The Feasibility of Biosolids Composting for the City of Winnipeg

by

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A Thesis/Practicum submitted to the Faculty of Graduate Studies of The University

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-- Murray

ABSTRACT

To investigate the potential for biosolids composting in the City of Winnipeg a feasibility study was initiated by the University of Manitoba. A process design for the biosolids windrow composting facility using leaves as a bulking agent was conducted. The principal factors affecting the facility design were the biosolids quantity, water content, and the carbon-to-nitrogen ratio (C/N). The process design was carried out based on the 1994 biosolids production of the City of Winnipeg. In total the City processed 48,702 wet tonnes of dewatered biosolids at an average of 26% total solids in 1994. Assuming an optimal moisture content of 55% for the feedstock mixture and using leaves at an assumed 20% moisture content and recycle at 40%, the C/N ratio was calculated to be 26. This value falls within the acceptable range of C/N ratio for rapid composting rate. Because leaves may not provide sufficient structural strength to the pile during windrow composting, an additional bulking agent such as wood chips may be required to provide an adequate structural integrity to the windrows.

Area requirements for the active composting, curing, and compost storage were determined based on the methods presented in Rynk *et al.* (1992). The total area calculations including curing and storage area, revealed that 0.5m^2 per wet tonne of biosolids is required to windrow compost the biosolids. It was also determined that the existing biosolids storage pad (56,100 m^2 total area) would be quite sufficient to contain

the windrow composting facility (23,280 m^2).

A bench-scale composting process demonstration was conducted using the City's dewatered biosolids mixed with leaves and recycle product. High operating temperatures were achieved during all the demonstrated cycles and as a result the pathogen reduction criteria of the Canadian Council of Ministers of Environment (CCME) were easily met. Compost samples were also analysed for heavy metal concentrations and the results of the analysis indicated that the compost product obtained using the biosolids as feedstock meets all the Category B requirements of the CCME.

Cost estimates for the biosolids windrow and static pile composting facilities were conducted based on the methods and curves presented in U.S. EPA (1985b). The total annual cost including capital costs, for the windrow composting facility was estimated to range from $893,000 to $1,012,000 per year. This range depends on the feasibility of using the existing storage pad. The total cost for the existing biosolids disposal program in 1994 was $954,000. Based on this preliminary analysis it is recommended that windrow composting for the City of Winnipeg be further investigated. Composting will dramatically improve the quality of the biosolids and may offer an economic advantage.

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NOMENCLATURE AND ABBREVIATIONS

LACSD	–	Los Angeles County Sanitation Disrict
MSW	–	municipal solid waste
CCME	–	Canadian Council of Ministers of Environment
U.S.EPA	–	U.S. Environmental Protection Agency
NEWPCC	–	North End Water Pollution Control Centre
WEF	–	Water Environment Federation
SVR	–	Surface to Volume Ratio
°C	–	degree Celsius
°F	–	degree Fahrenheit
ft	–	foot (feet)
yd	–	yard
TS	–	total solids
VS	–	volatile solids
BVS	–	biodegradable volatile solids
NBVS	–	nonbiodegradable volatile solids
WAT	–	water
mg	–	milligram(s)
g	–	gram(s)

M	–	moisture content
dt	–	dry tonne(s)
m	–	mass
kg	–	kilogram(s)
WINGRO	–	the biosolids land application program of the City of Winnipeg
FC	–	fecal coliform
cm	–	centimetre(s)
ha	–	hectare(s)

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CHAPTER 1

INTRODUCTION

As we progress toward the 21st century, the management of wastewater biosolids in an efficient, cost-effective, and environmentally-sound manner is becoming a major challenge to municipal sewage agencies (Hay *et al.* 1993). A wide variety of biosolids treatment and disposal methods is currently in use, such as composting, land application, and land filling. Among all biosolids management options currently implemented, composting is one of the simplest and fastest growing processes. The 1996 biosolids composting survey indicates that the number of operating biosolids composting facilities in the United States has increased from 61 in 1983 to 330 in 1996 (Goldstein *et al.* 1996).

The purpose of this study was to investigate the feasibility of a composting facility for the City of Winnipeg's biosolids utilization program. Such a biosolids composting facility could potentially be of significant value to the City of Winnipeg, which is one of the largest cities located in the western part of Canada with a population of about 700,000 people. The City generates an average of 46,570 wet tonnes of dewatered wastewater biosolids per year at an average of 26% total solids. The North End Sewage Treatment Plant was opened in 1937; since then the plant has been upgraded and expanded and is now known as the North End Water Pollution Control Centre. It is the largest of three wastewater treatment facilities serving the City of Winnipeg, and treats a greater portion of Winnipeg's wastewater. In treating the City's wastewater and producing those biosolids, the North End Water Pollution Control Centre involves the following physical and biological processes: pre-aeration, screening, grit removal, primary sedimentation, and pure oxygen secondary treatment.

The incoming sewage passes through bar screens which remove large objects such as sticks, rags, and garbage. The sewage is then agitated gently with air in the first part of the tank. Primary treatment is the first step in separating the fine solid material from the liquid wastewater. The second step in removing any remaining organic matter from the wastewater before it flows from the treatment plant to the river is secondary treatment. From the oxygen reactor tanks, the mixture flows into the final settling tanks where the bacteria-laden biosolids settle to the bottom of the tank. The final effluent is then released into the river and the biosolids are sent to the digesters for anaerobic digestion. Bacteria that do not require oxygen begin to feed on the biosolids in the oxygen-free environment inside the digesters. Heat exchangers are used to regulate the temperature inside the digesters, keeping it around 37°C. The bacteria feed on the biosolids for at least 10 days and decompose (stabilize) it. After the oxygen-free digestion, the biosolids are sent to the dewatering system where most of the liquid is removed. The anaerobically digested and dewatered biosolids are loaded onto trucks and taken to agricultural land where they are spread through a program called WINGRO.

The City of Winnipeg disposed to landfill about 11% of the total biosolids produced yearly by mixing it with the municipal solid waste. This disposal happened when fields were inaccessible because of moisture in the spring. Land filling although not used in the past two years,may be a disposal option if needed. However, it has several disadvantages including potential operational problems (i.e., leachate management and gas hazards), limited life of the site, and increased difficulty in finding new approved sites. In general, the odours associated with the handling of biosolids result in public concerns and difficulties with regulatory approvals. The high pathogen levels and heavy metals result in application restrictions because of the health risks.

Agricultural land application of biosolids provides nutrients for crop growth and organic matter for soil conditioning; it avoids potential water pollution problems resulting from land filling and air pollution problems caused by incineration. Because biosolids contain heavy metals, toxic pollutants, and pathogens, this disposal method involves risks. Some of the common metals present in wastewater biosolids are likely to pose a significant hazard. The trace elements that pose a potential hazard are: cadmium, copper, molybdenum, nickel, and zinc (U.S. EPA 1993). The organic compounds that are attributed to biosolids land application include polynuclear aromatic hydrocarbons, chlorinated phenolics, pesticides, polybrominated biphenyls (PBBs), polychlorinated biphenyls (PCBs), phthalates, and other potentially toxic persistent materials (U.S. EPA 1993). The potential risk of infection to humans, animals, and plants from application of wastewater biosolids is attributable to the presence of pathogenic organisms in the biosolids. Pathogens that pose a potential hazard to human and animal health enter municipal sewage from a variety of sources including humans infected with enteric diseases, effluents from abattoirs, rendering plants and dairies, and animal feces.

The goal of this project was to investigate the technical and economical feasibility of implementing biosolids windrow composting in Winnipeg. The specific objectives were:

1. To determine the current status of wastewater biosolids management in Winnipeg by reviewing the existing biosolids management reports and making personal contact with the individuals responsible for the biosolids management.

2. To complete a preliminary design of a windrow composting facility for the City of Winnipeg's biosolids disposal operations.

3. To conduct a lab-scale biosolids composting study to determine the final trace element concentrations of the compost, and to demonstrate the ability of composting to inactivate pathogens.

4. To compare the current costs of the existing biosolids disposal operations of the City with the estimated costs for biosolids windrow and static pile composting facilities.

1.1 Structure of this report

In Chapter 2, the literature review of biosolids windrow composting includes a brief history and background of windrow composting, the City of Winnipeg's existing biosolids management report, factors affecting process design, and an economic evaluation of biosolids windrow composting.

In Chapter 3, the methods and results include a conceptual process design of a biosolids windrow composting facility for the City of Winnipeg, and a preliminary economic comparison of the existing biosolids disposal program and composting options. Chapter 4 contains conclusions and further recommendations.

CHAPTER 2

LITERATURE REVIEW

2.1 History and background of composting

Composting in its simple and traditional form has been practised by farmers and gardeners throughout the world for many centuries. While knowledge of composting is evident from Biblical, medieval, and more current accounts, the history of the modern era of composting begins with Albert Howard, a British government agronomist. Howard spent the years 1905 to 1934 in India where he recognized that soil must be fertile to produce healthy plants, and that fertility required a high percentage of humus (Haug 1980).

One of the first references to the composting of wastewater biosolids as the primary substrate appeared in 1950 (Haug 1993). In that year, Ullrich and Smith reported on experiments conducted in Austin, Texas using digested biosolids mixed with hardwood sawdust. The mixture was then windrow composted for about 11 weeks. As Haug says, Reeves (1959) reported that digested biosolids from the City of El Paso, Texas were air dried for 4 to 6 months and then mixed with hardwood sawdust. The mixture was windrow composted for 2 to 3 months. Water was added and the mixture turned by a grader at 2 to 3 week intervals. These experiments yielded successful results.

A major adaptation that has allowed the windrow system to be more easily applied to wet substrates is the concept of recycling dry compost to blend with wet feed. The concept was pioneered for biosolids composting by the Los Angeles County Sanitation District (LACSD) in 1972 to compost approximately 89.3 dt/day of digested, dewatered biosolids cake. The operation evolved and improved over the years and remained at the plant site until 1991 when it was moved to a more remote location because of odour concerns. The Upper Occoquan Sewer Authority, Virginia began operating a windrow composting facility in 1980 processing about 7.4 dt/day. The facility was the first to use advanced design concepts such as roofed coverage for all-weather operations, concrete pad flooring for better equipment access and improved housekeeping, and permanent surface manifolds for suction aeration. A large advanced windrow system was developed by the Denver Metropolitan Wastewater Reclamation District in the early 1980s. The facility was designed for 89.3 dt/day and included almost 16 acres under roof, both positive and negative aeration capability, and over 165,500 standard cubic feet per minute of installed aeration capacity.

There are a number of other successful biosolids windrow systems. In early 1991, the San Joaquin Composting Co. began operating a windrow facility under contract to the City of Los Angeles composting about 89.3 dt/day of digested, dewatered biosolids at 20% total solids amended with product recycle, agricultural residues (almond wastes, cotton gin trash, and rice hulls) and municipal yard wastes. The City of Austin, Texas began operating a windrow facility composting 8.9 dt/day of biosolids in 1987. Air dried cake is blended with tree trimmings, leaves, and yard waste, and composted to produce "Dillo Dirt."

The literature on composting contains many definitions of the process. Some are very narrow and others are broad enough to include what can be considered, and more properly understood as, digestion, an essentially different process occurring in nature and involving similar materials but under different circumstances. For the purpose of this study, I will use Haug's definition. According to Haug (1993):

> Composting is the biological decomposition and stabilization of organic substrate, under conditions that allow development of thermophilic temperatures as a result of biologically produced heat, to produce a final product that is stable, free of pathogens and plant seeds, and can be beneficially applied to land. Substantial quantities of heat are produced in the initial part of the process, causing the temperature to rise. This, in turn, vaporizes moisture, thereby reducing the weight and volume of the biomass by some 50% during the maturation process. Thus, composting is a form of waste stabilization, but one that requires special conditions of moisture and aeration to produce thermophilic temperatures. Those temperatures are generally considered to be above 45°C. Maintenance of thermophilic temperatures is the primary mechanism for pathogen inactivation and seed destruction.

At present, there are three primary aerobic composting methods in use: the windrow composting method, the aerated static pile method, and the in-vessel method. Detailed descriptions of static pile and in-vessel composting methods are beyond the scope of this study but can be located in WEF (1995a), Rynk *et al.* (1992), Haug (1993). The main focus of the following discussion will be the windrow composting method.

2.2 Existing biosolids land application program (WINGRO)

The agricultural land application of biosolids in the City of Winnipeg is conducted under a program called WINGRO. The WINGRO program consists of delivering, spreading, and incorporating biosolids to farmland in rural municipalities surrounding Winnipeg. The biosolids are applied (year-round, weather permitting) only once to a field at a rate not exceeding 56 dry tonnes per hectare. The City is presently targeting fields within 50 km of the North End Water Pollution Control Centre (Amy 1996). Including contingency, approximately 130 ha of land are needed annually between September and March, while another 130 ha is required during each growing season (WWDD 1990). The dewatered biosolids from the North End Water Pollution Control Centre are hauled by covered trucks to the fields where a back-hoe is used to transfer the biosolids to spreader vehicles equipped with flotation tires. These vehicles apply the biosolids to the surface of the land. The biosolids are then disked into the soil by the contractor as soon after application as possible (WEF 1995b).

2.2.1 Monitoring results of trace metals movement from biosolids to the soil and plant absorption of those trace metals

In 1988, the City of Winnipeg, in conjunction with the Soil Sciences Department of the University of Manitoba's Faculty of Agriculture, began a seven- to ten-year joint research project. The specific objectives of this research were to provide data for an economic analysis of various biosolids disposal rates, considering crop yield, biosolids nutrients, fertilizer requirements, and crop quality, and to establish soil lifetime loading limits of biosolids considering the short- and long-term plant availability and fate of plant nutrients and metals.

In January and February 1988, dewatered biosolids from the drying beds were applied on test plots at rates of 0, 10, 25, 50, and 100 dry tonnes per hectare and, in the following two months, the test plots were disked to mix the biosolids into the soil which was then seeded with wheat. Researchers collected 320 samples which they analysed for soil pH, conductivity, nutrients, and heavy metals. Preliminary soil analysis results for the City's test plots indicated an increase in crop yield at higher biosolids application rates and a trend to reduced concentrations of nutrient and heavy metals in the soil following the initial increases associated with earlier biosolids application (WWDD 1992).

In the same year, the Soil Science Department of the University of Manitoba established a test plot to study plant availability of trace metals from the biosolids as affected by time, soil chemistry, and other environmental conditions such as temperature, moisture content etc. Some of the preliminary conclusions from the study were that the application of biosolids at increasingly higher rates can produce corresponding increases in grain yield; that the cadmium content in grain was unaffected by biosolids applications up to four times the regulated rate of 56 dry tonnes per hectare; that the amount of cadmium taken up by the grain was small compared to the amount added to soil even at higher levels of inorganic cadmium; that the metals were bound by the soil and biosolids themselves, i.e., they did not move downward significantly; and, that the potential for copper and zinc transfer from biosolids to soil appeared to be low (WWDD 1992).

2.3 Composting systems

Of the three general types of composting systems (windrow, static pile, and in-vessel), the windrow system is the least complex. In the windrow system, a mixture of biosolids and bulking agents is placed in long rows (windrows) that are turned using mobile equipment. The major parameters through which windrow composting process design is carried out are the quantity of the raw material (biosolids) to be handled (mass and volume), the moisture content, and C/N ratio. Moisture content and C/N ratio must be maintained at their optimum range for the composting process to proceed successfully. A moisture content of between 50 and 60% is most suitable for composting and should be maintained during the period of active bacterial reaction (Tchobanoglous *et al.* 1993). An initial C/N ratio of between 20 and 40 is recommended as the optimal range for a rapid composting process (Rynk *et al.* 1992). The optimal range of the moisture content and C/N ratio of biosolids is achieved by blending those biosolids with a bulking agent. Because biosolids contain a high amount of water (75 to 80%) and a lower value of C/N ratio (about 15) for active composting, they must be mixed with amendments (bulking agents) that contain less moisture and high C/N ratios (Tchobanoglous *et al.* 1993). The amendments also provide structural integrity and porosity to the biosolids composting pile. A variety of amendments can be used in biosolids windrow composting such as wood chips, straw, sawdust, yard waste, leaves etc.

Biosolids windrow composting typically takes 30 to 60 days or longer to complete the compost cycle, depending on climate and season. The process of composting is considered complete when it satisfies the product quality criteria for compost standardization established by CCME (1996).

There are two types of windrow processes: the conventional windrow (the most common method) and the aerated windrow. The two processes differ in their method of aeration. The conventional process receives its aeration through natural ventilation, such as convective air movement and diffusion. The aerated method combines aspects of aerated static-pile and the conventional windrow processes. In the aerated method, windrows are constructed over an aeration system and aerated mechanically using blowers to supplement natural ventilation. Among the advantages of the aerated method are a smaller land requirement, enhanced odour control, improved drying, and better process control and performance during inclement weather. Because the process requires installation of an aeration system and other facilities, the capital cost of the aerated method exceeds that of the windrow method (Hay *et al.* 1993). Processing steps include constructing windrows from a mixture of biosolids and recycled finished compost (recycle) or external bulking agents, turning the windrows, and composting for several weeks to produce a product suitable for distribution and marketing.

Windrows may be constructed in a variety of ways, and proper construction plays a crucial role in the success of the composting process. The conventional method involves loading dewatered biosolids and amendment into a tractor trailer, dumping the tractor-trailer loads end-to-end to form long rows, then mixing the rows with mobile equipment such as a composter machine which straddles the windrows, or with a front-end loader. Alternatively, the dewatered biosolids and amendment may be laid on the field in adjoining parallel rows and combined with a front-end loader before the mixing step. The construction method used must produce a windrow that has the proper porosity and moisture content, and that is large enough to sustain thermophilic biological decomposition.

For the process to work properly, biosolids and amendment must be mixed thoroughly which is best accomplished using mobile composting equipment (composting machines) or front-end loaders. Amendments (bulking agents) increase porosity to promote oxygen penetration and to provide supplemental nutrients to sustain longer periods of intense biological activity in windrows. Both the type and amount of amendment affect the duration and magnitude of the temperature required for pathogen inactivation. Better mixing is achieved with mobile composting machines which travel lengthwise through a windrow and use a high-speed, rotating drum fitted with fixed teeth or flails to mix the biosolids, bulking agents, and recycled material (WEF 1995a). A list of typical characteristics of amendments used in biosolids windrow composting processes are presented in Table 2.1.

Table 2.1 Typical characteristics of material used to amend biosolids.

Material	Bulk density (kg/m^3)	Moisture content (%)	VS (% of TS)	C : N
Wood chips	297	32.9	-	271
Straw	224	12	80	128
Sawdust	260	39	95	442
Rice hull	130	14	95	-
Yard waste	237	18	97	22.8
Leaves	59	20-40	-	40-80

Sources - WEF (1995a), Haug (1993), Rynk *et al.* (1992) and Tchobanoglous *et al.* (1993).

The height and cross section of the completed windrow depend on the volume of biosolids and bulking agents in the windrow, and the equipment used for turning and aeration. Rynk *et al.* (1992) presented various dimensional properties of windrows. Typical specifications of three types of windrows used for composting facilities are presented by Hay *et al.* (1993) in Table 2.2.

Table 2.2 Comparison of typical windrow properties (Hay *et al.* 1993)

Windrow properties	Windrow type		
	Small	Large	Very large
Height, m (ft)	0.9 (3.0)	1.4 (4.5)	2.1 (7.0)
Base width, m (ft)	3.7 (12.0)	4.3 (14.0)	7.0 (23.0)
Volume per length, m^3m^{-1} (yd^3ft)	2.3 (0.9)	3.10 (1.25)	8.8 (3.5)
Volume per area, m^3ha^{-1} (yd^3ac^{-1})	1,890 (1,000)	2,830 (1,500)	6,610 (3,500)
Surface-to-volume ratio m^2m^{-3}(ft^2ft^3)	2.6 (0.8)	1.6 (0.5)	0.80 (0.25)

The length of windrows depends on the daily biosolids quantity and quality, mix ratio of bulking agent and biosolids, and field size. For larger operations where adequate field space is available, it is advisable to compost each daily batch of biosolids in a separate windrow so that each bath can be composted and monitored separately (Rynk *et al.* 1992). Windrow lengths vary, ranging from less than approximately 30 m (100 ft) to more than approximately 245 m (800 ft) (WEF 1995a). Adjoining windrows should be spaced far enough apart to allow a front-end loader to travel between them to clean up any material deposited between the windrows during turning. A space between rows of approximately 3 m (10 ft) is normally sufficient.

If the windrow is properly constructed and turned, within a few weeks of the start of composting, internal temperature should reach or exceed 55℃ and stay above this level most of the cycle. High windrow temperatures must be maintained to kill pathogenic organisms and dehydrate the windrow. Because of low nutrient and moisture levels, a decline in microbial activity occurs at the end of a composting cycle, causing a decrease in windrow temperature.

After placement on the field, a windrow typically requires 30 to 60 days or longer to complete the compost cycle, depending on climate and season. Rainy conditions and cool, ambient temperatures may prolong the cycle by many weeks. During composting, windrows should be turned regularly, at least three times per week. Turning accomplishes several process requirements, including reducing particle size, mixing and homogenizing windrow materials, increasing porosity to maintain aerobic conditions, aerating the windrow contents, promoting drying through release of trapped water vapour, and exposing windrow materials to high interior temperatures to allow for effective pathogen inactivation.

The location of a composting facility must provide the required area and limit environmental risks, odour, and noise. Odour problems may occur in biosolids, MSW, yard waste, food waste, and other composting facilities. During decomposition, odorous compounds are generated that, when emitted into the atmosphere, are a nuisance to populations living near the composting facilities (Epstein 1997). Therefore, composting sites should be distant from sensitive locations such as schools, hospitals, nursing homes, business, and residences. The site must be preferably out of their view to avoid the possible negative perception (Rynk *et al.* 1992).

The composting cycle is considered complete when a windrow meets operating objectives for time, temperature, and turning, and satisfies product quality criteria for moisture, pathogen density, particle size, or other factors. Space availability will determine how long a given windrow will remain on the composting pad. Because detention times are shorter in the summer than in the winter, pad size should be based on winter conditions. Long compost cycles produce a drier, more stable product than do shorter cycles (Haug 1993).

After the completion of the composting cycle, windrows are broken down using a front-end loader. The finished material may be stored, further processed, or mixed with other materials before distribution and marketing. To improve marketability, the compost can be screened to remove large clumps and other foreign materials. A portion of the finished compost can be recycled and used as an amendment for the biosolids in the starting mixture (WEF 1995a).

2.4 Process design

2.4.1 Factors affecting windrow composting design

A number of variables and environmental factors affect the design and operating of a windrow composting system. Important process variables are 1) biosolids characteristics (quantity, moisture content, C/N ratio), 2) temperature, 3) aeration, 4) bulking agent type, 5) windrow size, 6) turning frequency and 7) other environmental factors such as cool temperature.

The total solids (TS) content of the biosolids determines the volume of bulking agent that must be combined with biosolids to construct the windrow. Typically, sufficient bulking agent is added to boost the solids concentration of the starting compost mixture to 40 to 60% (WEF 1995a). If the biosolids are too wet, large volumes of bulking agent will be required. An optimum moisture content of the compost mixture is important for the microbial decomposition of the organic matter. Since water is essential for nutrient solubilization and cell protoplasm, a moisture content below 20% can severely inhibit the biological process and too much water will block the passage of air, causing the compost pile to become anaerobic. A moisture content of between 50 and 60% is most suitable for composting and should be maintained during the periods of active bacterial reactions (Hay *et al*, 1993).

The self-induced temperature increase characteristic of composting is at first favourable to heat generation and other visible signs of microbial activity. During composting process there is a substantial amount of heat generated. This heat generation occurs as a result of utilization of the organic matter inside the composting mass by microorganisms. In aerobic composting system, aerobic microorganisms require oxygen for respiration. The biologically produced heat generated within a composting mass is important to maximize decomposition rate; and to produce a material which is microbiologically "safe" for use (Haug 1993). Microbial activities during composting are optimum at 50 to 60°C. It is generally known that compost temperatures greater than 65°C will significantly reduce the rate of oxidation in compost piles. If some of this heat is not removed, temperature generally becomes unfavourably high, suppressing the biological generation of heat. On the other hand, most pathogenic microorganisms are inactivated effectively at temperatures above 50°C. So the key concern is to control temperatures in the compost pile in such a way as to optimize both the breakdown of organic material and pathogen inactivation (WEF 1995a).

Oxygen levels at both conventional and aerated windrow processes should be continuously maintained at greater than 5% throughout duration of the composting cycle (Haug 1993). Routine turning of conventional windrow provides oxygen to the microorganisms to sustain the thermophilic decomposition process and prevent the development of anaerobic conditions that cause odors. The optimum level of air needed lies between 15% and 20% of the internal atmosphere (WEF 1995a). Aerobic composting is inhibited when oxygen is less than 10% by volume of the atmosphere within the biomass. Therefore careful attention must be paid to oxygen levels and temperature to avoid excessive aeration and cooling of the windrows.

Bulking agent (amendments) increase porosity to promote oxygen penetration and provide supplemental food source to sustain longer periods of intense biological activity in windrows (WEF 1995a). Both the type and amount of amendment affect the duration and magnitude of the temperature elevation in a windrow, which in turn affect drying and pathogen destruction (Rynk *et al.* 1992). There are a number of amendment types available, some of which were presented in Table 2.1. Amendments provide energy, are a source of carbon, and provide structural integrity. They also increase solids content and void space or porosity.

The size (cross-sectional area) of a windrow affects the magnitude of the internal temperature elevation. If the windrow is too small, the high temperatures needed for pathogen destruction will not be generated, and good disinfection results will not be achieved. Thus, large windrows achieve more effective pathogen destruction than small windrows. During composting, it is important to ensure that a uniform cross-section is maintained along the entire length of a windrow's axis, as irregular cross sections may prevent the high temperatures need to kill pathogens (WEF 1995a). Typical windrow sizes were presented in Table 2.2.

The purposes of turning are tovent the heat and windrow. Turning provides oxygen to the microorganisms, homogenizes the windrow materials, grinds up the substrate particles to expose new surfaces to biodegradation, releases trapped water vapour, and ensures that all materials is exposed to higher temperatures at the core of the windrow (Hay *et al.* 1993). A turning frequency of every other day (three times per week) is a good compromise for most conventional windrow operations (WEF 1995a). There is a trade-off between windrow temperature and the drying rate, and both factors must be optimized to ensure minimum drying times and satisfactory destruction. If windrows are turned too often, lethal temperatures will not build up, and the probability of pathogen survival will be greatly increased and a marked decline in temperature may result if turning is not performed often enough during a composting cycle. Detailed descriptions of the factors that affect composting and their impacts are provided in WEF (1995a), Haug (1993), Hay *et al.* (1993), Rynk *et al.* (1992).

Ambient environmental conditions, such temperature and precipitation are important variables affecting windrow composting. Cool ambient temperatures such as of Manitoba may adversely affect the process of windrow composting. Cool winter temperatures reduce composting productivity by extending the drying time and slowing down the process of pathogen inactivation. Although cool temperatures are known to slow down the process to some extent, field trials of windrow composting during cool temperatures have demonstrated that windrow composting works successfully in winter months (Lynch and Cherry 1996). The results of a study conducted by Lynch and Cherry

(1996) indicate that agricultural wastes could be successfully composted in the winter months of Idaho with aerated windrow composting system. The ambient temperatures of the region during the study period ranged from -27 to 15 °C. The study concludes that the composting process was successful i.e., thermophilic temperatures were attained and the cycle took 50 to 80 days after the piles heated up but one concern was that the lower areas of the pile which contacted the incoming cold air remained cool (30 to 40 °C) throughout the composting cycle. Temperatures between 30 to 40 °C are not sufficient to successfully inactivate the possible pathogens. In relation to the weather conditions of Winnipeg, A review of the past 10 years of meteorological data of Winnipeg found that the coldest 15 day period occurred in January, 1994. The mean temperature was -27.5°C, (standard deviation = 3.44) the maximum temperature was 21.1°C and the minimum was -32.8° C (Chen 1997). The ambient temperatures of Winnipeg are lower than of Idaho. Therefore since cooler temperatures of the area mean more difficulties in attaining thermophilic temperatures during windrow composting, a particular attention must be paid in implementing a windrow composting during the winter months of Winnipeg. Some of the recommended conditions for rapid composting are summarized in Table 2.3.

Table 2.3 Recommended conditions for rapid composting after Rynk *et al.* (1992) (McCartney 1997).

Condition	Reasonable range[1]	Preferred range
C:N ratio	20:1 to 40:1	25:1 to 30:1
Moisture content (%)	40 to 65[2]	50 to 60
Oxygen concentrations (%)	>5	>>5
Particle size (mm; in.)	3.2; 1/8 to 13; 1/2	varies[2]
pH	5.5 to 9.0	6.5 to 8.0
Temperature (°C; °F)	45; 110 to 65; 150	55; 130 to 60; 140
Bulk density (wet kg/m^3)	<650	-

[1] Recommendation for rapid composting.

[2] Function of specific materials, pile size, weather conditions, etc.

2.5 Economic evaluation of biosolids composting

The cost estimates for the biosolids composting systems were conducted using the U.S. EPA (1985b) manual for estimating biosolids management costs. The manual provides preliminary cost estimating curves covering capital, operating, and maintenance costs for commonly used processes in municipal wastewater biosolids treatment, storage, transport, use, or disposal. The cost manual is designed for use by municipal wastewater treatment and biosolids management authorities, program and project planners, government regulatory officers, designers, and consulting engineers to assist in obtaining preliminary cost estimates for common municipal wastewater biosolids management processes.

Preliminary base capital costs and base annual operation and maintenance costs are formulated in the manual through the use of curves developed for each of the biosolids management processes. These curves are based on cost algorithms. The cost curves allow the user to obtain rapid approximate cost estimates for biosolids management processes based on only one or two process variables (e.g., annual biosolids volume and distance hauled from the treatment plant).

For each biosolids management process in the manual, a base capital cost curve and a total base annual operation and maintenance cost curve are presented. In addition, annual O&M component curves are presented for most processes. Base capital cost curves include mechanical equipment, concrete, steel, electricity and instrumentation, and installation labour. Annual O&M component curves provided for each process include the following, where applicable: annual labour hours required, annual electrical energy required, annual fuel required, annual chemical required, annual maintenance material costs, and other annual O&M requirements as needed. These curves allow the user flexibility to specify costs for these components which may vary significantly with geographic region. In addition, the user can easily identify the cost components which have a major impact on overall O&M costs.

2.6 Site selection

A site of any biosolids composting facility should provide the required area and conditions for all weather composting and must limit environmental risks and public relations such as odour and noise. The convenience of a particular composting site must be weighed against factors such as area proximity to neighbours, visibility and drainage (Rynk *et al.* 1992). The site must also consider the intensity of the odour release, the direction of prevailing wind, the material to be handled, and the method of composting implemented. One of the major problems associated with biosolids composting is odours. During decomposition of organic matter, odorous compounds are generated that, when emitted into the atmosphere are a nuisance to the population living near the facility (Epstein 1997). The acceptability of the odour levels is a function of local wind and weather conditions and it may vary from month to month. The acceptability of the odour level also greatly depends on the attitude of the neighbouring receptors towards it since the presence of the odours may focus public attention on health issues, as people often associate malodours with negative health impacts (Epstein 1997).

In terms of specific separation line, there are no universal hard rules on the size of the buffer zone for biosolids windrow composting facility. The restrictions depend on the above mentioned factors and may differ from site to site (Rynk *et al.* 1992). Several states in the United States have restricted the operations of biosolids composting facilities in proximity to residences and businesses. New York and Maine for example, require a buffer zone of 500 ft (152m) for biosolids composting facility, while California is proposing at least 300ft (91m) from any residence or hospital (Epstein 1997). However these restrictions may be for facilities that are equipped with odour treatment systems.

A sketch of the storage pad of the City of Winnipeg that is used to store the biosolids during wet periods is presented in Appendix V. The distance from the storage pad to a row of businesses from the south is about 300m and from the east the distance to a residential area is about 800m. During the periods of storage of the biosolids in the pad, the City of Winnipeg had received several odour nuisance complaints from these neighbouring receptors (Amy 1997). The Illinois Institute of Technology which conducted an odour investigation on biosolids stored on the storage pad for the City of Winnipeg, reported that the odours from biosolids on the pad would be detected at a distance of 500 to 1000m by 50 to 85% of the population if six weeks production of biosolids was stored on the pad (Wardrop and Maclaren 1992). It is also reported that housing development is being carried out towards the storage pad which, in the long run may encroach on the buffer areas of the pad (Amy 1997).

2.7 Environmental impacts of windrow composting

2.7.1 Odour generation and control in windrow composting systems

Factors that cause odour emissions from windrows and cause the detection of odours outside the composting site include improper storage of the biosolids, mixing or turning the feedstock, the number of newly constructed windrows on the field, the surface to volume ratio (SVR) of the windrows, the temperature of the windrows, and the type and amount of amendment in the windrows. Also, the distance of the composting site to sensitive odour receptors, odour transport conditions such as wind direction and speed, and other minor factors including dust emissions, digested biosolids characteristics, and leachate drainage can yield detectable odour levels.

Haug (1993) indicates that Livingston (1984) found that surface odour emissions increase linearly with the internal temperature beneath the surface of a windrow. Odour emissions are higher during the summer when internal windrow temperature are maximal. The use of certain amendments such as rice hulls and sawdust that also increase temperature can increase odour generation as well.

Based on several years of odour panel evaluations of ambient air samples collected at the surfaces of windrows, it was determined that 83% of the total odours released from a windrow occur between turnings, with the balance emitted during and immediately after turning (Haug 1993); odour levels decline to a baseline level within a few minutes of turning (U.S. EPA 1985a). The highest odour emissions occur in the early days of composting. After several days, odour emissions decrease to a low baseline level and remain at that level throughout the remainder of the composting cycle.

Some mitigation measures for odour control include decreasing the quantity of material composted during periods of potential high odour generation, changing the amendment used in the windrows, turning only during low-wind periods, maintaining a sufficient buffer zone around the site, and using barriers such as fences and trees to disperse odours before they are transported to surrounding areas (Rynk *et al.* 1992).

When a windrow is not turned, a crust will form on the surface of the windrow which reduces odour release. However, during the period that a windrow is not turned, it could become anaerobic; and, when the windrow is finally turned, obnoxious odours are likely to be released to the environment (Hay *et al.* 1993). To prevent crust buildup and creation of anaerobic conditions, it is important to maintain routine turning schedules.

Controlling odours by using additives containing enzymes and bacterial cultures to alter the metabolism of organic matter has not proven successful. No discernible differences in odour emissions have been observed in studies between windrows treated with additives and those not treated (Hay *et al.* 1993). The best form of odour control during windrow composting is to maintain sufficient aeration through proper turning/mixing while keeping the compost site clean and orderly.

2.7.2 Leachate and runoff control in windrow composting

Leachate and precipitation runoff controls are major considerations in site layout of windrow composting systems. There are three basic sources of moisture at the compost site: condensate (i.e., moisture in the air that is pulled through the pile), leachate (i.e., liquid that drains from the compost mix), and runoff (i.e., precipitation that reaches the composting pad directly without going through a compost pile). The amount of condensate or leachate generated during composting is a function of the moisture content of the biosolids and ambient conditions. Leachate and runoff are of great concern during windrow composting since there exists a potential for nearby ground water or surface water contamination and odour problems. They can also create both odour problems and possible ice formation which can be dangerous for heavy equipment operations.

Generally data on characteristics of leachate from different composts including wastwwater biosolids are meagre. As reported in Epstein (1997), results of analysis of leachate from MSW compost for heavy metals by Sawhney et al. (1994) indicated that the concentration of heavy metals increased withthe amount of compost however, the average concentration of these metals was below U.S EPA drinking water limits. Initial concentrations were relatively high, but later concentrations were extremely low. Less than 2% of the total metals were leached. Epstein (1997) also reports that using lysimeters, Chrestensen (1983) studied the potential leaching of several heavy metals from two refuse-biosolids composts. The leaching of Cd, Ni, and Zn decreased rapidly in each successive water application to the lysimeter. A slow leaching rate was observed i.e., only 0.07% to 7% of the compost content of Cd, Cu, Pb, and Zn was leached within the first year.

Leachate and condensate can be controlled by installing collection devices underneath the piles connected to a system which consists of condensate trap, leachate pumps, and a collection pond. To prevent pooling of runoff, the compost pad should have a slope of at least 2 percent (U.S. EPA 1985a). Another approach to runoff control is to construct a roof over all or part of the compost operation; however, this approach will increase the cost of biosolids composting.

2.7.3 Compost quality

The process of composting can be considered complete only when the product is biologically stable, hygienically safe, and not phytotoxic. The Canadian Council of Ministers of Environment (CCME 1996) has established a criteria for the standardization of compost quality. These criteria include maturity, foreign matter specifications, maximum allowable concentration of trace elements, and the reduction of pathogenic organisms. The criteria established by CCME (1996) are presented in Table 2.4.

Table 2.4 Main criteria for compost quality by the CCME (1996).

CHARACTERISTICS	CRITERIA	
Maturity	1. 2 of following 3 requirements must be met a) C/N ≤25 b) O_2 uptake <150mg O_2/kgVS/hr c) germination of cress & radish > 90% rate of control sample & growth rate ≥ 50% or 2. compost must mature for ≥ 21 days & compost will not warm up when submitted to 20°C or 3. Compost curing time ≥ 21 days & VS reduction > 60% or 4. If no other maturity test is made, compost curing time = 6 months in aerobic condition	
Foreign matter	compost should not contain sharp matter > 3mm or any foreign matter > 25mm	
Trace elements	Category A (mg/kg dry wt)	Category B (mg/kg dry wt)
As	13	75
Cd	3	20
Co	34	150
Cr	210	-
Cu	100	-
Hg	0.8	5
Mo	5	20
Ni	62	180
Pb	150	500
Se	2	14
Zn	500	1,850
Pathogens	When feedstock contains human pathogens: Material shall attain 55°C for 15 days with minimum 5 times turnings and FC < 1,000 MPN g^{-1} ds^{-1} or *Salmonella sp.* < 3 MPN $(4g)^{-1}$ ds^{-1}	

An important facet of the composting process is the determination of the point at which digestion of biosolids has been completed. In general, a composted product should contain a low organic content that will not undergo further degradation when discharged on land, and the pathogens should be inactivated. Some additional approaches to measure the degree of compost stabilization include: temperature decline at the end of batch composting; the presence of particular constituents such as nitrates, and the absence of others such as ammonia; lack of attraction of insects or development of insect larvae in the final product; the absence of obnoxious odour; and the presence of a white or grey colour due to the growth of actinomycetes (Inbar *et al.* 1990).

In cases where the composted products are to be applied to crops and where public health aspects are a concern, the time required for pathogen die-off during composting is another important criterion to be considered. The time required for a satisfactory degree of composting would depend on the environmental factors in and around the compost heap. Some manufacturers have produced mechanical composting reactors which claim to yield satisfactory compost within a short period. However, these reactors are both expensive and difficult to operate, and the composted materials will usually need additional time for curing or nitrification (WEF 1995a). Because both stages of waste stabilization and curing occur during batch composting, the compost product is suitable for use in agriculture or horticulture. However, it is advisable that the quality of the compost products be regularly checked according to the Canadian Council of Ministers of Environment (CCME 1996)) criteria for compost standards.

Heavy metals have a potential to enter the food chain if food crops or livestock feed are grown on compost-amended soil, or if cattle forage in a compost-amended area, and may harm children who consume nonfood substances such as soil or compost. Since composting is a biological process, it does not eliminate metals. Composting may however, reduce the concentration of metals to a certain extent, depending on the type and amount of bulking agent. Using wood chips as a bulking agent the concentration of metals can be reduced by about 25% after composting (U.S. EPA 1985a). Table 2.5 shows a typical decrease in Cd, Cu, Pb, and Zn concentrations during composting of biosolids with wood chips (Epstein 1997). Mass is lost during composting, increasing the concentration of heavy metals in the biosolids however, the addition of bulking agent lowers the concentration of those metals in the final compost product. This eventually reduces the potential risk posed by the heavy metals of biosolids application to the soil (Epstein 1997). The final concentration is a function of the concentration in all feedstock materials. The final level of heavy metal content of biosolids compost determines how the product will be used. Compost can be classified as Category A and B depending on the metal levels (Table 2.4).

Table 2.5 Effect of bulking agent usage on heavy metal content of biosolids compost (Epstein 1997).

Element	Digested biosolids (mg/kg)	Digested biosolids compost (mg/kg)	Raw biosolids (mg/kg)	Raw biosolids compost (mg/kg)
Cadmium	19	9	10	8
Copper	723	250	419	300
Lead	577	320	426	290
Zinc	1760	1000	978	770

2.8 Summary of Chapter 2

The City of Winnipeg generates an average of 46,570 wet tonnes of anaerobically digested and dewatered biosolids at an average of 26% TS. About 89% of the produced biosolids are spread onto agricultural land every year, while the remaining 11% is land filled. The annual cost for the existing biosolids disposal operations of the City in 1994 was $954,000. These biosolids are hauled one-way a distance of 50 km to rural areas for land application.

While land application of the biosolids provides nutrients for crop growth and organic matter for soil conditioning, it involves some risks due to the presence of pathogens and heavy metals. It also produces a significant amount of odour during its operation that can affect the surrounding area.

The major parameters through which windrow composting process design is carried out are the quantity of the raw material (biosolids) to be handled (mass and volume), the moisture content, and C/N ratio. Moisture content and C/N ratio must be maintained at their optimum range for the composting process to proceed successfully. A moisture content of between 50 and 60% is most suitable for composting and should be maintained during the period of active bacterial reaction (Tchobanoglous *et al.* 1993). An initial C/N ratio of between 20 and 40 is recommended as the optimal range for a rapid composting process (Rynk *et al.* 1992).

CHAPTER 3

METHODS AND RESULTS

3.1 Process design

The principal design concerns for a composting process are raw material quantities, moisture content, and carbon-to-nitrogen ratio. Average characteristics of the City's biosolids from 1991 to 1995 are reported in Table 3.1. The raw material characteristics for the preliminary process design are summarized in Table 3.2. The process design was accomplished using 1994 data from the City of Winnipeg because that year was the most recent for which data was available at the time of the calculations, and in that year the City generated the largest quantity of biosolids to date. In 1994, the City of Winnipeg generated about 48,702 wet tonnes (12,662 dry tonnes) of dewatered biosolids at an average of 26% total solids at its North End Water Pollution Control Centre.

Table 3.1 Average City of Winnipeg biosolids characteristics from 1991 to 1995 (inclusive).

Biosolids Characteristics	Value
Quantity - wet tonnes	46,570
- dry tonnes	12,175
Moisture content (%)	26
Bulk density (kg/m^3)	1,079[1]
C/N	15.7[2]
Volume (m^3)	43,160

[1] Source of Density - U.S.EPA (1985a); [2] C/N - Tchobanoglous *et al.* (1993)

Table 3.2 Raw material characteristics used for the preliminary process design.

Material	Quantity (wet tonnes/year)	Bulk density (kg/m^3)	Moisture content (%)	C/N
Biosolids	48,702	1,079	74	15.7
Leaves	12,907	59.3	20	60
Recycle	30,345	513	40	24.4

Feedstock- to-recycle ratio = 2:1

Calculation of the amount of each component in the feedstock to be mixed as a conventional windrow was done according to the following equation:

$$M_{total} \times 0.55 = M_{sludge} \times W_{sludge} + M_{leaves} \times W_{leaves} + M_{recycle} \times W_{recycle} \qquad 3\text{-}1$$

where M = mass (kg)

W = moisture content (%)

0.55 - corresponds to the target moisture content of the pile

A flow diagram with the corresponding materials balance is presented in Figure 3.1. The resulting C/N ratio of the mixture was calculated to be 26. This value falls within the acceptable range of 20 to 40 (Rynk *et al.* 1992). A bar diagram representation of the feedstock materials is presented in Figure 3.2. The process design was conducted considering only leaves as a bulking agent for mixing with the biosolids however, Leaves may not provide the adequate structural integrity required for windrow piles, however, about 44,000 tonnes of yard waste is generated yearly in the City of Winnipeg (Speers 1989) which may be used as additional amendment for adequate structural strength of the windrow piles.

The area requirement for the windrow composting facility was estimated using the methods presented in Rynk *et al.* (1992) except the density of the feedstock mixture which was assumed to be 999.7 kg/m^3 (U.S. EPA 1985b).The height, width, and length of each windrow assumed was 1.8 m (6 ft), 3 m (10 ft) and 91 m (300 ft) respectively (Rynk *et al.* 1992). The slope of the pad should be, at least, 2% (U.S. EPA 1985a). Calculations determined that 18 windrows of 329 m^3 each would be required. The total area for active composting, curing, and compost storage was estimated to be 17,460 m^2, 2,716 m^2, and 3104 m^2 respectively. As shown in Figure 3.1, the active composting, curing, and product storage times are considered as 60, 60, and 90 days respectively (Rynk *et al.* 1992). This assumptions were taken directly from the typical values of composting times for windrow composting presented in Rynk et al. (1992).

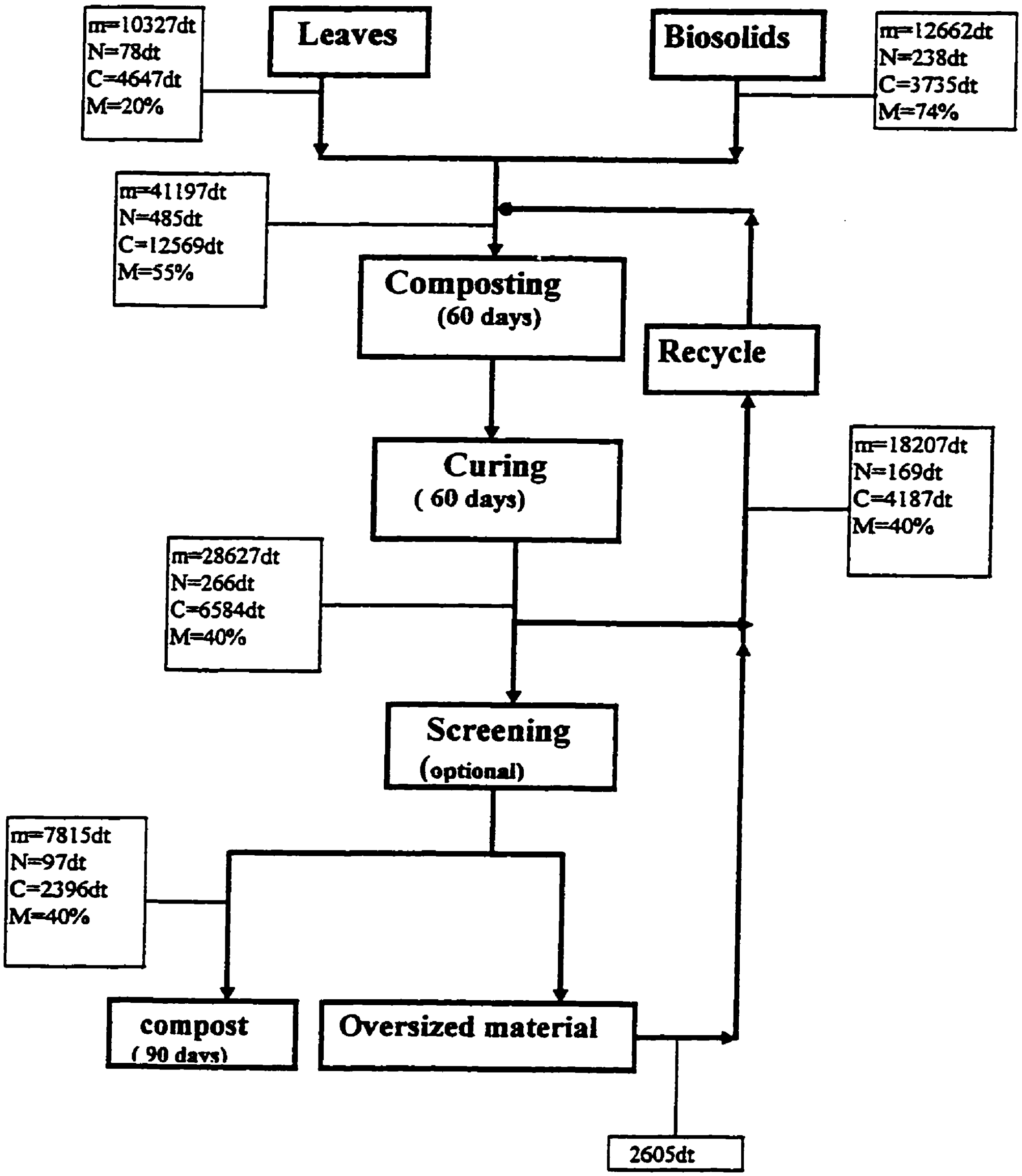
The area layout of the windrow composting facility is presented in Figure 3.3. The results of the area requirement calculations suggest that about 0.5 m^2 is required for composting, curing, and storage per wet tonne of biosolids produced each year. The area of the existing storage pad of the City is 56,100 m^2. This area is significantly large enough to contain the total area required (23,280 m^2) for the windrow composting facility of the City's biosolids thus, there is sufficient extra land for equipment storage and storage of amendment if necessary.

According to my existing facilities survey results, HCK Inc., of Carson, California estimated its area per unit for its composting facility at 0.6 m^2 per wet tonne. Therefore, on the existing storage pad of the City of Winnipeg, about 62,200 wet tonnes of biosolids can be composted per year, 30% more biosolids than the total amount currently generated by the City of Winnipeg on a yearly basis.

Leachate (liquid that drains from the compost mix) and runoff (precipitation that reaches the pad directly without going through a compost pile) are major considerations in composting site layout. These are of great concern and can create ground water contamination, odour problems and the potential for ice formation during winter months, which is dangerous for heavy equipment operation. Leachate problems can be controlled by installing collection devices underneath the piles connecting to a system consisting of leachate pumps and a collection pond. However, the existing pad of the City of Winnipeg which is currently utilized for biosolids storage already contains surface drainage collection system (Amy 1996), thus any leachate concerns during composting on the pad would be eliminated.

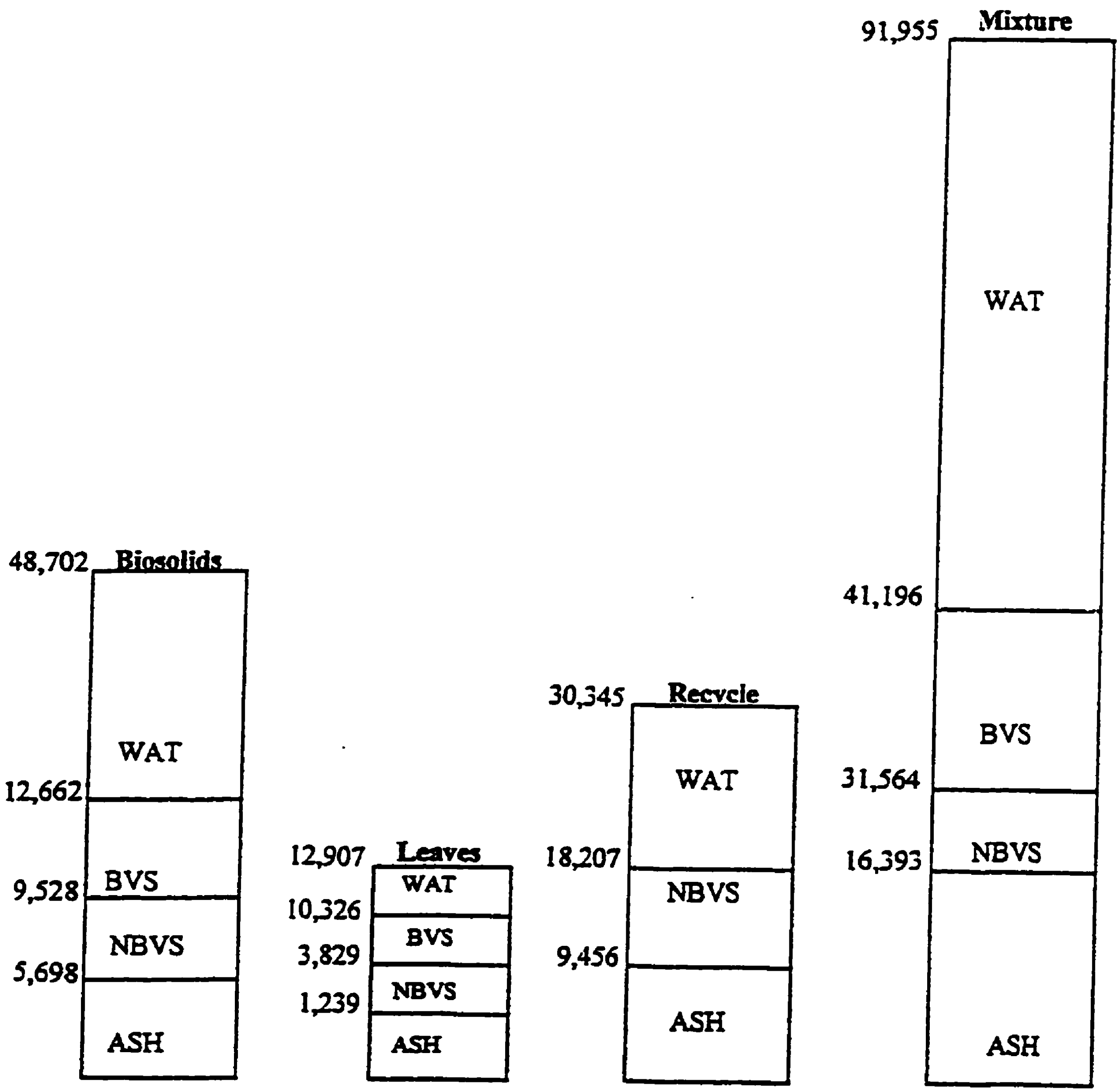
The environmental concerns that affect the current biosolids disposal program of the City of Winnipeg are trace elements and pathogenic organisms. Because metals in the biosolids are conserved in the soil-biosolids mixture, application of the biosolids to cropland causes an increase in the concentration of potentially phytotoxic heavy metals in the soils. Many different groups of pathogenic organisms including bacteria, viruses, and parasites that are of greatest concern to public health may be found in municipal wastewater biosolids. However, an adequately monitored composting process with elevation of temperatures above 55°C for 15 days with a minimum of 5 turnings is proven to thermally inactivate the enteric pathogens (CCME 1996).

Figure 3.1 Flow diagram and material balance of the composting facility based on annual loads.



m - mass (dry tonnes), N - nitrogen (dry tonnes), C - carbon (dry tonnes) and M - % moisture content

Figure 3.2 Bar diagram of WAT, BVS, NBVS and ASH for the three components and mixture in tonnes.



WAT - water, BVS - biodegradable volatile solids, NBVS - nonbiodegradable volatile solids and ASH - ash.

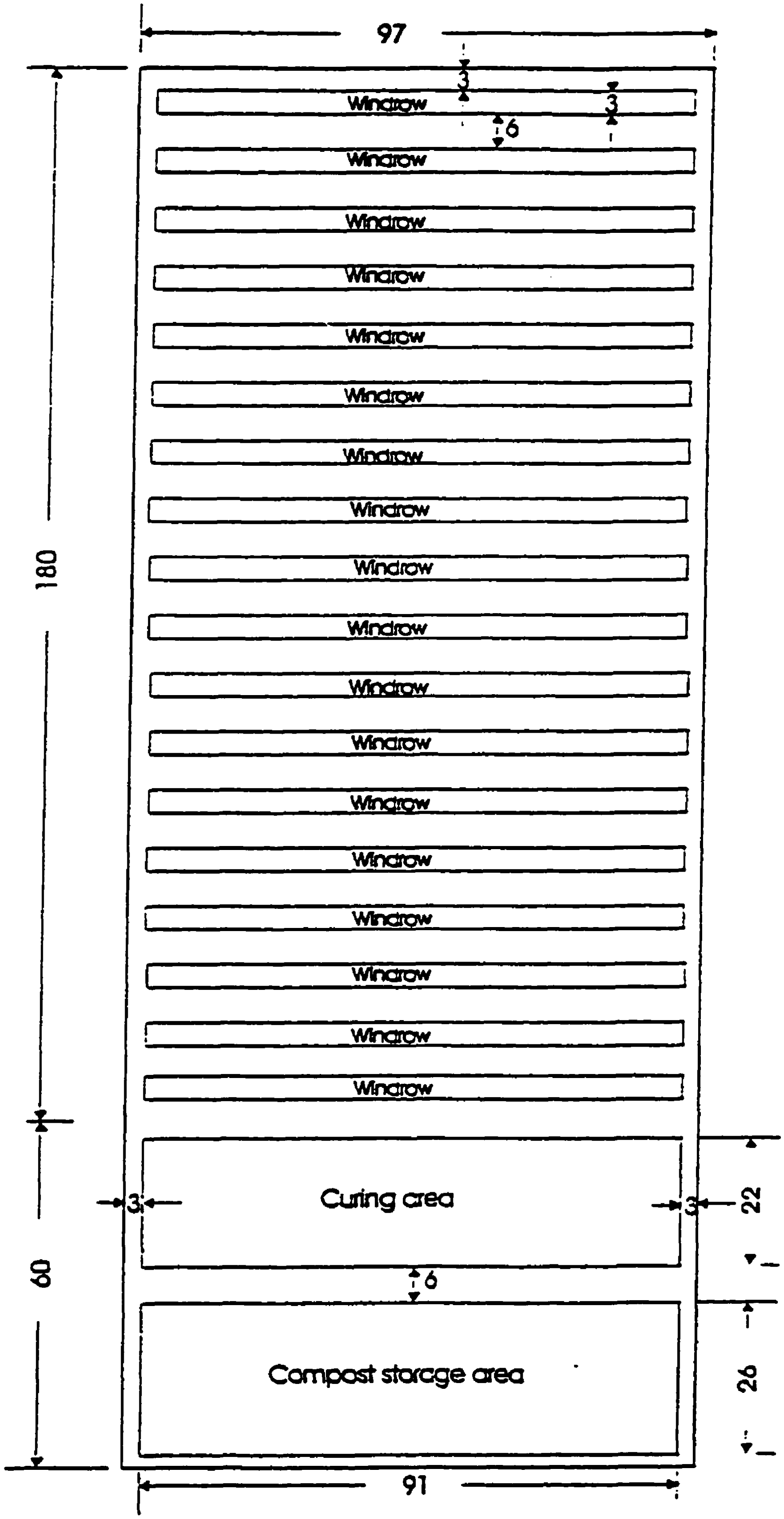


Figure 3.3 Area layout for the windrow composting facility in meters

3.2 Technical demonstration of the composting process

The composting experiment processed a feedstock made up of three components in an aerobic bioreactor: biosolids, leaves, and compost recycle. The objective of the experiment was to demonstrate the ability of composting to inactivate the potential pathogens and to determine the trace element content of the final compost product.

3.2.1 Experimental equipment and methodology

The reactor was monitored throughout the entire composting process. Parameters analysed included: moisture content, total solids (TS), volatile solids (VS), and temperature. The total and volatile solids were determined according to method 2540G APHA (1989) at the beginning and end of each cycle. However, for the volatile solids determination, before the samples were placed in a muffle furnace (550℃) they were placed over a bunsen burner until the sample turned a gray colour and the smoke production ceased. The burning procedure was used for two reasons: to avoid oxygen depletion in the muffle furnace and to prevent the smoke from the samples from depositing residue on the walls of the furnace. A crucible holder was designed and built, consisting of a metal plate with four holes cut in it supported by metal legs. The crucibles sat in the holes with their bottoms exposed to the flame. The system prevented the flames from jumping into the samples and greatly reduced the time required by preparing all four samples simultaneously.

Moisture content was also measured every three days using an infra-red Moisture Balance. The moisture content was corrected by adding water when the value dropped below 55%. Temperature was measured every day using a Cole-Parmer Model 8402-00 Thermistor Thermometer equipped with a YSI reusable temperature probe. Temperature readings were taken with this probe from the top of the reactor at five different points in the middle of the pile and the average values were used to plot the temperature profile.

1. Collection of the feedstock materials

Leaves in plastic garbage bags were picked up from the King's Park "Leaf It With Us" depot. Dewatered biosolids were collected from the North End Water Pollution Control Centre (NEWPCC) and stored in refrigerated 5 gallon plastic pails. For the initial cycle, compost material required for recycling was obtained from the most actively composting pile at the Summit Road Leaf Composting site of the City of Winnipeg.

2. Feedstock preparation (mixing)

Biosolids have a high moisture content and bulk density which requires conditioning before they can be composted because almost all of the void spaces in the biosolids are occupied by water. This high moisture and bulk density problem was corrected by adding leaves and compost recycle, and mixing it thoroughly with the biosolids to reach an optimum value. Mixing the biosolids with the leaves and the recycling compost was a very difficult task because of the high plasticity of the biosolids combined with the extremely low bulk density of the leaves. Mixing is one of the most important factors in poor reactor performance if not conducted properly. An attempt was made to mix the feedstock with a shovel and two other turning tools, but none of these was successful in preventing clumping of the biosolids. The only way in which a relatively uniform mixture could be achieved was by hand mixing with rubber gloves.

Shredding the leaves prior to mixing was attempted during the initial stage of the work. Shredding reduced the volume of the leaves significantly making them easier to work with, and theoretically speeding up the reaction rate in the pile. However, this volume reduction led to a decrease in the effectiveness of the leaves as a bulking agent which required more frequent turning of the pile during composting. Moreover, shredding the leaves was both difficult and time consuming. Therefore, unshredded leaves, although more awkward to mix because of their lower bulk density, performed as a superior bulking agent.

3. Operation and monitoring

After mixing the three components, the mixture was composted in a 240 L Schaefer Model SSI Compostainer with a 57 cm base, 51 cm width and 102 cm height. The reactor was placed in a chamber to control the temperature, and the internal temperature of the chamber was kept at 45°C. The reason to keep the reactor in a chamber of 45 C was to accelerate the process of the composting start-up and to prevent the possible heat loss. The feedstock was turned every three days after loading the reactor to replenish the oxygen supply and to mix. Turning was attempted initially using a backyard composter mixing tool, but it was found that the two tongues on the bottom of this tool kept sticking to the shaft rendering it useless. A small spade-like shovel was used to mix the pile although it required much physical effort.

3.2.2 Results of the demonstration

Three composting cycles of approximately 15 days each were completed. The primary criterium used for cycle termination was the decline of temperature of the mass to the level of the chamber temperature. This is due to the fact that most of the self heating process of organic matter is the result of microbial respiration i.e., when the mass is insulated, the heat generated increases the temperature of the mass. An increase in temperature affects the microbial population through changes in mesophilic and thermophilic organisms, which in turn affects the rate of decomposition. Microbial respiration can therefore be used as an indicator of decomposition and the stability of compost product. A general relationship for respiration and temperature as a function of composting time is presented in Figure 3.4. Equation 3-1 was used to determine the required ratios of biosolids to leaves to recycle. The summary of the feedstock recipes used in the technical demonstration of composting process is presented in Table 3.3.

Figure 3-4 General relationshipfor respiration and temperature as a function of time (Epstein 1997).

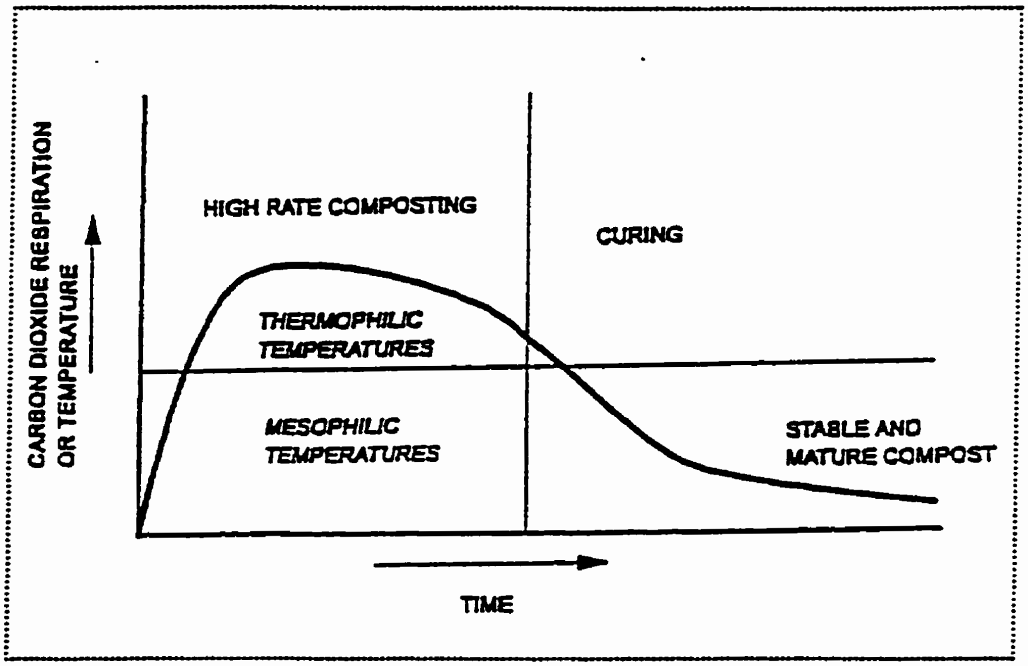


Table 3.3 Summary of the feedstock recipes used in the technical demonstration of the composting process.

	Biosolids		Leaves		Recycle	
Cycle No.	moisture content (%)	dry mass (kg)	moisture content (%)	dry mass (kg)	moisture content (%)	dry mass (kg)
1	75	2.3	24	8.4	69.2	3.2
2	75	2.9	19.8	6.0	57	6.4
3	76	2.5	20	5.4	54	7.8

The temperature profile in the reactor during cycle 1 is plotted in Figure 3.5. The volatile reduction during all the composting cycles is reported in Table 3.4. Calculations of the total and volatile solids analysis are presented in Appendix IV. The peak on day 5 corresponds to a replenished oxygen supply for the microorganisms after the turning on day 4 of the cycle. The downward portion of the curve corresponds to the depletion of the available volatile organic matter by the microorganisms. The low value for the pile temperature on day 12 of the cycle may be due to moisture content dropping to 48%. The moisture content was subsequently corrected by water addition, and the pile temperature is shown to rebound as a result. During the cycle the moisture content was maintained at around 55%. The temperature elevation and volatile solids reduction during the entire period of the cycle was successful. To examine the effect of different feed ratios, the mixing ratio during a second cycle was changed.

Table 3.4 Volatile solids removal during each reactor cycle.

	Volatile solids		
Cycle No.	Initial (kg)	Final (kg)	Removal (%)
1	10.40	7.56	27.3
2	12.80	9.2	28
3	10.66	7.3	31.5

The temperature profile in the reactor during cycle 2 is plotted in Figure 3.6. The temperature of the pile remained over the 55℃ range for ten consecutive days. An extremely high value of the pile temperature of 72.2℃ was recorded on the second day of the cycle. The temperature profile indicates that the microorganisms were inactive after day 11 of the cycle. For further examination, the ratio changed to 1:2 in cycle 3. The total VS destroyed during the cycle is reported in Table 3.4.

During the process of cycle 2, fecal coliform (FC) were found to decrease from an initial concentration of 1.07×10^7 MPN g^{-1} ds^{-1} at day 0 to below the method detection limit of 200 MPN g^{-1} ds^{-1} by day 4 (Zhang 1996). It should be noted that the reduction of the pathogen content below the method detection limit of 200 MPN g^{-1} ds^{-1} (Zhang 1996) should increase the value of the biosolids, i.e., the compost use restrictions would be reduced; therefore, uses in and around the City of Winnipeg could be investigated. However, it is also important to note that pathogen inactivation was achieved under controlled laboratory conditions not in the harsh climate of Winnipeg winters. Implementing a full scale biosolids windrow composting operation in Winnipeg may be problematic because of these harsh conditions. The cold weather may decrease the operating temperatures of windrows and may slow down the process of pathogen inactivation. The net result may be longer processing times, and consequently, an increase in area requirements.

The temperature profile in the reactor during cycle 3 is plotted in Figure 3.7. The results of cycle 3 showed a significant improvement over the previous cycle as the temperature of the reactor attained above 55 °C for 13 consecutive day. However as the moisture content of the reactor fluctuated the temperature seemed to be affected in the same manner. The temperature increased rapidly at the beginning of the cycle until the moisture content dropped to about 50%. Water was then added to increase the moisture content to about 55% but more water was added than needed and the moisture content increased to 62% as a result of which took 3 days to heat up again. At day 6, as moisture content reached its optimum value a very high temperature was recorded, which then gradually decreased with the moisture content. Towards the end of the cycle moisture content correction didn't seem to affect the temperature decline indicating the biodegradable volatile solids were exhausted.

Leaves and compost product samples of cycle 3 were analysed for heavy metal concentrations and the results of the analysis are presented in Table 3.5. The heavy metal concentrations of the City's biosolids were obtained from NEWPCC (Appendix I) while the trace elements of the compost and leaves were sent to Envirotest, a private laboratory, for analysis (Appendix I). The results are compared with maximum allowable concentrations of trace elements established by CCME (1996) in Table 3.6. The results of the heavy metals analysis for the final compost product, in Table 3.5, indicate that the initial concentrations of all the analysed heavy metals in the biosolids were reduced by over 50% in the final compost product as a result of dilution by bulking agent. The heavy metal content reduction during composting indicates that composting the biosolids mixed with bulking agents would lower the potential risks posed by biosolids application to the soil. The heavy metal concentrations of the final compost product using the biosolids of the City of Winnipeg as a feed stock were lower than the typical concentrations of the heavy metals of compost product reported in Table 2.4 (except Cu). As compared in Table 3.6, the compost product using the City's biosolids as a feedstock meets the CCME (1996) Category B requirements of compost guidelines.

Table 3.5 Trace elements in the biosolids, leaves, and final compost product.

Trace elements	Biosolids (mg/kg)		Leaves (mg/kg)		Compost (mg/kg)	
	Mean	Std. Dev.	Mean	Std. Dev.	Mean	Std. Dev.
As	-	-	1.24	0.11	3.12	0.22
Cd	15	3.5	0.5*	0	6.7	0.2
Cr	1830	623	5.7	1.925	599	20
Co	-	-	2.4	0.2	4.8	0.1
Cu	1129	276	11.1	0.5	505	9
Pb	227	6.1	10.5	0.5	97.5	3.5
Hg	-	-	0.061	0.001	0.87	0.033
Mo	-	-	2.5*	0	7.85	0.05
Ni	45	4	5.25	0.15	22.3	0.5
Si	-	-	0.26	0.005	1.2	0
Zn	1464	308	69	0.4	651	14

x = 2, x - number of samples

*Below the method detection limit, the value reported is 1/2 the method detection limit.

Source of biosolids trace elements - 1994 data of NEWPCC (Appendix I c).

Table 3.6 Trace elements in the final compost in comparison to the maximum trace element concentration limits by CCME (1996).

Trace elements	Compost (mg/kg)	Maximum allowable concentration by CCME (1996) (mg/kg)	
		Category A	Category B
As	3.12	13	75
Cd	6.7	3	20
Cr	599	210	1060
Co	4.8	34	150
Cu	505	100	757
Pb	97.5	150	500
Hg	0.87	0.8	5
Mo	7.85	5	20
Ni	22.3	62	180
Si	1.2	2	14
Zn	651	500	1850

Figure 3.5 Temperature profile of cycle 1.

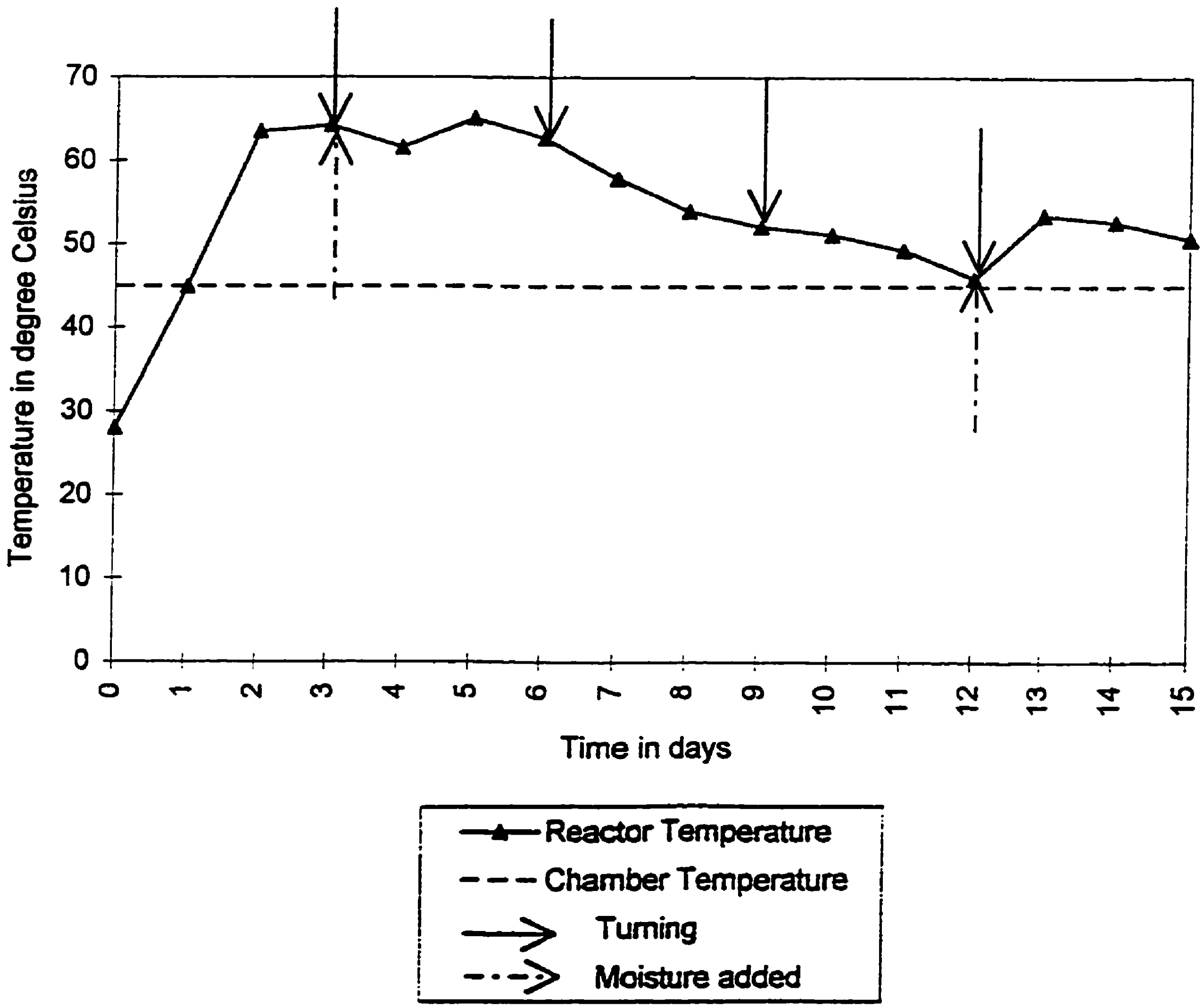


Figure 3.6 Temperature profile of cycle 2.

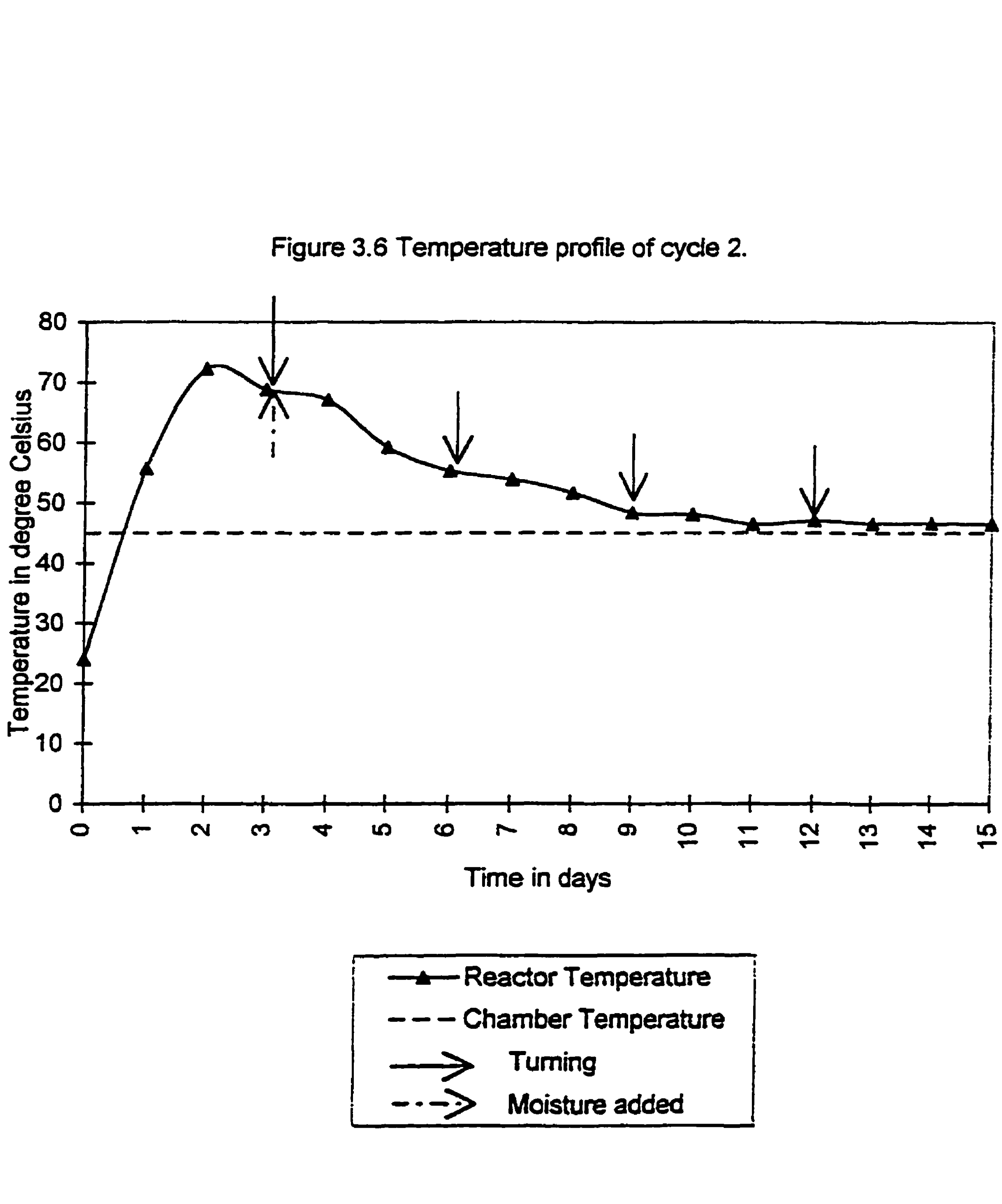
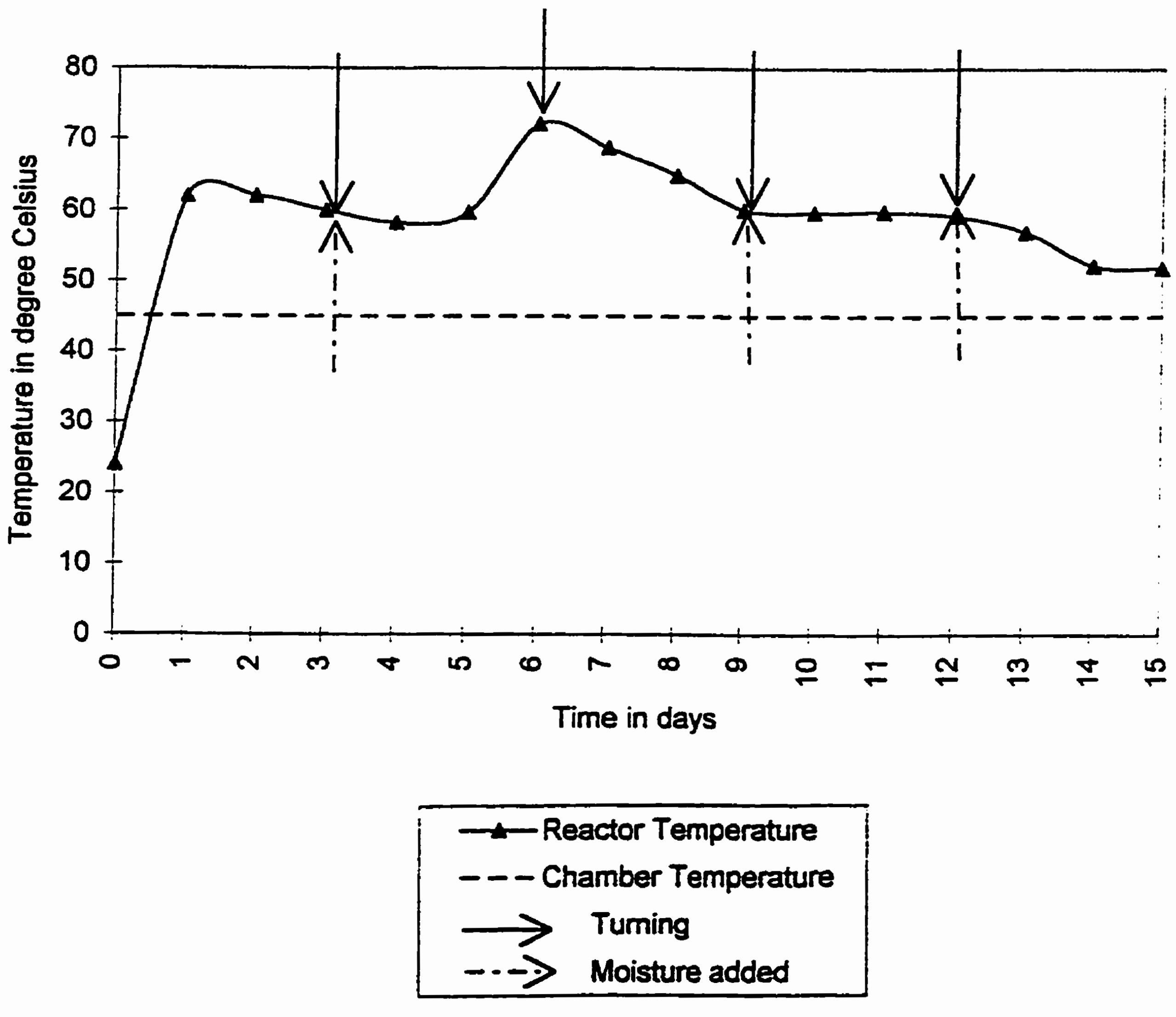


Fig 3.7 Temperature profile of cycle 3.



3.3 Economic comparison of the existing biosolids disposal program of the City of Winnipeg and a possible biosolids composting facility

Capital costs and annual operation and maintenance cost estimates of a possible windrow and static pile composting system for the City of Winnipeg's biosolids were conducted. These cost estimates were calculated based on the methods and cost curves presented in the U.S. EPA (1985b). It must be noted that there was no direct link between the development of the process design and the economic assessment of the windrow composting facility. The cost of the existing biosolids disposal program of Winnipeg was broken down into transportation, land filling, and agricultural land application costs using a comparison method with the cost estimates of these three components calculated based on U.S. EPA (1985b). The City of Winnipeg's existing biosolids transportation, land filling, and agricultural land application costs were also estimated based on U.S. EPA (1985b) for determining a correction factor. In the cost estimates of biosolids windrow and static pile composting methods, the cost of transportation of the biosolids and base capital costs of the composting processes with their annual operation and maintenance costs were calculated separately. The step by step calculations of all the cost estimates and the method for determining the correction factor are presented in the Appendix V.

The existing biosolids storage pad of the City of Winnipeg currently used to store biosolids during wet seasons was considered to be the composting site. The round trip from NEWPCC to the existing storage pad is 10 miles (16 km) and the area of the pad is 56,100

m^2. Therefore, the costs of site clearing, grading, and paving were excluded from the base capital costs since the area of the windrow composting facility can be contained in the existing biosolids storage area. The costs of any bulking agent and its transportation were included in the base capital of the composting (U.S. EPA 1985b). Revenue from the sale of the compost has not been considered in the cost estimates. Composting also diverts material from landfill, thus conserving substantial landfill space. This was also not included in the cost estimates.

The annual cost estimate of the existing biosolids disposal program of the City of Winnipeg based on U.S. EPA (1985b), the break down of the current cost of the program, and the calculated correction factors for each cost component are presented in Table 3.7. The cost estimates for the composting alternatives are presented in Table 3.8 and compared inTable 3.9. Table 3.8 presents the values calculated using the U.S. EPA (1985b) method where column 1 is the cost estimate of the windrow composting facility before applying the correction factor, column 2 is the cost estimate of the windrow composting facility after the correction factor application, column 3 is the cost estimate of the windrow composting facility assuming that the storage pad of the City does not exist, and column 4 is the cost estimate of a static pile composting facility after applying the correction factor.

Table 3.7 Determination of correction factors for each component of the City of Winnipeg's program (to nearest thousand).

	Break down of the actual cost (1994)	Cost estimate of the existing program based on US.EPA (before correction factor)	Calculated correction factor
Biosolids transportation cost	$635,000	$319,000	1.9905
Biosolids land application cost	$214,000	$131,000	1.6336
Biosolids land filling cost	$105,000	$50,000	2.1000
Total cost	$954,000	$500,000	1.9080

Table 3.8 Cost estimates of biosolids windrow and static pile composting methods based on U.S. EPA (1985b) (to nearest thousand).

	Windrow			Static pile
	Cost estimates before correction factor	Cost estimates after correction factor	Cost estimates excluding storage pad	Cost estimates excluding storage pad
	1	2	3	4
Transportation cost including O&M cost of transportation	$121,000	$241,000	$241,000	$241,000
Composting cost including O&M cost of composting	$399,000	$652,000	$771,000	$2,993,000
Total cost	$520,000	$893,000	$1,012,000	$3,234,000

Correction factor for transportation cost including O&M cost of transportation =1.9905 from Table 3.7,

Correction factor for composting cost including O&M cost of composting = 1.6336 from Table 3.7.

Table 3.9 Cost estimate comparison of the existing biosolids disposal program and estimates for both the window and static pile composting options (to nearest thousand).

	Existing program	Windrow composting	Static pile composting
Biosolids transportation cost including O&M cost of transportation	$635,000	$241,000	$241,000
Disposal or composting cost including O&M cost of disposal or composting	$319,000	$652,000	$2,993,000
Total cost	$954,000	$893,000	$3,234,000

The cost values of the windrow and static pile composting systems reported here are annual costs including capitalized equipment. As shown in Table 3.8, the cost estimate for a windrow composting program using the existing storage pad as a composting site is estimated at $893,000. The total cost for the existing program in 1994 of the City's biosolids disposal program was $954,000. Based on the preliminary economic analysis, windrow composting of the City's biosolids on the existing biosolids storage pad may be economically feasible. The availability of the storage pad, which is estimated to be sufficient for the windrow composting site as reported in Section 3.1, has a considerable impact on reducing the capital cost of the composting process because costs such as site clearing, grading, and paving were excluded from the capital cost of composting. The total cost reduction for the composting facility is also attributed to the significant decrease of the cost in transportation since the round trip distance of the existing biosolids disposal program is about 100 km while the round trip distance of the composting site (storage pad) is about 16 km. However using the storage pad for the biosolids windrow composting facility may not be realistic because the existing buffer zone may not be sufficient since several odour nuisance complains were reported by the neighbouring receptors. The neighbouring receptors may have also negative attitude towards any activity that involves biosolids in the pad due to the odour nuisance they experienced before. The other barrier is the undergoing housing development towards the pad which may encroach on the buffer areas in the long term. This indicates that another location may have to be found, which would bring the cost estimate up to $1,012,000 (Table 3.8).

The results of the economic analysis also suggest that biosolids composting unit costs would be around $18 per wet tonne. To compare this value to existing facilities, a survey was conducted. Details of the survey can be found in Appendix VI. My cost survey of an existing biosolids windrow composting facility, HCK Inc., of Carson, California, revealed that their cost per unit was between $6 and $10 (U.S.), however this Figure reflects only O&M costs and excludes capital costs and unit cost of transportation. The respondent estimated the company's capital costs at $500,000 U.S. Amortized over 20 years at an annual interest rate of 6%, and taking O&M unit cost $8 per wet tonne, the equivalent annual payment per wet tonne is estimated using the equivalent annual-worth method (Riggs *et al.* 1983) to be about $ 0.44 U.S. per wet tonne. Therefore the companies unit cost per wet tonne excluding transportation cost is calculated to be $8.44 U.S. ($11.60

Canadian). The Figure is comparable to the estimate obtained for the City of Winnipeg ($13). Detailed calculations of the equivalent annual cost are presented in Appendix VI.

3.4 Summary of Chapter 3

The principal factors of a composting process design are the quantity of the material to be handled, the moisture content, and the C/N ratio. The quantity of biosolids generated in 1994 (48,702 wet tonnes at an average of 26% total solids) was considered for the design of the windrow composting facility. The initial moisture content of feedstock was designed to be 55% and the average moisture content of the leaves and recycled material were assumed to be 20% & 40% respectively. Using the above design factors, a flow diagram with its corresponding materials balance of the composting facility is presented in Figure 3.1. The average initial C/N ratio of the windrows was found to be 26 which is at an acceptable range of 20 to 40 (Rynk *et al.* 1992) for a rapid composting rate.

A bench scale composting experiment of biosolids mixed with leaves and recycled material was demonstrated to evaluate the ability of composting to inactivate the pathogenic organisms that can pose a public health hazard, and to determine the trace element concentrations in the final compost product. High temperature elevations for pathogen inactivation were achieved and fecal coliforms were reduced below the method detection limit of 200 MPN g^{-1} ds^{-1} (Zhang 1996) in 4 days. The final compost product analysis for heavy metals indicates that the compost product obtained using the City of

Winnipeg's biosolids as a feedstock meets the CCME Category B requirements of the Canadian compost guidelines.

The cost of the biosolids windrow composting facility for the City of Winnipeg considering the existing storage pad as a composting site is estimated to be $893,000 per year. The total cost for the existing biosolids disposal program of the City of Winnipeg is $954,000 per year. The preliminary cost analysis suggests that windrow composting on the existing storage pad is economically feasible, the site may not be usable due to public concerns about odour. Area requirement calculations suggest that 0.5 m^2 per wet tonne of biosolids is required for the windrow composting facility. The availability of the storage pad which is estimated to be sufficient for the windrow composting site has a considerable impact in reducing the total cost of the composting process because costs such as site clearing, grading, and paving would be excluded from the capital cost. The total cost reduction for composting is also reduced in biosolids transportation because the round trip distance for the existing program is about 100 km, while the round trip distance for the composting site (storage pad) is about 16 km. Based on the economic analysis, the composting unit cost would be about $18 per wet tonne which was similar to a facility operating in Carson, California ($11.60 per wet tonne). The cost results also suggest that the cost estimate of biosolids windrow composting is significantly lower than the cost of the static pile composting system.

Leachate and runoff that can create ground or surface water contamination, odour problems, and the potential for ice formation during winter months are major considerations in the biosolids windrow composting site layout. However, the existing pad of the City of Winnipeg which is currently used for biosolids storage, is equipped with a leachate collection system (Amy 1996) and any leachate and/or runoff concerns are not anticipated during composting. Based on the above methods implemented and results obtained, some conclusions are drawn in Chapter 4.

CHAPTER 4

CONCLUSIONS AND RECOMMENDATIONS

Based on the results of this investigation of the City of Winnipeg's dewatered biosolids composting feasibility, the following conclusions were made:

1. Preliminary economic analysis suggests that biosolids windrow composting on the storage pad has the potential for saving the City about $100,000 each year. This cost reduction occurs because the composting pad already exists and the transportation costs are significantly less. However, implementing biosolids windrow composting on the storage pad may not be feasible since odour complains were reported by the neighbouring receptors during the biosolids storage thus, a newsite may have to be located, which would increase the cost of the facility.

2. The ability of the biosolids composting process to inactivate pathogens through elevated operating temperatures has been demonstrated during the bench-scale demonstrations. Hence, composting will increase the value of the product by reducing the pathogen content, thereby removing many of the user restrictions applied to the existing program. The material could be made available to local soil markets.

3. A key technical concern will be the ability of the system to meet the pathogen reduction criteria during winter months .

4. Laboratory analysis of the final compost product for heavy metal concentrations determined that the biosolids compost product meets all the Category B requirements of the Canadian Compost Quality Guidelines.

5. While leaves are known to be an excellent source of carbon to the feedstock when mixed with biosolids, they may not provide sufficient structural strength to the windrow. Therefore, additional bulking agents such as yard waste, wood chips, or sawdust may be required to provide adequate structural integrity and this may be determined during the pilot scale analysis.

Preliminary technical and economical feasibility analyses suggest that windrow composting of biosolids may be feasible in the City of Winnipeg, therefore the following recommendations are made:

1. Because of the extreme weather conditions of Manitoba, a pilot study of biosolids composting must be conducted to confirm that the system can achieve the required operating temperatures for pathogen inactivation purposes and to assist with a more accurate economic analysis.

2. As part of the pilot study, more detailed economic assessment must be conducted.

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APPENDIX IA

ENVIROTEST LABORATORY ANALYSIS

ENVIRO - TEST LABORATORIES
MANITOBA TECHNOLOGY CENTRE
745 Logan Avenue
Winnipeg, Manitoba R3E 3L5
TEL: (204) 945-3705 FAX: (204) 945-0763

Malu: Your Copy! D.

FAX and Mail
Page 1

Tingley J
Civil & Geological Engineering Dept
403-15 Gilson St U. of Manitoba
Winnipeg MB R3T 5V6

Date Received :97/ 2/17
Date Reported :97/ 3/12
Work Order:W970202042

Submitted By:Beyene M

97-A6853

Analysis of Biological - Vegetation
Sample I.D. #1A) Leaves
Location U of M - Civil Engineering Dept
Date Sampled 97/ 2/17
Time Sampled 15:17

	Results	Units	Date Analysed
Arsenic - Total	1.13	ug/g	97/ 2/27
Cadmium - Total	< 1	ug/g	97/ 3/ 3
Chromium - Total	6.2	ug/g	97/ 3/ 3
Cobalt - Total	2.6	ug/g	97/ 3/ 3
Copper - Total	11.6	ug/g	97/ 3/ 3
Lead - Total	11.	ug/g	97/ 3/ 3
Mercury - Total	0.062	ug/g	97/ 3/ 6
Molybdenum - Total	< 5	ug/g	97/ 3/ 3
Nickel - Total	5.1	ug/g	97/ 3/ 3
Prep Veg Hot Plate/I	completed		97/ 3/ 3
Prep ICP Inorganic	Completed		97/ 3/ 6
Weight for Vegetation	1.00	g	97/ 2/19
Selenium Total	0.25	ug/g	97/ 2/28
Zinc - Total	69.4	ug/g	97/ 3/ 3

Approved By: Paul Nicolas

Date 97/ 3/12

ENVIRO - TEST LABORATORIES
MANITOBA TECHNOLOGY CENTRE
745 Logan Avenue
Winnipeg, Manitoba R3E 3L5
TEL: (204) 945-3705 FAX: (204) 945-0763

97-A6854

Analysis of Biological - Vegetation
Sample I.D. #1B) Leaves (Duplicate)
Location U of M - Civil Engineering Dept
Date Sampled 97/ 2/17
Time Sampled 15:17

	Results	Units	Date Analysed
Arsenic - Total	1.35	ug/g	97/ 2/27
Cadmium - Total	< 1	ug/g	97/ 3/ 3
Chromium - Total	5.2	ug/g	97/ 3/ 3
Cobalt - Total	2.2	ug/g	97/ 3/ 3
Copper - Total	10.6	ug/g	97/ 3/ 3
Lead - Total	10.	ug/g	97/ 3/ 3
Mercury - Total	0.060	ug/g	97/ 3/ 6
Molybdenum - Total	< 5	ug/g	97/ 3/ 3
Nickel - Total	5.4	ug/g	97/ 3/ 3
Prep Veg Hot Plate/I	completed		97/ 3/ 3
Prep ICP Inorganic	Completed		97/ 3/ 6
Weight for Vegetation	1.04	g	97/ 2/19
Selenium Total	0.26	ug/g	97/ 2/28
Zinc - Total	68.6	ug/g	97/ 3/ 3

97-A6855

Analysis of Biological - Vegetation
Sample I.D. #2A) Compost
Location U of M - Civil Engineering Dept
Date Sampled 97/ 2/17
Time Sampled 15:17

	Results	Units	Date Analysed
Arsenic - Total	2.90	ug/g	97/ 2/27
Cadmium - Total	6.5	ug/g	97/ 3/ 3
Chromium - Total	579.	ug/g	97/ 3/ 3
Cobalt - Total	4.7	ug/g	97/ 3/ 3
Copper - Total	496.	ug/g	97/ 3/ 3
Lead - Total	94.	ug/g	97/ 3/ 3
Mercury - Total	0.905	ug/g	97/ 3/ 6

Approved By: Paul Nicolas Date 97/ 3/12

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	Results	Units	Date Analysed
97-A6855 (continued)			
Molybdenum - Total	7.8	ug/g	97/ 3/ 3
Nickel - Total	21.8	ug/g	97/ 3/ 3
Prep Veg Hot Plate/I	completed		97/ 3/ 3
Prep ICP Inorganic	Completed		97/ 3/ 6
Weight for Vegetation	1.06	g	97/ 2/19
Selenium Total	1.2	ug/g	97/ 2/28
Zinc - Total	637.	ug/g	97/ 3/ 3

97-A6856

Analysis of Biological - Vegetation
Sample I.D. #2B) Compost (Duplicate)
Location U of M - Civil Engineering Dept
Date Sampled 97/ 2/17
Time Sampled 15:17

	Results	Units	Date Analysed
Arsenic - Total	3.34	ug/g	97/ 2/27
Cadmium - Total	6.9	ug/g	97/ 3/ 3
Chromium - Total	619.	ug/g	97/ 3/ 3
Cobalt - Total	4.9	ug/g	97/ 3/ 3
Copper - Total	514.	ug/g	97/ 3/ 3
Lead - Total	101.	ug/g	97/ 3/ 3
Mercury - Total	0.839	ug/g	97/ 3/ 6
Molybdenum - Total	7.9	ug/g	97/ 3/ 3
Nickel - Total	22.8	ug/g	97/ 3/ 3
Prep Veg Hot Plate/I	completed		97/ 3/ 3
Prep ICP Inorganic	Completed		97/ 3/ 6
Weight for Vegetation	1.09	g	97/ 2/19
Selenium Total	1.2	ug/g	97/ 2/28
Zinc - Total	665.	ug/g	97/ 3/ 3

Approved By: Paul Nicolas Date 97/ 3/12

APPENDIX IB

STATISTICAL DATA OF THE BIOSOLIDS OF THE CITY OF WINNIPEG

DEWATERED SLUDGE PRODUCTION

Month	Total Wet Wt.	Total Dry Wt.	% T.S. (avg)	Wet Wt. per Day	Dry Wt. per Day
Jan-91	2916.35	666.11	22.8%	94.08	21.49
Feb-91	3078.08	799.55	26.0%	109.93	28.56
Mar-91	3433.23	950.11	27.7%	110.75	30.65
Apr-91	3936.54	1172.74	29.8%	131.22	39.09
May-91	4418.76	1312.53	29.7%	142.54	42.34
Jun-91	4538.60	1325.33	29.2%	151.29	44.18
Jul-91	4845.82	1336.57	27.6%	156.32	43.12
Aug-91	3766.90	918.92	24.4%	121.51	29.64
Sep-91	3439.54	766.65	22.3%	114.65	25.56
Oct-91	3744.93	821.13	21.9%	120.80	26.49
Nov-91	4426.49	1012.59	22.9%	147.55	33.75
Dec-91	3304.09	756.16	22.9%	106.58	24.39
Avg(Sum)	4157.69	1138.79	27.2%	136.25	37.32
Avg(Win)	3483.86	834.28	24.0%	114.95	27.55
Avg(Year)	3820.78	986.53	25.6%	125.60	32.44
Tot(Sum)	24946.16	6832.74			
Tot(Win)	20903.17	5005.65			
Tot(Year)	45849.33	11838.39			

DEWATERED SLUDGE PRODUCTION

Month	Total Wet Wt.	Total Dry Wt.	% T.S. (avg)	Wet Wt. per Day	Dry Wt. per Day
Jan-92	2842.50	626.79	22.1%	91.69	20.22
Feb-92	2744.46	614.40	22.4%	98.02	21.94
Mar-92	4377.18	1172.85	26.8%	141.20	37.83
Apr-92	3289.49	989.28	30.1%	109.65	32.98
May-92	4125.28	1227.81	29.8%	133.07	39.61
Jun-92	5219.28	1516.12	29.0%	173.98	50.54
Jul-92	4167.15	1271.60	30.5%	134.42	41.02
Aug-92	3168.08	900.30	28.4%	102.20	29.04
Sep-92	4277.36	1236.40	28.9%	142.58	41.21
Oct-92	2960.52	743.93	25.1%	95.50	24.00
Nov-92	2730.08	648.64	23.8%	91.00	21.62
Dec-92	2943.92	667.32	22.7%	94.97	21.53
Avg(Sum)	4041.11	1190.25	29.5%	132.65	39.07
Avg(Win)	3099.78	745.66	23.8%	102.06	24.52
Avg(Year)	3570.44	967.95	26.6%	117.36	31.79
Tot(Sum)	24246.64	7141.51			
Tot(Win)	18598.66	4473.93			
Tot(Year)	42845.30	11615.44			

DEWATERED SLUDGE PRODUCTION

Month	Total Wet Wt.	Total Dry Wt.	% T.S. (avg)	Wet Wt. per Day	Dry Wt. per Day
Jan-93	3100.80	674.58	21.8%	100.03	21.76
Feb-93	3235.40	724.67	22.4%	115.55	25.88
Mar-93	3556.22	970.24	27.3%	114.72	31.30
Apr-93	3755.58	1112.49	29.6%	125.19	37.08
May-93	3235.92	953.82	29.5%	104.38	30.77
Jun-93	4642.00	1298.47	28.0%	154.73	43.28
Jul-93	3675.26	1023.74	27.9%	118.56	33.02
Aug-93	3060.22	958.54	31.3%	98.72	30.92
Sep-93	3897.52	1051.96	27.0%	129.92	35.07
Oct-93	3679.31	864.52	23.5%	118.69	27.89
Nov-93	4156.78	975.43	23.5%	138.56	32.51
Dec-93	4128.90	928.59	22.5%	133.19	29.95
Avg(Sum)	3711.08	1066.50	28.9%	121.92	35.02
Avg(Win)	3642.90	856.34	23.5%	120.12	28.22
Avg(Year)	3676.99	961.42	26.2%	121.02	31.62
Tot(Sum)	22266.50	6399.02			
Tot(Win)	21857.41	5138.03			
Tot(Year)	44123.91	11537.05			

DEWATERED SLUDGE PRODUCTION

Month	Total Wet Wt.	Total Dry Wt.	% T.S. (avg)	Wet Wt. per Day	Dry Wt. per Day
Jan-94	3838.96	864.86	22.5%	123.84	27.90
Feb-94	3947.60	960.40	24.3%	140.99	34.30
Mar-94	4440.98	1278.03	28.8%	143.26	41.23
Apr-94	3659.93	1058.31	28.9%	122.00	35.28
May-94	3933.64	1137.43	28.9%	126.89	36.69
Jun-94	4021.38	1140.66	28.4%	134.05	38.02
Jul-94	3646.60	1020.86	28.0%	117.63	32.93
Aug-94	4547.46	1214.94	26.7%	146.69	39.19
Sep-94	4916.94	1230.50	25.0%	163.90	41.02
Oct-94	3813.66	928.45	24.3%	123.02	29.95
Nov-94	4141.78	1018.89	24.6%	138.06	33.96
Dec-94	3792.94	927.80	24.5%	122.35	29.93
Avg(Sum)	4120.99	1133.78	27.7%	135.19	37.19
Avg(Win)	3995.99	996.41	24.8%	131.92	32.88
Avg(Year)	4058.49	1065.09	26.2%	133.56	35.03
Tot(Sum)	24725.95	6802.70			
Tot(Win)	23975.92	5978.43			
Tot(Year)	48701.87	12781.13			

DEWATERED SLUDGE PRODUCTION

Month	Total Wet Wt.	Total Dry Wt.	% T.S. (avg)	Wet Wt. per Day	Dry Wt. per Day
Jan-95	4831.12	1037.77	21.5%	155.84	33.48
Feb-95	3194.37	684.50	21.4%	114.08	24.45
Mar-95	4030.96	1015.99	25.2%	130.03	32.77
Apr-95	4282.90	1341.03	31.3%	142.76	44.70
May-95	5750.28	1575.99	27.4%	185.49	50.84
Jun-95	4817.80	1328.55	27.6%	160.59	44.29
Jul-95	4464.86	1202.70	26.9%	144.03	38.80
Aug-95	3349.78	876.64	26.2%	108.06	28.28
Sep-95	3782.28	982.83	26.0%	126.08	32.76
Oct-95	4589.92	1102.76	24.0%	148.06	35.57
Nov-95	4263.05	1032.31	24.2%	142.10	34.41
Dec-95	3973.02	924.78	23.3%	128.16	29.83
Avg(Sum)	4407.98	1217.96	27.6%	144.50	39.94
Avg(Win)	4147.07	966.35	23.3%	136.38	31.75
Avg(Year)	4277.53	1092.15	25.4%	140.44	35.85
Tot(Sum)	26447.90	7307.74			
Tot(Win)	24882.44	5798.11			
Tot(Year)	51330.34	13105.85			

APPENDIX IC

ANALYTICAL RESULTS OF THE BIOSOLIDS OF THE CITY OF WINNIPEG

TABLE I(c)

1990-91 SLUDGE DISPOSAL PROGRAM

ANALYTICAL RESULTS FOR DEWATERED SLUDGE

BIWEEKLY SAMPLE NUMBER	SAMPLING from	PERIOD to	SLUDGE DISPOSAL AREA**	NH3-N (mg/kg)	TKN (mg/kg)	TOTAL PHOS (mg/kg)	SODIUM* PHOS. (mg/kg)	CADMIUM (mg/kg)	COPPER (mg/kg)	LEAD (mg/kg)	ZINC (mg/kg)	NICKEL (mg/kg)	CHROMIUM (mg/kg)	pH	TOTAL SOLIDS (%)	PCB (ug/g)	CONDUCT. (umhos/cm)
90-19	9 Sep 90	22 Sep 90	[illegible]	5690	49300	15300	344	11.0	1070	331	1490	81	1480	7.4	21.9	<1.0	4900
90-20	23-Sep-90	6 Oct-90	89-5	7980	46500	14400	400	11.7	1110	311	1700	111	1610	7.5	25.9	<1.0	5700
90-21	7-Oct-90	20-Oct-90	89-5/7	8600	47100	16900	476	13.1	1130	301	1710	111	1640	7.7	24.2	<1.0	5300
90-22	21-Oct-90	3-Nov-90	89-5	9170	56300	17800	420	13.0	1260	296	2260	126	1680	7.7	24.5	<1.0	5900
90-23	4-Nov-90	17-Nov 90	89-5	9980	52700	19300	440	15.4	1190	265	2300	99	1560	7.8	24.5	<1.0	5300
90-24	18-Nov-90	1-Dec-90	89-5/6	11800	55000	18900	520	16.0	1110	263	1750	81	1450	7.8	25.4	<1.0	5100
90-25	2-Dec-90	15-Dec-90	89-6	9420	28700	20700	520	13.9	1190	297	1750	80	1600	7.7	25.8	<1.0	4800
90-26	16-Dec 90	29-Dec-90	89-6/7	9850	30200	21700	688	13.4	1240	301	1880	72	1790	7.7	23.2	<1.0	8000
91-01	30-Dec 90	12-Jan 91	89-7	10100	38200	19100	840	12.3	1300	272	1490	65	1450	7.8	23.0	<1.0	4500
91-02	13-Jan 91	26-Jan-91	89-7	10400	19800	17700	944	[illegible]	1200	220	1500	67	1520	7.8	22.7	<1.0	3600
91-03	27-Jan-91	9-Feb-91	89-7	10700	22100	17100	928	11.4	1280	240	1690	72	1500	7.8	22.3	<1.0	3400
91-04	10-Feb-91	23-Feb-91	89-7	9800	21400	17100	848	9.8	1060	230	1420	55	1210	7.9	27.1	<1.0	3700
91-05	24-Feb 91	9-Mar-91	89-7	8700	15700	14000	928	10.4	1070	240	1810	57	1420	8.0	27.8	<1.0	3900
91-06	10-Mar-91	23-Mar-91	89-7	9410	28200	14900	888	11.2	990	231	1500	58	1440	7.9	27.4	1.2	3600
91-07	24 Mar 91	6 Apr 91	89-7	4100	28200	14100	712	9.0	820	251	1330	50	1010	8.1	31.9	<1.0	3800
91-08	7-Apr-91	20-Apr-91	BR	3810	30200	14400	788	8.4	800	237	1040	57	1110	7.7	31.1	1.4	4800
91-09	21-Apr-91	4-May-91	BR	7280	25100	11900	872	7.8	780	243	1080	60	1130	7.8	34.5	1.4	4700
91-10	5-May-91	18-May-91	BR/89-7	7510	26500	13200	780	7.7	710	278	1140	52	1090	7.8	30.6	<1.0	4800
91-11	19-May-91	1 Jun 91	89-7/90-5	9800	35200	14400	840	8.0	750	276	1070	62	1400	7.7	28.8	<1.0	5000
91-12	2 Jun 91	15 Jun 91	90-6	4300	30200	11700	784	8.8	790	276	1240	60	1470	7.7	28.5	<1.0	4300
91-13	16 Jun-91	29-Jun-91	BR/90-6	10800	40000	11600	890	8.3	870	289	1650	88	1410	7.2	22.6	<1.0	12000
91-14	30-Jun-91	13-Jul-91	BR/90-6	7000	27900	14000	864	8.7	900	428	1800	62	1260	7.3	29.8	<1.0	12300
91-15	14-Jul-91	27-Jul 91	90-5	7700	29700	13800	888	9.0	830	419	1680	58	1210	7.3	27.8	<1.0	11500
91-16	28-Jul-91	10-Aug-91	90-5/91-1	8200	33800	14600	784	10.3	1130	360	2320	74	1100	7.2	26.3	<1.0	11300
91-17	11 Aug 91	24-Aug-91	91-1	NA	37400	15400	818	11.4	1320	330	2350	93	1490	7.1	24.0	<1.0	12000
91-18	25-Aug-91	7 Sep-91	91-1	10100	38300	15300	848	NA	NA	NA	NA	NA	NA	7.1	23.5	<1.0	11500
			MEAN	9128	34385	15892	708	10.9	1040	287	1816	73	1400	7.8	28.3		8292
			STD DEV	1187	10927	2516	178	2.3	188	53	376	20	203	0.3	3.3		3080

*odium Bicarbonate Extractable Phosporous

**Field Number of Brady Road Landfill (BR)

NA=not analyzed

TABLE I(c)

1991-92 SLUDGE DISPOSAL PROGRAM

ANALYTICAL RESULTS FOR DEWATERED SLUDGE

BIWEEKLY SAMPLE NUMBER	SAMPLING PERIOD from	SAMPLING PERIOD to	SLUDGE DISPOSAL AREA**	NH3-N (mg/kg)	TKN (mg/kg)	TOTAL PHOS (mg/kg)	SODIUM* PHOS (mg/kg)	CADMIUM (mg/kg)	COPPER (mg/kg)	LEAD (mg/kg)	ZINC (mg/kg)	NICKEL (mg/kg)	CHROMIUM (mg/kg)	pH	TOTAL SOLIDS (%)	PCB (ug/g)	CONDUCT. (umhos/cm)
91-19	8-Sep-91	21-Sep-91	91-1	8900	42900	16100	612	13.6	1690	281	2410	61	1670	7.4	21.6	0.74	6400
91-20	22-Sep-91	5-Oct-91	91-1	[illegible]	39600	14800	584	12.0	1560	295	2320	63	1570	7.5	21.7	0.45	5400
91-21	6-Oct-91	19-Oct-91	91-1	7300	40300	15000	656	14.3	1320	328	2230	47	1500	7.5	22.0	0.43	670.0
91-22	20-Oct-91	2-Nov-91	91-1	8400	38400	14800	NR	12.3	1150	298	2250	58	1340	NR	23.6	0.26	NR
91-23	3-Nov-91	16-Nov-91	91-1	9100	44100	18000	NR	11.7	1300	352	2130	58	1710	NR	22.3	0.53	NR
91-24	17-Nov-91	30-Nov-91	91-1	9000	42700	17700	908	9.1	1150	316	1740	53	1780	7.9	22.4	0.39	6700
91-25	1-Dec-91	14-Dec-91	91-3	9700	42900	19000	896	9.9	1310	323	2170	59	2150	8.0	22.1	0.35	6700
91-26	15-Dec-91	28-Dec-91	91-3	9700	40400	19200	NR	11.2	1280	281	1940	48	2300	NR	22.9	0.48	NR
92-01	29-Dec-91	11-Jan-92	91-3	9570	44800	20800	944	15.3	1460	288	1950	54	2800	7.5	21.6	0.44	7300
92-02	12-Jan-92	25-Jan-92	91-3	9950	45100	20800	976	14.6	1480	262	1790	55	2870	7.5	21.1	0.45	7700
92-03	26-Jan-92	8-Feb-92	91-3	10200	46800	22600	936	13.3	1460	251	1810	51	2840	7.6	21.6	0.50	7300
92-04	9-Feb-92	22-Feb-92	91-2	10200	47400	30600	NR	12.2	1440	270	1950	60	2760	7.7	20.2	<1.0	6300
92-05	23-Feb-92	7-Mar-92	91-2	8900	40300	25400	796	12.2	1450	283	2020	58	2900	7.6	23.7	<1.0	7000
92-06	8-Mar-92	21-Mar-92	91-2	7400	34400	18800	790	10.1	1130	279	1880	67	1910	7.5	27.2	<1.0	10500
92-07	22-Mar-92	4-Apr-92	91-2	7700	32000	17000	722	8.4	950	255	1710	55	1950	7.3	29.3	<1.0	11000
92-08	5-Apr-92	18-Apr-92	[illegible]	7800	30800	14600	788	8.1	770	226	1500	48	1840	7.4	31.7	<1.0	10500
92-09	19-Apr-92	2-May-92	III	8600	32200	13600	844	8.9	690	227	1750	48	1880	7.5	30.8	<1.0	9250
92-10	3-May-92	16-May-92	III & PAD	7900	32000	13700		10.1	720	269	1400	51	1830	7.4	29.7	0.75	9500
92-11	17-May-92	30-May-92	91-4	9300	35500	15500		11.7	780	255	1430	45	1940	7.5	29.3	0.63	10000
92-12	31-May-92	13-Jun-92	91-4	9000	37000	15800		10.7	820	263	1590	50	2030	7.5	29.1	0.51	12900
92-13	14-Jun-92	27-Jun-92	91-4	8300	20900	14900		11.9	840	285	1950	58	2020	7.6	29.9	0.50	11000
92-14	28-Jun-92	11-Jul-92	91-4,91-10	8700	23400	14700		12.4	750	286	1920	64	1790	7.6	30.3	0.44	12000
92-15	12-Jul-92	25-Jul-92	91-4,91-10	8400	21700	13700		10.1	690	278	1640	55	1450	7.7	30.8	0.29	13000
92-16	26-Jul-92	8-Aug-92	91-4,91-10	8300	20800	14400		10.9	820	298	1810	58	1400	7.6	29.9	0.37	13000
92-17	9-Aug-92	22-Aug-92	91-4,91-10	8400	31900	14500		10.5	920	291	1720	46	1590	7.6	28.1	0.44	13000
92-18	23-Aug-92	5-Sep-92	91-4,91-10	8000	33700	13800		11.2	880	289	1710	46	1560	7.8	28.1	0.43	13000
			MEAN	8724	36231	17300	804	11.4	1108	282	1874	55	1976	7.6	25.8	0.48*	9520
			STD DEV	[illegible]	8020	4085	130	1.9	317	29	267	6	484	0.2	4.0		2629

** Field Number ... [illegible] Landfill (III)
* Median Value

NR = not analyzed

TABLE I(b)

1992-93 SLUDGE DISPOSAL PROGRAM

ANALYTICAL RESULTS FOR DEWATERED SLUDGE

BIWEEKLY SAMPLE NUMBER	SAMPLING from	PERIOD to	SLUDGE DISPOSAL AREA**	NH3-N (mg/kg)	TKN (mg/kg)	TOTAL PHOS. (mg/kg)	CADMIUM (mg/kg)	COPPER (mg/kg)	LEAD (mg/kg)	ZINC (mg/kg)	NICKEL (mg/kg)	CHROMIUM (mg/kg)	pH	TOTAL SOLIDS (%)	PCB (ug/g)	CONDUCT. (umhos/cm)
92-19	6-Sep-92	19-Sep-92	91-4	7100	30400	13500	11.4	870	278	1440	39	1460	6.9	29.3	0.5	18000
92-20	20-Sep-92	3-Oct-92	91-4	7500	31100	14500	11.8	960	299	1680	45	1610	7.0	27.1	0.4	20000
92-21	4-Oct-92	17-Oct-92	91-4/92-1	8800	33200	15500	12.5	1220	252	2600	48	1490	7.3	26.6	0.5	9500
92-22	18-Oct-92	31-Oct-92	92-1	9000	36600	17000	14.8	1260	235	2460	49	1780	7.3	23.4	0.4	12500
92-23	1-Nov-92	14-Nov-92	92-1	9900	45600	17200	14.4	1310	233	2420	53	1970	7.3	24.4	0.4	12000
92-24	15-Nov-92	28-Nov-92	92-1	10600	47900	18000	14.8	1430	228	2150	53	2040	7.5	23.9	0.4	9000
92-25	29-Nov-92	12-Dec-92	92-1/92-4	11300	50100	18900	15.1	1500	234	1850	54	1940	7.6	23.0	<0.3	8500
92-26	13-Dec-92	26-Dec-92	92-4	10100	46900	16300	19.2	1500	241	2290	55	1900	7.4	24.1	0.4	9000
93-01	27-Dec-92	9-Jan-93	92-4/#3	11500	49200	16800	19.6	1440	217	2170	52	1700	7.4	22.0	0.3	7500
93-02	10-Jan-93	23-Jan-93	#3	11100	50200	17000	18.5	1530	212	1720	53	1710	7.5	21.6	0.3	7500
93-03	24-Jan-93	6-Feb-93	#3	10200	45100	17000	20.1	1420	212	1750	59	1340	7.5	22.2	<0.1	8000
93-04	7-Feb-93	20-Feb-93	#1 / #4	10000	44000	14300	20.4	1510	215	1630	53	1570	7.5	23.3	<0.1	8000
93-05	21-Feb-93	6-Mar-93	#4 / #5	12200	47300	15900	20.2	1400	236	1850	73	1350	7.3	23.0	<0.1	8500
93-06	7-Mar-93	20-Mar-93	#4	11100	39600	13500	16.1	1130	219	1710	73	1250	7.3	27.4	<0.1	9000
93-07	21-Mar-93	3-Apr-93	#4	10100	36400	12900	13.6	1130	205	1450	63	1100	7.2	29.7	<0.1	8500
93-08	4-Apr-93	17-Apr-93	#1 / #2	9500	48300	11000	10.8	1000	191	1190	54	880	7.3	30.4	<0.1	7500
93-09	18-Apr-93	1-May-93	#1	7300	31600	13100	10.3	900	186	1070	53	880	7.4	28.9	0.5	7500
93-10	2-May-93	15-May-93	#1 / #2	7100	32300	13000	12.0	1050	220	1220	66	1130	7.4	29.0	0.1	6500
93-11	16-May-93	29-May-93	#2 / #4 / #7	7400	29600	13400	11.3	940	199	1300	58	1050	7.4	30.3	0.3	6000
93-12	30-May-93	12-Jun-93	#4	9200	33800	14400	NS	NS	NS	NS	NS	NS	7.4	28.7	0.1	6500
93-13	13-Jun-93	26-Jun-93	#1 / #4	9000	31500	14500	14.1	1010	210	1620	55	1290	7.6	27.3	0.1	6500
93-14	27-Jun-93	10-Jul-93	#1 / #2 / #8	8400	33000	13600	13.4	890	217	1670	50	1290	7.5	28.8	0.1	7000
93-15	11-Jul-93	24-Jul-93	#1 / #8	8000	31700	13800	17.7	950	222	1580	50	1010	7.3	26.8	<0.1	6500
93-16	25-Jul-93	7-Aug-93	#1	8700	28800	13200	17.6	950	341	1480	48	820	7.3	29.0	<0.1	6000
93-17	8-Aug-93	21-Aug-93	#1 / #2	7400	28100	11600	14.1	880	607	1400	50	830	7.4	31.1	<0.1	6000
93-18	22-Aug-93	4-Sep-93	#1 / #2	7500	27400	11000	11.6	750	565	1350	49	860	7.9	30.5	<0.1	5500
			MEAN	9231	38098	14681	15.0	1157	259	1722	54	1369	7.4	26.6	*0.21	8731
			STD.DEV	1536	8109	2121	3.3	251	104	417	8	389	0.2	3.1		3473

** SITE #1 is the Drying Bed Storage Pad and SITE #2 is Brady Rd Landfill

*Median Value

NA=not analyzed

TABLE I(b)

1993-94 SLUDGE DISPOSAL PROGRAM

ANALYTICAL RESULTS FOR DEWATERED SLUDGE

BIWEEKLY SAMPLE NUMBER	SAMPLING PERIOD from	to	SLUDGE DISPOSAL SITE**	NH3-N (mg/kg)	TKN (mg/kg)	TOTAL PHOS (mg/kg)	CADMIUM (mg/kg)	COPPER (mg/kg)	LEAD (mg/kg)	ZINC (mg/kg)	NICKEL (mg/kg)	CHROMIUM (mg/kg)	pH	TOTAL SOLIDS (%)	PCB (ug/g)	CONDUCT (umhos/cm)
93-19	5-Sep-93	18-Sep-93	#1/#2/#6	7900	31800	11500	11.9	890	419	1540	46	1080	8.1	27.5	<0.1	6000
93-20	19-Sep-93	2-Oct-93	#5	8200	37800	13600	14.7	990	409	1660	45	1320	8.0	25.4	<0.1	8000
93-21	3-Oct-93	16-Oct-93	#5/#2	9100	40400	7800	19.6	1250	356	1620	44	1750	8.0	24.0	0.3	9000
93-22	17-Oct-93	30-Oct-93	#9	9800	43400	13000	22.4	1370	290	1540	44	2280	7.7	22.6	<.01	7500
93-23	31-Oct-93	13-Nov-93	#9	9600	45500	8600	20.4	1350	318	1390	50	2290	8.1	23.2	0.2	8000
93-24	14-Nov-93	27-Nov-93	#5	9500	44300	9700	20.4	1360	280	2350	52	2480	8.2	23.5	0.3	9000
93-25	28-Nov-93	11-Dec-93	#9	11100	43500	10500	19.4	1390	256	1820	48	2650	8.3	23.4	0.2	8000
93-26	12-Dec-93	25-Dec-93	#9	11300	46600	21174	17.6	1500	222	1660	46	2950	8.2	21.8	0.7	5500
94-01	26-Dec-93	8-Jan-94	#9	11730	51400	18430	18	1600	200	1500	46	2650	8.1	21.7	0.7	7500
94-02	9-Jan-94	22-Jan-94	#9	11500	47600	17500	17.2	1560	230	1690	56	2650	8.1	22.8	0.8	6500
94-03	23-Jan-94	5-Feb-94	#9	11200	51000	17152	17.2	1590	222	1810	48	2990	8.3	22.4	0.8	8000
94-04	6-Feb-94	19-Feb-94	#5, #10	11900	46500	18278	13.6	1330	188	1380	44	2190	8.2	24.6	1.1	7000
94-05	20-Feb-94	5-Mar-94	#10	11200	42500	17742	11.3	1260	158	1220	42	2020	8.1	25.3	1.0	6500
94-06	6-Mar-94	19-Mar-94	#10	9300	34400	14219	11.2	990	142	1180	41	1470	8.5	29.2	0.9	7500
94-07	20-Mar-94	2-Apr-94	#10	9900	34800	13262	11.7	900	140	1320	39	1370	8.2	28.6	0.5	8000
94-08	3-Apr-94	16-Apr-94	#1/#2	10100	31400	15242	11.8	910	147	1310	42	1360	8.1	28.4	0.2	7000
94-09	17-Apr-94	30-Apr-94	#1/#2	13600	36300	15134	11.3	880	138	1070	38	1470	8.1	29.1	0.2	6000
94-10	1-May-94	14-May-94	#1/#2	9400	37400	16055	11.2	790	132	1050	41	1500	8.2	23.1	0.2	7000
94-11	15-May-94	28-May-94	#1/#2/#11	9500	33000	15678	11.7	820	164	1290	47	1530	8.1	28.9	0.2	6000
94-12	29-May-94	11-Jun-94	#11	8800	32000	14990	11.6	810	185	1210	48	1380	8.1	28.0	0.3	6000
94-13	12-Jun-94	25-Jun-94	#1/#11	10000	35800	16742	15.2	870	152	1200	46	1600	NS	27.1	0.2	6000
94-14	26-Jun-94	9-Jul-94	#1/#11	9500	3400	16845	NS	NS	NS	NS	NS	NS	8.0	27.1	0.2	5500
94-15	10-Jul-94	23-Jul-94	#1	9400	31000	14993	15.8	530	242	1300	42	1080	8.0	27.9	0.2	6000
94-16	24-Jul-94	6-Aug-94	#1/#11	9100	35000	14697	16.2	910	242	1370	43	1080	7.8	27.1	0.2	5500
94-17	7-Aug-94	20-Aug-94	#11	7600	36000	14018	13.8	950	215	1290	45	1170	8.0	26.9	0.1	5000
94-18	21-Aug-94	3-Sep-94	#11	7500	34000	15470	12.1	1020	205	1230	45	1410	7.8	25.3	0.2	4500
			MEAN	9803	37969	14727	15.1	1129	227	1464	45	1530	8.1	25.0	0.48*	6788
			STD DEV	1262	5454	3251	3.5	276	81	308	4	623	0.2	2.6		1201

** SITE #1 is the Drying Bed Storage Pad and SITE #2 is Brady Rd Landfill
*Median Value

NS=no sample

TABLE I(b)

1994-95 SLUDGE DISPOSAL PROGRAM

ANALYTICAL RESULTS FOR DEWATERED SLUDGE

BIWEEKLY SAMPLE NUMBER	SAMPLING PERIOD from	to	SLUDGE DISPOSAL AREA**	NH3-N (mg/kg)	TKN (mg/kg)	TOTAL PHOS (mg/kg)	CADMIUM (mg/kg)	LEAD (mg/kg)	ZINC (mg/kg)	NICKEL (mg/kg)	COPPER (mg/kg)	CHROMIUM (mg/kg)	pH	TOTAL SOLIDS (%)	PCB (ug/g)	CONDUCT (umhos/cm)
94-19	9/4/94	9/17/94	#1/#11/#12	9100	35600	16300	11.5	236	1400	41	1160	1880	7.9	24.4	0.2	5900
94-20	9/18/94	10/1/94	#12	8500	36200	16400	12.0	257	1650	44	1170	1840	8.1	25.3	<0.3	5500
94-21	10/2/94	10/15/94	#12/#1/#2	8800	41000	17000	11.4	249	1560	48	1310	1770	8.2	25.1	<1.0	6100
94-22	10/16/94	10/29/94	#2/#1/#13	10800	40400	16600	10.0	246	1580	47	1340	1510	8.2	23.4	<0.3	6600
94-23	10/30/94	11/12/94	#2/#10/#13	9700	41500	17500	10.8	226	1760	42	1280	1090	8.0	24.3	<0.3	7000
94-24	11/13/94	11/26/94	#10/#2	9700	41600	16800	12.0	219	1590	50	1290	1000	8.3	25.1	<0.3	6400
94-25	11/27/94	12/10/94	#10	9400	39700	17100	12.8	215	1463	46	1215	1060	8.1	26.3	<1.0	7000
94-26	12/11/94	12/24/94	#10/#13/#12	9400	42100	17000	14.7	253	1990	43	1260	1650	8.1	26.1	<0.3	7400
95-01	12/25/94	1/7/95	#12	11700	49800	19500	14.3	216	1970	37	1520	1300	8.1	21.1	<0.3	4000
95-02	1/8/95	1/21/95	#12	11900	49200	20300	14.1	218	1750	40	1600	1650	8.1	20.8	<0.3	5400
95-03	1/22/95	2/4/95	#12/#13	11200	45900	18600	15.4	203	1600	39	1540	1880	8.1	21.8	<0.4	5600
95-04	2/5/95	2/18/95	#13	11800	46300	19500	19.9	180	1610	37	1620	2300	7.9	21.7	<0.4	5600
95-05	2/19/95	3/4/95	#13	11200	46300	19300	18.3	185	1870	39	1580	2350	8.0	22.1	0.4	5700
95-06	3/5/95	3/18/95	#13	9300	44000	18500	18.4	186	1680	42	1580	2330	8.2	23.8	0.4	6600
95-07	3/19/95	4/1/95	#1/#2	9900	33300	16400	13.5	158	1300	40	1190	1630	8.0	28.1	<0.25	5000
95-08	4/2/95	4/15/95	#1/#2	10100	27700	12200	8.8	192	1150	41	880	1440	8.1	31.7	<0.26	4900
95-09	4/16/95	4/29/95	#1/#2	10600	29400	12600	7.7	187	1140	42	820	1410	8.1	31.6	<0.26	4500
95-10	4/30/95	5/13/95	#1/#2	9400	28500	14600	8.6	183	1130	43	920	1520	8.0	26.9	<0.26	5600
95-11	5/14/95	5/27/95	#1/#2	9500	30400	15600	9.3	188	1130	52	880	1510	8.3	26.2	<1.0	5000
95-12	5/28/95	6/10/95	#1/#2/#13	8800	28900	15000	9.7	216	1320	54	900	1370	8.2	29.6	<1.0	4000
95-13	6/11/95	6/24/95	#13/#14	10000	28500	15300	8.9	207	1510	47	920	1370	7.9	27.7	<1.0	5300
95-14	6/25/95	7/8/95	#14	9500	30800	14700	10.8	207	1360	46	950	1340	8.1	27.7	<1.0	4800
95-15	7/9/95	7/22/95	#14/#1	9400	30500	15000	10.6	187	1270	43	1030	1090	8.0	27.3	<1.0	4700
95-16	7/23/95	8/5/95	#1/#14	9100	34800	16200	10.7	191	1760	41	1090	920	8.1	26.3	<1.0	4100
95-17	8/6/95	8/19/95	#14/#1	7600	36400	16500	10.2	183	1800	42	1200	1180	8.0	25.8	<1.0	4800
95-18	8/20/95	9/2/95	#14	7500	31000	15200	9.6	212	1620	43	1170	1270	8.1	26.2	<1.0	4000
			MEAN	9765	37323	16504	12.1	209	1537	43	1209	1545	8.1	25.7	0.48*	5442
			STD DEV	1153	7102	2019	3.2	24	256	4	253	399	0.1	2.9		981

** SITE #1 is the Drying Bed Storage Pad and SITE #2 is Brady Rd. Landfill

*Median Value

NS-no sample

TABLE I(b)

1994-95 SLUDGE DISPOSAL PROGRAM

ANALYTICAL RESULTS FOR DEWATERED SLUDGE

BIWEEKLY SAMPLE NUMBER	SAMPLING PERIOD from	to	SLUDGE DISPOSAL AREA**	NH3-N (mg/kg)	TKN (mg/kg)	TOTAL PHOS (mg/kg)	CADMIUM (mg/kg)	LEAD (mg/kg)	ZINC (mg/kg)	NICKEL (mg/kg)	COPPER (mg/kg)	CHROMIUM (mg/kg)	pH	TOTAL SOLIDS (%)	PCB (ug/g)	CONDUCT. (umhos/cm)
94-19	9/4/94	9/17/94	#1/#11/#12	9100	35600	16500	11.3	236	1400	41	1160	1880	7.9	24.4	0.2	5900
94-20	9/18/94	10/1/94	#12	8500	36200	16400	12.0	257	1650	44	1170	1940	8.1	25.3	<0.3	5500
94-21	10/2/94	10/15/94	#12/#1/#2	8800	41000	17000	11.4	249	1560	48	1310	1770	8.2	25.1	<1.0	6100
94-22	10/16/94	10/25/94	#2/#1/#13	10800	40400	16600	10.0	246	1580	47	1340	1510	8.2	23.4	<0.3	6600
94-23	10/30/94	11/12/94	#2/#10/#13	9700	41500	17500	10.8	226	1760	42	1280	1090	8.0	24.3	<0.3	7000
94-24	11/13/94	11/26/94	#10/#2	9700	41600	16800	12.0	219	1590	50	1290	1000	8.3	25.1	<0.3	6400
94-25	11/27/94	12/10/94	#10	9400	39700	17100	12.8	215	1453	46	1215	1060	8.1	26.3	<1.0	7000
94-26	12/11/94	12/24/94	#10/#13/#12	9400	42100	17000	14.7	253	1990	43	1280	1650	8.1	26.1	<0.3	7400
95-01	12/25/94	1/7/95	#12	11700	49400	19500	14.3	216	1570	37	1520	1400	8.1	21.1	<0.3	4000
95-02	1/8/95	1/21/95	#12	11900	49200	20300	14.1	218	1750	40	1600	1650	8.1	20.8	<0.3	5400
95-03	1/22/95	2/4/95	#12/#13	11200	45900	18800	15.4	203	1600	39	1540	1880	8.1	21.8	<0.4	5600
95-04	2/5/95	2/18/95	#13	11800	46300	19500	19.9	180	1610	37	1620	2300	7.9	21.7	<0.4	5600
95-05	2/19/95	3/4/95	#13	11200	46900	19300	18.3	185	1870	39	1580	2350	8.0	22.1	0.4	5700
95-06	3/5/95	3/18/95	#13	9300	44000	18500	18.4	186	1680	42	1580	2330	8.2	23.8	0.4	6600
95-07	3/19/95	4/1/95	#1/#2	9900	33300	15400	13.5	188	1300	40	1190	1630	8.0	28.1	<0.25	5000
95-08	4/2/95	4/15/95	#1/#2	10100	27700	12200	8.8	192	1150	41	880	1440	8.1	31.7	<0.25	4900
95-09	4/16/95	4/29/95	#1/#2	10600	29400	12600	7.7	187	1140	42	820	1410	8.1	31.6	<0.26	4500
95-10	4/30/95	5/13/95	#1/#2	9400	28500	14600	8.6	183	1130	43	920	1520	8.0	26.9	<0.26	5600
95-11	5/14/95	5/27/95	#1/#2	9500	30400	15600	9.3	186	1130	52	880	1510	8.3	26.2	<1.0	5000
95-12	5/28/95	6/10/95	#1/#2/#13	8800	28900	15000	9.7	216	1320	54	900	1370	8.2	29.6	<1.0	4000
95-13	6/11/95	6/24/95	#13/#14	10000	28500	15300	8.9	207	1510	47	920	1370	7.9	27.7	<1.0	5300
95-14	6/25/95	7/8/95	#14	9500	30800	14700	10.8	207	1360	45	950	1340	8.1	27.7	<1.0	4800
95-15	7/9/95	7/22/95	#14/#1	9400	30500	15000	10.6	187	1270	43	1030	1090	8.0	27.3	<1.0	4700
95-16	7/23/95	8/5/95	#1/#14	9100	34800	16200	10.7	191	1760	41	1090	920	8.1	26.3	<1.0	4100
95-17	8/6/95	8/19/95	#14/#1	7600	36400	16500	10.2	183	1800	42	1200	1180	8.0	25.8	<1.0	4800
95-18	8/20/95	9/2/95	#14	7500	31000	15200	9.6	212	1620	43	1170	1270	8.1	26.2	<1.0	4000
			MEAN	9765	37323	16504	12.1	209	1537	43	1209	1545	8.1	25.7	0.48*	5442
			STD DEV	1159	7102	2019	3.2	24	256	4	253	399	0.1	2.9		981

** SITE #1 is the Drying Bed Storage Pad and SITE #2 is Brady Rd. Landfill

*Median Value

NS-no sample

TABLE I(b)

1994-95 SLUDGE DISPOSAL PROGRAM

ANALYTICAL RESULTS FOR DEWATERED SLUDGE

BIWEEKLY SAMPLE NUMBER	SAMPLING PERIOD from	to	SLUDGE DISPOSAL AREA**	NH3-N (mg/kg)	TKN (mg/kg)	TOTAL PHOS (mg/kg)	CADMIUM (mg/kg)	LEAD (mg/kg)	ZINC (mg/kg)	NICKEL (mg/kg)	COPPER (mg/kg)	CHROMIUM (mg/kg)	pH	TOTAL SOLIDS (%)	PCB (ug/g)	CONDUCT (umhos/cm)
94-19	9/4/94	9/17/94	#1/#11/#12	9100	35600	16300	11.3	236	1400	41	1160	1880	7.9	24.4	0.2	5900
94-20	9/18/94	10/1/94	#12	8500	36200	16400	12.0	257	1650	44	1170	1940	8.1	25.3	<0.3	5500
94-21	10/2/94	10/15/94	#12/#1/#2	8800	41000	17000	11.4	249	1560	48	1310	1770	8.2	25.1	<1.0	6100
94-22	10/16/94	10/29/94	#2/#1/#13	10800	40400	16800	10.0	246	1580	47	1340	1510	8.2	23.4	<0.3	6600
94-23	10/30/94	11/12/94	#2/#10/#13	9700	41500	17500	10.8	226	1760	42	1280	1090	8.0	24.3	<0.3	7000
94-24	11/13/94	11/26/94	#10/#2	9700	41600	16800	12.0	219	1590	50	1290	1000	8.3	25.1	<0.3	6400
94-25	11/27/94	12/10/94	#10	9400	39700	17100	12.8	215	1453	46	1215	1060	8.1	26.3	<1.0	7000
94-26	12/11/94	12/24/94	#10/#13/#12	9400	42100	17000	14.7	253	1990	43	1280	1650	8.1	26.1	<0.3	7400
95-01	12/25/94	1/7/95	#12	11700	49800	19500	14.3	216	1570	37	1520	1800	8.1	21.1	<0.3	4000
95-02	1/8/95	1/21/95	#12	11900	49200	20300	14.1	218	1750	40	1600	1650	8.1	20.8	<0.3	5400
95-03	1/22/95	2/4/95	#12/#13	11200	45900	18600	15.4	203	1600	39	1540	1880	8.1	21.8	<0.4	8800
95-04	2/5/95	2/18/95	#13	11800	46300	19500	19.9	180	1610	37	1620	2300	7.9	21.7	<0.4	5600
95-05	2/19/95	3/4/95	#13	11200	46900	19300	18.3	185	1870	39	1580	2350	8.0	22.1	0.4	5700
95-06	3/5/95	3/18/95	#13	9300	44000	18500	18.4	186	1680	42	1580	2330	8.2	23.8	0.4	6600
95-07	3/19/95	4/1/95	#1/#2	9900	33300	15400	13.5	158	1300	40	1190	1630	8.0	28.1	<0.25	5000
95-08	4/2/95	4/15/95	#1/#2	10100	27700	12200	8.8	192	1150	41	880	1440	8.1	31.7	<0.25	4900
95-09	4/16/95	4/29/95	#1/#2	10600	29400	12600	7.7	187	1140	42	820	1410	8.1	31.6	<0.26	4500
95-10	4/30/95	5/13/95	#1/#2	9400	28500	14600	8.6	183	1130	43	920	1520	8.0	26.9	<0.26	5600
95-11	5/14/95	5/27/95	#1/#2	9500	30400	15600	9.3	188	1130	52	880	1510	8.3	26.2	<1.0	5000
95-12	5/28/95	6/10/95	#1/#2/#13	8800	28900	15000	9.7	216	1320	54	900	1370	8.2	29.6	<1.0	4000
95-13	6/11/95	6/24/95	#13/#14	10000	28500	15300	8.9	207	1510	47	920	1370	7.9	27.7	<1.0	5300
95-14	6/25/95	7/8/95	#14	9500	30800	14700	10.8	207	1360	45	950	1340	8.1	27.7	<1.0	4800
95-15	7/9/95	7/22/95	#14/#1	9400	30500	15000	10.6	187	1270	43	1030	1090	8.0	27.3	<1.0	4700
95-16	7/23/95	8/5/95	#1/#14	9100	34800	16200	10.7	191	1760	41	1090	920	8.1	26.3	<1.0	4100
95-17	8/6/95	8/19/95	#14/#1	7600	36400	16500	10.2	183	1800	42	1200	1180	8.0	25.8	<1.0	4800
95-18	8/20/95	9/2/95	#14	7500	31000	15200	9.6	212	1620	43	1170	1270	8.1	26.2	<1.0	4000
			MEAN	9765	37323	16504	12.1	209	1537	43	1209	1545	8.1	25.7	0.48*	5442
			STD DEV	1158	7102	2019	3.2	24	256	4	253	399	0.1	2.9		981

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*Median Value

NS-no sample

APPENDIX II

CALCULATIONS OF FEEDSTOCK PREPARATION AND FEEDING CONDITION OF SUBSTRATE

Calculations of the amount of each component of the feedstock to be mixed as a windrow were done as follows:

$$M_{total} = M_{sludge} + M_{leaves} + M_{recycle}$$

$$M_{total} \times 0.55 = M_{sludge} \times W_{sludge} + M_{leaves} \times W_{leaves} + M_{recycle} \times W_{recycle}$$

where M = mass (kg)

W = moisture content (%)

0.55 - corresponds to the target moisture content of the pile

Total wet biosolids = 48.702 Tonnes
" dry " = 12.662 Tonnes
Average moisture content = 74%
Total Nitrogen = 12.662 x 0.0188 = 238 dry tonnes
Average Nitrogen content in biosolids (dry) = 1.88%
Total carbon = 12.662 x 0.295 = 3735.3 dry tonnes
([illegible])
M of leaves = 20% Recycle ratio = 3:1 = F:R
" recycle = 40%
$0.74(48702) + 0.2(0.67M_T - 48702) + 0.4(0.33M_T) = 0.55M_T$
M_r = 30.345 wet tonnes = 18207 dry tonnes
M_L = 12,907 wet tonnes
= 10.327 dry tonnes

Total Nitrogen in leaves = 10327 x 0.0075
= 77.5 dry tonnes

Total carbon in leaves = 10327 x 0.45
(Tchobanoglous 1993) = 4647 dry tonnes

Total Nitrogen in Recycle = 18207 × 0.0093

= 169 dry tonnes

Total Carbon in recycle = 18207 × 0.23

= 4187.6 dry tonnes

M_T = 12,662 + 10,327 + 18,207

= 41,197 dry tonnes

Total Nitrogen in the feedstock

= 238 + 77.6 + 169

= 484.6 dry tonnes

Total Carbon in feedstock

= 3735.3 + 4,647 + 4,187.6

= 12569 dry tonnes, $C/N = \frac{12569}{484.6} = \underline{\underline{26}}$

Total mass (M) after composting:

Total volatile solids = total carbon × 2

= 12570 × 2 = 25140 dry tonnes

Net compostable dry weight

= 41197 − 25140 =

= 16057 dry tonnes

50% of volatile solids destruction assumed

25140 x 0.5 = 12570 dry solids destroyed

∴ Total mass after composting

= 16057 + 12570

= 28627 dry tonnes before recycling

After recycling 28627 − 18207 = 10420 dry tonnes

Total Nitrogen in compost

= 10420 x 0.0093 = 97 dry tonnes

Total carbon in compost

10420 x 0.23 = 2396 dry tonnes

Total mass of compost after screening

= 10420 x 0.75 = 7,815 dry tonnes

Total mass of oversized material
= 2605 dry tonnes

ASH – [5698 + 1239 [illegible] – 5698 – 1239 [illegible]] · 30.5% = 9456 tonnes

WAT = 30345 – 30345 · 60% = 12138 tonnes

<u>Mixture</u>

E·C – 3134 + [illegible] = [illegible] tonnes

NBYS = 3830 + 2590 + 8751 = 15171 tonnes.

ASH = 5698 + 1239 + 9456 = 16393 tonnes.

WAT = 36040 + 2581 + 12138 = 50759 tonnes.

APPENDIX III

AREA REQUIREMENT CALCULATIONS FOR THE WINDROW COMPOSTING FACILITY

Area requirement calculations

Daily biosolids production of the city = 133.5 wet tonnes

Biosolids density = 999.7 kg/m^3 ([illegible] 1995, [illegible] 134)

$$\text{Biosolids volume} = \frac{133500\ kg}{999.7\ kg/m^3} = 133.5\ m^3$$

Volume of material pad must hold

$= 133.5 \times 60 = 8010\ m^3$

where SRT = 60 days ([illegible] et al [illegible])

Shrinkage factor = 0.75 ([illegible] et al 199[illegible], p [illegible])

$0.75 \times 8010 = 6007.5\ m^3$

Assuming the [illegible] of the windrow 300 ft (91 m) ([illegible]) and the bucket loader can build a windrow 6 feet (1.8 m) high, 10 feet (3 m) wide (Rynk 1992) and these dimensions allow adequate air movement.

Windrow volume (V) = windrow cross sectional area x length where $A = \frac{2}{3} \times b \times h$

$V = \frac{2}{3} \times 1.8 \times 3 \times 91 \quad m \times m^2$

$= 329\ m^3$

Number of windrow = Volume of material / volume of a windrow

$= \frac{6007.5 m^3}{329 m^3} = 18$ Windrows

Overall pad width = 97 and length = 180 m

Therefore the total area required for composting

$= 180 \times 97$ m x m = 17460 m^2 (Fyne 1998: 75)

Assume the curing piles are 2 m high and they are stacked toe-to-toe (no space between the piles):

The volume of compost material in curing area

$= 133.5 m^3 \times 60 = 8010$ m^3

where curing time = 60 days.

Shrinkage factor = 0.5

$8010 \times 0.5 = 4005 m^3$

Curing area = Volume of material / Average pile height

$= \frac{4005 m^3}{2 m} = 2002 m^2$

Area layout = 28 x 97 = 2716 m^2 - 3 m on both sides

$$\text{Number of windrows} = \frac{\text{Volume of material}}{\text{volume of a windrow}}$$

$$= \frac{6007.5\,m^3}{329\,m^3} = 18 \text{ windrows}$$

Overall pad width = 97 and length = 180 m

Therefore the total area required for composting

$= 180 \times 97$ m×m $= 17460\ m^2$ ([illegible] 1993, p. 75)

Assume the curing piles are 2 m high and they are stacked toe-to-toe (no space between the piles):

The volume of compost material in curing area

$= 133.5\ m^3 \times 60 = 8010\ m^3$

where curing time = 60 days. ([illegible])

Shrinkage factor = 0.5

$8010 \times 0.5 = 4005\ m^3$

$$\text{Curing area} = \frac{\text{Volume of material}}{\text{average pile height}}$$

$$= \frac{4005\ m^3}{2\ m} = 2002\ m^2$$

Area layout $= 28 \times 97 = 2716\ m^2$ [illegible] 3 m on both sides

[illegible]

$[illegible] \times [illegible] \times [illegible] = 6007.5\ m^3$

[illegible] Storage [illegible] = [illegible] days ([illegible])

Storage [illegible] = $\frac{6007.5\ m^3}{2.5\ m} = 2403\ m^2$ ([illegible])

area layout = 32 m x 97 m = 3104 m^2 (3 m [illegible])

Total area required = 23,38[illegible] m^2

APPENDIX IV

TOTAL AND VOLATILE SOLIDS ANALYSIS, TEMPERATURE AND MOISTURE MESUREMENTS

Total and volatile solids analysis of the technical demonstration.

Cycle 1

Day	Sample (samp.)	No. of Cru.	Cru. (g)	Cru. + wet samp. (g)	(5)	Cru. + dried samp (g)	(6)	Cru. + ignited samp. (g)	(6)/(5) ×100 (TS)	(7)	[(6)-(7)] / (6) ×100 (VS)
			(1)	(2)	(2)-(1)	(3)	(3)-(1)	(4)		(4)-(1)	
0	1	4	67.55	87.25	19.7	76.16	8.61	69.00	43.71	1.45	83.16
	2	6	68.19	91.96	23.77	78.45	10.26	70.78	43.16	2.59	74.76
	3	7	67.15	87.22	20.07	75.96	8.81	69.40	43.90	2.25	74.46
15	1	4	67.56	78.48	10.92	72.18	4.62	69.22	42.31	1.66	64.07
	2	6	68.19	79.53	11.34	72.66	4.47	69.73	39.42	1.54	65.55
	3	7	67.15	77.45	10.3	71.58	4.43	68.69	43.01	1.54	65.24

	weight (kg)	average TS	average VS
Day 0	30.9	43.5	77.46
Day 15	27.15	42.0	64.95

Cycle 2

Day	Sample (samp.)	No. of Cru.	Cru. (g) (1)	Cru. + wet samp. (g) (2)	(5) (2)-(1)	Cru. + dried samp (g) (3)	(6) (3)-(1)	Cru. + ignited samp. (g) (4)	(6)/(5) ×100 (TS)	(7) (4)-(1)	[(6)-(7)] / (6) ×100 (VS)
0	1	10	67.77	78.43	10.66	72.69	4.92	68.73	46.15	0.96	80.49
	2	11	64.84	75.21	10.37	69.66	4.82	65.79	46.48	0.95	80.29
	3	15	64.67	75.04	10.37	69.66	4.99	65.56	48.12	0.89	82.16
15	1	A-7	97.53	105.19	7.66	101.19	3.66	98.82	47.78	1.29	64.75
	2	82	85.16	93.86	8.7	89.68	4.52	86.84	51.95	1.68	62.83
	3	5	100.60	107.60	7.0	104.03	3.43	101.89	49.00	1.29	62.39

	weight (kg)	average TS	average VS
Day 0	34.0	46.92	80.98
Day 15	29.6	49.00	63.32

Cycle 3

Day	Sample (samp.)	No. of Cru.	Cru. (g) (1)	Cru. + wet samp. (g) (2)	(5) (2)-(1)	Cru. + dried samp (g) (3)	(6) (3)-(1)	Cru. + ignited samp. (g) (4)	(6)/(5) ×100	(7) (4)-(1)	[(6)-(7)] / (6) ×100
0	1	12	67.02	77.23	10.21	71.23	4.21	67.94	41.23	0.92	78.15
	2	16	69.54	77.02	7.48	72.65	3.11	70.22	41.58	0.68	78.14
	3	17	67.79	77.43	9.64	71.44	3.65	68.64	37.86	0.85	76.71
15	1	11	64.84	74.34	9.5	69.14	4.3	66.64	45.26	1.8	58.14
	2	12	67.04	79.54	12.5	72.54	5.5	69.34	44.00	2.3	58.18
	3	7	67.15	75.08	7.93	70.80	3.65	68.70	46.03	1.55	57.53

	weight (kg)	average TS	average VS
Day 0	34.0	40.22	77.67
Day 15	28.2	45.00	57.95

Temperature measurements for cycle 1

	Temperature (° C)					
	Number of Points					
Day	1	2	3	4	5	Average
0	28.0	28.0	28.0	28.0	28.0	28.0
1	48.0	45.0	44.7	43.2	43.9	45.0
2	66.5	63.8	63.2	61.5	62.3	63.5
3	65.6	64.0	64.0	63.2	64.0	64.2
4	63.2	62.0	61.6	60.0	61.1	61.6
5	67.8	66.2	64.5	62.8	64.2	65.1
6	64.6	63.0	62.2	61.8	62.0	62.7
7	60.0	58.0	57.8	56.1	57.5	57.9
8	55.2	54.0	54.0	53.0	54.0	54.0
9	53.0	52.0	52.0	51.2	52.5	52.1
10	52.7	52.2	51.0	50.1	50.1	51.2
11	50.0	49.2	48.5	48.9	49.9	49.3
12	46.5	46.2	45.5	45.0	46.3	45.9
13	54.2	53.8	53.1	52.6	54.0	53.5
14	53.0	52.8	52.5	52.0	53.0	52.7
15	52.0	50.0	50.0	50.0	51.0	50.6

Temperature measurements for cycle 2

	Temperature (° C)					
	Number of Points					
Day	1	2	3	4	5	Average
0	24.0	24.0	24.0	24.0	24.0	24.0
1	56.0	55.8	55.6	55.0	56.0	55.7
2	73.4	73.0	72.0	70.5	72.0	72.2
3	70.2	69.0	68.2	68.0	68.4	68.8
4	67.2	66.9	67.0	66.8	67.0	67.0
5	60.0	59.2	58.8	58.3	59.6	59.2
6	56.0	55.0	54.9	55.2	55.4	55.3
7	54.0	54.0	53.8	53.6	54.0	53.9
8	52.0	51.8	51.2	50.8	52.0	51.6
9	49.0	48.0	47.9	48.0	49.0	48.4
10	48.0	48.0	47.2	48.4	48.6	48.0
11	47.0	46.5	46.0	46.2	46.4	46.4
12	47.0	47.0	47.0	47.0	47.0	47.0
13	46.5	46.5	46.4	46.6	46.5	46.5
14	46.5	46.8	46.5	46.5	46.5	46.6
15	46.5	46.4	46.6	46.5	46.5	46.5

Temperature measurements for cycle 3

	Temperature (° C)					
	Number of Points					
Day	1	2	3	4	5	Average
0	24.0	24.0	24.0	24.0	24.0	24.0
1	62.0	61.8	62.0	62.0	62.2	62.0
2	62.0	62.0	62.0	62.0	62.0	62.0
3	60.0	60.0	60.0	60.0	60.0	60.0
4	60.0	58.0	58.0	57.0	58.0	58.2
5	60.0	59.0	60.0	58.9	60.0	59.6
6	72.0	71.5	72.8	72.1	72.4	72.2
7	70.0	68.0	69.0	68.2	69.0	68.8
8	65.0	64.8	65.0	65.0	64.5	64.9
9	60.5	60.5	59.5	59.5	60.5	60.1
10	60.0	60.0	58.5	59.5	60.0	59.6
11	61.0	60.0	59.5	59.2	59.5	59.8
12	60.0	59.0	59.0	59.1	59.0	59.2
13	58.0	57.2	57.1	56.8	55.4	56.9
14	52.2	52.2	52.2	52.1	52.3	52.2
15	52.0	51.8	51.9	51.8	52.2	51.9

Moisture determinations of cycle 1

Day	Moisture before correction (%)	Moisture after correction (%)
0	56.5	-
4	52	57.4
8	54	-
12	48.2	58.5
15	57	-

Moisture determinations of cycle 2

Day	Moisture before correction (%)	Moisture after correction (%)
0	56	-
4	54	59.2
8	58.6	-
12	58	-
15	51	-

Moisture determinations of cycle 3

Day	Moisture before correction (%)	Moisture after correction (%)
0	59	-
4	53.2	58
8	56	-
12	52.7	59.4
15	55	-

APPENDIX V

COST CALCULATIONS, CORRECTION FACTOR DETERMINATIONS AND SKETCH OF THE STORAGE PAD

The break down of the existing biosolids disposal program of the City of Winnipeg was conducted as follows:

The total cost of the existing biosolids disposal program =$954,000.00 (Mr. B. Amy).

The biosolids landfilling cost = $105.489.00. (Mr. B. AMY)

The total existing program cost

= biosolids transporation cost + biosolids landapplication cost + biosolids landfilling cost.

Thus. Biosolids transportation cost + landapplication cost

= 954.000 - 105,489

= $ 848.511.00

The transportation & landapplication costs are not broken down (Mr. B. Amy).
The ratio of the biosolids transportation: landapplication: landfilling cost calculation base on US-EPA 1985 showed that:

878,000 : 295,000 : 149,800

ie 878 + 295 = 149.8

= 7.83. while in the case of the

real existing program; the ratio of the biosolids transportation + landapplication : landfilling

= 848,511 : 105,489

= 8.0, a value very close to the ratio based on US-EPA 1985.

Therefore the ratio of the biosolids transportation cost to the biosolids transportation + land application is use to break down the existing program cost.

The total transportation cost = $\frac{876.8}{876.8 + 295} \times 848.511$

= \$634,899

The total landapplication cost = $\frac{295}{876.8 + 295} \times 848.511$

= \$ 213,394.00.

The total landfilling cost = \$105,489

Biosolids transportation cost estimation based on EPA-1985 for the City of Winnipeg was conducted as follows:

The means of the biosolids transportation is truck hauling. The base capital cost for biosolids transportation includes purchase of trucks (US-EPA 1985).

1. 88% of the city biosolids goes to landapplication.

Total annual biosolids production of the City = 12,781 dry tonnes

∴ 88% × 12,781 = 11,247.3 dry tonnes

Average moisture content = 26.2%

Annual biosolids volume = 11 Million gallons (US-EPA 1985, P 208. Fig 10-2)

The round trip of the hauling distance = 50-100 = 31 - 62 miles (Mr. B. Amy) Average is taken = 50 mi

∴ The base Capital cost = $580,000.00 (US-EPA 1985, p. 148, Fig. 9-4)

Biosolids are hauld 262 days per year (Mr. B. Amy).

Annual volume of biosolids = 11 Mgallons ~ 10 Mgal

The base capital cost adjustment multiplication factor = 0.86. (US-EPA 1985, P 151, Fig 9-7)

Therefore, the adjusted base capital transport cost to landapplication:
= 580,000 x 0.86 = $498800.00
498,800 x 0.2374 = $ 118,415.00

2. 12% of biosolids goes to landfill.

12% x 12,781 = 1533 dry tonnes.

Ave. moisture content = 26.2%

Annual biosolids volume for landfill
= 1.5 million gallons.

(US-EPA 1985, P. 202. Fig 10-17)

The round trip hauling distance to the landfill = 30 miles - (McCartney, D.)

The base capital cost for landfilling
= $150,000.00 (US-EPA, P. 148. Fig 9-4). N=5 i=6%
150,000 x 0.2374 = $ 35,610.00
The volume of biosolids to landfill is too small and as a result the multiplication factor is close to one.

Therefore the total biosolids transportation base capital cost

= Base capital cost for transportation to landapplication
+ " " " " landfilling
= 118,415 + 35,610 = $154,025.00

3. Operation and maintenance cost for biosolids transportation includes: O & M laborer, fuel, and O & M materials and supplies (US-EPA 1985)

a. O & M costs for landapplication:

Annual biosolids volume = 10 M. gallons

The round trip hauling distance = 50 miles

The O & M cost for landapplication = $130.000.00
(US-EPA 1985 P. 149, Fig. 9-5)

b. O & M costs for the 12% biosolids to landfill

Annual biosolids to landfill volume = 1.5 M.g

The round trip to landfill = 30 miles

∴ The O & M costs for landfilling = 35,000.00
(US-EPA 1985 P 149, Fig 9-5)

The total O & M costs for the biosolids transportation

= O & M costs of transportation to landapplication
+ O & M costs of transportation to landfill

= 130.000 + 35,000

= $165,000.00.

Hence, The total biosolids transportation cost based on US-EPA for the city of Winnipeg

= total biosolids transportation base capital cost + total biosolids transportation O & M cost

= 154,025 + 165.000

= $319,025.00

Hence, The total biosolids transportation cost based on US-EPA for the city of Winnipeg

= total biosolids transportation base capital cost + total biosolids transportation O & M cost

= 154,025 + 165,000

= $319,025.00

FIGURE 9-4

BASE CAPITAL COST OF DEWATERED SLUDGE TRUCK HAULING AS A FUNCTION OF ANNUAL VOLUME HAULED AND ROUND TRIP HAUL DISTANCE

Assumptions: Truck loading time = 0.4 hr; truck unloading time = 0.4 hr; trucks average 30 mph for 20-, 50-, and 100-mile hauls, 40 mph for 200- and 400-mile hauls; work schedule is 7 hr/day, 200 days/yr (see Figure 9-7 for days per year adjustment factor); volumetric conversions factor: 1 cu yd = approximately 202 gal.

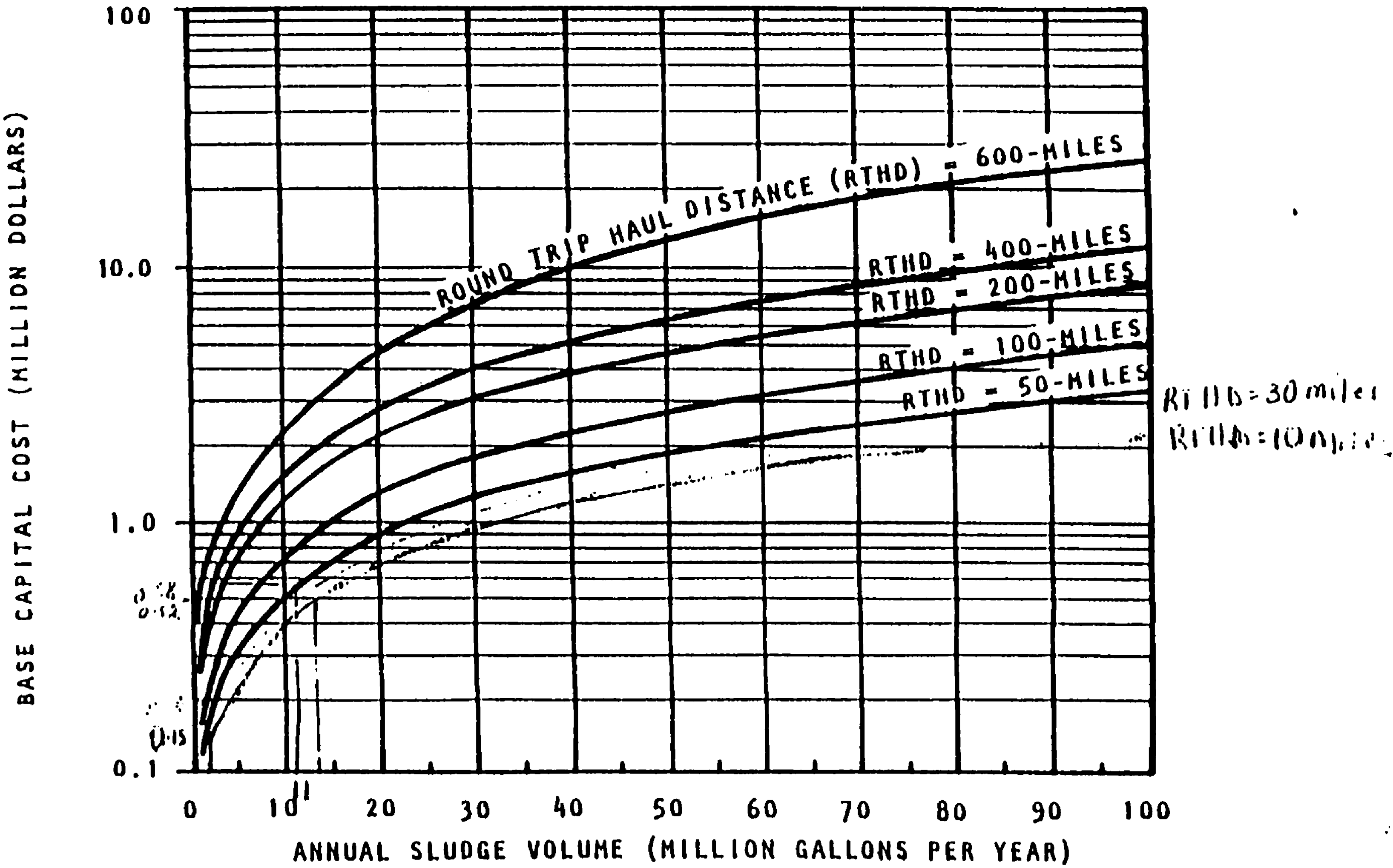


FIGURE 9-5

BASE ANNUAL O&M COST OF DEWATERED SLUDGE TRUCK HAULING AS A FUNCTION OF ANNUAL VOLUME HAULED AND ROUND TRIP HAUL DISTANCE

Assumptions: Design parameters are the same as for Figure 9-4; cost of diesel fuel = $1.35/gal; cost of labor = $13.50/hr; volumetric conversion factor: 1 cu yd = approximately 202 gal.

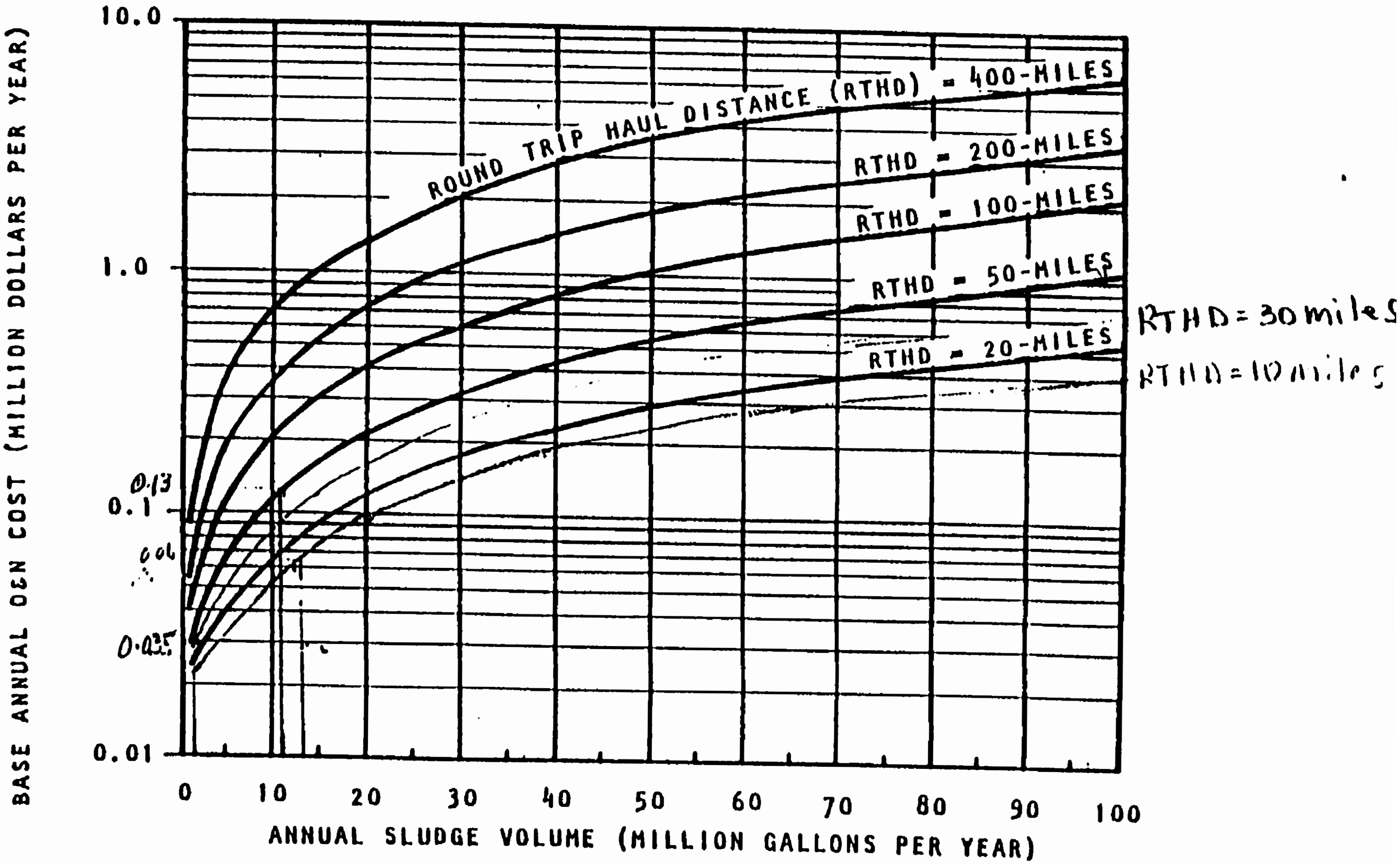


FIGURE 9-7

CAPITAL COST ADJUSTMENT MULTIPLICATION FACTOR TO ACCOUNT FOR VARYING DAYS PER YEAR THAT SLUDGE IS HAULED

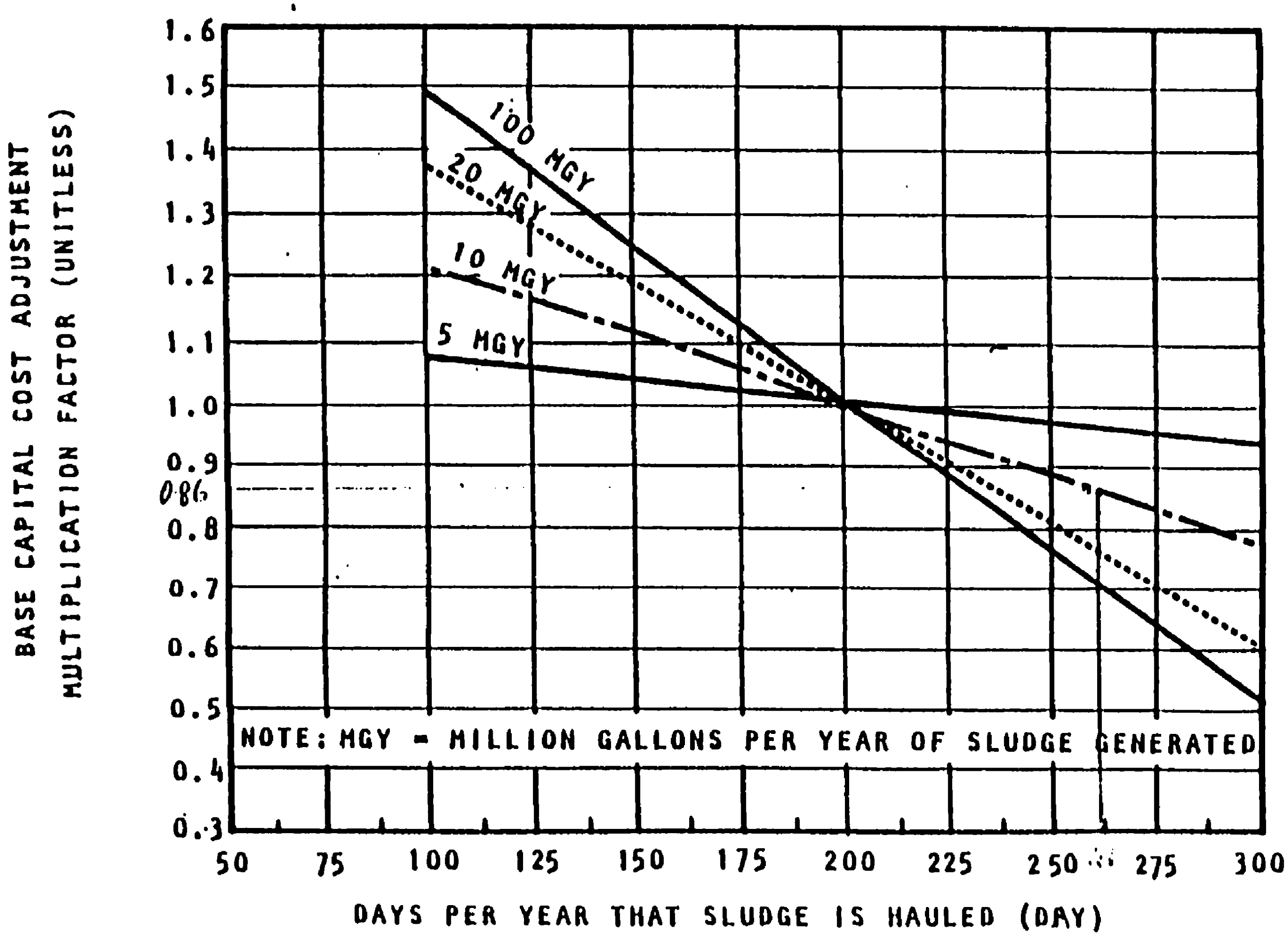
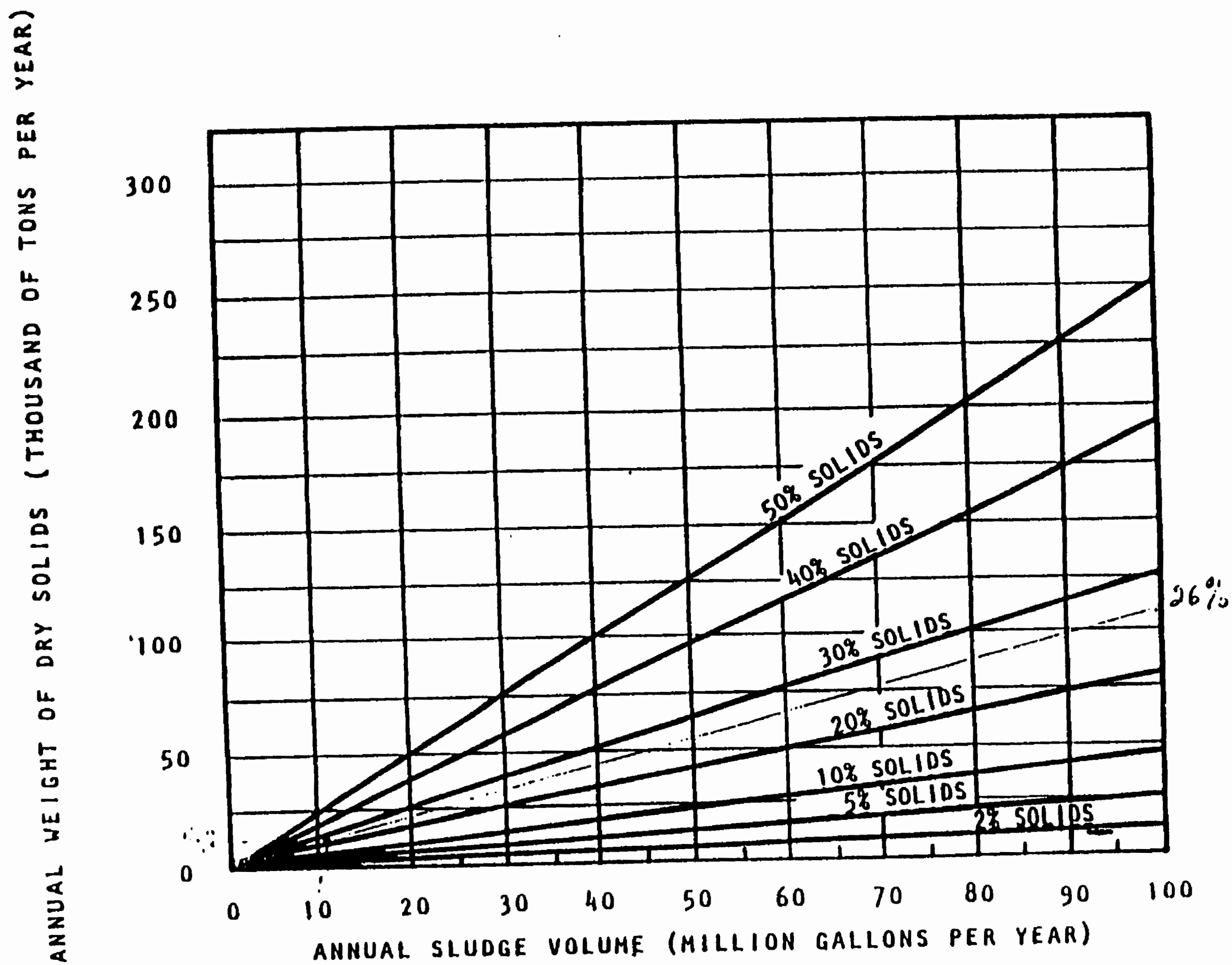


FIGURE 10-21

WEIGHT OF SLUDGE DRY SOLIDS CONTENT AS A FUNCTION OF WET SLUDGE VOLUME AND SOLIDS CONCENTRATION



Biosolids landapplication cost estimation based on EPA-1985 for the City of Winnipeg was conducted as follows:

1. The base capital cost for landapplication includes purchase of spreading and ploughin[g] vehicles, purchase of unloading machines and maintainance materials. (US-EPA 198[5])

Annual landapplied biosolids volume = 11 M.ga[l]

the base capital cost = $390,000.00
(US-EPA 1985, P.178, Fig 10-1)

The number of biosolids application days per year = 181 (Mr. B. Amy).

biosolids volume (Annual) = 11 M. gallons ~ 10 M.ga[l]

The cost multiplication factor = 0.55
(US-EPA 1985 P. 181, Fig 10-4)

The adjusted base capital cost for biosolids landapplication = 0.55 x 390,000
= $215,000.00   N = 5 i = 6%

215,000 x 0.2374 = $51,041.00

2. The operation & maintainance costs for landapplication include labour, fuel, vehicle and site maintainance. (US-EPA 1985

Annual biosolids volume = 11 M. gall.

biosolids application rate = 56 x 26.270/0.4047
≃ 6.00 drytonnes/acre.
(in the range of 5-20 dt/a

The O & M cost for the biosolids landapplication

= $ 80,000.00 (US-EPA 1985, P. 179, Fig. 10-2).

The total cost for agricultural landapplication

= The base capital cost of landapplication

+ the O & M cost for landapplication.

= 55,041 + 80,000 = $ 131,041.00

FIGURE 10-1

BASE CAPITAL COST OF APPLYING SLUDGE TO CROPLAND AS A FUNCTION OF ANNUAL SLUDGE VOLUME APPLIED AND DRY SOLIDS APPLICATION RATE

Assumptions: Design parameters are listed in Table 10-1 (see Figure 10-4 to adjust for difference in days per year of application).

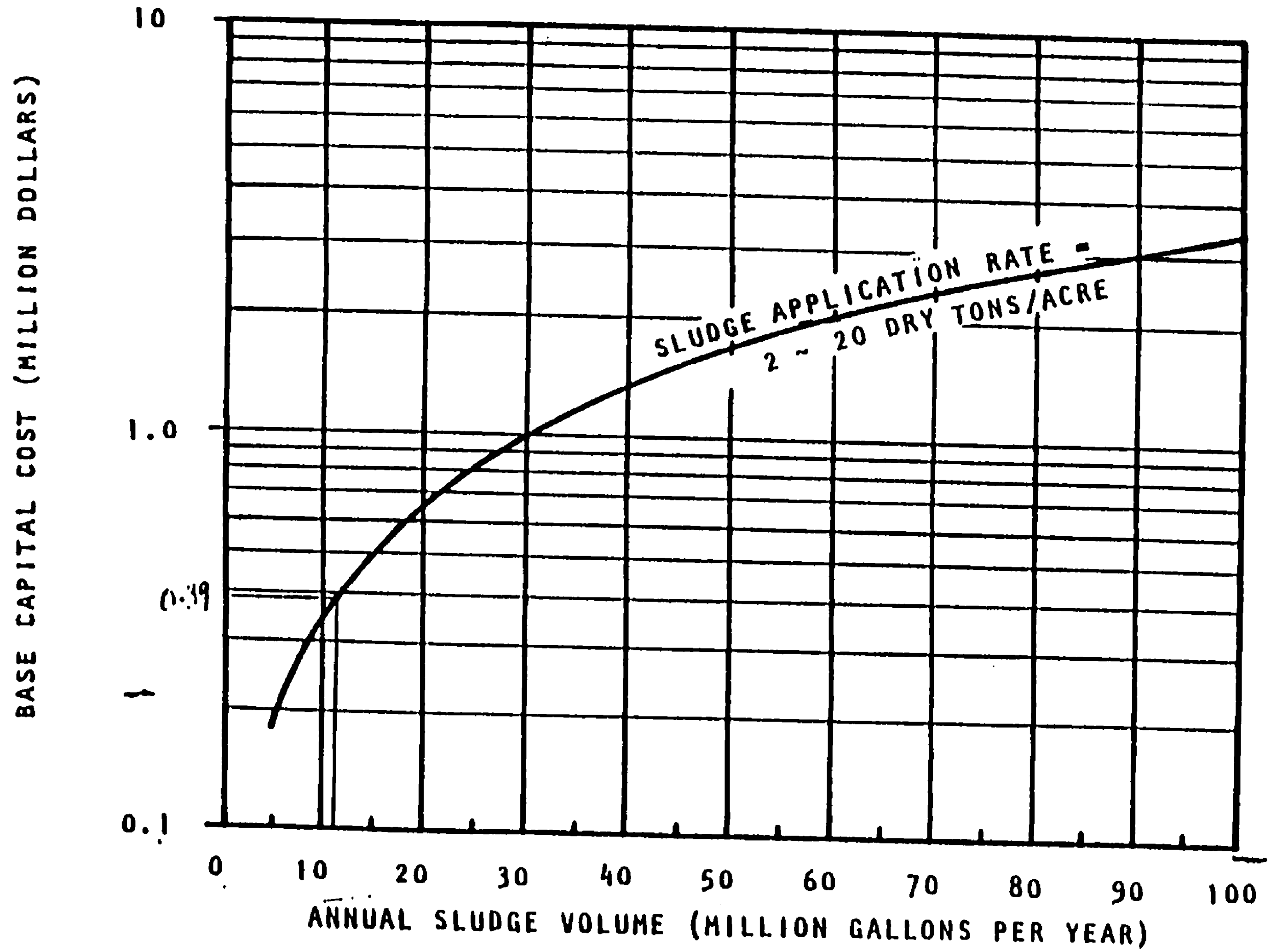


FIGURE 10-2

BASE ANNUAL O&M COST OF APPLYING SLUDGE TO CROPLAND AS A FUNCTION OF ANNUAL SLUDGE VOLUME APPLIED AND DRY SOLIDS APPLICATION RATE

Assumptions: Design parameters are listed in Table 10-1.

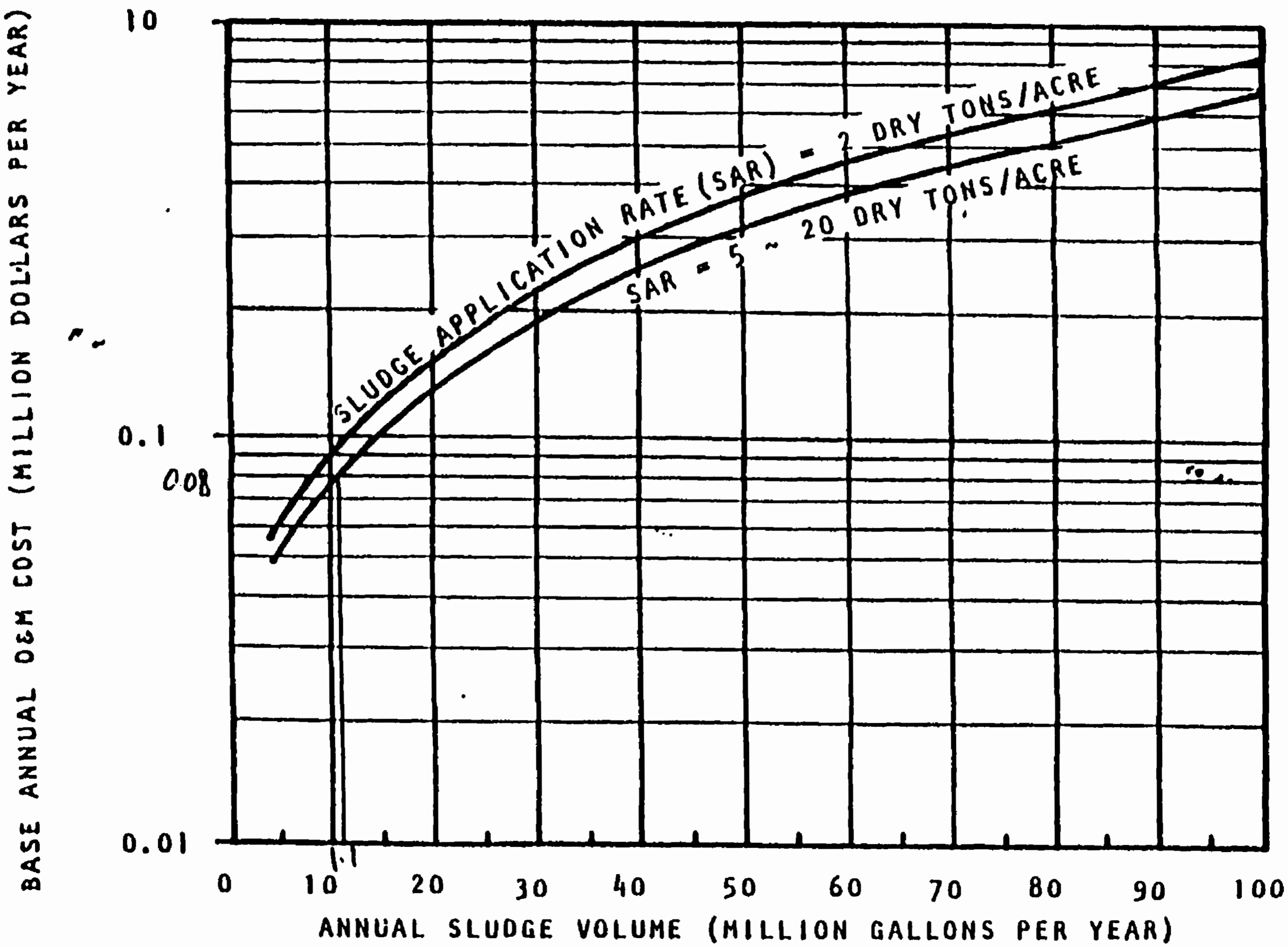
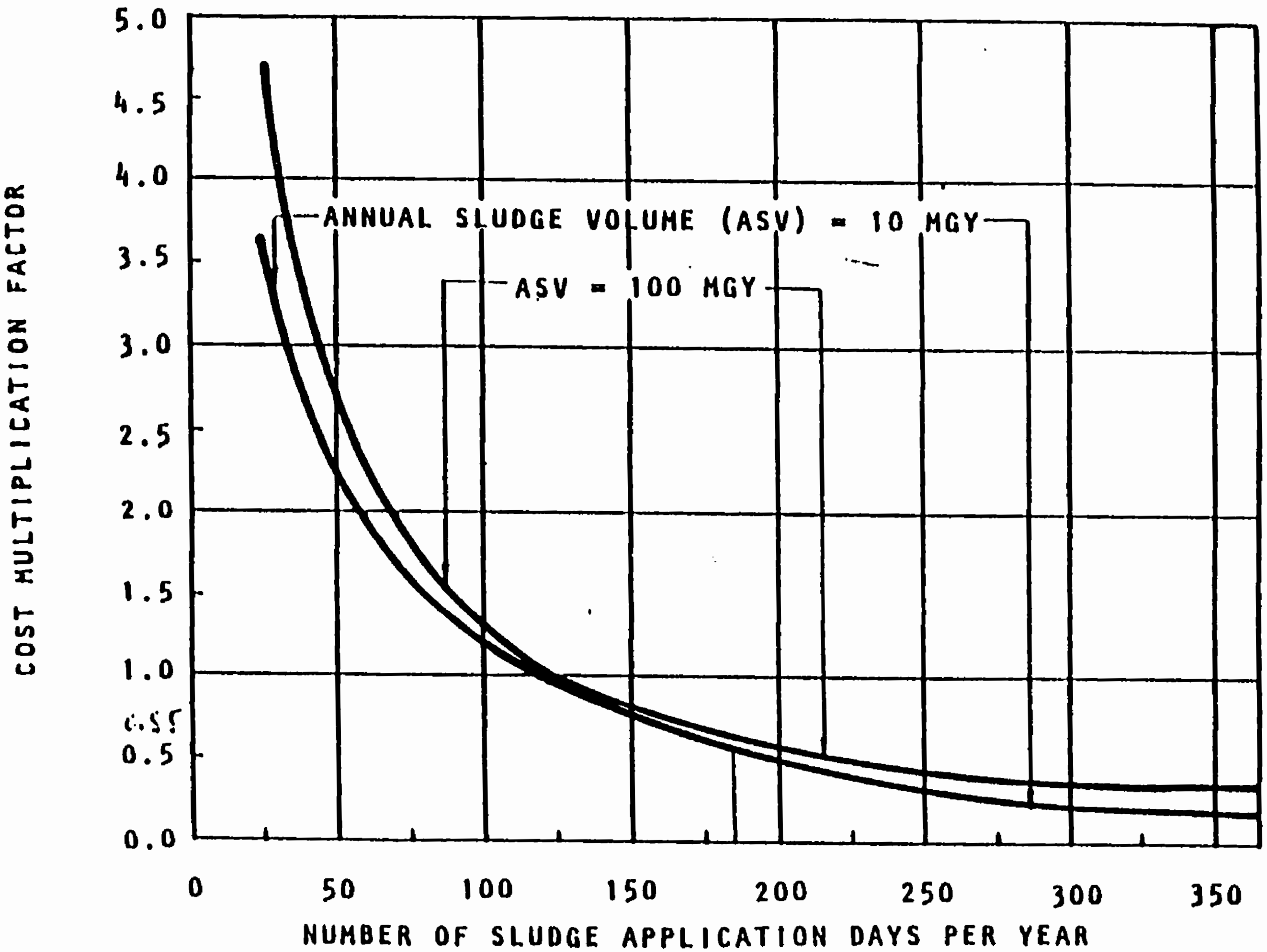


FIGURE 10-4

MULTIPLICATION FACTOR TO ADJUST SLUDGE APPLICATION TO CROPLAND COSTS IN FIGURE 10-1 FOR VARIATIONS IN DAYS OF APPLICATION PER YEAR

Assumptions: Design parameters are listed in Table 10-1; number of days per year that sludge is applied is variable.



Biosolids landfilling cost estimation based on EPA-1985 for the City of Winnipeg was conducted as follows:

1. The base capital cost for landfilling includes purchase of land, site clearing and grading, purchase of spreading and unloading vehicles

Annual biosolids that go to landfill = 1.5 M. gallon

The base capital cost = $240,000.00
(US-EPA 1985, P. 202, Fig. 10-17)

All assumption in (US-EPA 1985, P 207, Table 10-[illegible] are applicable except for land cost.

land cost assumption = $3.120 /acre
land cost in the existing program = $0.00
(Mr. B. Amy)
Annual biosolids volume = 1.5 M. gallons.

Land required = 35 acres
Assumed land cost = 35 x 3,120 = 190,200.00

∴ Adjusted base capital for landfilling

= 240,000 - 190,200 = $130,800.00 N=5 i=6%
130,000 x 0.2374 = $31,051.00

2. The O & M cost for the landfilling includes labour, fuel, vehicle & site maintainance.

Annual biosolids to landfill volume = 1.5 M. gall.

FIGURE 10-17

BASE CAPITAL COST OF A MUNICIPALLY OWNED SLUDGE LANDFILL AS A FUNCTION OF ANNUAL SLUDGE VOLUME RECEIVED

Assumptions: Design parameters are listed in Table 10-5.

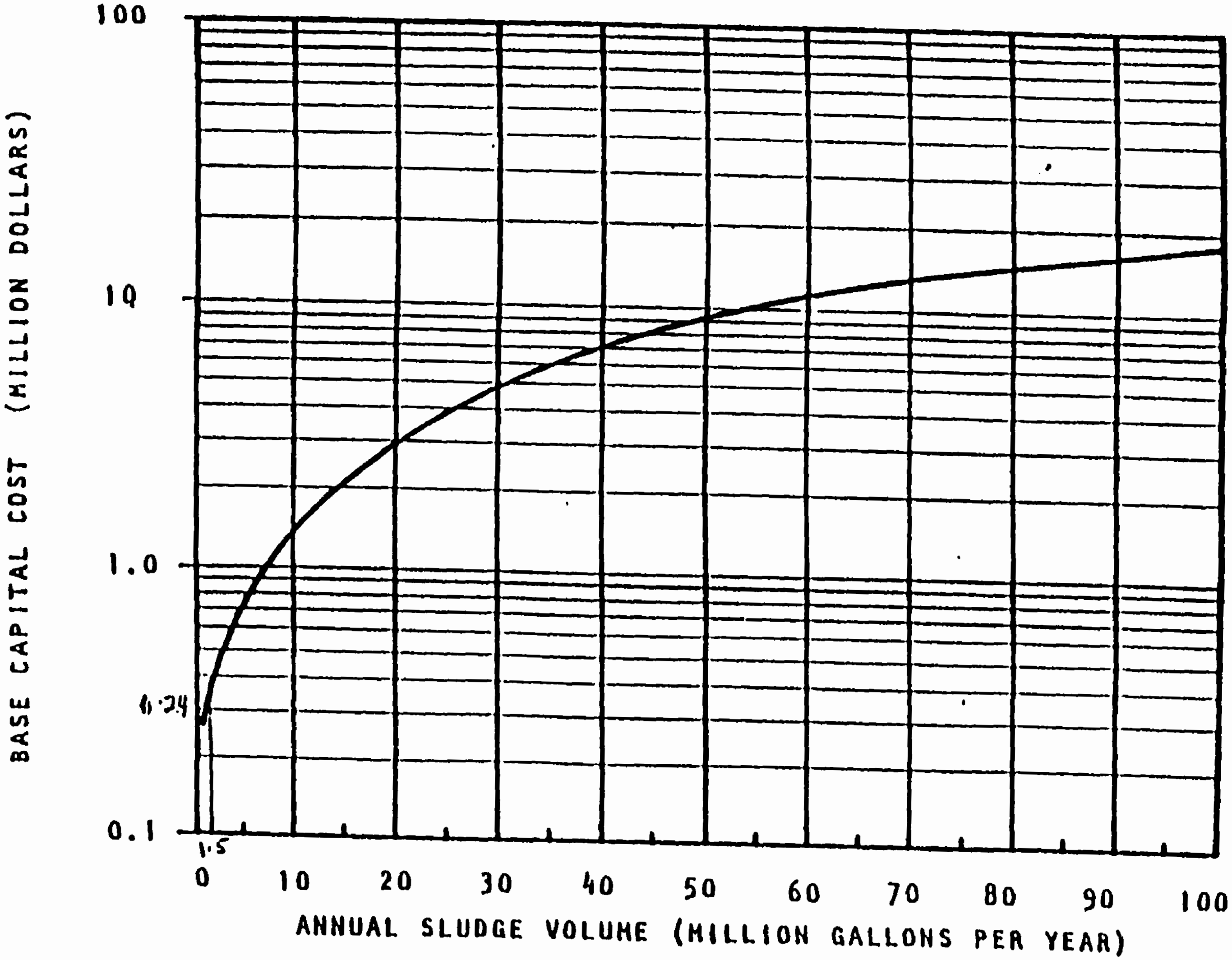
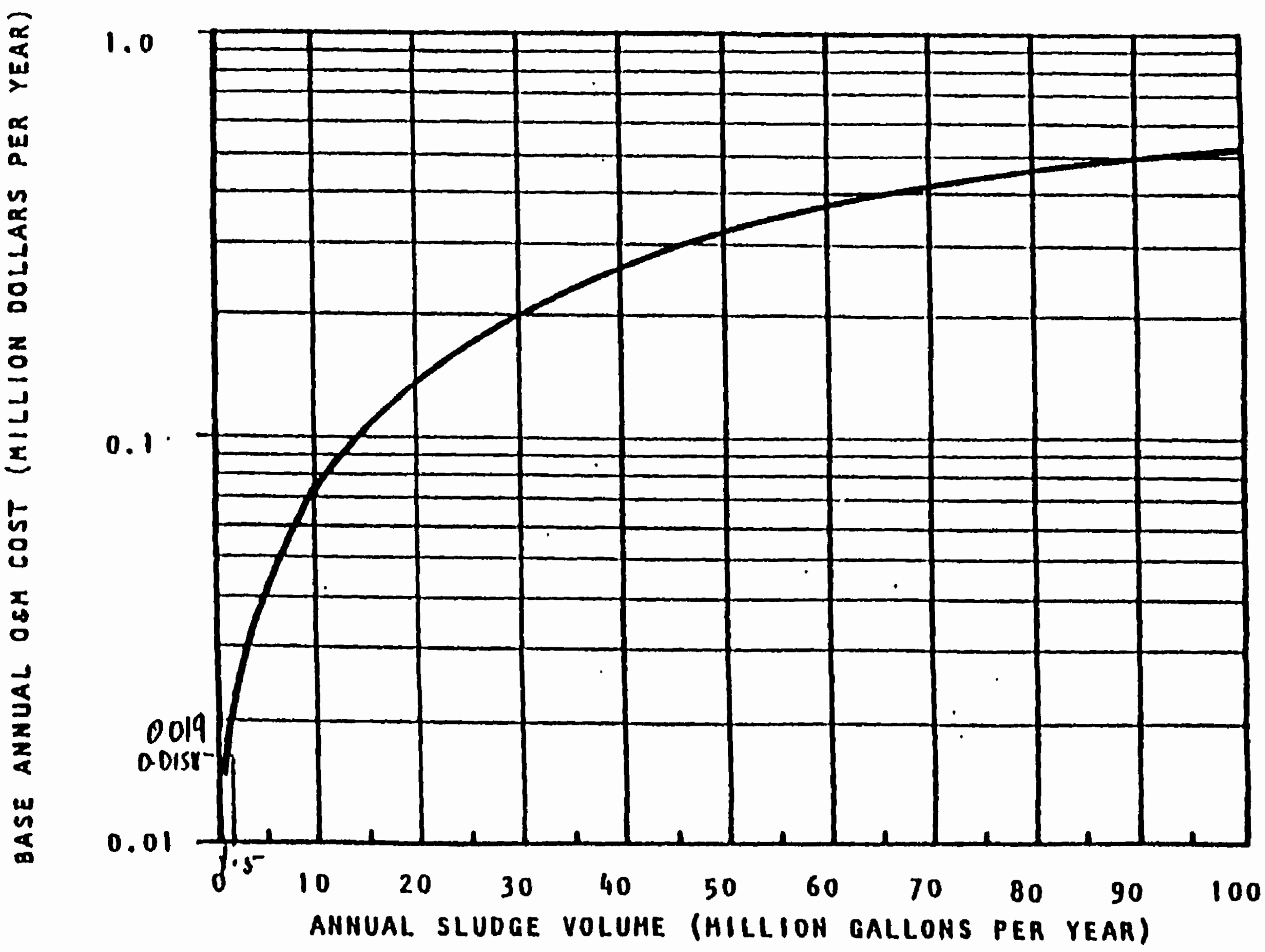


FIGURE 10-18

BASE ANNUAL O&M COST FOR A MUNICIPALLY OWNED SLUDGE LANDFILL AS A FUNCTION OF ANNUAL SLUDGE VOLUME RECEIVED

Assumptions: Design parameters are listed in Table 10-5.



A possible biosolids windrow composting cost estimation based on US-EPA for the City of Winnipeg was conducted as follows:

1. Capital costs of windrow composting include purchase of land, site clearing and grading paving of composting area, purchase of windrow turning machine and front-end load purchase and construction of unloading and mixing structure and construction of a maintainance & operation building.

- Daily biosolids production = 35.03 dry tonnes.
% TS = 26.2%
All the produced biosolids is to be composted.
composting site is to be the existing storage pad.
The area of the existing pad = 165m x 340m = 56,100 m^2
= 13.9 acres (Mr. D. H...)

The base capital cost = $ 1,000,000.00
(US-EPA 1985, P131, Fig 8-1)
All assumptions in EIS-EPA 1985, P 134, Table 8-1 are applicable except for land cost, site clearing, light, medium & extensive grading. To adjust the the base capital cost:

a) land cost unit = $ 3,120/acre [US-EPA Table 8-1]
Existing land cost unit = $0.0 (Mr. B. Amy)
Daily biosolids production = 35.03 dry tonnes.
% TS = 26.2% ≃ 25%
Total area required = 8.4 acres.
(US-EPA 1985. p. 135, Fig 8-4).
Assumed land cost = 8.4 x 3,120 = $ 26,204.00
Existing land cost = $0.0

b). Site clearing fraction = 0.7 (US-EPA. 1985, P. 134 T.8

Assumed area to be cleared = 0.7 x 8.4 = 5.9 acres.
Assumed cost of site clearing = $ 1,560.00/acre
total assumed cost for site clearing = $ 1,560 x 5.9
= $ 9,204.00.
existing site clearing cost = $ 0.0

c). light grading fraction = 0.3
assumed area for light grading = 0.3 x 8.4 = 2.5 acres
assumed cost of area grading = $ 1,040 / acre.
total assumed cost for light grading = 1,040 x 2.5
= $ 2,600.00
existing light grading cost = $ 0.0 (Mr. B. Amy)

d) medium grading fraction = 0.4
assumed area for medium grading = 0.4 x 8.4 = 3.4 acr
assumed cost of medium grading = $ 2,600.00/acre
(US-EPA 1985, P. 134, Table 8-1)
total assumed cost for medium grading = 2,600 x 3.4
existing cost unit $0.0
= $ 8,840.00

e). extensive grading fraction = 0.3
assumed area for extensive grading = 0.3 x 8.4 = 2.5
assumed cost for extensive grading = $ 5,200 / acre
US-EPA 1985, P. 134, Table 8-1)

Total assumed cost for extensive grading
= 5,200 × 2.5 = $13,000.00
The existing cost for extensive grading = $0.0

f). Paving cost:
Assumed paving area = 8.4 acres.
Assumed cost of paving = 8.4 × 60,320 = $506,688.00
(US-EPA 1985, P. 134, Fig. 8-1)
∴ existing paving cost = $0.0

Thus, the adjusted base capital for windrow composting = Capital cost − (land cost + site clearing cost + light, medium & extensive grading cost + paving cost)

Adjusted base capital = $1,000,000 − ($26,204 + $9,204 + $2,600 + $8,840 + $13,000 + $506,688)
= $433,464.00. amortized at N=10 i = 6%
433,464 × 0.13587 = $58,894.00

2. Operation & maintenance cost for windrow composting.
The O&M costs include O&M labour, fuel for composting and ancillary machinery and O&M materials & supplies. (US-EPA 1985)

Daily biosolids production = 35.03 dry tonnes
% TS = 26.2 ≈ 25%

Base annual operation & maintenance capital cost = $340,000.00
(US-EPA 1985, P. 132, Fig 8-1)

3. a) Biosolids transportation costs:

The transportation to composting site includes truck purchase.

total annual dry biosolids production = 12,781 Tonn.

% TS = 26.2%

Annual biosolids volume = 12 Million gallons
(US-EPA 1985, p. 208, Fig. 10-21)

The round trip hauling distance = 10 miles.
(Mr. B. Amy).

* The base capital cost $520,000.00.

biosolids are hauld 262 day per year. (Mr. B. Amy)
Annual biosolids volume = 12 M. gallons ≃ 10 M. gall
Base capital cost adjustment multiplication factor = 0.86 (US-EPA 1985, P. 148, Fig 9-4).

adjusted base capital cost = 0.86 × 520,000
= $ 447,200.00.

Thus, The base capital cost for the biosolids transportation to composting site
= $ 447,200.00, N=10 i=6%
447,200 × 0.13587 = $60,761.00

b). O & M costs for transportation: include O&M labour, fuel for vehicles & O&M materials & supplies.

Annual biosolids volume = 12 million gallons

The round trip hauling distance = 10 miles (16 km)
(Mr. B. Amy)

The O & M cost for the biosolids transporation
= $60,000.00 (US-EPA 1985, P. 148, Fig 9-4)

Thus, The total transportation cost to composting site = total transportation base capital cost + biosolids transportation O & M cost

= $ 60,761 + $ 60,000

= $ 120,761.00

Therefore, The total cost for windrow composting

= Base capital cost for composting (amortized) O & M cost for composting + transportation cost + O & m cost for transportation

= $ 58,894 + $ 340,000 + $ 60,761 + $ 60,000

= $ 519,655.00

excluding the existing pad:

Base capital cost = capital cost - land cost

= $1000,000 - $ 26,204 = $ 973,796 × 0.13587 = $ 132,309.00

Total cost for windrow = $ 132,309 + $340,000 + $ 120,761
per year

= $ 593,070

FIGURE 8-1

BASE CAPITAL COST OF WINDROW SLUDGE COMPOSTING AS A FUNCTION OF THE WEIGHT OF DRY SLUDGE SOLIDS COMPOSTED DAILY AND SLUDGE SOLIDS CONCENTRATION

Assumptions: Design assumptions are listed on Table 8-1.

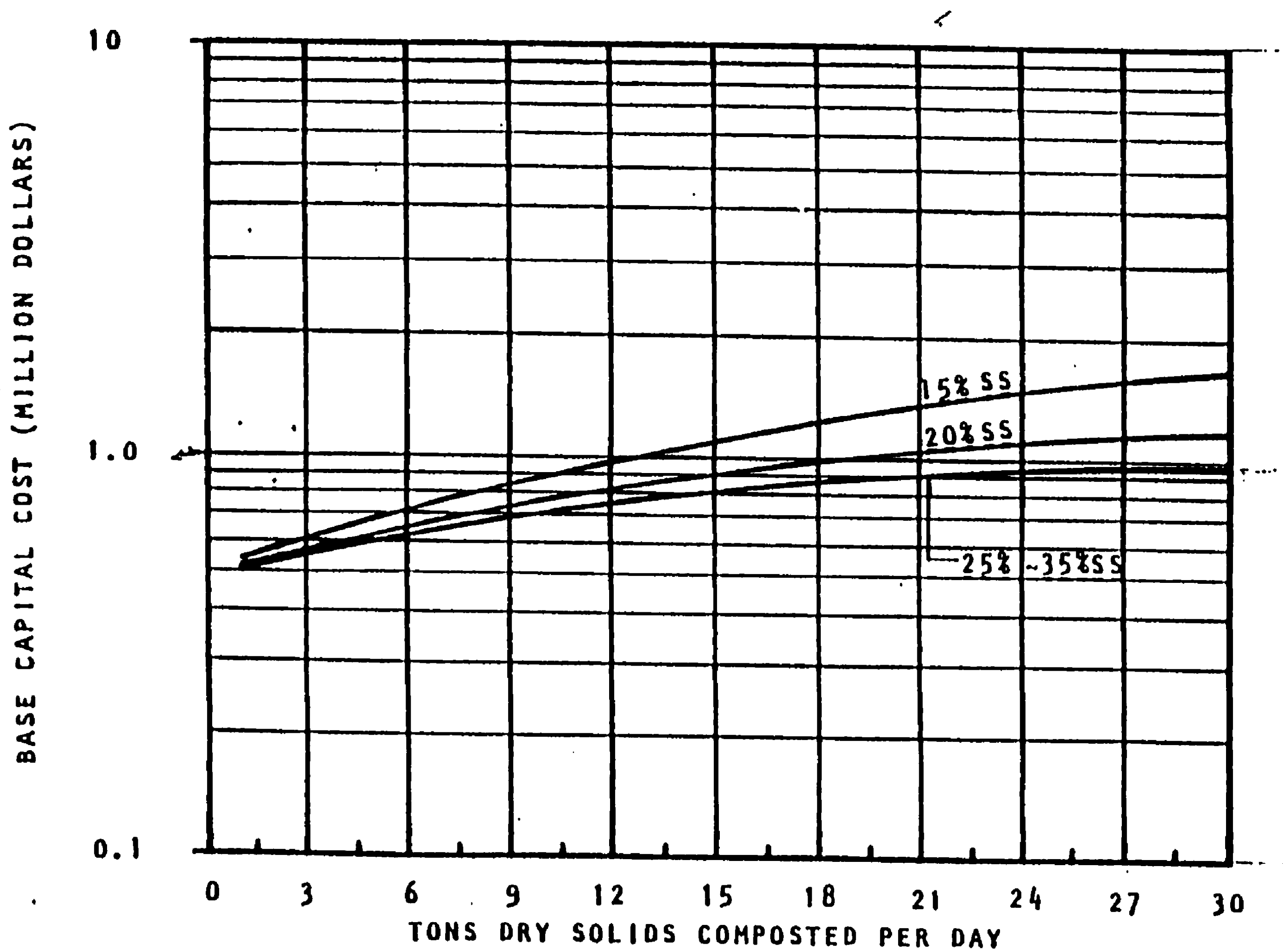


FIGURE 8-2

BASE ANNUAL O&M COST OF WINDROW SLUDGE COMPOSTING AS A FUNCTION OF THE WEIGHT OF DRY SLUDGE SOLIDS COMPOSTED DAILY AND SLUDGE SOLIDS CONCENTRATION

Assumptions: Design assumptions are listed on Table 8-1.

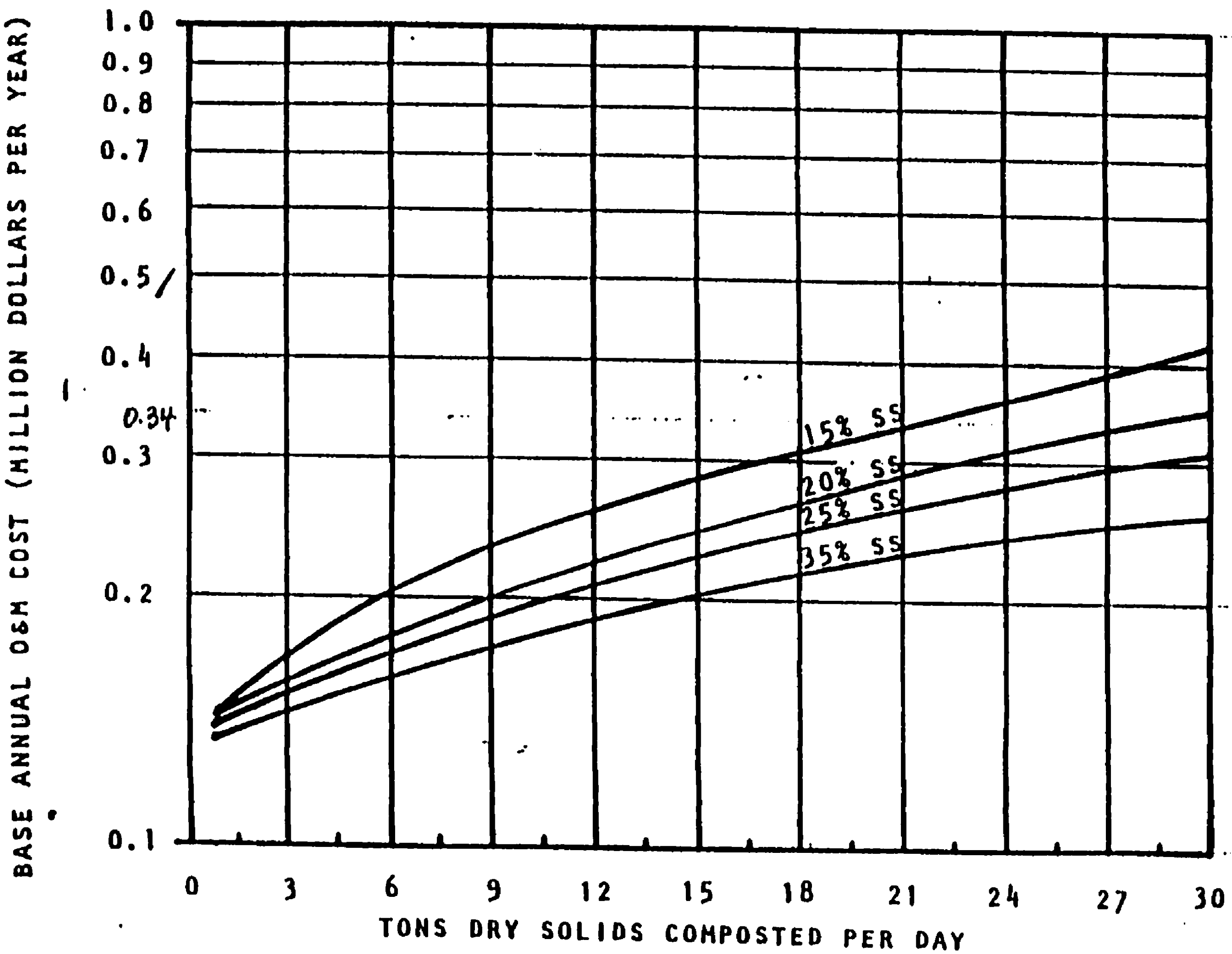


TABLE 8-1

ASSUMPTIONS USED IN OBTAINING COSTS AND REQUIREMENTS FOR WINDROW COMPOSTING SHOWN IN FIGURES 8-1 THROUGH 8-4

Parameter	Assumed Value
Percent sludge solids in dewatered sludge	20 percent
Percent volatile solids in dewatered sludge solids	35 percent
Percent volatile solids destroyed during composting	30 percent
Percent solids in compost product	65 percent
Dewatered sludge specific weight	1,820 lb/yd^3
Compost product specific weight	865 lb/yd^3
Mixed dewatered sludge and compost specific weight	1,685 lb/yd^3
Windrow cross section	35 ft^2
Windrow length	300 ft
Truck unloading and mixing area	300 ft^2/ton/day dry solids
Finished compost storage area	900 ft^2/ton/day dry solids
Fraction of site requiring clearing (brush and trees)	0.7
Fraction of site requiring light grading	0.3
Fraction of site requiring medium grading	0.4
Fraction of site requiring extensive grading	0.3
Cost of site clearing (brush and trees)	$1,560/acre
Cost of light grading	$1,040/acre
Cost of medium grading	$2,600/acre
Cost of extensive grading	$5,200/acre
Cost of land	$3,120/acre
Cost of diesel fuel	$1.35/gal
Cost of labor	$13.50/hr
Cost of paving	$60,320/acre

FIGURE 8-4

AREA REQUIRED FOR WINDROW SLUDGE COMPOSTING AS A FUNCTION OF THE WEIGHT OF DRY SLUDGE SOLIDS COMPOSTED DAILY AND SLUDGE SOLIDS CONCENTRATION

Assumptions: Design assumptions are listed on Table 8-1.

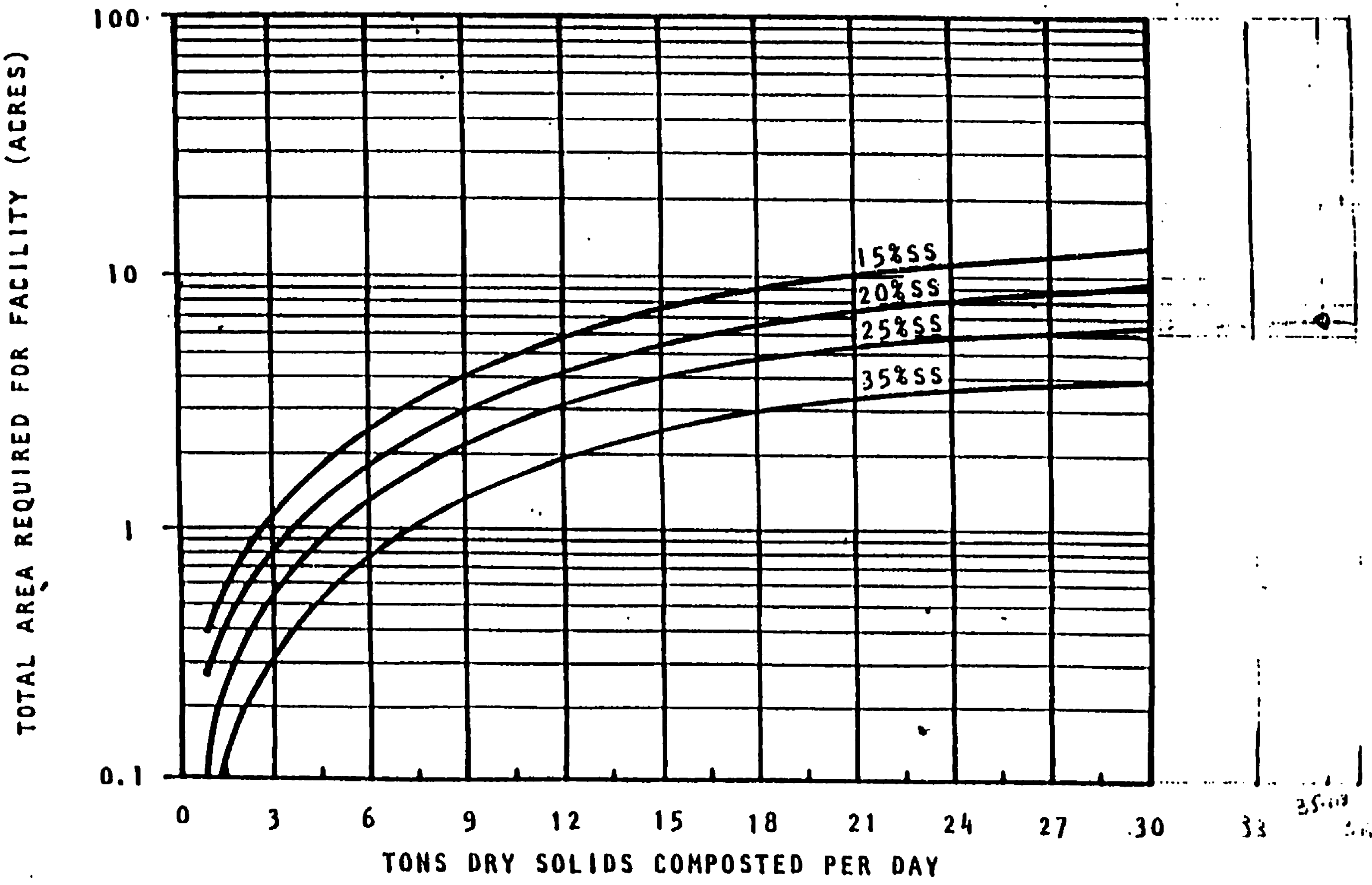


FIGURE 9-4

BASE CAPITAL COST OF DEWATERED SLUDGE TRUCK HAULING AS A FUNCTION OF ANNUAL VOLUME HAULED AND ROUND TRIP HAUL DISTANCE

Assumptions: Truck loading time = 0.4 hr; truck unloading time = 0.4 hr; trucks average 30 mph for 20-, 50-, and 100-mile hauls, 40 mph for 200- and 400-mile hauls; work schedule is 7 hr/day, 200 days/yr (see Figure 9-7 for days per year adjustment factor); volumetric conversions factor: 1 cu yd = approximately 202 gal.

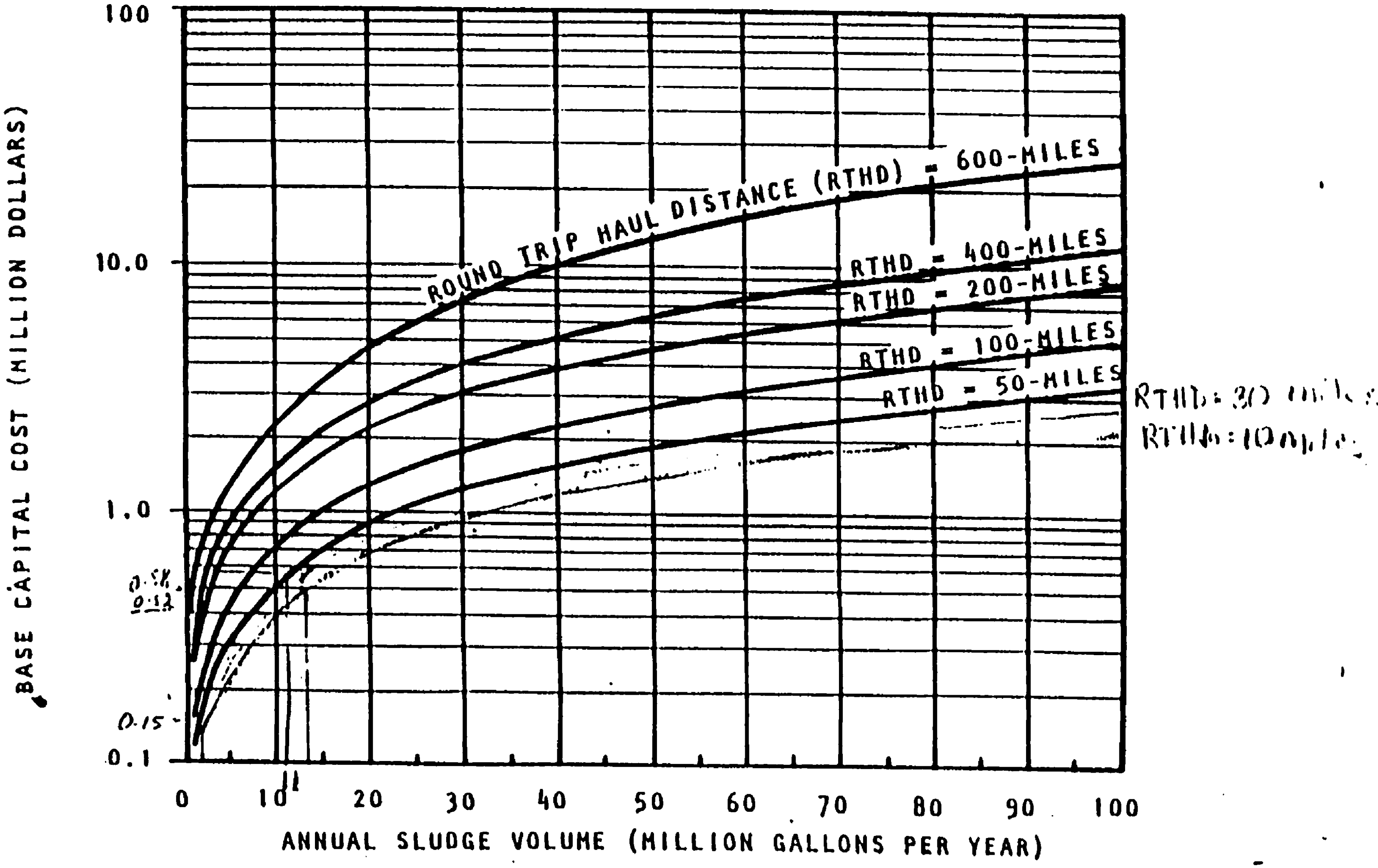
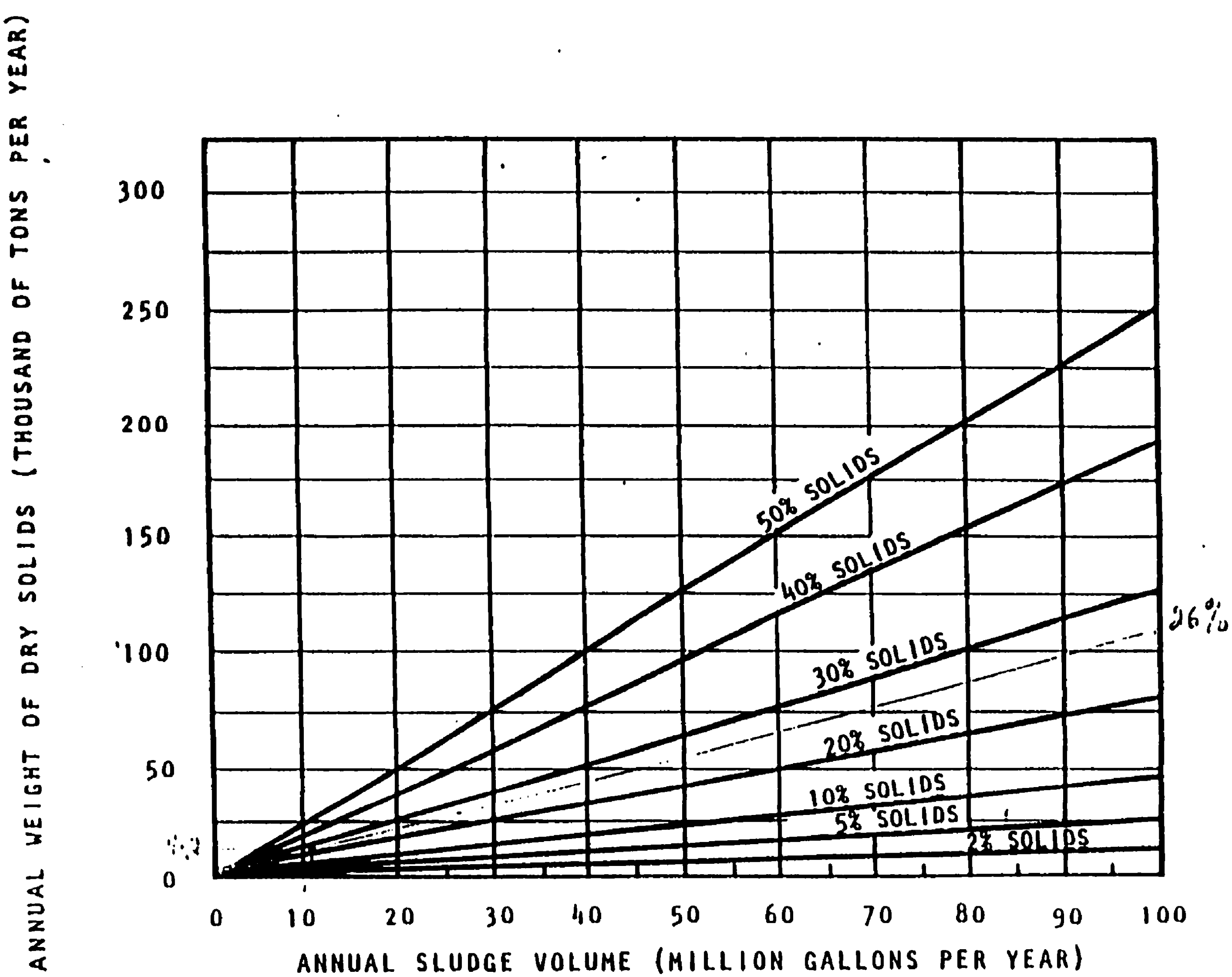


FIGURE 10-21

WEIGHT OF SLUDGE DRY SOLIDS CONTENT AS A FUNCTION OF WET SLUDGE VOLUME AND SOLIDS CONCENTRATION



A possible biosolids static pile composting cost estimation based on US-EPA for the City of Winnipeg was conducted as follows:

capital costs of static pile composting include unloading and mixing, aerated pile composting, drying, bulking agent, purchase of land site clearing and grading, paving.

Daily biosolids production = 35.03 dry tonnes
% TS = 26.2

All produced biosolids is to be composted.

composting site is to be in the existing pad:
The area of the pad = 165m x 340m = 56,100 m^2 = 13.9 acres
The base capital cost $6,900,000.00
(US-EPA 1985, P. 136, Fig 8.5).

All assumptions in US-EPA, 1985, P.140 Table 8-2 are applicable except for land cost, site clearing, light, medium & extensive grading.

To adjust the base capital cost:

a). Land cost unit = $3,120/acre (US-EPA Table 8-2)
existing land = 13.9 acres (Mr. D. McGinns).
Daily biosolids production = 35.03 dry tonnes
% TS = 26.2 ≈ 25%
Total area required = 17 acres.
(US-EPA 1985, P. 142, Fig 8-8)
Assumed area cost = 17 x 3,120 = $53,040.00
existing area cost = (17-13.9) x 3,120 = $9,672.00

b). Site clearing fraction = 0.7
(US-EPA 1985, P. 140, Tab. 8-2).

Assumed area to be cleared = 0.7 x 17 = 11.9 acres.
Assumed cost unit for site clearing = $1,560 /acre.
Assumed cost of site clearing = $1,560 x 11.9 = $18,564
existing site clearing cost = $0.0

c). light grading fraction = 0.3
Assumed area required = 0.3 x 17 = 5.0 acres.
Unit cost for light grading = $1,040.00/acre
Total assumed cost = 5.0 x 1,040 = $5,200.00
Existing light grading cost = $0,0.

d) Medium grading fraction = 0.4
Assumed area required = 0.4 x 17 = 6.8 acres.
Unit cost for medium grading = $2,600.00/acre
(US-EPA, 1985, Table 8-2)
Total assumed cost for medium grading = 6.8 x 2600
= $17,680.00

existing unit cost for medium grading = $0.0

e). extensive grading fraction = 0.3
Assumed area required = 5.0 acres.
Unit cost for extensive grading = $5.260/acre.
Total assumed cost = 5,260 x 5.0 = $26,000.00

f). paving cost:
Assumed paving area = 17 acres = 1,829,200 ft^2
Assumed unit of cost for paving = $3.15/$ft^2$
Assumed cost = 3.15 x 1,829,200 = $5,761,980.00

existing area of paving = 17-13.9 = 3.1 acres = 333560 ft^2
existing cost " = \$3.15 × 333,560 = \$ 1,050,714.00

Thus, the adjusted base capital for static pile composting

= \$ 6,900,000 - (\$43,368 + \$18,564 + \$5,200

+ \$17,680 + \$26,000 + \$4,711,266)

= \$ 2,077,922.00 amortizing at N = 10, i = 6%,

2,077,922 × 0.13587 = \$282,327.00

2. Operation and maintenance cost for static pile composting. This includes O&M labour, fuel for composting and ancillary machinery and O&M materials and supplies.

Daily biosolids production = 35.03 dry tonnes

% TS = 26.2 ~ 25%

Base annual O & M capital cost = \$ 900,000.00
(US-EPA 1985, P. 137, Fig 8-6).

3 Total cost for the biosolids transportation

= \$ 121,761 (from calculations for windrow composting transportation cost)

Thus, the total cost for static pile composting

= \$ 282,327 + \$ 900,000 + \$ 120,761 = \$ 1,303,088

4. - Excluding the existing pad:

The adjusted capital cost

= capital cost - land cost

= \$6,900,000 - \$43,368

= \$6,856,632.00 * 0.13587 = \$931,610

Total cost for static pile composting

= \$931,610 ... \$900,000 + \$120,761

= <u>\$1,952,371</u>

FIGURE 8-5

BASE CAPITAL COST OF AERATED STATIC PILE SLUDGE COMPOSTING AS A FUNCTION OF THE WEIGHT OF DRY SLUDGE SOLIDS COMPOSTED DAILY AND SLUDGE SOLIDS CONCENTRATION

Assumptions: . Design assumptions are listed on Table 8-2.

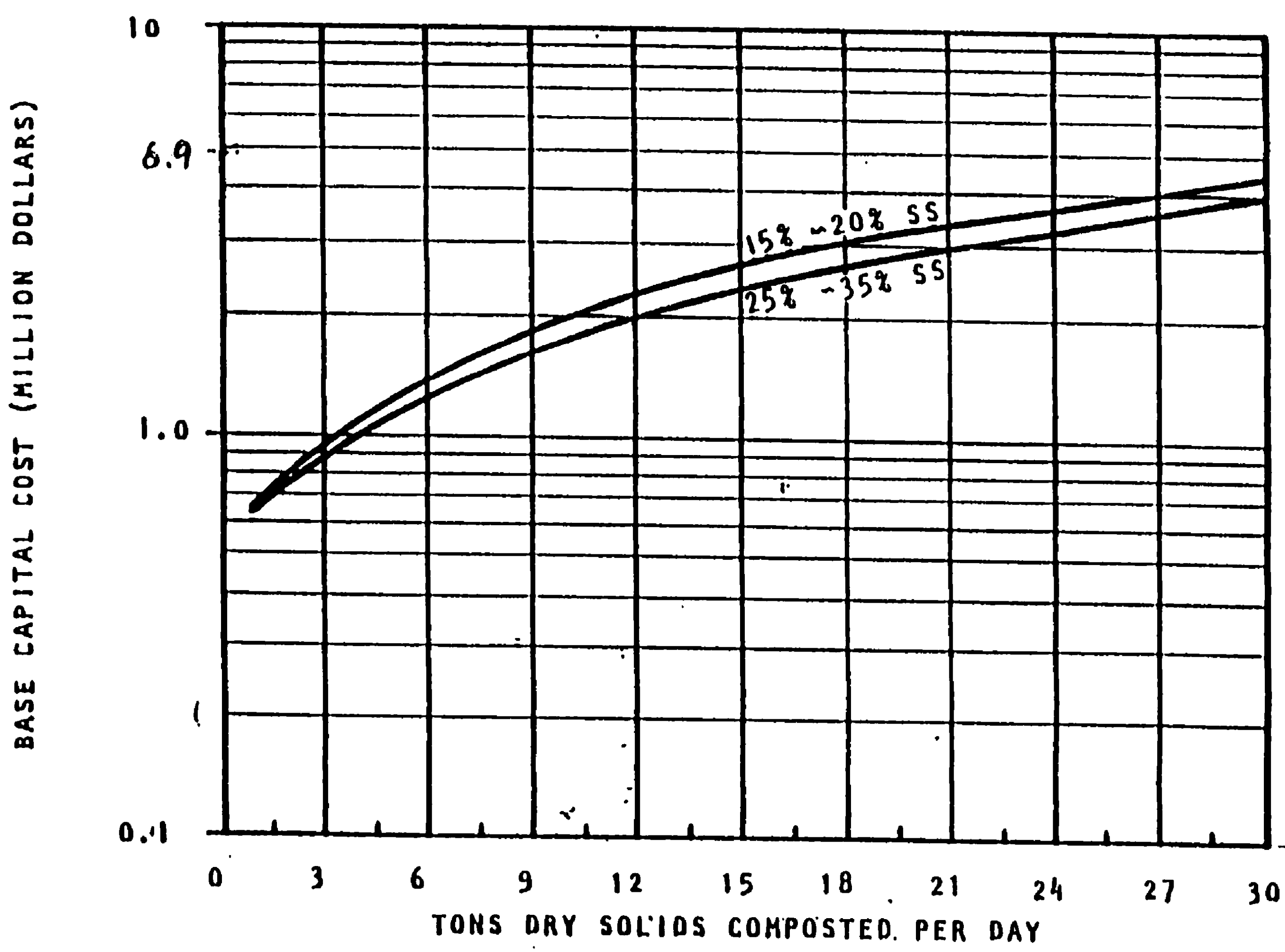


FIGURE 8-6

BASE ANNUAL O&M COST OF AERATED STATIC PILE SLUDGE COMPOSTING AS A FUNCTION OF THE WEIGHT OF DRY SLUDGE SOLIDS COMPOSTED DAILY AND SLUDGE SOLIDS CONCENTRATION

Assumptions: Design assumptions are listed on Table 8-2.

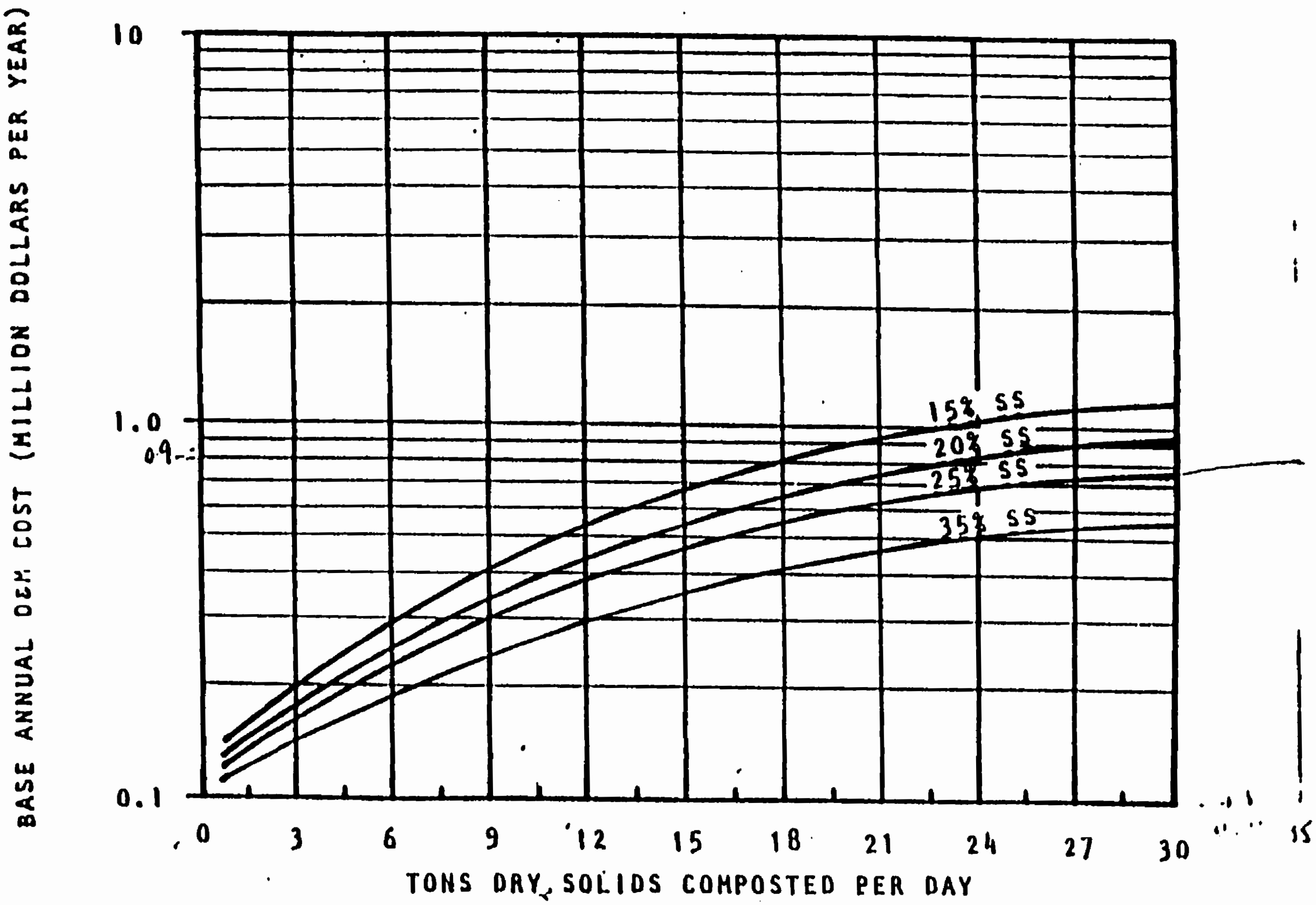


TABLE 8-2

ASSUMPTIONS USED IN OBTAINING COSTS AND REQUIREMENTS FOR AERATED STATIC PILE COMPOSTING SHOWN IN FIGURES 8-5 THROUGH 8-8

Parameter	Assumed Value
Percent sludge solids in dewatered sludge	20 percent
Percent volatile solids in dewatered sludge solids	35 percent
Percent volatile solids destroyed during composting	45 percent
Percent solids in compost product	65 percent
Compost product specific weight	1,000 lb/yd^3
Mixed dewatered sludge and bulking agent specific weight	1,100 lb/yd^3
Bulking agent mixing ratio	2.5 yd^3/ton dewatered sludge
New bulking agent mixing ratio	0.625 yd^3/ton dewatered sludge
New bulking agent specific weight	500 lb/yd^3 dewatered sludge
Recycled bulking agent mixing ratio	1.875 yd^3/ton dewatered sludge
Recycled bulking agent specific weight	600 lb/yd^3
Truck unloading and mixing area	300 ft^2/ton/day dry solids
Composting area	7,000 ft^2/ton/day dry solids
Drying area	3,000 ft^2/ton/day dry solids
Finished compost storage area	900 ft^2/ton/day dry solids
Bulking agent storage area	2,000 ft^2/ton/day dry solids
Fraction of site requiring clearing	0.7
Fraction of site requiring light grading	0.3
Fraction of site requiring medium grading	0.4
Fraction of site requiring extensive grading	0.3

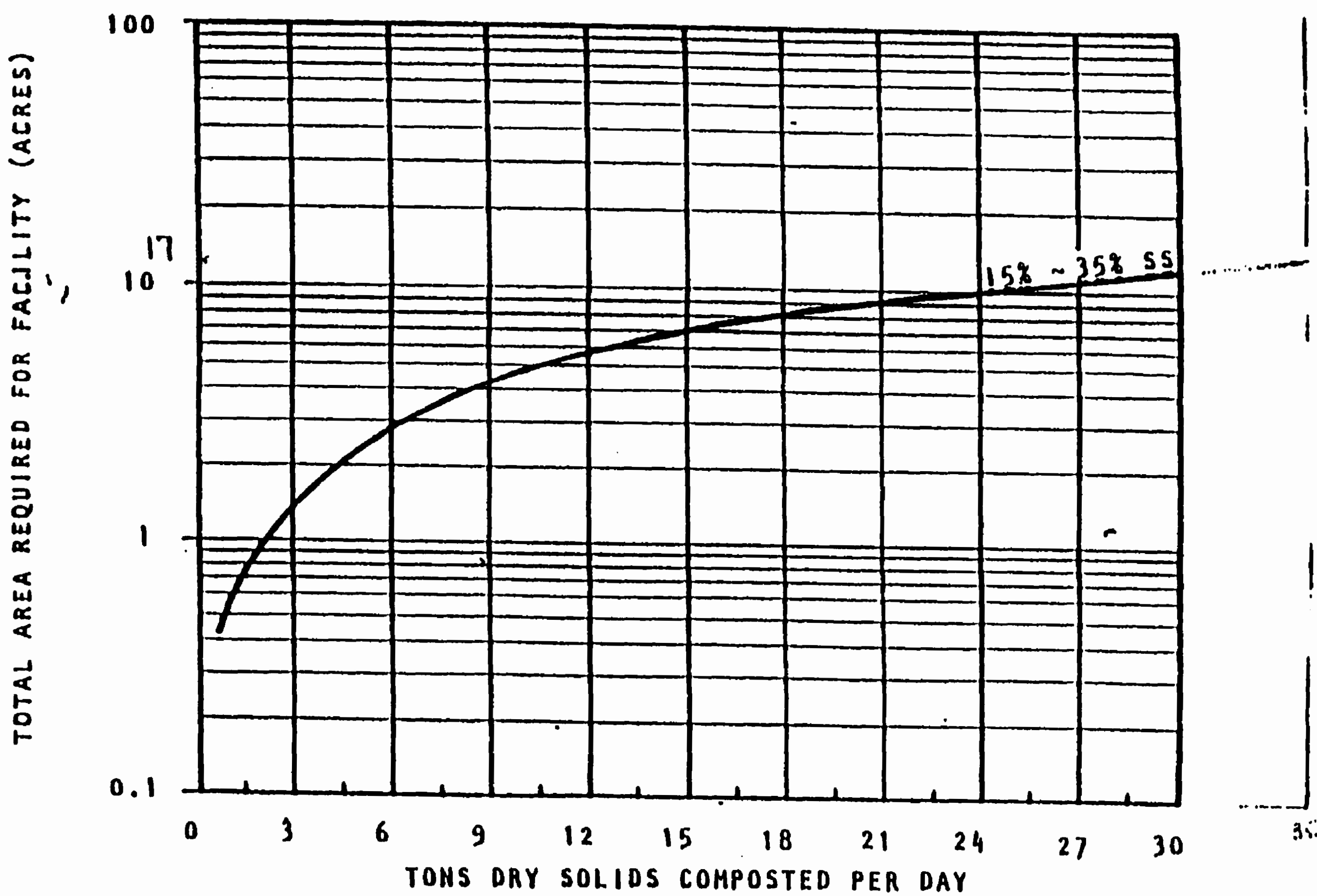
Table 8-2 (continued)

Parameter	Assumed Value
Cost of site clearing	\$1,560/acre
Cost of light grading	\$1,040/acre
Cost of medium grading	\$2,600/acre
Cost of extensive grading	\$5,200/acre
Cost of land	\$3,120/acre
Cost of diesel fuel	\$1.35/gal
Cost of electricity	\$0.094/kWhr
Cost of labor	\$13.50/hr
Cost of paving	\$3.15/ft^2

FIGURE 8-8

AREA REQUIRED FOR AERATED STATIC PILE SLUDGE COMPOSTING AS A FUNCTION OF THE WEIGHT OF DRY SLUDGE SOLIDS COMPOSTED DAILY

Assumptions: Design parameters are listed on Table 8-2.



Correction factor calculation:

Let C_1 - cost of the existing biosolids disposal program

C_2 - estimated cost of the future windrow composting facility based on US-EPA (1985)

C_3 - cost of the static pile composting facility

C_4 - estimated cost for the existing biosolids disposal program US-EPA (1985)

C'_2 - corrected cost of the future windrow composting facility

C'_3 - corrected cost of the static pile facility

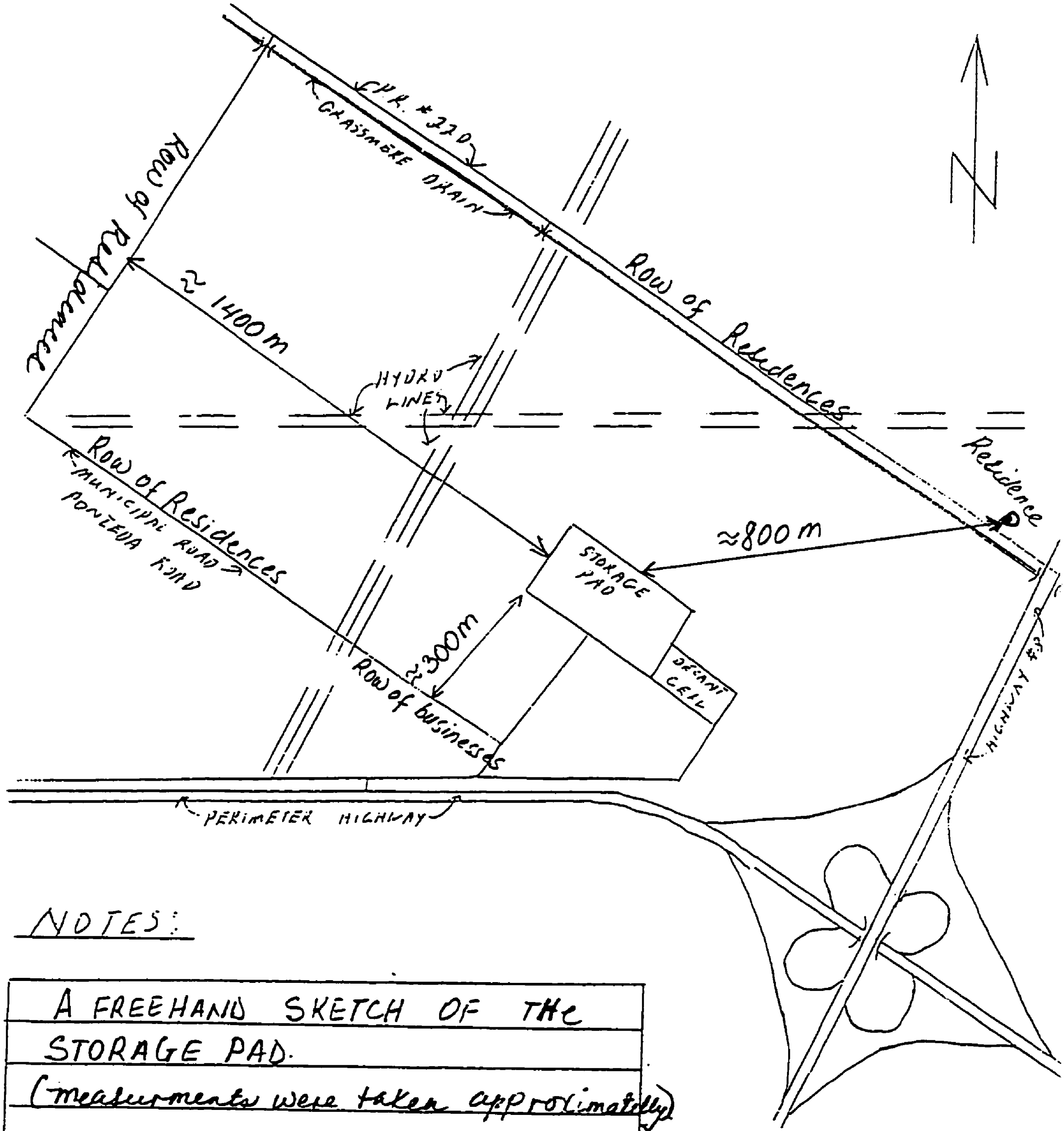
F - correction factor

Assuming that $C_4 = C_1$, then:

$$F = C_1/C_4$$

$$C'_2 = C_2 \times F$$

$$C'_3 = C_3 \times F$$



NOTES:

A FREEHAND SKETCH OF THE STORAGE PAD.
(measurments were taken approximately)

DATE:

WIND:

APPENDIX VI

OBJECTIVE, METHODS AND RESULTS OF THE SURVEY

Survey

1. Purpose

The purpose of the survey was to obtain a background information about operating biosolids composting facilities of similar design and operating conditions and compare those results with the preliminary cost analysis of a possible biosolids windrow composting for the City of Winnipeg.

2. Units of analysis

10 units of analysis that are believed to have the same composting method and relatively closer handling capacity to the amount of biosolids produced by the City of Winnipeg were identified. All the unit of analysis are individual.

3. Method of collection

There are three types of methods of collection

- telephone survey
- mailed questionaries
- interviews

The suggested method of the survey was telephone and mailed (faxed) questionaries incorporated together because it yields more immediate and complete results, results that may not be easily or quickly obtained by implementing only telephone survey or mailed questionaries system of collection.

Contacted Companies (units of analysis)

1. South San Francisco, California
   Tillo Products (10,000 dt/year)
   Tel. (415) 589-9033
   Contact: Dave Westerbeck

2. Fort Wayne, Indiana
   Nat-Serv-All Inc. (7,000 dt/year)
   tel: (219) 747-4117
   contact: Merl Walker

3. Los Angeles, California
   Lost Hills (80 dt/day)
   tel: (714) 371-3929
   contact: Joe Oltman

4. Russellville, Arkansas
   Organigro Inc.
   Tel: (501) 968-5837
   contact: Bo Smith

5. Corona, California
   Corona (1,500dt/day)
   tel: (714) 734-7030
   contact: John Bremer

6. Carson, California
   Joint Water Pollution Control
   tel: (213) 775-2351
   contact: Ross Caballero

7. Carson, California
   HCK Inc.
   tel: (310) 328- 0107
   contact: Kathy Kellogg

8. Thermal, California
   Chino Corona Farms Inc.
   Contact: Larry Vaughan

9. Chino Basin Municipality
   Water District (26 dt/day)

10. Aldergrove, BC
Biowaste Management/The answer to Garden Products Ltd. (slude + yard + manure)
tel: (604) 856-6221
contact: Rick Chase

Faxed Letter

February, 1997

Dear Sir/Madam

As I explained it during our telephone conversation, I am a graduate student at the University of Manitoba working on " The Feasibility of Biosolids Composting for the City of Winnipeg"for my Msc. Thesis. To compare my economic feasibility data I require some basic information from existing facilities such as yours. Your input is valuable. If you can't FAX me back the answers of the questionnaire by the end of February, 1997 please contact me so that alternative arrangements can be made. All obtained data are to be kept strictly confidential.

I am thankful for your time and cooperation in this matter And I look foreword to reviewing your information. If you require further clarification, please contact me via FAX or leave a message with my supervisor, Dr. Daryl McCartney.

Tel. For messages - (204) 474-6558 Dr. Daryl McCartney, Thesis Supervisor.
FAX - (204) 261-9534

M. Beyene

Department of Civil and Geological, University of Manitoba
Winnipeg, Manitoba
R3T 5V6
Canada

TICK ... Carson CA.

Survey questions

1. What method of composting is used (windrow, static pile, in-vessel or other)? Windrow
2. What is the amount of biosolids (sludge) composted a year in dry or wet tonnes? 100,000 wet
3. What is the total area required for the composting facility including storage? approx 20-30 acres
4. What is the type and amount of bulking agent used to compost the biosolids in a yearly basis?
approx 200,000 yards of wood shavings.
5. What is the total cost of the bulking agent a year? proprietary
6. What is the transportation cost of the biosolids from their source to the composting site in yearly basis? $15/ton What is the round trip hauling distance? 150 miles
7. The transportation cost of the biosolids:

includes	excludes	
~~?~~		~~Capital cost~~ ?
☑	☐	Annual O&M cost
☑	☐	Management cost

If excluded, do you know the separate costs? no

8. The cost of the bulking agent:

includes	excludes	
☑	☐	Transportation cost

If excluded, do you know the separate costs? ______

9. What is the capital cost of the biosolids composting? guess $500,000 ... 1991
10. The capital cost of the biosolids composting:

includes	excludes	
☐	☒	Purchase of land
☒	☐	Site clearing, grading, paving costs
☒	☐	Purchase of equipment

if excluded, do you know the separate costs? ______

11. What is the annual operation and maintenance (O&M) cost of composting? ______ O&M.
12. What is the average cost of composting the biosolids per dry or wet tonne? $6 - $10 /wet
13. Do you obtain any revenue for the finished compost ($ per dry or wet tonne)? yes proprietary ~~approx~~ $24/ton
14. What was your worst start-up problem? land lord
15. If you could change something at this point, what would it be? ______
difficulty of permitting in So California

environmental
SLUDGE MANAGEMENT SERVICES

FAX COVER SHEET

DATE:

TIME:

TO: M. Beyene

PHONE:

FAX: (204) 261-9534

FROM: Scott Thone

PHONE:

FAX:

RE:

CC:

Number of pages including cover sheet:

Message

P.O. Box 2023 • Russellville, Arkansas 72811 • 501-968-5837 • FAX: 501-968-2157

Dust to Cake sludge to get the heat we need to move to Class A. (N-Viro Process)

Survey questions

1. What method of composting is used (windrow, static pile, in-vessel or other) ? Windrow - Drying Technique.
2. What is the amount of biosolids (sludge) composted a year in dry or wet tonnes ? 3750 / Dry Tons.
3. What is the total area required for the composting facility including storage? 3 acres.
4. What is the type and amount of bulking agent used to compost the biosolids in a yearly basis ?
Kiln Dust.
5. What is the total cost of the bulking agent a year ? @ 170,000.
6. What is the transportation cost of the biosolids from their source to the composting site in yearly basis ? 200,000. What is the round trip hauling distance? 170 miles
7. The transportation cost of the biosolids:

includes	excludes	
☑	☐	Capital cost
☑	☐	Annual O&M cost
☑	☐	Management cost

If excluded, do you know the separate costs? ______.

8. The cost of the bulking agent :

includes	excludes	
☐	☑	Transportation cost

If excluded, do you know the separate costs? ______.

9. What is the capital cost of the biosolids composting? ______.
10. The capital cost of the biosolids composting:

Site was originally purchased and used for composting chicken litter.

includes	excludes	
☐	☐	Purchase of land
☐	☐	Site clearing, grading, paving costs
☐	☐	Purchase of equipment

if excluded, do you know the separate costs? ______.

11. What is the annual operation and maintenance (O&M) cost of composting? ______.
12. What is the average cost of composting the biosolids per dry or wet tonne ? ______.
13. Do you obtain any revenue for the finished compost ($ per dry or wet tonne)? Just Freight
14. What was your worst start-up problem ? ______.
15. If you could change something at this point, what would it be ? ______.

Equivalent annual (cost) payment (EAP) calculations

EAP = P(A/P, *i*, N) (Riggs *et al.* 1983),

where P - present value or purchase price

N - economic life of asset

i- interest rate expected on investment

(A/P, *i*, N) - capital recovery factor

According to the survey results, P = $500,000, N = 20 years (assumed), *i* = 6% (assumed), total amount of biosolids composted per = 100,000 wet tonnes, and (A/P, *i*, N) = 0.08719

Therefore, EAP = $500,000 (0.08719)= $43,595 U.S

The EAP per wet tonne = $43,595/100,000 = $0.44 U.S

The unit cost for composting excluding transportation cost = $8.00 + $0.44 = $8.44 U.S = $11.60 Canadian.

IMAGE EVALUATION TEST TARGET (QA-3)

150mm

6"

APPLIED IMAGE, Inc
1653 East Main Street
Rochester, NY 14609 USA
Phone: 716/482-0300
Fax: 716/288-5989