surface and groundwater supplies. Sites in close proximity to water supplies and with downslope movement to the supply should be avoided or utilized to a limited extent, unless a monitoring program is implemented. These considerations are incorporated into the draft New Jersey guidelines for application.

Economic Issues

The market potential for compost is the primary economic issue in utilization. In past United States composting experience, the marketing of compost to regain production costs was often applied as a criterion for success, an improbable standard that neglects the basic consideration that the immediate goal is waste disposal. That the waste is, in the economic and material sense, actually a misplaced resource does not give the material an economic value per se. While marketing is undoubtedly an attractive component of compost utilization, it is not a realistic measure of program success.

Kasper and Derr (1979) have summarized the recent United States experience in marketing of sludge compost (Table 36). On a wholesale bulk basis compost had a value of $16-30 per dry ton, which compares to their estimate of $12 per dry ton value of compost on a component basis (N, P, K, and organic matter). The value for a bagged product is $62-69 per dry ton from the limited cases available; bagging costs are estimated at $25-30 per dry ton. The bagging operation in Los Angeles is handled by a private vendor, while in Bangor, Me. bagging is done by the compost producer.

Table 36:
Actual and Estimated Wholesale and Retail Value of Bulk and Bagged Compost

Location	$/Wet Ton	$/Dry Ton	$/Cubic Yard
Bulk			
Bangor, Me.	11	17	5.50
Durham, N. H.	12	-	5.00
Los Angeles, Cal.	11	16	5.50
Windsor, Ont.	17	30	8.70
Bagged			
Los Angeles, Cal.	48	69	24.00
Bangor, Me.	40	62	20.00

Source: Kasper and Derr, 1979.

Chapter VI: Conclusions and Recommendations

Many of the basic conclusions and recommendations are included, either explicitly or implicitly, within the text. The comments included here are meant to focus on and summarize some of the issues raised earlier.

Sludge Quantity and Quality

The production and disposal of sludge have rarely been examined with an integrated approach. Sewage sludge is an externality of wastewater management, and as such its expedient disposal has resulted in degradation of common resources. Given the current limitations on disposal options and other governmental actions, the externalization of disposal costs is no longer tenable. Because this position prevailed in the past, however, there is considerable resistance to embarking on a new course. Unless this attitude changes and sludge production and disposal are unified, little progress can be expected in sludge management.

As the process of controlled biological decomposition of organic matter, composting is well-suited for sewage sludge solids, primarily an organic material. In a broad sense the technology for composting sludge has always been available; the specific needs are to expand this technology to suit modern applications, and to transfer the technology to those responsible for implementation. Both require major research and development efforts.

Sludge production in New Jersey is either heavily concentrated in a few areas, as with large regional systems serving densely settled urban areas, or widely dispersed, as with the many small treatment plants serving relatively isolated areas. The specific needs of the two groups are quite different. For large production units in urban areas the need is for composting technologies which minimize contact with the surrounding environment. For dispersed areas the need is for cooperative institutional arrangements which minimize the costs and impacts of regional solutions.

Of critical importance to the applicability of composting is the quality of sludge produced in the state. So long as sewage authorities are allowed to forego implementation of industrial pretreatment, any land application technology is limited. It is a terrible irony that the same sewage authorities who claim the impracticality of land application are those responsible for implementing pretreatment to produce less contaminated sludges. If this situation persists, land application will always be viewed with an attitude of impermanence and suspicion.

Bulking Agent Needs and Impacts

The range of potential bulking agents is broad, and the available quantity is sufficient for wide application. The supplies are dispersed, however, and require expanded institutional arrangements to provide reliable sources. Local availability will vary widely for each of the materials, and a concerted effort is needed to develop schedules and supplies. Of major importance to this development is the design of materials handling systems which are specific to each type of bulking agent. The system design should provide maximum flexibility if the composting operation intends to use more than one type of bulking agent.

Thus far in sludge composting the primary focus has been on a single material, high-grade wood chip. It is undoubtedly a suitable material and will continue to have wide applicability, but to view it as the only source is to deny the full potential of the process. Materials which should be given greater consideration include municipal solid waste, recycled compost, local wood wastes, and specific solid wastes totally reusable (e.g., shredded rubber). The burden to develop these materials fully is on the research and development community and its support agencies.

Site Selection and Impacts

Proper site selection is essential to the public acceptance of sludge composting. A site screening and selection procedure as outlined in the text should be an essential element of any composting plan. The choice among remote sites, nearby sites, and regional operations should be considered prior to a final decision on site location. When composting is selected for implementation in a densely settled area but transport to a remote site is too costly, the only alternative may be to develop a fresh technological approach to enclose the system. Conversely, when remote sites are available and suitable, the same considerations relative to careful site design should be followed; the mere remoteness of a site cannot substitute entirely for effective planning.

Closely related to site selection are the issues of suitable composting systems for many scales of operation and the arrangements necessary to develop regional composting facilities. With the large number of small treatment plants in New Jersey there is an urgent need for the development of small, easily managed composting systems. If these systems do not prove technologically or economically feasible, the only alternative is to institute a regional collection system for joint composting at a centralized site. Such a plan would require new organizational and institutional arrangements, with either counties, agencies, or utilities authorities assuming the lead role.

Compost Utilization

The costs of sludge composting do not stop when the compost is produced; the final disposition and utilization of the material remains the responsibility of the producing authority. While it is desirable to regain some of the costs of composting through utilization, this is no measure of success. If the authority must pay for utilization but the total cost of the process is still less than other alternatives, composting should be chosen.

There is ample land throughout New Jersey to accommodate whatever quantity of compost is produced. This is not to say, however, that the development of uses is a simple task. As with the introduction of any new technology or material, a great deal of managerial and public education is required. Educational programs should be a necessary part of any utilization program and should be conducted prior to distribution, not after problems have developed.

The uses that can accommodate the greatest volume of material are agricultural in exurban areas and parks and landfills in urban areas. So long as authorities permit sludges to be contaminated by undesirable elements, the full potential of these uses can never be realized. Industrial pretreatment is a necessity for the creation of an expanded range of uses for compost, including use on food chain crops.

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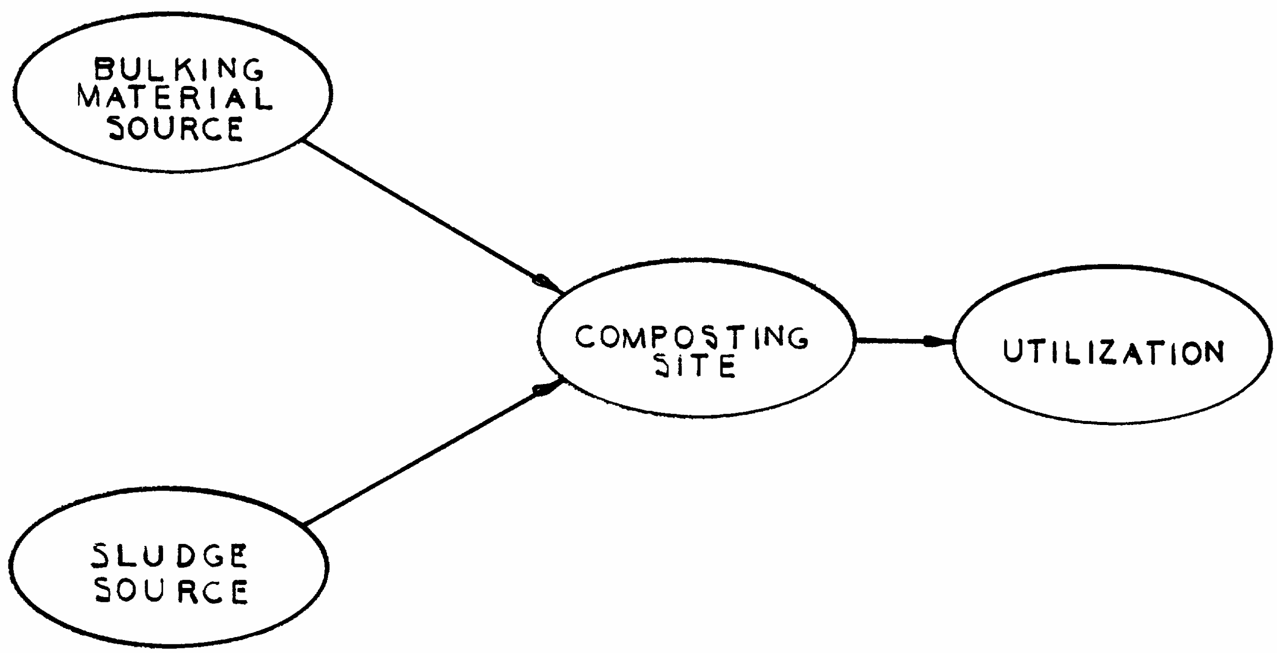
Appendix A

Model of Composting System

The "Generic Description of a Composting System" on the following page is introduced in Chapter 1 as a major factor in the scope and development of this report. The model identifies the basic resources, processes, flows, and interrelationships involved in the operation of a composting system. It directly or indirectly suggests the four components of this investigation of statewide applicability, and is discussed in more detail in the text and in a companion report on a systems analysis of a composting operation.


BULKING MATERIAL SOURCE
SLUDGE SOURCE
COMPOSTING SITE
UTILIZATION

Appendix B

Components and Evaluation Criteria for Statewide Applicability

In Appendix B, also discussed in Chapter 1 in reference to the report approach, the four components are divided into the factors of resource quantity, quality, and availability. For each of the factors evaluative criteria developed for this study are introduced. These criteria provide the basis for analyzing each component and supply a framework for data collection.

Sludge and Its Source

Factors

Sludge quantity

1. Current:
   a. Dewatering ___ Yes ___ No
   b. % Solids ___ %
   c. Bulk density ___ lbs./cu. yd.
   d. Maximum 7-day production ___ dry tons/day
   e. Average 7-day production ___ dry tons/day
   f. Seasonal variability (resorts) ___ Yes ___ No

2. Future (10 year horizon):
   a. Dewatering ___ Yes ___ No
   b. % Solids ___ %
   c. Average 7-day production
      (high estimate) ___ dry tons/day
      (low estimate) ___ dry tons/day

Sludge quality

1. Current:
   a. ___ Domestic ___ Industrial ___ Mixed (___ % domestic)
   b. ___ Primary ___ Activated sludge ___ Trickling filter
      ___ Other (tertiary, chemical, etc.)
   c. Analysis:

pH	___		Magnesium	___	%
C/N ratio	___		Iron	___	mg/kg
Volatile solids	___	%	Manganese	___	mg/kg
Nitrogen	___	%	Copper	___	mg/kg
Phosphorous	___	%	Zinc	___	mg/kg
Potassium	___	%	Nickel	___	mg/kg
Chlorine	___	%	Chromium	___	mg/kg
Sulfur	___	%	Cadmium	___	mg/kg
Sodium	___	%	Lead	___	mg/kg
Calcium	___	%			

2. Future:
   a. ___ Domestic ___ Industrial ___ Mixed (___ % domestic)
   b. ___ Primary ___ Activated sludge ___ Trickling filter
      ___ Other (tertiary, chemical, etc.)
   c. Analysis

pH	___		Magnesium	___	%
C/N	___		Iron	___	mg/kg
Volatile Solids	___	%	Manganese	___	mg/kg
Nitrogen	___	%	Copper	___	mg/kg
Phosphorous	___	%	Zinc	___	mg/kg
Potassium	___	%	Nickel	___	mg/kg
Chlorine	___	%	Chromium	___	mg/kg
Sulfur	___	%	Cadmium	___	mg/kg
Sodium	___	%	Lead	___	mg/kg
Calcium	___	%			

Bulking Agents

Factors

Bulking agent quantity

1. Minimum 4-week production ___ cu. yds./day
2. Maximum 4-week production ___ cu. yds./day
3. Average 4-week production ___ cu. yds./day
4. Bulk density ___ lbs./cu. yd.
5. Solids content ___ %
6. Mix ratio (based on desired final mixture of 40% solids) ___ :1 ratio
7. Recoverability (dependent on screening operation) ___ %

Bulking agent quality

1. Carbon available ___ Yes ___ No
2. Carbon content ___ %
3. Bulking characteristics:
   a. Porosity ___ Poor ___ Fair ___ Good
   b. Surface area ___ Poor ___ Fair ___ Good
   c. Pneumatic conductivity ___ Poor ___ Fair ___ Good
4. Analysis:

C/N ratio	___	Magnesium	___ %
Volatile solids	___ %	Iron	___ mg/kg
Total nitrogen	___ %	Manganese	___ mg/kg
Total phosphorous	___ %	Copper	___ mg/kg
Potassium	___ %	Zinc	___ mg/kg
Chlorine	___ %	Nickel	___ mg/kg
Sulfur	___ %	Chromium	___ mg/kg
Sodium	___ %	Cadmium	___ mg/kg
Calcium	___ %	Lead	___ mg/kg

Bulking agent availability

1. Constant or seasonal supply — Months of the year available

   ___ Jan. ___ Feb. ___ March ___ April
   ___ May ___ June ___ July ___ August
   ___ Sept. ___ Oct. ___ Nov. ___ Dec.
2. Regular collection and schedule ___ Yes ___ No
   ___ Daily ___ Weekly ___ Monthly
3. Processing required and type ___ Yes ___ No ___ Type
4. Cost/volume $___/cu. yd.
5. Cost/volume utilized $___/cu. yd./dry ton of sludge processed
6. Gross cubic yards/dry ton of sludge processed ___ cu. yds./dry ton
7. Cubic yards consumed/dry ton of sludge processed ___ cu. yds./dry ton
8. Specific location

Composting Sites

Factors

Composting site quantity

	Acres		Dry Tons Handled	
	Present	Future	Present	Future
1. Acres available				
2. Acres required (formula)				
3. Buffer requirement				

4. Probability of nearby land being acquired ___ Poor ___ Fair ___ Good

Composting site quality

1. Vacant ___ Yes ___ No
2. Undeveloped area ___ % of total site
3. Access ___ Primary road ___ Secondary road
   ___ Residential street
4. Surrounding land uses ___ % Commercial ___ % Industrial
   ___ % Residential ___ % Public
5. Prevailing wind ___
6. Land uses affected by prevailing winds ___ % Commercial ___ % Industrial
   ___ % Residential ___ % Public
7. Distance to surface water bodies ___ feet
8. Depth to water table ___ feet

Composting site availability

1. Proximity to sludge source ___ miles from sludge source
2. Ownership ___ Public ___ Private
3. Zoning ___ Commercial ___ Industrial
   ___ Residential ___ Public

Utilization

Factors

Compost quantity

1. Total compost produced ___ dry tons/year
2. Compost output/dry sludge input ___ dry tons compost/___ dry tons sludge
3. Bulk density ___ lbs./cu. yd.
4. Solids content ___ %

Compost quality--certification program

1. Physical factors
   a. Moisture holding capacity ___ % of dry weight
   b. Texture ___ % diameter screen
2. Chemical factors
   a. Organic matter ___ % of total solids
   b. Cation exchange capacity ___ meg/100 gr.

c. pH	___	n. Iron	___ mg/kg
d. C/N ratio	___	o. Manganese	___ mg/kg
e. Total nitrogen	___ %	p. Copper	___ mg/kg
f. Ammonium nitrogen	___ %	q. Zinc	___ mg/kg
g. Phosphorous	___ %	r. Nickel	___ mg/kg
h. Potassium	___ %	s. Chromium	___ mg/kg
i. Chlorine	___ %	t. Cadmium	___ mg/kg
j. Sulfur	___ %	u. Lead	___ mg/kg
k. Sodium	___ %	v. Nitrogen release rate ___ %	
l. Calcium	___ %	of total nitrogen/year	
m. Magnesium	___ %	w. Organic matter decomposition	
		___ % mineralized/yr.	

3. Biological factors
   a. Total coliform — Test for presence (+) or absence (-)
   b. Fecal coliform — + or -
   c. Ascaris ova — + or -
   d. Salmonella — + or -

Compost availability

1. Production
   Minimum ___ dry tons/quarter
   Maximum ___ dry tons/quarter
   Average ___ dry tons/quarter

Hierarchy of uses

1. Private residential
   a. food applications
   b. nonfood applications
2. Private food
   a. field crops for food and feed
   b. garden crops for food and feed
   c. fruit trees

3. Private nonfood
   a. greenhouses
   b. nurseries
   c. golf courses
   d. landscape contractors
   e. turfgrass farmers
   f. industrial park grounds
   g. cemeteries
4. Public agencies
   a. public parks
   b. playgrounds
   c. roadsides and median strips
   d. military installations
   e. public grounds
5. Land reclamation
   a. landfill cover
   b. strip-mined lands
   c. sand and gravel pits
6. Landfill-compost disposal

Appendix C

Sludge Quantity Calculations

The equations in Appendix C are referred to in Chapter II of the text. These formulae estimate the quantity of sludge solids produced by primary and secondary wastewater treatment. The calculations included in the text identify the specific physical characteristics of dewatered sludge that are most important for sewage sludge composting.

Sludge Quantity Calculations

Waste solids production in primary and secondary processing can be estimated using the following formulae:

$Ws = Ws_p + Ws_s$

where Ws = total dry solids, lb./day

Ws_p = raw primary solids, lb./day

Ws_s = secondary biological solids, lb./day

$Ws_p = f \times SS \times Q \times 8.34$

where Ws_p = primary solids, lb. of dry weight/day

r = fraction of suspended solids removed in primary settling

SS = suspended solids in unsettled wastewater, mg/l

Q = daily wastewater flow, mgd

8.34 = conversion factor, lb./mg per mg/l

$Ws_s = K \times BOD \times Q \times 8.34$

where Ws_s = biological sludge solids, lb. of dry weight/day

K = fraction of applied BOD that appears as excess biological growth in waste activated or filter humus, assuming about 30 mg/l of BOD remaining in the secondary effluent

BOD = concentration in applied wastewater, mg/l

Q = daily wastewater flow, mgd

The specific gravity of solid matter in a sludge can be computed from the relationship:

$$\frac{Ws}{Ss\gamma} = \frac{Wf}{Sf\gamma} + \frac{Wv}{Sv\gamma}$$

where Ws = weight of dry solids, lb.

Ss = specific gravity of solids

y = unit weight of water, $lb./ft.^3$

Wf = weight of fixed (nonvolatile) solids, lb.

Sf = specific gravity of fixed solids

Wv = weight of volatile solids, lb.

Sv = specific gravity of volatile solids

The specific gravity of organic matter is 1.2-1.4, while the solids in chemically coagulated water vary from 1.5 to 2.5. The value for a solids slurry is calculated from

$$S = \frac{Ws + Ws}{(Ws/1.00) + (Ws/Ss)}$$

where S = specific gravity of wet sludge

Ww = weight of water, lb.

Ws = weight of dry solids, lb.

Ss = specific gravity of dry solids

The volume of waste sludge for a given amount of dry matter and concentration of solids is given by:

$$V = \frac{Ws}{(s/100)yS} = \frac{Ws}{\{(100-p)/100\}yS}$$

where V = volume of sludge, ft.^{3}

Ws = weight of dry solids, lb.

s = solids content, %

y = unit weight of water, 62.4 lb./ft.^{3}

S = specific gravity of wet sludge

p = water content, %

Sources: Clark, J. W., W. Viessman, Jr., and M. J. Hammer, 1977. Water Supply and Pollution Control, 3rd edition, lEP-A Dun-Donelley Publisher, New York, N. Y.

Metcalf & Eddy, Inc., 1979. Wastewater Engineering: Treatment Disposal Reuse, McGraw-Hill Book Co., New York, N. Y.

Appendix D

Somerset County Demonstration Study

As part of the analysis one county, Somerset, N. J., was selected to demonstrate the approach suggested in this report. The following information represents a partial listing of the data gathered in Somerset County, taken from earlier progress reports on this project. The inventory components are selected to indicate the type and availability of information pertinent to a thorough analysis of sludge composting. These data are part of the set utilized in the linear programming analysis of composting site selection, which is explained in detail in Chapter IV.

Table 1

Information Sources for Treatment Plant Inventory

Code	Source
A	Somerset County Board of Chosen Freeholders Upper Raritan Watershed Wastewater Facilities Plan Inventory Report, February, 1976. Prepared by Malcolm Pirnie, Inc.
B	Sewer Collection Systems in Somerset County (map) Somerset County Planning Board, 1976.
C	N.J. D.E.P., Division of Water Resources Public Wastewater Facilities Section Wastewater Management System Update of Sewage Treatment Plant Master File
D	Inventory of Existing Discharges (task 4.1) Raritan Basin Water Quality Planning Office of Areawide Planning Division of Water Resources N.J. D.E.P. Trenton, N. J. February 8, 1978.
E	LORDS (Land Oriented Reference Data System) N.J. D.E.P., Bureau of Geology and Topography Sewage and Landfill Overlay Sheets 25 and 28 August, 1975.
Tel.	Telephone conversation with the STP operators, owners, engineers or some other well-informed person, for each STP in the County.

Sewage Treatment Plant Inventory

Township or Borough	Information Source A	B	C	D	E	tel.	In Operation	Comments
1. <u>Bedminster Twp.</u>								
Bedminster Inn WTP	*			*	*		No	This plant is no longer in operation.
Bedminster Twp. WTP	*	*		*		*	Yes	This is the AT&T STP.
Cowperthwaite's WTP	*	*	*	*	*		Yes	
Fiddler's Elbow WTP	*		*	*		*	Yes	
N. J. State Garage and Maintenance Bldg.	*		*			*	Yes	
2. <u>Bernards Twp.</u>								
Bernards Municipal	*	*	*		*	*	Yes	
Lyons Hospital WTP	*					*		
Old Mill Inn WTP	*	*				*	No	This WTP is tied in with the Municipal WTP.
3. <u>Bernardsville</u>								
Bernardsville Municipal S A	*	*	*	*	*	*	Yes	
4. <u>Bound Brook</u>								
5. <u>Branchburg Twp.</u>								
Azoplate Corp.		*	*	*	*	*	Yes	
Azoplate Corp.		*			*	*	No	The Azoplate Corp. in Somerville has the STP; this plant neutralizes the water and sends it to the municipal sewer.
Branchburg Farm WTP	*	*	*	*	*	*	Yes	
Branchburg STP				*	*			This STP is also known as Windy Willow and is no longer in operation.
Central School WTP	*	*		*	*	*	Yes	
Fox Hollow WTP	*	*		*	*	*	Yes	
Neshanic Station WTP	*	*		*	*	*	Yes	

(continued)

Sewage Treatment Plant Inventory--Continued

Township or Borough	Information Source						In Oper-ation	Comments
	A	B	C	D	E	tel.		
6. Bridgewater Twp.								
American Cyanamid WTP	*	*	*	*	*	*	Yes	
Houdaille Construction	*	*		*	*	*	No	This plant is no longer a STP; hold tank is pumped out periodically.
J-M Corp. Research Center		*		*	*	*	No	Out of use.
Northover Camp WTP	*	*		*	*	*	Yes	
RCA		*			*	*	No	Both of these are out of use for years.
RCA		*			*	*	No	
St. Bernards Parish	*	*	*	*	*	*	Yes	
Somerset County Shopping Center WPT	*	*	*	*	*		Yes	
Somerset-Raritan Valley S A	*	*	*	*	*	*	Yes	
Washington Valley School WTP	*	*	*	*	*	*	Yes	
7. Far Hills								
Borough of Far Hills Sewage System	*	*	*	*	*	*	No	This STP has been connected to the Bedminster Twp. WTP.
8. Franklin Twp.								
Franklin Shopping Ctr.			*			*	No	Applied for and received a permit for preliminary treatment but never built the facilities.
9. Green Brook Twp.								
10. Hillsborough Twp.								
Belle Mead Depot WTP	*	*			*	*	Yes	
Fieldhedge WTP	*	*		*	*	*	Yes	
River Road WTP	*	*		*	*	*	Yes	
Squibb Inst. WTP	*	*	*	*	*	*	Yes	
V A Supply Depot WTP	*	*		*	*	*	Yes	

(continued)

Sewage Treatment Plant Inventory--Continued

Township or Borough	Information Source A	B	C	D	E	tel.	In Operation	Comments
11. <u>Manville</u>								
J-M Corp.		*	*	*	*	*	Yes	
Manville Borough School System	*	*		*	*	*	Yes	
12. <u>Millstone</u>								
13. <u>Montgomery Twp.</u>								
Beden's Brook C C		*	*	*	*	*	Yes	
Belle Mead Consumer's Farmer Milk Coop		*			*	*	No	Out of use.
Burnt Hill Orchard Rd. School			*	*	*	*	Yes	
Carrier Clinic		*		*	*	*	Yes	
J&J Baby Products ind.			*	*		*	Yes	
J&J Baby Products dom.			*	*		*	Yes	
Millstone River		*	*	*	*	*	Yes	
3-M Co. upper		*		*	*	*	Yes	
3-M Co. lower		*		*	*	*	Yes	
Montgomery H. S.		*		*	*	*	Yes	
N. J. Neuro Psychiatric Inst.		*	*	*	*	*	Yes	
Sleepy Hollow		*	*	*	*	*	Yes	
14. <u>North Plainfield</u>								
15. <u>Peapack-Gladstone</u>								
Peapack-Gladstone STP	*	*	*		*	*	Yes	
16. <u>Raritan</u>								
17. <u>Rocky Hill</u>								
18. <u>Somerville</u>								
19. <u>S. Bound Brook</u>								
20. <u>Warren Twp.</u>								
Bardy Farms WTP	*	*	*	*	*	*	Yes	
Stage 1 and 2 WTP	*	*	*		*	*	Yes	
Stage 3 WTP	*	*	*	*	*	*	Yes	
Stage 4 WTP	*	*	*		*	*	Yes	
21. <u>Watchung</u>								
Wally's Tavern		*	*	*	*	*	Yes	

Sewage Treatment Plant Inventory

Township or Borough	Map #	% Ind.	% Dem.	Design Capacity (mgd)	% of Utilized Capacity	Treatment Process	Solids Concentration of Availability of Dewatering	Estimated Sludge Generation (dry tons/ day)	Heavy Metal Content Analysis	Present Method of Sludge Disposal	Acreage Available	Comments
1. Bedsminster Twp.												
Bedminster Twp. WTP	1		100	.20375	50	CP w/D	4-5%	.202	no	sent to Somerset-Raritan for incineration	municipally owned land around them (flood areas, etc.)	Also known as AT&T
Cowperthwaite's WTP	2		100	.001	100	PS		.0006	no	septic tank clean-out		
Fiddler's Elbow WTP	3		100	.0175	winter 0 summer 50	AS	3%	.02	no	a scavenger comes once in the summer	the golf club owns 2000 acres	
N. J. State Garage and Maintenance Building	4		100	.003	60	AS w/D	18%	.002	no	sent to the borough landfill	small ball field adjacent to the WTP	
2. Bernards Twp.												
Bernards Municipal WTP	5		100	1.2	58	PS+TF w/D	no	.735	no	a farmer takes it	10 acres at the STP;	100% domestic but has some chemcals
Lyons Hospital WTP	6		100	.5	60-70	PS w/D	10%	.188	no	landfilled on hospital property	the hospital owns 44 acres, the plant is on 4 acres	
3. Bernardsville												
Bernardsville Municipal S A	7		100	.5	90	AS w/D	15-20%	.338	no	buried with the garbage at the landfill on Pill Hill Rd., Bernardsville	no land at the STP	Drying beds
4. Bound Brook	sends to the Middlesex County Sewerage Authority System											

(continued)

Township or Borough	Map #	% Ind.	% Dem.	Design Capacity (mgd)	% of Utilized Capacity	Treatment Process	Solids Concentration of Availability of Dewatering	Estimated Sludge Generation (dry tons/ day)	Heavy Metal Content Analysis	Present Method of Sludge Disposal	Acreage Available	Comments
5. Branchburg Twp. The S A is a customer of the Somerset-Raritan Valley S A.												
Azoplate Corp.	8	100		.5	60	PS	over 50%	.313	yes	picked up by outside service and spread on farmland	approx. 16 acres of rough land	
Branchburg Farm WTP	9		100	.015		PS+AS	no	.018	no	spread as manure	125 pasture acres	Not all solids go through the STP. It is 100% domestic and has animal organics
Central School WTP	10		100	.016	25	AS	no	.018	no	taken by scavenger to landfill	large school property	
Fox Hollow WTP	11		100	.05	58	PS+AS	no	.059	no	landfill	open space in the area	The plant is owned by the township on township land
Neshanic Station WTP	12	15	85	.062	42	AS	no	.07	no	taken by scavenger to landfill	no land	Serves one plastic industry
6. Bridgewater Twp. The S A is a participant of the Somerset-Raritan Valley S A, which serves 52 percent of the township population; 6 percent of the population is served by the Middlesex County S A.												
American Cyanamid WTP	13	100		25.0	75	CP	yes	41.25	no	incinerated, then the ashes are landfilled	a few scattered acres	They expect to incinerate for a long time.
Northover Camp WTP	14		100	.006	0	PS		.004	no	scavenger empties the holding tank	100 acres at the WTP	It services six small cottages.
St. Bernards Parish	15		100	.02	5	PS	no	.013	no	when the holding tank is full, it is taken to the township STP	one school and one home on 27½ acres	
Somerset County Shopping Center WTP	16		100	.025	80	PS+TF		.023				

(continued)

Sewage Treatment Plant Inventory--Continued

Township or Borough	Map #	% Ind.	% Dem.	Design Capacity (mgd)	% of Utilized Capacity	Treatment Process	Solids Concentration of Availability of Dewatering	Estimated Sludge Generation (dry tons/ day)	Heavy Metal Content Analysis	Present Method of Sludge Disposal	Acreage Available	Comments
Somerset-Raritan Valley S A	17	12	88	10.0	85	PS+ASwD	yes	7.0	yes	incineration	they have enough land to double their capacity	
Washington Valley School WTP	18		100	.006	100	AS	no	.007	no	tank truck takes it to Somerset-Raritan	2 or 3 acres at the school	
7. Far Hills	connected to the Bedminster Twp. S A											
8. Franklin Twp.	sends to Middlesex and to South Brunswick											
9. Green Brook Twp.	sends to Middlesex County S A through the Plainfield Joint Meeting											
10. Hillsborough Twp.	the S A is a customer of the Somerset-Raritan Valley S A; about 228 homes are served by the Manville Borough Sewer System											
Belle Mead Depot WTP	19		100	.075	43	PS+TF		.065				
Fieldhedge WTP	20		100	.05	100	PS	no	.031	no	trucked to a dump in Freehold	no land	
River Road WTP	21		100	.117	100	PS	no	.073	no	trucked to a dump in Freehold	no land	
Squibb Inst. WTP	22		100	.045	8	AS w/D	a little	.03	yes	a scavenger takes to or it is land-spread within the next 48 hours and plowed	370 acres of which only 5% are built	No dangerous chemicals.
V A Supply Depot WTP	23		100	.045	89	TF	100%	.011	no	dried and buried on the premises	70 or 80 acres at the plant	Very little; buried two or three times a year.

(continued)

Township or Borough	Map #	% Ind.	% Dem.	Design Capacity (mgd)	% of Utilized Capacity	Treatment Process	Solids Concentration of Availability of Dewatering	Estimated Sludge Generation (dry tons/ day)	Heavy Metal Content Analysis	Present Method of Sludge Disposal	Acreage Available	Comments
11. <u>Manville</u>												
J-M Copr.	24	100		6.0	100	PS		3.75		sent to the munici- pal STP		"What they have you wouldn't want to compost."
Manville Borough S System	25		100	2.0	65	PS+TF	20%	2.34		bury the dry sludge	4 acres	
12. <u>Millstone</u>	no public sewer system											
13. <u>Montgomery Twp.</u>												
Beden's Brook C C	26		100	.01	40	AS	no	.011	no	scavenger	no land	
Burnt Hill Orchard Road School	27		100	.017	60-70	AS w/D	no	.012	no	scavenger	no land	
Carrier Clinic	28		100	.05	64	AS w/D	no	.034	no	held in a digestor until the scav- enger comes once or twice a month	300 or 400 acres of farmland around the plant	No danger- ous chemi- cals.
J&J Baby Products Ind.	29	100		.025	100	CP	no	.041	yes	trucked to the Lone Pine landfill in Freehold	20 or 30 acres at the plant (this is for both STP)	10,000 gal- lons/week of sludge trucked to the land- fill between both J&J STP. Both plants are in the same build- ing.
J&J Baby Products Dom.	30		100	.025	50	CP	no	.041	yes	same as above		
Millstone River	31		100	.3	60	AS w/D	no	.203	no	scavenger takes 4 loads every 2 months, 1 load = 3000 gallons	no land	
3-M Co. upper	32		100	.2	10	PS w/D	no	.075	no	scavenger comes once every 3 or 5 years	2000 acres with nothing on them (for both plants)	No danger- ous chemi- cals. No industrial wastes are treated.
3-M Co. lower	33		100	.2	10	PS w/D	no	.075	no	same as above		Same as above.

(continued)

Sewage Treatment Plant Inventory--Continued

Township or Borough	Map #	% Ind.	% Dem.	Design Capacity (mgd)	% of Utilized Capacity	Treatment Process	Solids Concentration of Availability of Dewatering	Estimated Sludge Generation (dry tons/ day)	Heavy Metal Content Analysis	Present Method of Sludge Disposal	Acreage Available	Comments
Montgomery H S	34		100	.04	10-25	AS	no	.045	no	holding tank; eventually taken to another STP	10-15 acres at the plant	
N. J. Neuro Psychiatric Inst.	35		100	.5	40	PS+TFw/D	till almost dry	.306	no	plowed into adjacent farmland	hospital owns 1000 acres of which one-half are farmland	Sludge dried in sand beds, cleared twice a year yielding 800 ft^3 per year. No chemicals.
Sleepy Hollow	36		100	.037	120	AS	no	.042	no	scavenger	9 acres	Will expand to .2 mdg to be ready summer of 1979
14. <u>N. Plainfield</u> sends to the Middlesex County S A by the Plainfield Joint Meeting												
15. <u>Peapack-Gladstone</u>												
Peapack-Gladstone STP	37		100	.19	100	AS w/D	100%	.128	yes	compost in the summer and truck to Freehold in the winter	10 acres at the plant	They compost using top soil; they don't know what to do with their compost.
16. <u>Raritan</u> the S A is a participant of the Somerset-Raritan Valley S A												
17. <u>Rocky Hill</u> serviced by Montgomery Twp. by the Millstone River STP												
18. <u>Somerville</u> the S A is a participant of the Somerset-Raritan S A												
19. <u>S. Bound Brook</u> sends to the Middlesex County S A												

(continued)

Township or Borough	Map #	% Ind.	% Dem.	Design Capacity (mgd)	% of Utilized Capacity	Treatment Process	Solids Concentration of Availability of Dewatering	Estimated Sludge Generation (dry tons/ day)	Heavy Metal Content Analysis	Present Method of Sludge Disposal	Acreage Available	Comments
20. Warren Twp.												
Bardy Farms WTP	38		100	.01 (in Sept. '78 .04)	now 150 40	PS+AS	100%	.047	yes	the 4 plants combined produce 25 tons/year of dried sludge, which goes to the Somerset County Park Commission who composts or land applies it	no land	Drying beds, no heavy metals.
Stage 1 and 2 STP	39		100	.3	100	AS w/D	100%	.203	yes	same as above	8-10 acres	They expect to use this land for expansion some day. Drying beds.
Stage 3 WTP	40		100	.075	80	AS	100%	.084	yes	same as above	no land	Drying beds.
Stage 4 WTP	41		100	.4	75	AS w/D	100%	.27	yes	same as above	no land	Drying beds.
21. Watchung	S A sends to Middlesex County S A through the Plainfield Joint Meeting											
Wally's Tavern	42		100	.04	33	AS	no	.045	no	scavenger empties the tank once a month	no land	

Sewage Treatment Plants Ranked by Design Capacity

		Col. 1	Col. 2	Col. 3	Col. 4	Col. 5	Col. 6	Col. 7	Col. 8	Col. 9	Col. 10	Col. 11
							Estimated Sludge Generation[1]					
Rank	Sewage Treatment Plant	Design Capacity (MGO)	Operating Level (% of Design Capacity	% Ind.	% Dom.	Dewatering	Dry Tons/ Day at Operating Level	Dry Tons/ Day at Design Capacity	Wet Gal./ Day at Operating Level	Wet Gal./ Day at Design Capacity	Wet Tons/ Day at Operating Level	Wet Tons/ Day at Design Capacity
1	American Cyanamid WTP	25.0	75	100		Assume 20%	30.938	41.250			154.688	206.250
2	Somerset Raritan Valley S.A.	10.0	85	12	88	Assume 20%	5.950	7.000			29.750	35.000
3	J-M Corp.	6.0	100	100			3.750	3.750	17,000	17,700		
4	Manville Boro. S. Syst.	2.0	65		100	20%	1.521	2.340			7.605	11.700
5	Bernards Municipal WTP	1.2	58		100	NO	.426	.735	1,528	2,634		
6	Lyons Hospital WTP	.5	65		100	10%	.122	.188	471	725		
7	Bernardsville Municipal S.A.	.5	90		100	20%	.304	.338			1.521	1.690
8	Azoplate Corp.	.5	60	100		50%	.188	.313			.378	.630
9	N. J. Neuro Psychiatric Inst.	.5	40		100	Assume 90%	.122	.306			.136	.340
10	Stage 4 WTP	.4	75		100	100%	.203	.270			.203	.270
11	Millstone River	.3	60		100	NO	.122	.203	2,095	3,492		
12	Stage 1 and 2 STP	.3	100		100	100%	.203	.203			.203	.203
13	Bedminster Township WTP	.20375	50		100	5%	.101	.202	313	626		
14	3-M Co. Upper	.2	10		100	NO	.008	.075	29	290		
15	3-M Co. Lower	.2	10		100	NO	.008	.075	29	290		
16	Peapack-Gladstone STP	.19	100		100	100%	.128	.128			.128	.128
17	River Road WTP	.117	100		100	NO	.073	.073	345	345		
18	Belle Mead Depot WTP	.075	43		100		.028	.065	119	277		
19	Stage 3 WTP	.075	80		100	100%	.067	.084			.067	.084
20	Neshanic Station WTP	.062	42	15	85	NO	.029	.070	505	1,203		
21	Fox Hollow WTP	.05	58		100	NO	.034	.059	200	345		
22	Fieldhedge WTP	.05	100		100	NO	.031	.031	148	148		
23	Carrier Clinic	.05	65		100	NO	.022	.034	373	582		
24	Squibb Institute WTP	.045	8		100	NO	.002	.030	42	524		
25	V. A. Supply Depot WTP	.045	89		100	100%	.010	.011			.010	.011
26	Montgomery HS	.04	18		100	NO	.008	.045	140	776		
27	Bardy Farms WTP	.04	40		100	100%	.019	.047			.019	.047
28	Wally's Tavern	.04	33		100	NO	.015	.045	256	776		
29	Sleepy Hollow	.037	120		100	NO	.050	.042	862	718		
30	Somerset County Shopping Center WTP	.025	80		100		.018	.022	74	92		

(continued)

Sewage Treatment Plants Ranked by Design Capacity--Continued

		Col. 1	Col. 2	Col. 3	Col. 4	Col. 5	Col. 6	Col. 7	Col. 8	Col. 9	Col. 10	Col. 11
							Estimated Sludge Generation[1]					
Rank	Sewage Treatment Plant	Design Capacity (MGO)	Operating Level (% of Design Capacity	% Ind.	% Dom.	Dewatering	Dry Tons/ Day at Operating Level	Dry Tons/ Day at Design Capacity	Wet Gal./ Day at Operating Level	Wet Gal./ Day at Design Capacity	Wet Tons/ Day at Operating Level	Wet Tons/ Day at Design Capacity
31	J&J Baby Products Ind.	.025	100	100		NO	.041	.041	128	128		
32	J&J Baby Products Dom.	.025	50		100	NO	.021	.041	64	128		
33	St. Bernards Parish	.02	5		100	NO	.001	.013	3	59		
34	Fiddler's Elbow WTP	.0175	25		100	3%	.005	.020	85	340		
35	Burnt Hill Orchard Road School	.017	65		100	NO	.008	.012	129	198		
36	Central School WTP	.016	25		100	NO	.005	.018	78	310		
37	Branchburg Farm WTP	.015	Assume 100		100	NO	.018	.018	104	104		
38	Beden's Brook CC	.01	40		100	NO	.004	.011	78	194		
39	Northover Camp WTP	.006	0		100		0	.004	0	18		
40	Washington Valley School WTP	.006	100		100	NO	.007	.007	116	116		
41	N. J. State Garage & Maintenance Building	.003	60		100	18%	.001	.002			.008	.013
42	Cowperthwaite's WTP	.001	100		100		.001	.001	3	3		
Grand Total		48.906					44.612	48.222	26,017	33,141	194.716	256.366
100% Industrial Total		31.525					34.917	45.354	17,828	17,828	155.066	206.88
Domestic Total		17.381					9.695	12.868	8,189	15,313	39.650	49.486

Notes: STP = Sewage Treatment Plant; WTP = Waste Treatment Plant; SA = Sewerage Authority.

[1] Formulae for sludge generation calculations:

Treatment processes for each plant are found in Table 3.

$$\text{Column 6} = \frac{\text{Col. 1 x Col. 2 x (Col. 2, Table 4)}}{2,000}$$

$$\text{Column 7} = \frac{\text{Col. 1 x (Col. 2, Table 4)}}{2,000}$$

Column 8 = Col. 1 x Col. 2 x (Col. 3, Table 4)

Column 9 = Col. 1 x (Col. 3, Table 4)

$$\text{Column 10} = \frac{\text{Col. 6}}{\text{Col. 5}}$$

$$\text{Column 11} = \frac{\text{Col. 7}}{\text{Col. 5}}$$

Solid Waste Origin Report by Municipality
Somerset County[1]

Municipality (Waste Origin)	Population (1970 Census)	Municipal Waste[2] Cubic Yards	Municipal Waste[2] Tons	Vegetative Waste[3] Cubic Yards	Vegetative Waste[3] Tons
Bedminster Township	2,597	3,770	1,170	165	33
Bernards Township	13,305	12,842	4,444	637	127
Bernardsville Borough	6,652	3,300	1,155		
Bound Brook Borough	10,450	7,304	2,550		
Branchburg Township	5,742	4,437	1,553		
Bridgewater Township	30,235	27,525	9,524	106	22
Far Hills Borough	780	45	16		
Franklin Township	38,389	18,605	6,262	6	1
Green Brook	4,302	4,378	1,532		
Hillsborough Township	11,061	3,618	1,262		
Manville Borough	13,029	60	21		
Millstone Borough	630				
Montgomery Township	6,353	2,966	1,038		
N. Plainfield Borough	21,796	25,049	8,031		
Peapack-Gladstone Bor.	1,924	59	21		
Raritan Borough	6,691	4,938	1,024	75	15
Rocky Hill Borough	917	1,360	476		
Somerville Borough	13,652	34,110	11,701		
S. Bound Brook Borough	4,525	9,845	3,440		
Warren Township	8,592	10,600	3,710		
Watchung Borough	4,750	16,664	5,834		
Various[4]		14,088	4,366	874	175
Totals	206,372	205,563	69,130	1,863	373

Notes:
1. N.J.D.E.P., Solid Waste Administration, Waste Origin Report by Municipality for 1976.

2. As defined in the Rules of the Solid Waste Administration: Household waste from private residents; commercial waste which originates in wholesale, retail, or service establishments such as restaurants, stores, markets, theatres, hotels, and warehouses; and institutional waste material originating in schools, hospitals, research institutions, and public buildings. Laboratory wastes and infectious wastes are not included in this category.

3. As defined in the Rules of the Solid Waste Administration: Waste materials from farms, plant nurseries, and greenhouses produced from the raising of plants. This waste includes such crop residues as plant stalks, hulls, leaves, and tree wastes processed through a wood chipper.

4. Collectors who make pick-ups in several towns in the county.

Sewage Treatment Plants in Somerset County
with Land Available[1]

Township or Borough	Sewage Treatment Plant	Acreage Available	Publicly Owned	Institutional
Bedminster Township	Bedminster Township WTP	Municipally owned land around them (floor areas, etc.)	X	
	Fiddler's Elbow WTP	The golf club owns 2,000 acres		
	N. J. State Garage and Maintenance Building	Small ball field adjacent to the STP		X
Bernards Township	Bernards Municipal WTP	10 acres at the plant	X	
	Lyons Hospital WTP	The hospital owns 44 acres; the plant is on 4 acres		X
Branchburg Township	Azoplate Corp.	Approximately 16 acres of rough land		
	Branchburg Farm WTP	125 pasture acres		
	Central School WTP	Large school property	X	
Bridgewater Township	American Cyanamid WTP	A few scattered acres		
	Northover Camp WTP	100 acres at the WTP		
	St. Bernards Parish	One school and one home on 27½ acres		X
	Somerset-Raritan Valley SA	They have enough land to double their capacity	X	
	Washington Valley School WTP	2 or 3 acres at the school	X	
Hillsborough Township	Belle Mead Depot WTP		X	
	Squibb Inst. WTP	370 acres of which only 5 percent are built		
	VA Supply Depot WTP	70 or 80 acres at the plant	X	
Manville Borough	Manville Borough S Syst.	4 acres	X	
Montgomery Township	Carrier Clinic	300 or 400 acres of farmland around plant		X
	J & J Baby Products Industrial and Domestic	20 or 30 acres for both plants		
	3-M Co. upper and lower	2,000 acres with nothing on them		
	Montgomery High School	10-15 acres at plant	X	
	N. J. Neuro Psychiatric Institute	The hospital owns 1,000 acres of which one-half are farmland		X
	Sleepy Hollow	9 acres on which they plan to expand	X	
Peapack-Gladstone Borough	Peapack-Gladstone STP	10 acres at the plant	X	
Warren Township	Stage 1 and 2 STP	8-10 acres	X	

Notes: 1. Telephone survey.

Landfill Sites of Somerset County[1]

Township or Borough	Facility Name	Open	Closed	Total Acreage	Used Acreage	Type of Waste	Public Ownership
Bernards Twp.	Bernards Twp. Sanitary	X		32	25	Ind. & residential	X
Bernardsville Borough	Borough of Bernardsville Sanitary Landfill	X		4	4	90% residential	X
Bound Brook Borough	Bound Brook Borough SWDA		X	Unspecified	Unspecified	Grass clippings	X
Hillsborough Township	Hillsborough Twp. Sanitary Landfill	X		10	3	100% residential	X
Manville Borough	Johns-Manville Sales Corp. Sanitary Landfill	X		> 10	Unspecified	Ind. & residential	
Montgomery Township	N. J. Neuropsychiatric Institute	X		> 1	Unspecified	Hospital use only	
	Montgomery Twp. SWDA Composting Facility		X	1	1	Leaves & grass cuttings	X
	Montgomery Twp. SWDA Dump		X	1	1	TV sets, refrigerators, washing machines, etc.	X
N. Plainfield Borough	N. Plainfield Borough SWDA		X	3	Unspecified	Leaves	X
Peapack-Gladstone Borough	Peapack Quarry		X	3	Unspecified	Construction & demolition, wastes, sand and grit	
Raritan Borough	Borough of Raritan Sanitary Landfill	X		50	25	Residential	X
Somerville Borough	Somerville Sanitary Landfill	X		55	33	95% residential; 5% ind. (mainly paper)	X

Notes: 1. N. J. Department of Environmental Protection, Solid Waste Facility Directory, 1977. The information in the Directory was checked by telephone to develop information on open/closed, total and used acreage, type of waste and ownership.

Qualified Farmland in Somerset County[1]

Municipality	Cropland Harvested	Cropland Pastured	Permanent Pasture	Woodland	Total Devoted to Agricultural and Horticultural Use
Bedminster	3,001	1,266	2,512	2,811	9,591
Bernards	1,402	583	690	1,988	4,662
Bernardsville	224	62	172	219	678
Branchburg	4,024	389	1,753	606	6,773
Bridgewater	1,007	72	293	392	1,765
Far Hills	124	57	90	167	438
Franklin	7,734	878	1,616	2,791	13,019
Green Brook	10	4	5	0	20
Hillsborough	9,802	770	3,173	3,034	16,779
Manville	46	0	0	5	51
Millstone	108	15	0	8	131
Montgomery	6,781	477	1,215	1,853	10,326
Peapack-Gladstone	1,026	87	160	502	1,775
Rocky Hill	70	0	0	0	70
Warren	901	166	221	598	1,887
Watchung	6	0	1	10	17
Total for Somerset County	36,266	4,826	11,901	14,984	67,982

Notes: 1. Data compiled from the Eighth Report of Data from FA-1 Forms for 1976 Tax Year, "Farmland Assessment Act of 1964," Chapter 48, Laws of 1964, New Jersey Division of Taxation, 1976.

Appendix E

Literature Review of Compost Factors, Uses, and Limitations

The following compilation, which is referred to extensively in Chapter V, is a selective review of the factors which contribute to sludge compost utilization. It identifies a range of potential compost uses, and presents information relevant to the benefits, limitations, and controlling parameters for compost use.

1. Private Residential

A. Food Applications

Mode of distribution: bulk or bagged (50 pounds)

Beneficial properties: macronutrients (N, P, K, C, pH, Ca, S, Mg)

micronutrients (Fe, Mn, Zi, B, Cu, Cl, Mo)

organic matter

Detrimental properties: heavy metals (Cd, Pb, Zn, Ni, Cu)

toxic organics (PCB's, etc.)

salts (Ca, Na, S, Mg, Cl)

Mineralization rates: N - 6 percent max. at 40 T/A loading{30}
4.4 percent w/raw sludge compost (N=1.37 percent){31}
8.5 percent digested sludge compost (N=.99 percent){31}

C - 16 percent evolved in 54 days{30}

P - extractable (inorganic) P of 48-81 percent of total (1.5 percent total P){32}

S - extractable (inorganic)S of 8-11 percent of total (.4 percent totals){32}

Sufficient P and S present at 20T/A rate{32}

Salt tolerance{35}:

Crop	MMHOS/CM	Salinity Level
alfalfa, potato, orchard grass	3	Low ≤ 3
corn	5	Medium 4-5.5
soybean	5.5	Medium 4-5.5
sorghum	6	High 6-7
wheat, tall fescue	7	High 6-7
sugarbeet	10	Very high 8-13
tall wheatgrass	11	Very high 8-13
barley	12	Very high 8-13
bermudagrass	13	Very high 8-13

Loading rates: based on crop requirement for N, P at >20 T/A
P level too high (P=.61 percent)[33]

Tentative E.P.A. limits (from Sludge Newsletter October 31, 1978:

bulk products to homeowners must have <25ppm Cd, <600ppm Pb, <10ppm PCB's

B. Nonfood Applications

Mode of distribution: bulk or bagged (1-5-pound soil mixes, 50-pound bags)

Beneficial properties: macronutrients, micronutrients, organic matter, moisture holding capacity

Detrimental properties: heavy metals, toxic organics, salts

Loading rates: solid waste (S.W.) compost at 500 T/A for new lawns, 45-90 T/A in three-year cycle for established lawns[3]

raw sludge compost (N 1.6 percent, P 1.0 percent, K .2 percent) - new lawns 100-200 T/A tilled in pre-planting[5]
established lawns - 25-35 T/A topdress[5]

for nursery beds (deciduous trees) - 50-100 T/A sufficient for two or more crops of seedlings over four-year period[19]& {23}

For nursery beds (coniferous trees) - 50-100 T/A incorporated into soil is optimum[24]

Tentative E.P.A. limits (same as 1.A.)

2. Private Food

A. Field Crops for Food and Feed

Distribution mode: bulk for soil conditioning and fertilizing

Beneficial properties: organic matter, macronutrients, micronutrients, moisture molding capacity, liming effect

Detrimental properties: heavy metals, toxic organics, salts

Mineralization rates:

N - 6 percent of total N maximum at 40 T/A loading{30}
4.4 percent w/raw sludge compost (N= 1.37 percent){31}
8.5 percent w/digested sludge compost (N=.99 percent){31}

C - 16 percent evolved in 54 days{30}

P - extractable (inorganic) P of 48-81 percent of total P (1.5 percent){32}

S - extractable (inorganic) S of 8-11 percent of total S (.4 percent){32}

sufficient P and S present at 20 T/A rate{32}

Phytotoxicity:

foliar values indicative of{6}
Zinc >500 ppm
Copper > 25 ppm
Nickel > 50 ppm
Manganese >500 ppm
Iron < 40 ppm

Loading rates:

raw sludge compost (N 1.6 percent, P 1.0 percent, K .2 percent){5}
pastures 50-100 T/A, depending on species, tilled in
pastures 25-50 T/A, broadcast periodically

Calculated on basis of N requirement of crop:

$$C = \frac{1}{Nac} \times R - (Nom + Nr)$$ {5}

where C = amount of compost needed in M.T./h.a.

Nac = kilograms of available N/M.T. of compost

R = N requirement of crop

Nom = N mineralized from soil organic matter

Nr = residual mineral N

$$Na = Ni\ (T) + (Nm \cdot Nq)T$$ (From H. Motto)

where Na = available nitrogen (pounds)

Ni = inorganic nitrogen content (%)

T = ton

Nm = mineralization rate (%)

Nq = total nitrogen in compost (%)

Calculated on basis of heavy metal additions:

Total amount of sludge metals allowed on agricultural land[36]

Metal	Soil C.E.C. 0-5	5-15	>15
	Maximum amount of metal (lbs./acre)		
Pb	500	1,000	2,000
Zn	250	500	1,000
Cu	125	250	500
Ni	50	100	200
Cd	5	10	20

Tentative E.P.A. limits:

Test for total N, NH_4, Ni, Cd, Zn, Cu, Pb, Hg, As, Se, annual application of cadmium:

Present--12/31/81	2 kg./ha./yr.
1/1/82--12/31/85	1.25 kg./ha./yr.
1/1/86	0.5 kg./ha./yr.

Cadmium controls not mandatory if sludge is applied to land used for growing animal feed grains.

B. Garden Crops for Food and Feed

Mode of distribution: bulk for soil conditioning and nutrients (same properties, rates, tolerances, and limits as in 2.A.)

C. Fruit Trees

Mode of distribution: bulk for soil conditioning and nutrients (same properties, rates, tolerances, and limits as in 2.A.)

3. Private Nonfood

A. Greenhouse Use (information related to potting soil mixes and floriculture included here)

Mode of distribution: bulk to greenhouse for own use, to general public in small bags (1-10 lbs.) or in pots as component of mix

Beneficial properties:	macronutrients (particularly N, P, K, Ca, Mg), micronutrients (particularly Cu, Zn), moisture holding capacity, pore space, pH (if 5.5-6.5)
Detrimental properties:	soluble salts (salts of Ca, Cl, Na, S, Mg), possibly heavy metals (Zn, Cu, B), pH (if >6.5-7.0)

Salt tolerance levels[17]:

- 1-2 millimhos standard for well fertilized mix
- 2-3 millimhos may be critical to salt sensitive plants and young transplants
- >3 millimhos toxic level for most container grown plants

Standards for potting soil media[18]:

Bulk density	721 - 962 kg/m^3 (45-60 $lb./ft.^3$) 1282 kg/m^3 (80 $lb./ft.^3$) 0.15 - 0.5 gm/cc (9 - 30 $lb./ft.^3$) 1.3 gm/cc (78 $lb./ft.^3$)
Water holding capacity	30-60 percent by volume 183 $liters/m^3$ (3.0 $gal./ft.^3$)
Total air spcae	5-20 percent by volume after drainage
pH	5.5 - 6.5
Cation exchange capacity	10-30 meq/100 gr. dry weight
Soluble salt content	<200 ppb or <2 millimhos where measured by electrical conductivity methods

Loading rates (as component of mix):

- in containers growing woody ornamentals - one-third of mix, replacing peat[16]
- in chrysanthemum culture - one-sixth to one-half of mix, replacing peat and/or perlite[15]
- in poinsettia culture - one-half of mix with either vermiculite, hardwood bark, soil, or peat[21]
- in containers of Japanese holly and cherry laurel - one-half to three-quarters of mix with subsoil or sand, replacing peat

Tentative E.P.A. limits (from Sludge Newsletter, October 31, 1978):

For commercial/industrial/governmental use of bulk products - if >15 percent moisture, must be stabilized and have <25 ppm Cd, <600 ppm Pb, <10 ppm PCB's
Warning label required = no food chain crops
if <15 percent moisture, then <75 ppm Cd, <1,000 ppm Pb, <10 ppm PCB's

B. <u>Nurseries</u> (information relating to nursery beds included here)

Mode of distribution: bulk to nursery for own use, bagged to general public for home use

Beneficial properties: macronutrients (N, P, K, C, Ca, Mg, pH), micronutrients (Mn, Al, Cu, Zn, B), organic matter, moisture holding capacity

Detrimental properties: needs supplemental K

Loading rates:

Raw sludge compost (N 1.6 percent, P 1.0 percent, K .2 percent) - for tree nurseries, 50-100 T/A tilled in prior to planting{5}
Raw sludge compost (N .9 percent, P .71 percent, K .17 percent, Ca 2.6 percent, Mg .3 percent, Zn .1 percent, Cu 0.25 percent) - with deciduous seedlings, tulips, and dogwoods, 50-100 T/A incorporated into soil is satisfactory, with 100 T/A near optimum{23}
Second crop of red maple grown on 100 T/A plot{19}
With conifer seedlings, Norway spruce and white pine, 50-100 T/A rates satisfactory, with 100 T/A near optimum{24}

Miscellaneous nursery uses:

Well decomposed s.w. compost used for plant fertilization with maple, oak, spruce, poplar, chestnut, oak, and sycamore{3}
Raw compost used as warm bed covering and finished compost used in ornamental gardens and forest nurseries

Tentative E.P.A. limits: same as those under 3.A.

C. <u>Golf Courses</u>

Mode of distribution: bulk for topdressing of greens, tees, and fairways

Beneficial properties: macronutrients, micronutrients, organic matter, moisture holding capacity

Detrimental properties: particle size

Loading rates:

Raw sludge compost (N 1.6 percent, P 1.0 percent, K .2 percent)

- sod, turf, new lawns - 100-200 T/A tilled into surface prior to seeding{5}
  sod, turf, established lawns - 25-35 T/A topdressed as recommended [5] with s.w. compost, 500 T/A for new lawns, 50-100 T/A for established lawn in a three-year cycle [3]

Specific golf course uses - leaf compost used in topdressing
  greens, aprons, collars, approaches, and tees - topdressing consists of one-fifth-one-third compost, with 2 $yds.^3$/green applied four-five times per year and 1 $yd.^3$/tee applied eight-ten times per year{36}
  typical maintainence schedule - topdress greens three-five times per season
    fertilize fairways with balanced fertilizer in fall, light Miloranite in July and August

D. Landscape Contractors

Mode of distribution: bulk for home lawns and beds; final users are homes, industries, institutions
(Refer to 1.B., 3.B., and 3.C. for other factors)

E. Turfgrass/Sod Farmers

Mode of distribution: bulk for soil conditioning; final users are homes, industries, institutions

Beneficial properties: macronutrients, micronutrients, organic matter, moisture holding capacity

Detrimental properties: particle size

Loading rates:

Raw sludge compost (N 1.6 percent, P 1.0 percent, K .2 percent)
- sod, turf, new lawns - 100-200 T/A tilled into surface prior to seeding{5}
  sod, turf, established lawns - 25-35 T/A topdressed as recommended{5}

Tentative E.P.A. limits same as those under 3.A.

F. Industrial Park Grounds

Mode of distribution: bulk directly to user for lawns and beds
(Refer to 1.B., 3.B., 3.C., and 3.E. for other factors)

G. Cemeteries

Mode of distribution: bulk directly to user for lawns
(Refer to 1.B., 3.B., 3.C., and 3.E. for other factors)

4. Public Agencies

A. Public Parks

Mode of distribution: bulk for reclamation, trails, vegetation establishment

Beneficial properties: macronutrients, micronutrients, organic matter, moisture holding capacity

Detrimental properties: heavy metals

Loading rates:

Raw sludge compost:
300-450 T/A for parkland establishment[25]
sod, turf, new lawns - 100/200 T/A tilled into surface prior to planting
sod, turf, established lawns - 25-35 T/A topdressed as recommended[5]

Solid waste compost:
500 T/A for new lawns, 50-100 T/A for established lawn in a three-year cycle[3]

Tentative E.P.A. limits (from Sludge Newsletter, October 31, 1978):

If sludge material is 15 percent moisture, then limits are <25 ppm Cd, <600 ppm Pb, <10 ppm PCB's with warning label stating no food chain crops
If <15 percent moisture then <75 ppm Cd, <1,000 ppm Pb, <10 ppm PCB's

B. Playgrounds

Mode of distribution: bulk for soil conditioner
(Refer to 4.A., 1.B., 3.C., and 3.E. for other factors)

C. Roadsides and Median Strips

Mode of distribution: bulk for cover establishment and maintenance
(Refer to 4.A., 1.B., 3.C., and 3.E. for other factors)

D. Military Installations

Mode of distribution: bulk for grounds
(Refer to 4.A., 1.B., 3.C., and 3.E. for other factors)

E. Public Grounds

Mode of distribution: bulk or bagged for lawns and beds
(Refer to 4.A., 1.B., 3.C., and 3.E. for other factors)

5. Land Reclamation

A. Landfill Cover

Mode of distribution: bulk for intermediate or final cover

Beneficial properties: organic matter, moisture holding capacity

Detrimental properties: toxic organics, heavy metals, NO_3

Loading rates:

6" intermediate cover layer would use 200 T/A
25" final cover layer would use 800 T/A
20" of refuse compost used in closing landfills[27]

B. Soil Improvement

Mode of distribution: bulk for soil conditioning properties

Beneficial properties: moisture holding capacity, moisture retention, pH, cation exchange capacity, organic carbon

Detrimental properties: salinity, chloride levels

Loading rates: of Beltsville, Md., raw sludge compost (N 1.6 percent, P 1.0 percent, K .2 percent) for improvement of various soil physical conditions[5]

Soil Texture	Soil Depth and Groundwater Conditions	Plants or Crops	Application Rate (T/A)
sand or gravel	shallow to groundwater (<4') with no intervening soil	grass or shrubs	25-50
sand or gravel	deep to groundwater (>6') with heavier material intervening	grass or shrubs agronomic crops	50-100 depends on fertilizer requirement
clays, clay loams, silty	shallow to groundwater	grass	25-200
clay loams	deep to groundwater	grass or turf	100-200
disturbed soils	deep to groundwater	parks, highways, construction sites	100-300 tilled into upper 6" layer

Miscellaneous properties:

Raw compost (mulch) is not completely decomposed and is not good as a plant nutrient but is good for soil physics and biology; finished compost (compost) is good as plant nutrient and soil conditioner{28}

Tentative E.P.A. limits (from Sludge Newsletter, October 31, 1978):

No loading rates given for land reclamation, but no food chain crops allowed

C. Strip-Mined Lands

Mode of distribution: bulk for vegetation establishment and soil conditioning

Beneficial properties: macronutrients, organic matter, pH, liming effect, moisture holding capacity, and retention

Detrimental properties: possibly NO_3, heavy metals

Loading rates:

with solid waste compost (N 1.0-1.3 percent, P .25 percent, K .25-.97 percent): 20-40 T/A on denuded soil of pH 4.1 to grow tall fescue{4}
125 T/A had liming effect resulting in decreased uptake of Zn (Zn 1500 ppm in compost){4}
184.5 T/A for land reclamation purposes, 14 and 26 T/A for light rates of application{26}
Application rates between 26 and 71 T/A are necessary to obtain a stabilized organic layer over mine spoil in two or three years{26}

Tentative E.P.A. limits (from Sludge Newsletter, October 31, 1978):

No loading rates given for land reclamation, but no food chain crops allowed

D. Sand and Gravel Pits

Mode of distribution: bulk for vegetation establishment

Beneficial properties: macronutrients, micronutrients, organic matter, cation exchange capacity, moisture holding capacity and retention, pH

Detrimental properties: possibly NO_3 pollution, heavy metals

Loading rates:

with sludge compost:
same as those for "sand and gravel" under 5.B.[5]
with solid waste compost (N 1.0-1.3 percent, P .25 percent, K .25-.97 percent): 20-40 T/A on denuded soil of pH 4.1 to grow tall fescue[4]
125 T/A had liming effect resulting in decreased uptake of Zn (Zn 1500 ppm in compost)[4]
184.5 T/A for land reclamation purposes, 14 and 26 T/A for light rates of application[26]

Tentative E.P.A. limits (from Sludge Newsletter, October 31, 1978):

No loading rates given for land reclamation, but no food chain crops allowed

6. Landfill

A. Compost Disposal

Mode of distribution: bulk disposal
(Since the material is treated as waste, its properties are irrelevent and no limits are set on the amount which can be disposed)

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