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Canadian Sludge Disposal Strategy- Processes, Problems and Priorities

for

Central Mortgage & Housing Corporation,
Ottawa, Ontario

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ABSTRACT

A system has been described in this report for use in the evaluation of alternative sludge management schemes in Canada.

To aid in the decision making process, indications of sludge production, treatment methods and ultimate disposal options are presented. Costs of major sludge management processes are also provided. Energy recovery processes are presented in light of the current concern about energy. Treatment and disposal are discussed in terms of design, operation and ability to assist in the recycling of waste sludge back into the environment.

This work has been conducted under contract with the Central Mortgage and Housing Corporation (CMHC), Ottawa, Ontario.

INTRODUCTION

Since the beginning of mankind, it has been natural for humans to consume raw materials for survival,and in the search for comfort. Every time a raw material is utilized, waste by-products are generated, and these wastes must be disposed of in the air, on the land or in the water. In the beginning,uninhabited space was abundant, so a little waste could easily be lost in the vast uninhabited areas. As time has progressed our population has increased geometrically, but our planet earth has remained unchanged in size. Civilization has reached the point where waste can no longer be lost in vast emptiness. It seems possible that ultimately man himself could be buried under mountains of waste.

Waste production stems from most human activities. Waste is generated from the food we consume and from the plants and animals which make up that food. The more raw materials we process in our modern industries, the more waste we produce. As stated in the laws dealing with conservation of mass and energy, this waste production will continue as long as mankind survives. In reality, raw material is converted to waste after extraction of useable energy and matter. In time the waste may decompose, be re-utilized for its essential components, and eventually become raw material again. What is really needed is a waste management system that speeds up the process of recycling, or a process that minimizes further waste production as a product of waste disposal. If a toxic waste is deposited in a river body and all the fish are killed, then waste itself has created more waste.

In order to protect our living environment, our technology has developed both simple and complex solutions to most waste management problems. Most waste material can be removed from wastewater by combinations of physical, chemical and biological treatment schemes.

Similarly, most pollutants can be removed from sources of polluted air prior to their escape into the atmosphere. In both instances waste treatment involves concentration of the waste products into smaller volumes, with a partial return of raw materials to the environment. It has been a misinterpretation of our society that waste treatment ends here. At this point the waste has only been concentrated and ultimate disposal must still be accomplished.

As our technology advances we are producing more wastes, and at the same time waste treatment technology is advancing such that more and more waste is being removed and concentrated for disposal. The introduction of tertiary or advanced wastewater treatment is a good example of increasing both waste production and waste recovery through technological development.

In the wastewater treatment field, the particulate and soluble matter in the water is removed by mechanical means, chemical precipitation, or by harvesting microorganisms which have been feeding on the waste. Each type of treatment collects a particular type of waste, all of which must be efficiently and carefully re-entered into the regenerative cycle.

In the end, most waste, or sludge as it is referred to in wastewater treatment, is deposited in or on the land as a form of ultimate disposal. To enhance the recovery of valuable components and speed the recycling of the waste to raw material, it is necessary to collect and treat the sludge. Also, as land availability decreases, the degree of treatment for the sludge must increase. Where it is feasible the sludge is returned to the land quickly, wherever possible. For areas where this is not feasible, the sludge must be reduced to its minimum volume and deposited in a safe and environmentally sound location. In large municipalities, reduction to minimum volume would typically mean incineration, followed by landfilling.

With the increase in our population, food production is a major problem, and treatment and disposal practices that will recover the fertilizer value of sludge and return it to the food chain need to be developed. With modern technology, however, toxic wastes are reaching the water, being removed, and concentrated in the sludge. Separation of toxic wastes is thus a prerequisite for optimum recycling practices.

To aid in the planning and selection of an appropriate sludge management scheme, this report discusses all major aspects of sludge treatment and disposal. An emphasis has been placed on methods providing maximum recycling capabilities. Where possible, an indication of current practices and regulations has been given.

The report has been prepared so that for a given community it will be possible to determine local sludge production, alternative treatment systems, costs of treatment, and energy recovery processes. Utilizing this material, a process for selecting the "best" sludge management alternatives is given.

To illustrate the importance of implementing "good" sludge management, a prediction of sludge production to the end of the century has been made. Treatment systems which are not currently practiced extensively are also discussed to emphasize the availability of modern technology to cope with our problems, where the initiative exists.

Section 1

SOLIDS SOURCES AND QUANTITIES

1 SOLIDS SOURCES AND QUANTITIES

Within any one community, the amount and nature of the sludge produced is dependent upon the characteristics of the incoming raw sewage and the type of treatment undertaken. As the number of treatment plants increases, the amount of sludge for ultimate disposal will increase. Similarly, as the degree of treatment changes (i.e. increased use of secondary treatment), the quantity and nature of the waste sludge will change.

The major sources of solids forming the treatment plants waste sludge are:

1. solids removed in bars, racks, screens
2. solids removed in grit chambers
3. solids settled out in primary clarifiers
4. solids as excess growth from biological treatment
5. solids precipitated by chemical treatment

The locations of these stages are indicated in Figure 1.1.

1.1 Racks and Screens

Although solids from Stage 1 and 2 are not normally classified as sewage sludge, they do account for a great portion of the solids from a community and they must be accounted for in the overall disposal scheme. These solids may or may not be disposed of along with the primary and secondary sludge.

The solids removed by bars, racks and screens will vary depending on the type of screen and spacing of the screening device. Metcalf and Eddy (1972) give an estimated value of 0.5 to 5.0 cubic feet of screenings per million gallons of wastewater treated, with an average of 2.0 cu.ft/MG. If combined sewers are used in the community, up to 30.0 cu.ft/MG can be removed during storm flow periods.

Screening facilities normally used are classified as either coarse screens, bar screens, micro screens, or comminuting devices. The coarse screens are mainly used to remove large objects (greater than 2 inches) such as wood, lumber and dead animals which have been washed into combined sewers. Bar screens are used to remove objects greater than one inch in diameter. These may be mechanically or hand cleaned. Micro screens are used to remove fine solids such as hair, string, seeds,etc. which might normally be removed in the grit chamber. This type of screening is only recently being used in sewage treatment plants. Comminuting devices which act as shredders are normally used as an alternate to bar screens in order to avoid damage to pumps from large objects. Using comminution allows the solids to pass on to the micro screens or into settling tanks where they are separated from the liquid waste.

1.2 Grit Chambers Grit chambers, which usually form part of, or come after screening devices, allow the denser suspended material such as sand and gravel to settle out. This is done by providing conditions where the flow velocity of the sewage is insufficient to keep the grit in suspension. Normally, sewers are designed to maintain a 2 foot per second flow. Reducing this flow to 1 foot per second will usually allow the grit to settle out (Standard Practice Manual #11). Very little of the organic matter settles out with the grit; however, most grit is washed to remove residual organic matter which might,upon decomposition, produce bad odours, and attract rodents and insects.

The quantity of grit removed may be as little as 0.33 cubic feet per million gallons treated, or as much as 24 cubic feet per million gallons treated (Metcalf and Eddy, 1972). Abnormal variations occur from heavy sanding of city streets or heavy run-off from the local landscape.

1.3 Primary Treatment Primary clarifiers may be used as either the sole treatment stage, as occurs in many Canadian communities, or they may be used as a form of pre-treatment designed to reduce the load on the biological portion of the plant. As well as removing settleable solids, the clarifiers will also remove floating scum or fines. Raw primary sludge usually has a very objectionable odour and a high percentage of water, two factors which make further treatment difficult.

The volume of raw primary sludge is often increased by the addition of chemical precipitation to the primary stage. This increase may be as much as 0.5 percent of the volume of sewage treated (Metcalf and Eddy, 1972). The increase is due to the increased settling brought about by the coagulants; the production of ferric hydroxide if iron coagulants are used; the production of aluminum hydroxide if alum is used and the production of calcium carbonate if lime is used. Each of these compounds increases the difficulty of dewatering raw primary sludge.

Primary clarifiers may also remove large quantities of sludge which are produced by water treatment plants and dumped into sanitary sewers. Oblenis et al (1972) reported fourteen percent of water plants surveyed in Canada deposited their waste sludge into sanitary sewers.

1.4 Secondary Treatment Secondary sludge coming from the biological portion of the treatment plant varies with the type of secondary treatment used and the degree to which the water was pretreated. Many plants omit the primary stage and introduce the raw sewage directly into the biological reactors. Typical biological treatment systems used are Rotating Biological Discs, Trickling Filters,and the many adaptations of the Activated Sludge Process.

1.4.1 Trickling Filters Trickling Filters consist of beds of permeable media such as rocks or plastic forms, to which microorganisms attach, just as algae attach to rocks in slow moving rivers. The sewage is sprinkled over the filter bed by rotating distributors and as it "trickles" through the filter media the microorganisms act on the organic content of the waste. As the layer of slime increases, the inner layer does not obtain an adequate source of food and thus enters the endogenous growth phase. While in this stage the microorganisms lose their ability to cling to the media and are sloughed off. This old or excess biological growth is removed in the clarifier following the filters.

1.4.2 Rotating Biological Discs Rotating biological discs are similar to Trickling Filters. However, in this case the waste is held relatively constant in a trough-like structure and the media holding the microorganisms is rotated through the waste. In this way, the microorganisms are alternately exposed to liquid and air. Waste sludge is produced as excess growth is sloughed off and collected in a classification unit. Generally this type of treatment forms part of a packaged sewage plant for small communities.

1.4.3 Activated Sludge Systems

The activated sludge system is the most popular treatment system and the most complex. The nature and quantities of sludge produced will depend on the nature of the waste treated, the type of activated sludge used, and the environmental conditions of the system. A few of the types of activated sludge plants are shown in Figure 1.2. Each of these systems is basically similar in that the waste is biologically stabilized in a reactor under aerobic conditions, or in a series of reactors having some aerobic and some anaerobic sections. After aeration, the liquor enters a clarifier where the cells are separated from the liquid. A portion of these cells is recycled back to the aeration chamber to ensure a continuous supply of living organisms.

The microorganisms assimilate the soluble organic substrates which enable them to reproduce. At the same time, a portion of the microorganisms is undergoing endogenous respiration or self destruction. When the reproduction exceeds the auto-oxidation, there is an excess sludge mass which must be wasted.To accomplish this, a portion of the sludge being recycled from the clarifier to the aeration chamber is wasted.

1.5 Septic Tanks Sludge also arises indirectly from the operation of septic tanks. This sludge is often disposed of into the sanitary sewers and thus will add to the solids content of the raw sewage. Because the septic tank has less than ideal conditions for anaerobic digestion, the sludge is usually black in appearance, and gives off foul odours resulting from the presence of hydrogen sulphide (Schroeder et al, 1977). Problems can arise from this type of sludge if local operators dump it into landfills or open waterways. If it is dumped into the sewer, it imposes a high loading on the treatment plant.

It is estimated that 900 gallons (U.S.) of sludge are produced per million gallons of sewage treated by septic tank systems.

1.6 Lagoons Lawson (1977) has indicated that a growing source of sludge is arising in the prairie provinces from the use of aerated lagoons, anaerobic lagoons and algae lagoons. There are now some 40 aerobic lagoon installations in the prairie provinces and there has been little experience in their sludge removal. There are many more anaerobic or algae lagoons in the west. The sludge production from algae lagoons is generally in the order of 0.3 inch per year and thus does not appear to be an immediate problem. A more immediate problem arises from the anaerobic lagoons which can accumulate 1 to 2 feet of sludge per year. Although this sludge is generally well digested and inoffensive, the problem of removal is still present. Primarily, the difficulty with this system is the lack of information on sludge disposal systems. An indication of sludge handling practices in the prairies has been given by Borlase (1977) and Dike (1977).

1.7 Prediction of Sludge Production The quantity of sludge that is produced from any system can be calculated by performing a solids balance around the primary clarifier and secondary treatment process as shown by Kormanik (1972). An adaptation of this scheme to a generalized secondary treatment plant was given by Vessilind (1974). The treatment system considered is shown schematically in Figure 1.3. The symbols used are defined as follows:

S	=	influent BOD (mg/1)
X	=	influent suspended solids (mg/1)
So	=	influent BOD (lb/day)
Xo	=	influent suspended solids (lb/day)
h	=	fraction of BOD not removed in primary clarifier
i	=	fraction of BOD not removed in secondary stage
Xf	=	plant effluent suspended solids (lb/day)
k	=	fraction of Xo removed in primary clarifier
j	=	fraction of solids not destroyed in digestion
Δx	=	net solids produced by biological action (lb/day)
Y	=	yield
Q	=	raw sewage flow (MGD)

Typical values used in these calculations are:

So	=	250 mg/1 x 8.34 x Q = lb/day
Xo	=	225 mg/1 x 8.34 x Q = lb/day
k	=	0.6
h	=	0.7
Xf	=	20 mg/1 x 8.34 x Q = lb/day
j	=	0.8 (aerobic), 0.5 (anaerobic)
i	=	0.1 (activated sludge), 0.2 (trickling filters)
Y	=	0.5 (activated sludge), 0.2 (trickling filters)

To calculate approximate sludge production values, the following steps are undertaken. These are general forms of the equations,and modifications must be made for special wastes or modified activated sludge plants. The constants are varied, depending on the type of sewage treatment plant used.

Raw Primary Sludge (RPS) = k So = lb/day

Volume RPS = (RPS/ Solids Fraction)/(8.34 lb/gal) = gal/day

BOD Removed (ΔS) = (hS - ihS) x 8.34 x Q = lb/day

Net Solids Production (ΔX) = (ΔS)Y = lb/day

Total Waste Activated Sludge (TWAS) = (1 - k)Xo - Xf + ΔX = lb/day

Volume TWAS = (TWAS/ Solids Fraction)/(8.34 lb/gal) = gal/day

The quantity of sludge produced by different treatment processes is given in Table 1.1 (Metcalf and Eddy, 1972). Additional sludge resulting from chemical treatment of primary sludge is given in Table 1.2 (EPA, 1974) Variations in sludge quantities resulting from chemical additions to the secondary treatment aerators and effluent are given in Table 1.3 and Table 1.4 respectively. Total sludge volumes as given by Knight et al (1973) are shown in Table 1.5.

Data in Tables 1.1 to 1.5 referring to"pounds per million gallons"refers to pounds of dry sludge per million gallons(U.S.)of sewage treated. The volume of wet sludge for disposal will depend on the concentration of the sludge. Normal solids concentrations for primary and secondary sludges are given in Table 1.6.

1.8 Sludge Production in Canada To obtain a realistic estimate of the quantity of sludge produced in Canada, an analysis of all the sewage treatment plants in all the provinces was made based on the data contained in the 1976/77 Directory and Environmental Handbook, published by Water and Pollution Control.

For each town, the following information was given, which was used to predict the quantity of sludge produced per day at each plant:

1. Actual population
2. Population served by the system
3. Average daily flow, MGD

4. Combined or separate sewers
5. Degree of treatment (primary, secondary)
6. Plant design capacity, MGD
7. Type of Treatment (activated sludge etc.)
8. Influent and Effluent characteristics
    (a) BOD, SS of influent (mg/l)
    (b) BOD, SS of effluent (mg/l)

Additional information was given but was not used in this analysis.

From the data provided, an analysis of each municipality was completed to provide the following information based on the total population:

1. Percent Population served
2. Average gallons/capita/day sewage treated
3. Pounds/day sludge produced
4. Pounds/capita/day sludge produced
5. Gallons of sludge produced at 2% and 10% solids.

Using this information and information given previously, the sludge treatment and sludge disposal practices were analysed for each province. Results for each province were given for:

1. Average gallons/capita/day sewage treated
2. Percent of the province having treatment
3. Sludge production as pounds/day
4. Sludge production as gallons/day
5. Total sewage treated
6. Total provincial population
7. Number of secondary treatment plants

8. Number of primary treatment plants
9. Number of communities without treatment.

All results were obtained using a CDC 6600 Fortran program, as illustrated in Appendix 1.1. Theoretical quantities of sludge produced were based on equations given by Kormanik (1972) and/or Metcalf and Eddy (1972). Where the sewage treatment type was not specified, the per capita production values used were (Wyatt, 1975):

Primary Treatment	0.12 lb/capita/day
Secondary Treatment	0.08 lb/capita/day
Chemical Treatment	0.05 lb/capita/day.

In general, a combination of primary and secondary treatment was used, giving 0.20 lb/capita/day of waste sludge. Where phosphorus removal was practiced, the 0.05 lb/capita/day value was added to the already calculated value for primary and secondary treatment.

1.8.1 Computer Predictions for Canada The mass of sludge produced per day from primary treatment of raw sewage is calculated as:

$$\text{lb/day} = k_1 \, (SS_{in} - SS_{out})(Q_{mgd})(8.34)$$

where k_1 is the primary clarifier efficiency ($\simeq$0.60)

From an activated sludge plant, the production value was based on the equation:

$$\text{lb/day} = k_2 \, [0.7(BOD_{in} - BOD_{out})(8.34)(Q_{mgd})] + k_3 \, [k_1 \, (SS_{in})(Q_{mgd})(8.34)] - [(SS_{out})(Q_{mgd})(8.34)]$$

where k_1 = primary clarifier efficiency (≃0.60)

k_2 = yield coefficient (≃0.50)

k_3 = $1 - k_1$ (≃0.40)

If a trickling filter operation was evaluated,the same basic equation was used, however, the values of the constants were changed. These same values have been assumed to apply to all suspended growth systems (i.e. Rotating Biological Contactors):

k_1 = 0.60

k_2 = 0.20

k_3 = 0.40

If the BOD removed from the process is unknown,then the sludge production equation is altered such that:

$$BOD_{out} = (k_4)(k_5)(BOD_{in})$$

where k_4 equals 0.10 for a normal activated sludge system and 0.20 for a suspended growth system. The value k_5 is the fraction of the BOD not removed in the primary clarifier and is generally equal to 0.70.

For lagoon treatment systems, the sludge production has been approximated as:

$$lb/day = [\,(SS_{in} - SS_{out})(8.34)(Q_{mgd})\,]$$
$$+ [\,0.65\ (BOD_{in} - BOD_{out})(Q_{mgd})(8.34)\,]$$

The values derived for each of the ten provinces are given in Table 1.7. In most cases the provincial per capita sewage production was below the 100 USGPD standard estimate and the 0.20lbs/capita/day sludge production estimate. This is mainly due, however, to the low percentage of the total provincial population served.

The provincial populations used, obtained from the "Water and Pollution Control" survey are, in most cases, less than the actual populations for late 1976 as reported in the Globe and Mail (Jan. 1977). If it is assumed that the population sampled is representative of the whole population, then the real sludge production values would be as shown in Table 1.8.

An example of a direct comparison of calculated versus real values is shown in Table 1.9 for four major Alberta cities as given by McCoy (1977). Correlations range from less than one percent to 170 percent variation. In McCoy's reported values the sludge value includes only that leaving the municipal plants and does not include septic tank or lagoon sludge.

1.8.2 Calculated Versus Real Production Values

After all the estimates had been completed as described, the values were sent to officials of the Environment Ministries in each of the provinces for verification. Included with the data was a request for information on the methods and regulations for sludge treatment and disposal in the province. This short letter and questionnaire is as shown in Appendix 1.2.

Comments received from each of the provinces were evaluated to determine the accuracy of the estimated production values and to make corrections to these values where necessary. In most cases no actual numerical value could be placed on sludge production, and only the variables used to estimate production could be verified. Quite often, only sludge production for the major urban areas had been studied, thus little information was available on small town and rural sludge production. The major comments received from each of the provinces are summarized as follows:

1.8.2.1 Manitoba

Environmental Management Division, Department of Mines, Resources, and Environmental Management.

Contact: C.B. Orcutt, Chief, Environmental Control Programs.

1. There are no regulations governing the disposal of sludge on land. Limits respecting sludge disposal are prescribed by Order of the Clean Environment Commission pursuant to the provisions of the Clean Environment Act.
2. Sludge disposal operations must be registered under the Clean Environment Act before applications can take place.
3. 730 acres per year are used for the disposal of sludge from the City of Winnipeg. It is anticipated that the loading rate will be reduced in the near future by increasing the disposal area to 1800 acres.
4. Decantation cells are used by the City of Winnipeg.
5. Future plans are to ensure that sludge is disposed of in an environmentally and agriculturally acceptable manner.
6. Average water used by rural communities served by public water supply systems (imp. gal/cap/day) 95.5

   Average water used by the City of Winnipeg 130.0
7. Percent of Province served by treatment facilities 81.3
8. Pounds of sludge produced per day 90,000 *
9. Gallons of sludge produced per day at 3% solids 300,000 *
10. Total sewage treated (M.I.G.P.D.) ** 82.2
11. Number of sewage treatment facilities

		Primary	Secondary
i)	continuous discharge	15	29
ii)	intermittent discharge(lagoons)	3	101
iii)	soil application	0	23

12. Population served

i)	continuous discharge	697,614
ii)	intermittent discharge	103,358
iii)	soil application	2,198
		803,170

13. Population used for calculations (1971 census) 988,247

* Sludge production for the City of Winnipeg. Other activated sludge plants are of the extended aeration or aerated lagoon type. Sludge production from these was considered minimal and is primarily disposed of in waste disposal grounds.

** Assume 80% of water produced reaches sewage treatment facility and 95.5 imp gal/cap/day produced (rural).

225,247 x 95.5 x .80/1000 =	17.20
City of Winnipeg (1976)	65.00
	82.20 M.I.G.P.D.

1.8.2.2 British Columbia

Water Resources Services, Pollution Control Branch,
Department of the Environment,
Contact: G.P.P. Talbott, Head, Services Section, Municipal Division.

1. At the present time, there are no specific regulations governing the disposal of sludge on land, other than contained in the "Pollution Control Objectives for Municipal Type Waste Discharges in British Columbia."
2. Conditions for sludge treatment and disposal are generally (but not always) encompassed as part of the permit conditions for sewage treatment works and sanitary landfills, and separate applications for sludge disposal have not been required to date. We do not, therefore, have easy access to the information you require.
3. Since the present system has obvious deficiencies, we are presently engaged in setting up a study program on sludge treatment

and disposal practices in the Province to determine the extent of the problems, and recommend courses of action. However, it will be at least 6 - 9 months time before this will be completed, and the information will be available.

4. The information obtained from the 1976-1977 Directory and Environmental Handbook, from our knowledge is somewhat incomplete, but unfortunately we do not have all the values in the form you require. We are checking our data sources and will try to come up with more accurate answers to Items, 1, 2, and 4 to 8.

1.8.2.3 Nova Scotia

Department of the Environment,
Contact: A.L. Carroll, Acting Director, Environmental Assessment.

1. In Nova Scotia the problems associated with solid waste management are continually being scrutinized by Department staff. However, the mode of treatment commonly utilized to handle municipal waste water, i.e. aerobic ponds, results in the production of a minimum amount of sludge requiring disposal. Any municipal sewage sludge that requires disposal is disposed of in sanitary landfill providing that the permission of the landfill operator has been obtained. In the near future, the Nova Scotia Department of the Environment should be commissioning a study involving a consultant that will serve to support the development of a Provincial strategy, the purpose of which will be to handle municipal and domestic sewage sludges. Consequently, at this point in time, I am unable to provide concrete information on the majority of your requests other than to say that such information should be available shortly.
2. Average water use (Imperial gallons/capita/day) 71.57
3. Percent of real population served by treatment facilities 11.37

4.	Pounds of sludge produced per day *	10,000 - 12,000
5.	Gallons of sludge produced per day at 2% solids**	60,000 - 72,000
6.	Total sewage treated (M.IG/D)	8.52
7.	Number of municipal sewage treatment plants	
	(a) primary	0
	(b) secondary	54
8.	Populations used for calculations	483,000
9.	Real population ***	813,043

* Amount recorded does not indicate amount requiring disposal

** Calculations made utilizing information supplied in your request

*** Population figure obtained from Statistics Canada, Halifax Office, February 21, 1977.

1.8.2.4 New Brunswick

Environment,

Contact: A.J. Cameron, Chief, Sanitary Engineering Section, Pollution Control Branch.

1.	Population of New Brunswick 1976 (preliminary)	672,856
2.	Population in Municipalities 1976	422,614
3.	% of (1)	62%
4.	Population on municipal sewer system in 1976 based on 1976 population	379,097
5.	% of (2)	89%
6.	Population with domestic waste treatment plants in 1976 based on 1976 population	199,367
7.	% of (3)	52.6%
8.	Population with municipal water supply and distribution systems based on 1976 population	346,782
9.	% of (2)	82%
10.	Population without sewer system (2-4)	43,517
11.	Population with a sewer system but without a waste water treatment plant (4-6)	179,730
12.	Population without a water system (2-8)	75,832

1.8.2.5 Ontario

Ministry of the Environment

Contact: G.M. Wood, Head, Solid Waste Unit, Municipal and Private Section, Pollution Control Branch.

1. Estimated Breakdown of Sludge Processing Facilities in Ontario(1976)

Method of Disposal	Number of Mechanical Treatment Plants	Quantity of Sludge (dry tons/year)	Percent of Total Sludge
Incineration	3	70,006	39.8
Application to farmland	133	59,754	34.0
Disposal by landfill	23	39,513	22.5
Disposal by other means (lagoons, dry beds, dump-site plus mine tailings, etc.)	51	6,512	3.7
Total	210	175,785	100.0

The total sludge area of agricultural land receiving sewage is approximately 103,000 acres (estimated for 1976).

2. Production Values for Water and Sewage

Ontario population (million)	8.15
Total capacity of Ontario's 459 municipal water works (M.I.G.D.)	1,769
Population served by municipal sewage treatment facilities (million)	6.4
Total sewage treated by municipal facilities (M.I.G.D.)	976
Pounds of municipal sludge produced per day (dry weight)	962,546
Imperial gallons of sludge produced per day (average T.S of 4.8%)	2,005,304
Number of sewage treatment facilities (April 1977)	337

3. Future Plans Regarding Sewage Sludge Management

The Ontario Ministry of the Environment has been encouraging the use of the nitrogen, phosphorus and organic content of sewage sludge, as fertilizer supplement and a soil conditioner in agricultural production. However, the major thrust of this activity has been complicated by the presence of metals in sewage sludge which, if allowed to accumulate in the soil may cause serious problems.

Guidelines have now been developed for the utilization of processed liquid sewage sludge on agricultural lands. The intent of these guidelines is to optimize the utilization of the nutrient value of sewage sludge (nitrogen, phosphorus and organic content) in agricultural production and at the same time, control the rate of nutrient application and the level of heavy metals accumulation in soil thereby minimizing the potential detrimental effects to food crops and environment (including surface and ground water systems). In addition to specifying the types of crops, the application sites and the soil characteristics suitable for the spreading of sewage sludge, the guidelines also set criteria on the quality as well as the rate of application of sewage sludge acceptable for utilization in crop production.

These guidelines have received the support, at the staff level, of the three participating Ministries (Agriculture and Food, Environment, and Health) and have been submitted for consideration as Government policy. Although a directive has not been received to date, it is anticipated that the guidelines will be adopted and a province-wide implementation program initiated in the near future.

4. Refer also to:

   a) Regulation 824 made under the Environmental Protection Act which prescribes standards for the location, maintenance and operation of an "organic soil conditioning site."

b) Application forms for Certificate of Approval for an organic waste management system and an organic waste site.

c) "1975 Operating Summary, Water Pollution Control Projects" "1975 Water and Sewage Treatment Works in Ontario"

1.8.2.6 Prince Edward Island

Department of the Environment

Contact: P.V. Rose, Director, Pollution Control Division

1. The information provided within the calculation sheet appears reasonable although some figures might appear high while others are low.

2. Primary Plants = 1
Secondary Plants = 2

3. Percent Province served:
   - excluding septic tanks: 60-65%
   - including septic tanks: 80-90%

1.8.2.7 Provinces not providing information

1. Alberta

Contact: R.N. Buggs, Director
Pollution Control Division
Alberta Department of the Environment.

2. Newfoundland

Contact: C.J. Downey, Assistant Deputy Minister
Environmental Management and Control Division
Department of Consumer Affairs and Environment.

3. Saskatchewan

Contact: R.A. MacDonald, Director
Water Pollution Control Branch
Environmental Protection Services
Environment Saskatchewan.

4. Quebec

Contact: Pierre Gagnon, Director
Waste Management
Urban Environment Branch
Quebec Environmental Protection Services.

1.9 Canadian Sludge Production to the Year 2000 On the basis of the computed per capita sludge production values, it is possible to determine the future sludge production rates, given the rate of population increases and the rate of increase of sludge production.

1.9.1 Canadian Population Growth From a historical standpoint, there has been an increase in the rate of population increase in Canada during the last 100 years as well as an overall increase in numbers. The increasing trend from 1880 to 1976 is shown in Figure 1.4 (Urquhart, 1965). The change in the rate of increase during this time is shown in Figure 1.5 with an extrapolated figure to the year 2000. If the population is to continue growing at this rate, the population would exceed 35 million by 1990 and 47 million by the year 2000. More conservative estimates given by Statistics Canada (1976) and Environment Canada (1975) indicate a maximum century end population of just under 36 million. Potentials for population growth in Canada are discussed in detail by Romaniuc (1973).

The analysis conducted by Environment Canada gives population projections based on 3 alternative fertility rates and net migration rates of Ø and 100,000 per year. The values from this study are as shown in Table 1.10. This data is also illustrated graphically in Figure 1.6

1.9.2 Canadian Water Use Growth Environment Canada(1975) also indicates that per capita water intake is increasing at 2 percent per year and the present daily intake of 125 Igpd is expected to climb to 200 gpd by 1880 and 300-350 by the year 2000. Based on these two sets of figures, the total water consumption to the end of the century can be calculated as shown in Table 1.11 An indication of the total water supply in Canada is also presented by Aggarwal (1977), in a national inventory of municipal waterworks and wastewater systems.

1.9.3 Canadian Sludge Production Growth From Table 1.7 the total sewage treated is given as 1750 million Imperial gallons per day, which is 49.7 percent of the total daily water use in 1976, as shown in Table 1.11. Present estimates show that about 66 percent of the urban population sewage is treated, 90 percent of which comes from communities greater than 50,000. It is also reported that 25 percent of the treated sewage receives primary treatment only. If all of Canada receives the same degree of treatment as that practiced in urban centres, then the total sewage treated and sludge production will be as shown in Table 1.12. Sludge production values are based on the averages given in Table 1.7, giving 1398.5 lb/million gallons (0.7 tons/MG).

If these numbers are indicative of future growth, we can expect a four-fold increase in sludge production within the next twenty-five years. A comparison of our growth in sludge production compared to that in the United States and Sweden is shown in Table 1.13 and Figure 1.7.

APPENDIX 1.1

COMPUTER PROGRAM FOR SLUDGE PRODUCTION

```
      PROGRAM SLUDGE(INPUT,OUTPUT,TAPE5=INPUT,TAPE6=OUTPUT)
C MUNICIPAL AND PROVINCIAL SLUDGE PRODUCTION IN CANADA
C RICHARD LAUGHTON, APPLIED CHEMISTRY
C CMHC CONTRACT 10054
C
C INITIALIZE AND READ DATA
      DIMENSION A(1200,13)
      INTEGER A
      DIMENSION B(1200,9)
      N=1200
      DO 2 I=1,N
      READ(5,500) (A(I,J),J=1,13)
  500 FORMAT(I4,I2,2I7,I6,2I1,I6,4I3,I1)
      IF(A(I,2).GT.10) GO TO 3
    2 CONTINUE
    3 CONTINUE
      I=0
      M=0
   10 C=0.0
      NOPE=0
      NPRIME=0
      NYES=0
      NSEC=0
      K=0
      AE=0.0
      AF=0.0
      E=0.0
      F=0.0
      RSL=0.0
      ASL=0.0
      ALLSLD=0.0
      POPSLD=0.0
      TWOSLD=0.0
      TENSLD=0.0
      P=0.0
      W=0.0
C MAIN PROGRAM
   15 I=I+1
      K=K+1
      T=(A(I,5)/100.0)
      IF(A(I,2).GT.10) GO TO 600
      IF(A(I,1).EQ.0) GO TO 400
      IF(A(I,7).EQ.0) GO TO 80
      NYES=NYES+1
      IF(A(I,4).EQ.0) GO TO 16
      IF(A(I,5).EQ.0) GO TO 17
      GO TO 18
   16 A(I,4)=A(I,3)
      IF(A(I,5).EQ.0) GO TO 17
      GO TO 18
   17 T=(A(I,4)*100.0)/1000000
   18 CONTINUE
      B(I,1)=A(I,1)
      B(I,2)=A(I,2)
      B(I,3)=A(I,4)*100.0/A(I,3)
      B(I,4)=(T*1000000.0)/A(I,4)
      C=C+A(I,3)
```

```
      E=E+B(I,3)
      F=F+B(I,4)
      W=W+T
      B(I,9)=(A(I,8)-A(I,5))/100.0
C CHECKING TREATMENT TYPE
      IF(A(I,7).EQ.1) GO TO 20
      NSEC=NSEC+1
      IF(A(I,13).EQ.1) GO TO 30
      IF(A(I,13).EQ.2) GO TO 40
      IF(A(I,13).EQ.3) GO TO 50
      IF(A(I,13).EQ.4) GO TO 60
      GO TO 70
C PRIMARY TREATMENT ONLY
   20 CONTINUE
      NPRIME=NPRIME+1
      IF(A(I,10).EQ.0) GO TO 21
      IF(A(I,12).EQ.0) GO TO 23
      B(I,5)=(A(I,10)-A(I,12))*T*8.34*0.6
   22 B(I,6)=B(I,5)/A(I,4)
      B(I,7)=(B(I,5)/0.02)/8.34
      B(I,8)=(B(I,5)/0.10)/8.34
      GO TO 15
   23 B(I,5)=A(I,10)*T*8.34*0.6
      GO TO 22
   21 B(I,5)=A(I,4)*0.12
      GO TO 22
C PRIMARY TREATMENT PLUS ACTIVATED SLUDGE
   30 X=0.50
      Z=0.1
   32 CONTINUE
      IF(A(I,10).EQ.0) GO TO 31
      IF(A(I,12).EQ.0) GO TO 31
      IF(A(I,9).EQ.0) GO TO 31
      IF(A(I,11).EQ.0) GO TO 34
   35 CONTINUE
      RSL=A(I,10)*T*8.34*0.6
      ASL=(X*(0.7*(A(I,9)-A(I,11)))*8.34*T)+(0.4*RSL)-(A(I,12)*T*8.34)
      B(I,5)=RSL+ASL
      GO TO 33
   31 B(I,5)=A(I,4)*0.20
   33 CONTINUE
      IF(A(I,6).EQ.0) GO TO 22
      P=A(I,4)*0.05
      B(I,5)=B(I,5)+P
      GO TO 22
   34 CONTINUE
      A(I,11)=Z*0.7*A(I,9)
      GO TO 35
C PRIMARY TREATMENT PLUS TRICKLING FILTERS, CHANGES X
   40 X=0.2
      Z=0.2
      GO TO 32
C AERATED LAGOONS
   50 CONTINUE
      IF(A(I,10).EQ.0) GO TO 31
      IF(A(I,12).EQ.0) GO TO 31
      IF(A(I,9).EQ.0) GO TO 31
```

```
          IF(A(I,11).EQ.0) GO TO 31
          RSL=(A(I,10)-A(I,12))*T*8.34
          ASL=(A(I,9)-A(I,11))*T*8.34
          ASL=ASL*0.65
          B(I,5)=RSL+ASL
          GO TO 33
C SEPTIC TANKS USED
   60 B(I,5)=T*810.0
          GO TO 33
C UNCLASSIFIED SEWAGE TREATMENT, 0.20 LBS/CAPITA
   70 B(I,5)=A(I,4)*0.20
          GO TO 33
C NO SEWAGE TREATMENT IN THE COMMUNITY
   80 B(I,1)=A(I,1)
          B(I,2)=A(I,2)
          DO 81 J=3,9
          B(I,J)=0.0
   81 CONTINUE
          C=C+A(I,3)
          NOPE=NOPE+1
          GO TO 15
C CALCULATE AND PRINT DATA ARRAY
  400 CONTINUE
          WRITE(6,402)
  402 FORMAT("1",10X,"MUNICIPAL SLUDGE PRODUCTION IN CANADA")
          WRITE(6,403)
  403 FORMAT("0",5X,"TOWN",2X,"PROVINCE",2X,"  POPULATION SERVED",
     12X,"AVERAGE GPCD",2X,"POUNDS/DAY",2X,"POUNDS/CAPITA/DAY",5X,
     1"GALS AT 2 ",2X,"GALS AT 10 ",2X,"MGD EXTRA")
          WRITE(6,404)
  404 FORMAT("0")
          K=K-1
  401 CONTINUE
          M=M+1
          IF(M.GE.I) GO TO 450
          ALLSLD=ALLSLD+B(M,5)
          POPSLD=POPSLD+B(M,6)
          TWOSLD=TWOSLD+B(M,7)
          TENSLD=TENSLD+B(M,8)
          WRITE(6,405) (B(M,J),J=1,9)
  405 FORMAT(" ",3X,F6.1,2X,F4.1,11X,F5.1,11X,F5.1,9X,F12.1,4X,F6.3,
     113X,F9.1,3X,F9.1,13X,F6.2)
          GO TO 401
  450 CONTINUE
C CALCULATE AND PRINT PROVINCIAL SUMMARY
          WRITE(6,420)
  420 FORMAT("1",10X,"PROVINCIAL SUMMARY OF SEWAGE SLUDGE PRODUCTION")
          WRITE(6,421)
  421 FORMAT("-",5X,"AVERAGE GPCD",2X,"PERCENT PROVINCE SERVED",2X,
     1"POUNDS/DAY",2X,"POUNDS/CAPITA/DAY",2X,"GALS AT 2 ",2X,
     1"GALS AT 10 ",2X,"WATER MGD",8X,"POPULATION")
          AE=E/K
          AF=F/K
          POPSLD=POPSLD/K
          WRITE(6,422)AF,AE,ALLSLD,POPSLD,TWOSLD,TENSLD,W,C
  422 FORMAT("0",7X,F6.2,8X,F6.2,15X,F12.1,4X,F6.3,10X,F12.1,3X,F12.1,
     14X,F7.2,10X,F12.1)
```

```
      WRITE(6,423)NOPE,NPRIME,NSEC,NYES
  423 FORMAT("0","NO TREATMENT= ",I3,2X,"PRIMARY ONLY= ",I3,2X,
     1"SECONDARY= ",I3,2X,"TOTAL PLANTS= ",I3)
      GO TO 10
  600 STOP
      END
```

ALBERTA 1

1. Athabaska
2. Banff
3. Barrhead
4. Beaverlodge
5. Bellevue
6. Black Diamond
7. Blairmore
8. Bonnyville
9. Bow Island
10. Brooks
11. Calgary - Bonnybrook
12. Calgary - Fishcreek
13. Camrose
14. Canmore
15. Cardston
16. Castor
17. Claresholm
18. Coaldale
19. Cold Lake
20. Coleman
21. Devon
22. Didsbury
23. Drayton Valley
24. Drumheller
25. Edmonton
26. Edson
27. Fairview
28. Fort McLeod
29. Fort McMurray
30. Fort Saskatchewan
31. Grand Centre
32. Grande Prairie
33. Hanna
34. High Level
35. High Prairie
36. High River
37. Hinton
38. Jasper
39. Lac La Biche
40. Lacombe
41. Leduc
42. Lethbridge
43. Magrath
44. Manning
45. McLennan
46. Medicine Hat
47. Morinville
48. Nanton
49. Okotoks
50. Olds
51. Peace River
52. Picture Butte
53. Pincher Creek
54. Ponoka
55. Provost
56. Raymond
57. Redcliff
58. Red Deer
59. Redwater
60. Rimbey
61. Rocky Mountain House
62. Slave Lake
63. Spirit River
64. St. Albert
65. St. Paul
66. Stettler
67. Stony Plain
68. Strathmore
69. Swan Hills
70. Sylvan Lake
71. Taber
72. Three Hills
73. Two Hills
74. Valleyview
75. Vauxhall
76. Vegreville
77. Vermilion
78. Viking
79. Vulcan
80. Wainwright
81. Waterton Park
82. Westlock
83. Wetaskiwin
84. White Court

BRITISH COLUMBIA 2

1. Abbotsford
2. Alberni-Clayoquot
3. Armstrong
4. Bralorne
5. Burns Lake
6. Campbell River
7. Castlegar
8. Chetwynd
9. Chilliwack
10. Comox
11. Coldstream District
12. Courtnay
13. Dawson Creek
14. Esquimalt Township
15. Fernie
16. Fort Nelson
17. Fort St. James
18. Fort St. John
19. Fruitvale
20. Grand Forks
21. Annacis Island, Vancouver
22. Iona Island, Vancouver
23. Lions Gate, Vancouver
24. Lulu Island, Vancouver
25. Hope
26. Kamloops
27. Kaslo
28. Kelowna
29. Kimberley
30. Kinnaird
31. Kitimat
32. Ladysmith
33. Lake Cowichan
34. MacAulay Point
35. Maple Bay
36. Maple Ridge District
37. Matsqui District
38. Merritt
39. Mission
40. Montrose
41. Nakusp
42. Nanaimo
43. Nelson
44. North Cowichan District
45. Oak Bay
46. Ocean Falls
47. Oliver
48. Osoyoos
49. Parksville
50. Penticton
51. Pitt Meadows
52. Port Alberni

British Columbia (contd)

53. Port Edward
54. Powell River District
55. Prince George
56. Prince Rupert
57. Princeton
58. Quesnel
59. Revelstoke
60. Rossland
61. Saanich (Central)
62. Saanich
63. Salmon Arm
64. Sidney
65. Smithers
66. Spallumcheen Township
67. Squamish
68. Summerland
69. Terrace
70. Trail
71. Ucluelet
72. Vanderhoof
73. Vernon
74. Victoria
75. Warfield
76. Williams Lake

MANITOBA 3

1. Altona
2. Angusville
3. Arborg
4. Argyle
5. Ashern
6. Baldur
7. Beausejour
8. Belmont
9. Benito
10. Berens River
11. Binscarth
12. Birtle
13. Boissevain
14. Bowsman
15. Brandon
16. Cameron
17. Carberry
18. Carman
19. Cartier Rural Municipality
20. Cartwright
21. Charleswood
22. Churchill
23. Crystal City
24. Cypreos River
25. Darlingford
26. Deloraine
27. Dauphin
28. Dominion City
29. East Kildonan
30. Elie
31. Elkhorn
32. Emerson
33. Erickson
34. Ethelbert
35. Flin Flon
36. Fort Gary
37. Gilbert Plains
38. Gillam
39. Gimli
40. Gladston
41. Glenboro
42. Grandview
43. Great Falls
44. Gretna
45. Hamiota
46. Hartney
47. Holland
48. Ile de Chene
49. Inglis
50. Kelwood
51. Killarney
52. Kleefeld
53. La Riviere
54. Lac Du Bonnet
55. Le Tellier
56. Lorette
57. Lynn Lake
58. MacGregor
59. Manitou
60. McAuley
61. McCreary
62. Medora
63. Melita
64. Miniota
65. Minitonas
66. Minnedosa
67. Morden
68. Morris
69. Neepawa
70. Newdale
71. North Kildonan
72. Oakburn
73. Oak Lake
74. Oakland
75. Oak River
76. Ochre River
77. Pilot Mound
78. Pinawa
79. Pine Falls
80. Plum Coulee
81. Portage La Prairie
82. Powerview
83. Rapid City
84. Roblin
85. Rivercrest
86. Rivers
87. Rosedale
88. Rossburn
89. Russell
90. St. Agathe
91. Ste Anne
92. St. Boniface
93. St. George
94. St. James
95. St. Jean Baptiste
96. St. Lazare
97. St. Pierre
98. Ste Rose du Lac

Manitoba (contd)

99. St. Vital
100 Sandy Lake
101 Selkirk
102 Snow Lake
103 Somerset
104 Souris
105 Steinbach
106 Strathclair
107 Swan Lake
108 Swan River
109 The Pas
110 Thompson
111 Treherne
112 Transcona
113 Tuxedo
114 Virden
115 Wawanesa
116 Waskada
117 West Kildonan
118 Winkler
119 Winnipeg
120 Winnipeg Beach
121 Winnipegosis

NEW BRUNSWICK 4

1. Atholville
2. Barkers Point
3. Bathurst
4. Buctouche
5. Campbellton
6. Caraquet
7. Chatham
8. Dalhousie
9. Dieppe
10. Edmondston
11. Fairvale
12. Fredericton
13. Grand Falls
14. Gunningsville
15. Hartland
16. Lewisville
17. Milltown
18. Moncton
19. Nackawic
20. Newcastle
21. Oromocto
22. Perth Andover
23. Plaster Rock
24. Renforth
25. Riverview Heights
26. Riviere Verte
27. St. Andrews
28. St. George
29. St. Jacques
30. Saint John
31. St. Leonard
32. St. Quentin
33. St. Stephen
34. Sackville
35. Shediac
36. Shippegan
37. Sussex
38. Woodstock

NEWFOUNDLAND 5

1. Bishops Falls
2. Bonavista
3. Botwood
4. Buchans
5. Burin
6. Carbonear
7. Catalina
8. Channel-Port-aux-Basques
9. Clarenville
10. Corner Brook
11. Deer Lake
12. Dunville
13. Fortune
14. Freshwater
15. Gander
16. Gander International Airport
17. Glenwood
18. Gloverton
19. Grand Bank
20. Grand Falls
21. Harbour Bretton
22. Harbour Grace
23. Hearts Content
24. Labrador City
25. Lewisporte
26. Marystown
27. Mount Pearl
28. Placentia
29. Ramea
30. St. Albans
31. St. Anthony
32. St. John's
33. St. Lawrence
34. Springdale
35. Stephenville
36. Stephenville Crossing
37. Wesleyville
38. Windsor

NOVA SCOTIA 6

1. Amherst
2. Antigonish
3. Berwick
4. Bible Hill
5. Bridgetown
6. Bridgewater
7. Canso
8. Dartmouth
9. Digby
10. Dominion
11. Donkin
12. Glace Bay
13. Halifax

Nova Scotia (contd)

14. Halifax County
15. Hantsport
16. Kentville
17. Liverpool
18. Louisbourg
19. Lunenburgh
20. Mahone Bay
21. Middleton
22. Mulgrave
23. New Glasgow
24. New Waterford
25. North Sydney
26. Oxford
27. Parrsboro
28. Pictou
29. Port Hawkesbury
30. Reserve Mines
31. Shelburne
32. Springhill
33. Stellarton
34. Stewiacke
35. Sydney
36. Sydney Mines
37. Trenton
38. Truro
39. Westville
40. Windsor
41. Wolfville
42. Yarmouth

ONTARIO 7

1. Acton
2. Alexandria
3. Alfred
4. Alliston
5. Amherstburg and Area
6. Anderton Township
7. Ancaster
8. Arnprior
9. Arthur
10. Athens
11. Atikokan
12. Aurora
13. Aylmer
14. Ayr
15. Baden
16. Balmertown
17. Barrie
18. Barry's Bay
19. Battawa
20. Beamsville
21. Belle River
22. Belleville
23. Bicroft
24. Binbrook
25. Blenheim
26. Blind River
27. Bobcaygeon
28. Bolton
29. Bowmanville
30. Bracebridge
31. Bradford
32. Brampton
33. Brantford
34. Brantford Township
35. Brighton
36. Brockville
37. Burlington
38. Caledonia
39. Calvert Township
40. Campbellford
41. Cardiff Township
42. Cardinal
43. Carleton Place
44. Casselman
45. Cayuga
46. Chapleau
47. Chatham
48. Chesley
49. Chesterville
50. Clinton
51. Cobalt
52. Cobourg
53. Cochrane
54. Cochenour
55. Colborne
56. Collingwood
57. Cornwall
58. Creighton Mines
59. Cumberland Township
60. Deep River
61. Delhi
62. Deseronto
63. Dresden
64. Dryden
65. Dundas
66. Dunnville
67. Durham

Durham Regional Municipality

68. Ajax (Duffin Ck.No.1 W.P.C.P)
68. Ajax (Duffin Ck.No.2 W.P.C.P)
69. Brock (Lake Simcoe W.P.C.P)
70. Brock (Beaverton River W.P.C.P)
71. Brock (Sunderland)
72. Newcastle (Soper Creek W.P.C.P)
73. Newcastle(Graham Creek W.P.C.P)
74. Newcastle (Orono)
75. Oshawa(Harmony Ck.No.1&2 WPCP)
75. Oshawa (Corbett Creek W.P.C.P)
76. Pickering (Frenchman Bay WPCP)
77. Scugog (Nonquon River W.P.C.P)
78. Uxbridge (Uxbridge Brk W.P.C.P)
79. Whitby (Corbett Creek W.P.C.P)
79. Whitby (Pringle Creek W.P.C.P)
79. Whitby (Brooklin)
80. Ear Falls
81. East Flamborough
82. Township of East Gwillimbury
    Holland Landing W.P.C.L
83. East York
84. Elliot Lake
85. Elora
86. Englehart
87. Espanola
88. Essex
89. Essex County
90. Exeter
91. Falconbridge
92. Fenelon Falls
93. Fergus

Ontario (contd)

94. Fonthill
95. Forest
96. Fort Francis
97. Frankford
98. Gananoque
99. Georgetown
100. Township of Georgina
     Sutton W.P.C.L.
101. Geraldton
102. Glanford
103. Glencoe
104. Gloucester
105. Goderich
106. Gravenhurst
107. Guelph
108. Hagersville
109. Haileybury
110. Hamilton (Hamilton-Wentworth)
111. Hanover (Regional Municipality)
112. Harriston
113. Harrow
114. Hawkesbury
115. Hearst
116. Huntsville
117. Ingersoll
118. Ingelside
119. Iroquois
120. Iroquois Falls
121. Kapuskasing
122. Kearns
123. Keewatin
124. Kemptville
125. Kendry Township
126. Kenora
127. Kincardine
128. King City
129. Kingston
130. Kingston Township
131. Kingsville
132. Kirkland Lake
133. Lakefield
134. Lambeth
135. Larder Lake
136. Leamington
137. Lindsay
138. Little Current
139. London
140. Long Sault
141. Longlac
142. L'Original
143. Lucan
144. Madoc
145. Manitouwadge
146. Marathon
147. Markdale
     Markham
148. John St. W.P.C.P.
149. Tuclor Lane W.P.C.P.
150. Unionville W.P.C.P.
151. Marmora
152. Massey
153. Mattawa
154. McGarry Township
155. McKenzie Is.
156. Meaford
157. Michipicoten Township
158. Midland
159. Milton
160. Milverton
170. Mississauga
180. Mitchell
181. Moore Township
182. Moose Factory
183. Morrisburg
184. Mount Forest
185. Mount Joy Township
186. Napanee
187. New Liskeard
188. Newmarket
     Niagara Regional Muncipality
     Fort Erie
189. River Plant
190. Crystal Beach
     Grimsby
191. Main
192. Lagoon
193. Beach
194. Niagara Falls
195. Stamford/Niag.
196. Chippawa
197. Niagara on the Lake
     Port Colborne
198. East
199. West
200. Port Dalhousie (St. Catharines & Thorold)
201. Welland and Pelham "
202. West Lincoln " "
203. Port Weller " "
204. Nipigon
205. North Bay
206. North York (by Metro Toronto)
207. Norwich
208. Norwood
209. Oakville
210. Osnabrook
211. Orangebille
212. Orillia
     Ottawa-Carleton
213. Green Creek
214. Watts Creek
215. Bilberry
216. Nepean Township
217. Owen Sound
218. Palmerston
219. Parkhill
220. Parry Sound
221. Pembroke
222. Penetanguishene

Ontario (contd)

223. Perth
224. Peterborough
225. Petrolia
226. Pickering Village
227. Picton
228. Plantagenet
229. Point Edward
230. Port Credit
240. Port Dover
250. Port Elgin
251. Port Hope
252. Port McNicoll
253. Port Perry
254. Port Stanley
255. Powassan
256. Prescott
257. Red Lake
258. Red Rock
259. Renfrew
260. Richmond Hill
261. Richmond Village
262. Ridgetown
263. Rockliffe Park
264. Rockland
265. St. Mary's
266. St. Thomas
267. Saltfleet Township
268. Sandwich West Township
269. Sarnia
270. Sault Ste Marie
271. Scarborough
272. Schreiber
273. Seaforth
274. Shelburne
275. Shuniah
276. Simcoe
277. Sioux Lookout
278. Smiths Falls
279. Smooth Rock Falls
280. Southampton
281. South Porcupine
282. South Peel
283. Stayner
284. Stirling
285. Stittsville
286. Stoney Creek
287. Stouffville
288. Stratford
289. Strathroy
290. Streetsville
291. Sturgeon Falls

Sudbury Regional Muncipality

292. Azilda
293. Capreol
294. Chelmsford Lagoon
295. Chelmsford W.P.C.P.
296. Coniston
297. Copper Cliff
298. Garson
299. Levack
300. Lively W.P.C.P.
301. Onaping
302. Sudbury
303. Valley East W.P.C.P.
304. Sunderland
305. Sutton
306. Tavistock
307. Tecumseh
308. Terrace Bay
309. Thessalon
310. Thornbury
311. Thunder Bay
312. Tilbury
313. Tillsonburg
314. Timmins

Toronto(Metro)

315. Ashbridge's Bay
315. Humber
315. Highland Creek
315. North Toronto
316. Trenton
317. Tuckersmith Township
318. Tweed
319. Vanier

Vaughan Township

320. Kleinburg W.P.C.P.
321. West Don W.P.C.P.
322. Vankleek Hill
323. Virginiatown
334. Walden
335. Walkerton
336. Wallaceburg
337. Wasaga Beach
338. Waterdown
339. Waterford

Waterloo Regional Municipality

340. Cambridge (Preston)
341. Cambridge (Galt)
342. Elmira
343. Hespeler
345. Kitchener
346. New Hamburg
347. St. Jacobs
348. Waterloo
349. Waubaushene
350. Wawa
351. West Lorne
352. Wheatley
353. Whitchurch-Stouffville
Stouffville W.P.C.P.
354. White River
355. Whitney Township
356. Wiarton
357. Winchester
358. Wilmot

Windsor

359. West Windsor
360. Little River
361. Wingham
362. Woodbridge
363. Woodstock
364. Wyoming
365. Yarmouth Township
366. York (by Metro Toronto)

PRINCE EDWARD ISLAND 8

1. Charlottetown
2. Montague
3. Parkdale
4. St. Eleanors
5. Souris
6. Summerside

QUEBEC 9

1. Acton Vale
2. Alma
3. Amos
4. Amqui
5. Anjou
6. Arthabaska
7. Arvida
8. Asbestos
9. Aylmer
10. Baie Comeau
11. Baie de Shawnigan
12. Baie d'Urfe
13. Baie St. Paul
14. Beaconsfield
15. Beauharnois
16. Beauport
17. Beaupre
18. Becancour
19. Bedford
20. Beebe Plain
21. Beloeil
22. Berthierville
23. Bic
24. Black Lake
25. Biosbriand
26. Bonaventure
27. Boucherville
28. Bromptonville
29. Brossard
30. Brownsburg
31. Buckingham
32. Cabano
33. Cadillac
34. Calumet
35. Campbell's Bay
36. Cap-de-la-Madelaine
37. Candiac
38. Cap Chat
39. Cap Sante
40. Cap St. Ignace
41. Carleton
42. Chambly
43. Chambord
44. Chandler
45. Chapais Abitibi
46. Charlemagne
47. Charlesbourg
48. Charny
49. Chateauguay Centre
50. Chateau Richer
51. Chibougamau
52. Chicoutimi
53. Chicoutimi Nord
54. Coaticook
55. Contrecoeur
56. Cote St. Luc
57. Courcelles
58. Courville
59. Cowansville
60. Crabtree
61. Danville
62. Delson
63. Desbiens
64. Deschaillons
65. Des Chenes
66. Deux Montagnes
67. Disraeli
68. Dolbeau
69. Dollard Des Ormeaux
70. Donnaconna
71. Dorion
72. Dorval
73. Drummondville
74. Duparquet
75. East Angus
76. East Broughton Station
77. Farnham
78. Fort Coulonge
79. Gagnon
80. Gaspe
81. Gatineau
82. Giffard
83. Granby
84. Grand Mere
85. Grande Riviere
86. Greenfield Park
87. Grenville
88. Hampstead
89. Hauterive
90. Hemmingford
91. Hudson
92. Hull
93. Huntingdon
94. Iberville
95. Ile Perrot
96. Jonquiere
97. Joliette
98. Kenogami
99. Kirkland
100. Lac au Saumon
101. Lachine
102. Lachute
103. Lac Megantic
104. Lacolle
105. Latle
106. La Malbaie
107. L'Ancienne Lorette
108. L'Annonciation
109. La Perade
110. La Prarie
111. La Presentation

Quebec (contd)

112. La Providence
113. La Salle
114. L'Assomption
115. La Sarre
116. La Turue
117. Laurentides
118. Lauzon
119. Laval
120. Lavaltrie
121. Lemoyne
122. Lennoxville
123. L'Epiphanie
124. Lesage
125. Levis
126. Longueuil
127. Lorraine
128. Loretteville
129. Louiseville
130. Magog
131. Malartic
132. Maniwaki
133. Marieville
134. Mascouche
135. Masson
136. Matane
137. Matagami
138. McMasterville
139. Metis Beach
140. Mistassini
141. Montebello
142. Mont Joli
143. Mont Laurier
144. Montmagny
145. Montmorency
146. Montreal
147. Montreal East
148. Montreal Nord
149. Montreal West
150. Mont Rolland
151. Nicolet
152. Noranda
153. Normandin
154. Notre Dame des Laurentides
155. Ormstown
156. Outremont
157. Papineauville
158. Pierrefonds
159. Pierreville
160. Pincourt
161. Plessisville
162. Pointe aux Trembles
163. Point Claire
164. Pointe Gatineau
165. Pont Rouge
166. Port Alfred
167. Port Cartier
168. Portneuf
169. Princeville
170. Quebec
171. Rawdon
172. Repentigny
173. Richelieu
174. Richmond
175. Rigaud
176. Rimouski
177. Riviere du Loup
178. Riviere du Moulin
179. Roberval
180. Rock Island
181. Rouyn
182. Rosemare
183. Roxboro
184. Ste Andre Avellin
185. Ste Agathe des Monts
186. Ste Anne de Beaupre
187. Ste Anne de Bellevue
188. Ste Anne de la Perade
189. Ste Anne de la Pocatiere
190. Ste Anne des Monts
191. Ste Anne des Plaines
192. St. Basile le Grand
193. St. Bruno de Montarville
194. St. Casimir
195. Ste Catherine
196. St Cesaire
197. St. Contant
198. St. Cuthbert
199. St.Denis Riviere Richelieu
200. St. Donat de Montcalm
201. Ste Elizabeth
202. St.Esprit
203. St.Eustache
204. St.Felicien
205. St.Felix de Valois
206. St.Foy
207. St.Francois
208. St. Gabriel
209. St. Genevieve
210. St. Georges de Beauce
211. St. Georges Ouest
212. St. Hilaire sur Richelieu
213. St. Hubert
214. St. Hyacinthe
215. St. Jacques (Montcalm)
216. St. Jean
217. St. Jean Baptise de Rouville
218. St. Jean Chrysostome
219. St. Jerome
220. St. Joseph
221. St. Joseph de Beauce
222. St. Joseph de Sorel
223. St. Jovite
224. Ste Justine
225. St. Lambert
226. St. Laurent
227. St. Leonard
228. St. Lin
229. St. Luc
230. St. Marc des Carrieres
231. St. Marie Beauce
232. St. Michel
233. St. Michel de Mistassini
234. St. Nicolas
235. St. Pacome
236. St. Pie
237. St. Pierre
238. St. Raphael
239. St. Raymond

Quebec (contd)

240. St. Saveurs
241. Ste Thecle
242. Ste Therese
243. St. Tite
244. Salaberry de Valleyfield
245. Sayabec
246. Schefferville
247. Scotstown
248. Senneterre
249. Sept Iles
250. Shawnigan
251. Shawnigan Sud
252. Shawville
253. Sherbrooke
254. Sillery
255. Sorel
256. Stanstead Plain
257. Sutton
258. Temiscaming
259. Templeton
260. Terrebonne
261. Thetford Mines
262. Tracy
263. Trois Rivieres
264. Valcourt
265. Val-D'Or
266. Victoriaville
267. Ville Marie
268. Ville St Pierre
269. Warwick
270. Waterloo
280. Waterville
281. Westmount
282. Windsor

SASKATCHEWAN 10

1. Assiniboia
2. Battleford
3. Bienfait
4. Biggar
5. Broadview
6. Canora
7. Carlyle
8. Carnduff
9. Carrot River
10. Churchbridge
11. Creighton
12. Davidson
13. Esterhazy
14. Estevan
15. Eston
16. Foam Lake
17. Fort Qu'Apelle
18. Gravelbourg
19. Grenfell
20. Gull Lake
21. Herbert
22. Hudson Bay
23. Humbolt
24. Indian Head
25. Kamsack
26. Kelvington
27. Kerrobert
28. Kindersley
29. Kipling
30. Langenburg
31. Lanigan
32. Leader
33. Lloydminster
34. Maple Creek
35. Meadow Lake
36. Melfort
37. Melville
38. Moose Jaw
39. Moosomin
40. Nipawin
41. North Battleford
42. Outlook
43. Oxbow
44. Ponteix
45. Preeceville
46. Prince Albert
47. Radville
48. Regina
49. Rosetown
50. Rosthern
51. Saskatoon
52. Shellbrook
53. Swift Current
54. Tisdale
55. Unity
56. Uranium City
57. Wadena
58. Wakaw
59. Watrous
60. Weyburn
61. Whitewood
62. Wilkie
62. Wolseley
63. Wynyard
64. Yorkton

MUNICIPAL SLUDGE PRODUCTION IN CANADA

TOWN	PROVINCE	%POPULATION SERVED	AVERAGE GPCD	POUNDS/DAY	POUNDS/CAPITA/DAY	GALS AT 2%	GALS AT 10%	MGD EXTRA *
1.0	1.0	0.0	0.0	0.0	0.000	0.0	0.0	0.00
2.0	1.0	100.0	100.0	706.4	.200	4235.0	847.0	0.00
3.0	1.0	96.3	111.1	540.0	.200	3237.4	647.5	-.30
4.0	1.0	100.0	100.0	161.4	.120	967.6	193.5	0.00
5.0	1.0	0.0	0.0	0.0	0.000	0.0	0.0	0.00
6.0	1.0	105.8	100.0	200.0	.200	1199.0	239.8	0.00
7.0	1.0	108.7	52.3	497.6	.200	2983.2	596.6	.17
8.0	1.0	97.9	53.6	560.0	.200	3357.3	671.5	.45
9.0	1.0	86.3	90.0	120.0	.120	719.4	143.9	-.09
10.0	1.0	100.0	100.0	797.2	.200	4779.4	955.9	0.00
11.0	1.0	82.2	157.1	67573.8	.186	405119.0	81023.8	14.80
11.0	1.0	100.0	100.0	3992.7	.051	23937.0	4787.4	.80
13.0	1.0	100.0	99.3	2014.6	.200	12077.9	2415.6	.50
14.0	1.0	95.7	207.1	276.2	.124	1656.0	331.2	.84
15.0	1.0	111.7	300.0	360.0	.120	2158.3	431.7	-.90
16.0	1.0	100.0	100.0	233.2	.200	1398.1	279.6	0.00
17.0	1.0	109.4	114.3	700.0	.200	4196.6	839.3	-.40
18.0	1.0	100.1	71.4	336.0	.120	2014.4	402.9	-.20
19.0	1.0	10.6	83.3	240.0	.200	1438.8	287.8	-.10
20.0	1.0	104.3	100.0	320.0	.200	1918.5	383.7	0.00
21.0	1.0	100.0	44.2	271.8	.120	1629.5	325.9	.20
22.0	1.0	75.0	466.7	300.0	.200	1798.6	359.7	-.70
23.0	1.0	100.0	71.7	837.4	.200	5020.4	1004.1	-.30
24.0	1.0	67.3	100.0	800.0	.200	4796.2	959.2	0.00
25.0	1.0	41.7	273.2	135611.7	.699	813020.0	162604.0	101.00
26.0	1.0	123.8	95.2	1050.0	.200	6295.0	1259.0	0.00
27.0	1.0	94.8	100.0	400.0	.200	2398.1	479.6	0.00
28.0	1.0	102.4	107.9	556.0	.200	3333.3	666.7	0.00
29.0	1.0	58.8	50.0	1200.0	.120	7194.2	1438.8	-.50
30.0	1.0	100.0	69.9	1145.2	.200	6865.7	1373.1	.60
31.0	1.0	100.0	71.4	560.0	.200	3357.3	671.5	-.20
32.0	1.0	100.0	72.5	3511.7	.204	21053.1	4210.6	.25
33.0	1.0	100.0	78.6	509.0	.200	3051.6	610.3	.10
34.0	1.0	124.2	100.0	240.0	.120	1438.8	287.8	0.00
35.0	1.0	166.7	40.0	1000.0	.200	5995.2	1199.0	.30
36.0	1.0	97.6	100.0	354.0	.120	2122.3	424.5	0.00
37.0	1.0	97.7	310.3	1289.2	.200	7729.0	1545.8	-2.00
38.0	1.0	250.0	60.0	686.0	.069	4113.0	822.6	-.60
39.0	1.0	55.8	100.0	120.0	.120	719.4	143.9	0.00
40.0	1.0	87.3	433.3	600.0	.200	3597.1	719.4	-1.30
41.0	1.0	0.0	0.0	0.0	0.000	0.0	0.0	0.00
42.0	1.0	100.0	107.7	12795.1	.273	76709.5	15341.9	-3.96
43.0	1.0	82.3	100.0	200.0	.200	1199.0	239.8	0.00
44.0	1.0	112.4	581.4	240.8	.200	1443.6	288.7	-.70
45.0	1.0	91.7	100.0	200.0	.200	1199.0	239.8	0.00
46.0	1.0	100.0	103.2	8557.5	.276	51304.0	10260.8	1.80
47.0	1.0	100.0	37.2	376.2	.200	2255.4	451.1	-.07
48.0	1.0	0.0	0.0	0.0	0.000	0.0	0.0	0.00
49.0	1.0	98.4	81.0	246.8	.200	1479.6	295.9	-.10
50.0	1.0	110.9	75.0	800.0	.200	4796.2	959.2	1.96
51.0	1.0	80.0	150.0	480.0	.120	2877.7	575.5	-.60
52.0	1.0	0.0	0.0	0.0	0.000	0.0	0.0	0.00
53.0	1.0	100.0	181.8	550.0	.200	3297.4	659.5	.50
54.0	1.0	113.3	100.0	600.0	.120	3597.1	719.4	0.00
55.0	1.0	66.4	100.0	120.0	.120	719.4	143.9	0.00
56.0	1.0	81.5	100.0	240.0	.120	1438.8	287.8	0.00
57.0	1.0	100.0	100.0	200.0	.200	1199.0	239.8	0.00
58.0	1.0	99.7	100.0	6000.0	.200	35971.2	7194.2	1.00

* refers to excess capacity of plant (10^6 gallons/day); (+) = oversized, (-) = undersized

59.0	1.0	9.8	100.0	29.4	.200	176.3	35.3	0.00
60.0	1.0	94.9	100.0	300.0	.200	1798.6	359.7	0.00
61.0	1.0	100.0	86.6	1205.8	.348	7229.2	1445.9	.20
62.0	1.0	94.4	88.2	572.5	.168	3432.0	686.4	.20
63.0	1.0	91.3	100.0	200.0	.200	1199.0	239.8	0.00
64.0	1.0	97.6	58.5	4100.0	.200	24580.3	4916.1	1.00
65.0	1.0	100.0	104.6	1276.6	.297	7653.4	1530.7	.55
66.0	1.0	98.1	47.6	840.0	.200	5036.0	1007.2	0.00
67.0	1.0	100.0	48.9	408.6	.200	2449.6	489.9	.20
68.0	1.0	87.3	100.0	120.0	.120	719.4	143.9	0.00
69.0	1.0	83.3	100.0	400.0	.200	2398.1	479.6	0.00
70.0	1.0	221.1	100.0	800.0	.200	4796.2	959.2	0.00
71.0	1.0	0.0	0.0	0.0	0.000	0.0	0.0	0.00
72.0	1.0	172.4	80.0	674.6	.270	4044.5	808.9	0.00
73.0	1.0	100.0	72.7	220.0	.200	1318.9	263.8	-.08
74.0	1.0	102.9	56.8	211.2	.120	1266.2	253.2	.10
76.0	1.0	0.0	0.0	0.0	0.000	0.0	0.0	0.00
77.0	1.0	101.0	100.0	360.0	.120	2158.3	431.7	0.00
78.0	1.0	102.6	248.8	144.7	.120	867.6	173.5	-.30
79.0	1.0	100.0	57.8	276.8	.200	1659.5	331.9	1.42
80.0	1.0	100.0	103.4	464.4	.120	2784.2	556.8	.30
81.0	1.0	100.0	100.0	21.0	.081	125.8	25.2	0.00
82.0	1.0	100.0	83.3	720.6	.200	4320.1	864.0	-.30
83.0	1.0	103.8	76.9	2061.6	.317	12360.0	2472.0	-.50
84.0	1.0	100.0	64.5	620.0	.200	3717.0	743.4	-.20
85.0	1.0	100.0	96.0	520.8	.200	3122.3	624.5	.25

MUNICIPAL SLUDGE PRODUCTION IN CANADA

TOWN	PROVINCE	%POPULATION SERVED	AVERAGE GPCD	POUNDS/DAY	POUNDS/CAPITA/DAY	GALS AT 2%	GALS AT 10%	MGD EXTRA
1.0	2.0	*****	80.0	2000.0	.200	11990.4	2398.1	.70
2.0	2.0	0.0	0.0	0.0	0.000	0.0	0.0	0.00
3.0	2.0	0.0	0.0	0.0	0.000	0.0	0.0	0.00
4.0	2.0	0.0	0.0	0.0	0.000	0.0	0.0	0.00
5.0	2.0	95.0	157.9	380.0	.200	2278.2	455.6	-.30
6.0	2.0	81.5	109.1	2003.6	.182	12012.0	2402.4	1.20
7.0	2.0	100.0	97.6	369.0	.120	2212.2	442.4	-.30
8.0	2.0	100.0	68.4	292.4	.200	1753.0	350.6	.90
9.0	2.0	37.5	60.0	3000.0	.200	17985.6	3597.1	-.90
10.0	2.0	0.0	0.0	0.0	0.000	0.0	0.0	0.00
11.0	2.0	2.3	100.0	20.0	.200	119.9	24.0	.01
12.0	2.0	83.3	42.9	787.8	.113	4722.7	944.5	-.30
13.0	2.0	0.0	0.0	0.0	0.000	0.0	0.0	0.00
14.0	2.0	0.0	0.0	0.0	0.000	0.0	0.0	0.00
15.0	2.0	90.5	100.0	324.0	.081	1942.4	388.5	0.00
16.0	2.0	91.7	95.2	252.0	.120	1510.8	302.2	1.80
17.0	2.0	71.4	65.0	240.0	.120	1438.8	287.8	.12
18.0	2.0	0.0	0.0	0.0	0.000	0.0	0.0	0.00
19.0	2.0	0.0	0.0	0.0	0.000	0.0	0.0	0.00
20.0	2.0	105.2	181.8	558.9	.169	3351.0	670.2	-.60
21.0	2.0	108.1	114.0	26271.0	.086	157500.0	31500.0	19.00
22.0	2.0	105.3	180.2	26071.3	.057	156303.0	31260.6	-12.70
23.0	2.0	83.9	97.4	6725.4	.058	40320.0	8064.0	.90
24.0	2.0	66.8	69.9	3362.7	.067	20160.0	4032.0	10.00
25.0	2.0	77.1	100.0	324.0	.120	1942.4	388.5	-.27
26.0	2.0	61.8	132.4	6800.0	.200	40767.4	8153.5	0.00
27.0	2.0	0.0	0.0	0.0	0.000	0.0	0.0	0.00
28.0	2.0	100.0	103.0	4416.0	.227	26475.0	5295.0	.50
29.0	2.0	100.0	187.5	1553.7	.194	9315.0	1863.0	3.00
30.0	2.0	0.0	0.0	0.0	0.000	0.0	0.0	0.00
31.0	2.0	100.0	192.3	2846.0	.219	17062.5	3412.5	.90
32.0	2.0	95.4	171.9	446.8	.120	2678.4	535.7	-.64
33.0	2.0	0.0	0.0	0.0	0.000	0.0	0.0	0.00
34.0	2.0	0.0	0.0	0.0	0.000	0.0	0.0	0.00
35.0	2.0	0.0	0.0	0.0	0.000	0.0	0.0	0.00
36.0	2.0	34.5	90.0	1541.7	.154	9243.0	1848.6	1.10
37.0	2.0	56.7	94.1	1296.0	.076	7769.8	1554.0	-1.60
38.0	2.0	100.0	100.0	1200.0	.200	7194.2	1438.8	-.10
39.0	2.0	0.0	0.0	0.0	0.000	0.0	0.0	0.00
40.0	2.0	98.6	52.8	227.4	.200	1363.3	272.7	-.06
41.0	2.0	0.0	0.0	0.0	0.000	0.0	0.0	0.00
42.0	2.0	45.5	100.0	2400.0	.120	14388.5	2877.7	4.00
43.0	2.0	100.0	138.3	455.4	.048	2730.0	546.0	1.20
44.0	2.0	0.0	0.0	0.0	0.000	0.0	0.0	0.00
45.0	2.0	100.0	78.9	2280.0	.120	13669.1	2733.8	-1.50
46.0	2.0	0.0	0.0	0.0	0.000	0.0	0.0	0.00
47.0	2.0	0.0	0.0	0.0	0.000	0.0	0.0	0.00
48.0	2.0	116.7	266.7	300.0	.200	1798.6	359.7	-.40
49.0	2.0	75.0	100.0	243.0	.081	1456.8	291.4	-.30
50.0	2.0	95.5	85.7	4169.0	.199	24994.3	4998.9	0.00
51.0	2.0	55.9	57.1	293.4	.112	1758.8	351.8	.25
52.0	2.0	94.7	263.2	10422.9	.549	62487.5	12497.5	0.00
53.0	2.0	0.0	0.0	0.0	0.000	0.0	0.0	0.00
54.0	2.0	99.1	68.5	700.1	.048	4197.5	839.5	.80
55.0	2.0	69.5	76.9	5509.6	.121	33031.3	6606.3	2.50
56.0	2.0	0.0	0.0	0.0	0.000	0.0	0.0	0.00
57.0	2.0	0.0	0.0	0.0	0.000	0.0	0.0	0.00
58.0	2.0	104.4	245.2	1305.0	.200	7823.7	1564.7	-.35

59.0	2.0	0.0	0.0	0.0	0.000	0.0	0.0	0.00
60.0	2.0	0.0	0.0	0.0	0.000	0.0	0.0	0.00
61.0	2.0	25.0	25.0	400.0	.200	2398.1	479.6	.05
62.0	2.0	0.0	0.0	0.0	0.000	0.0	0.0	0.00
63.0	2.0	0.0	0.0	0.0	0.000	0.0	0.0	0.00
64.0	2.0	143.8	42.9	319.8	.046	1917.0	383.4	.20
65.0	2.0	100.0	111.1	583.8	.130	3500.0	700.0	.30
66.0	2.0	0.0	0.0	0.0	0.000	0.0	0.0	0.00
67.0	2.0	77.8	100.0	1400.0	.200	8393.3	1678.7	1.30
68.0	2.0	0.0	0.0	0.0	0.000	0.0	0.0	0.00
69.0	2.0	69.6	112.5	702.6	.088	4212.0	842.4	.60
70.0	2.0	0.0	0.0	0.0	0.000	0.0	0.0	0.00
71.0	2.0	63.9	100.0	52.7	.081	315.6	63.1	0.00
72.0	2.0	100.0	181.5	330.6	.200	1982.0	396.4	0.00
73.0	2.0	0.0	0.0	0.0	0.000	0.0	0.0	0.00
74.0	2.0	98.6	100.0	12180.0	.200	73021.6	14604.3	0.00
75.0	2.0	0.0	0.0	0.0	0.000	0.0	0.0	0.00
76.0	2.0	83.3	160.0	2350.2	.470	14090.0	2818.0	.70

MUNICIPAL SLUDGE PRODUCTION IN CANADA

TOWN	PROVINCE	%POPULATION SERVED	AVERAGE GPCD	POUNDS/DAY	POUNDS/CAPITA/DAY	GALS AT 2%	GALS AT 10%	MGD EXTRA
1.0	3.0	99.2	54.3	516.0	.200	3093.5	618.7	.13
2.0	3.0	0.0	0.0	0.0	0.000	0.0	0.0	0.00
3.0	3.0	0.0	0.0	0.0	0.000	0.0	0.0	0.00
4.0	3.0	100.0	*****	81.0	.200	485.6	97.1	-.60
5.0	3.0	0.0	0.0	0.0	0.000	0.0	0.0	0.00
6.0	3.0	100.0	100.0	76.0	.200	455.6	91.1	0.00
7.0	3.0	95.8	166.7	480.0	.200	2877.7	575.5	0.00
8.0	3.0	0.0	0.0	0.0	0.000	0.0	0.0	0.00
9.0	3.0	0.0	0.0	0.0	0.000	0.0	0.0	0.00
10.0	3.0	100.0	100.0	44.8	.200	268.6	53.7	0.00
11.0	3.0	0.0	0.0	0.0	0.000	0.0	0.0	0.00
12.0	3.0	100.0	100.0	177.2	.200	1062.4	212.5	0.00
13.0	3.0	99.1	65.6	305.0	.200	1828.5	365.7	.20
14.0	3.0	90.0	22.2	90.0	.200	539.6	107.9	-.01
15.0	3.0	100.0	9.6	6230.0	.200	37350.1	7470.0	-.30
16.0	3.0	68.9	36.4	110.0	.200	659.5	131.9	-.02
17.0	3.0	0.0	0.0	0.0	0.000	0.0	0.0	0.00
18.0	3.0	0.0	0.0	0.0	0.000	0.0	0.0	0.00
19.0	3.0	0.0	0.0	0.0	0.000	0.0	0.0	0.00
20.0	3.0	0.0	0.0	0.0	0.000	0.0	0.0	0.00
21.0	3.0	0.0	0.0	0.0	0.000	0.0	0.0	0.00
22.0	3.0	87.3	285.7	4.0	.003	24.0	4.8	-.40
23.0	3.0	100.0	100.0	111.0	.200	665.5	133.1	0.00
24.0	3.0	0.0	0.0	0.0	0.000	0.0	0.0	0.00
25.0	3.0	0.0	0.0	0.0	0.000	0.0	0.0	0.00
26.0	3.0	100.0	104.1	192.2	.200	1152.3	230.5	-.10
27.0	3.0	98.6	91.3	1051.9	.120	6306.5	1261.3	-.80
28.0	3.0	0.0	0.0	0.0	0.000	0.0	0.0	0.00
29.0	3.0	0.0	0.0	0.0	0.000	0.0	0.0	0.00
30.0	3.0	0.0	0.0	0.0	0.000	0.0	0.0	0.00
31.0	3.0	0.0	0.0	0.0	0.000	0.0	0.0	0.00
32.0	3.0	96.4	125.0	160.0	.200	959.2	191.8	-.10
33.0	3.0	0.0	0.0	0.0	0.000	0.0	0.0	0.00
34.0	3.0	0.0	0.0	0.0	0.000	0.0	0.0	0.00
35.0	3.0	98.6	78.9	875.7	.099	5250.0	1050.0	-.40
26.0	3.0	0.0	0.0	0.0	0.000	0.0	0.0	0.00
37.0	3.0	0.0	0.0	0.0	0.000	0.0	0.0	0.00
38.0	3.0	100.0	100.0	500.0	.200	2997.6	599.5	.25
39.0	3.0	100.0	142.9	420.0	.200	2518.0	503.6	-.20
40.0	3.0	80.0	125.0	160.0	.200	959.2	191.8	-.06
41.0	3.0	0.0	0.0	0.0	0.000	0.0	0.0	0.00
42.0	3.0	0.0	0.0	0.0	0.000	0.0	0.0	0.00
43.0	3.0	128.1	100.0	20.7	.081	123.8	24.8	0.00
44.0	3.0	86.2	100.0	90.0	.200	539.6	107.9	0.00
45.0	3.0	0.0	0.0	0.0	0.000	0.0	0.0	0.00
46.0	3.0	99.5	34.5	69.5	.120	416.5	83.3	-.02
47.0	3.0	0.0	0.0	0.0	0.000	0.0	0.0	0.00
48.0	3.0	0.0	0.0	0.0	0.000	0.0	0.0	0.00
49.0	3.0	0.0	0.0	0.0	0.000	0.0	0.0	0.00
50.0	3.0	100.0	100.0	22.5	.081	135.0	27.0	0.00
51.0	3.0	80.0	100.0	1909.0	.955	11445.0	2289.0	.10
52.0	3.0	0.0	0.0	0.0	0.000	0.0	0.0	0.00
53.0	3.0	0.0	0.0	0.0	0.000	0.0	0.0	0.00
54.0	3.0	0.0	0.0	0.0	0.000	0.0	0.0	0.00
55.0	3.0	0.0	0.0	0.0	0.000	0.0	0.0	0.00
56.0	3.0	0.0	0.0	0.0	0.000	0.0	0.0	0.00
57.0	3.0	100.0	132.8	324.0	.108	1942.4	388.5	-.31
58.0	3.0	0.0	0.0	0.0	0.000	0.0	0.0	0.00

59.0	3.0	0.0	0.0	0.0	0.000	0.0	0.0	0.00
60.0	3.0	0.0	0.0	0.0	0.000	0.0	0.0	0.00
61.0	3.0	0.0	0.0	0.0	0.000	0.0	0.0	0.00
62.0	3.0	90.9	100.0	9.6	.120	57.6	11.5	0.00
63.0	3.0	0.0	0.0	0.0	0.000	0.0	0.0	0.00
64.0	3.0	100.0	37.9	52.8	.200	316.5	63.3	-.01
65.0	3.0	0.0	0.0	0.0	0.000	0.0	0.0	0.00
66.0	3.0	103.4	100.0	541.8	.200	3248.2	649.6	0.00
67.0	3.0	0.0	0.0	0.0	0.000	0.0	0.0	0.00
68.0	3.0	93.3	71.4	168.0	.120	1007.2	201.4	-.10
69.0	3.0	99.5	93.7	640.0	.200	3836.9	767.4	-.30
70.0	3.0	0.0	0.0	0.0	0.000	0.0	0.0	0.00
71.0	3.0	0.0	0.0	0.0	0.000	0.0	0.0	0.00
72.0	3.0	0.0	0.0	0.0	0.000	0.0	0.0	0.00
73.0	3.0	117.0	100.0	80.0	.200	479.6	95.9	0.00
74.0	3.0	37.6	57.1	42.0	.120	251.8	50.4	-.02
75.0	3.0	0.0	0.0	0.0	0.000	0.0	0.0	0.00
76.0	3.0	0.0	0.0	0.0	0.000	0.0	0.0	0.00
77.0	3.0	0.0	0.0	0.0	0.000	0.0	0.0	0.00
78.0	3.0	0.0	0.0	0.0	0.000	0.0	0.0	0.00
79.0	3.0	97.4	16.5	242.6	.200	1454.4	290.9	-.02
80.0	3.0	0.0	0.0	0.0	0.000	0.0	0.0	0.00
81.0	3.0	99.3	129.5	4803.8	.346	28800.0	5760.0	-.30
82.0	3.0	99.0	100.0	132.0	.200	791.4	158.3	0.00
83.0	3.0	0.0	0.0	0.0	0.000	0.0	0.0	0.00
84.0	3.0	0.0	0.0	0.0	0.000	0.0	0.0	0.00
85.0	3.0	101.7	100.0	39.5	.081	237.0	47.4	0.00
86.0	3.0	0.0	0.0	0.0	0.000	0.0	0.0	0.00
87.0	3.0	0.0	0.0	0.0	0.000	0.0	0.0	0.00
88.0	3.0	100.0	100.0	78.0	.120	467.6	93.5	0.00
89.0	3.0	0.0	0.0	0.0	0.000	0.0	0.0	0.00
90.0	3.0	0.0	0.0	0.0	0.000	0.0	0.0	0.00
91.0	3.0	0.0	0.0	0.0	0.000	0.0	0.0	0.00
92.0	3.0	0.0	0.0	0.0	0.000	0.0	0.0	0.00
93.0	3.0	0.0	0.0	0.0	0.000	0.0	0.0	0.00
94.0	3.0	0.0	0.0	0.0	0.000	0.0	0.0	0.00
95.0	3.0	0.0	0.0	0.0	0.000	0.0	0.0	0.00
96.0	3.0	97.4	100.0	54.0	.120	323.7	64.7	0.00
97.0	3.0	0.0	0.0	0.0	0.000	0.0	0.0	0.00
98.0	3.0	110.0	111.1	180.0	.200	1079.1	215.8	0.00
99.0	3.0	96.8	100.0	18000.0	.200	107913.7	21582.7	0.00
100.0	3.0	0.0	0.0	0.0	0.000	0.0	0.0	0.00
101.0	3.0	0.0	0.0	0.0	0.000	0.0	0.0	0.00
102.0	3.0	85.3	100.0	109.3	.081	655.1	131.0	0.00
103.0	3.0	0.0	0.0	0.0	0.000	0.0	0.0	0.00
104.0	3.0	96.5	100.0	110.2	.081	660.4	132.1	0.00
105.0	3.0	83.3	100.0	600.0	.120	3597.1	719.4	-.50
106.0	3.0	25.5	100.0	80.0	.200	479.6	95.9	0.00
107.0	3.0	0.0	0.0	0.0	0.000	0.0	0.0	0.00
108.0	3.0	97.1	83.3	1430.3	.397	8574.7	1715.0	.20
109.0	3.0	99.7	64.3	1556.0	.200	9328.5	1865.7	-.50
110.0	3.0	46.6	100.0	1769.2	.200	10606.7	2121.3	0.00
111.0	3.0	100.3	31.7	75.6	.120	453.2	90.6	.05
112.0	3.0	0.0	0.0	0.0	0.000	0.0	0.0	0.00
113.0	3.0	0.0	0.0	0.0	0.000	0.0	0.0	0.00
114.0	3.0	103.9	100.0	237.6	.081	1424.3	284.9	0.00
115.0	3.0	0.0	0.0	0.0	0.000	0.0	0.0	0.00
116.0	3.0	100.0	150.0	48.0	.120	287.8	57.6	-.06
117.0	3.0	0.0	0.0	0.0	0.000	0.0	0.0	0.00
118.0	3.0	100.0	73.2	820.0	.200	4916.1	983.2	-.30
119.0	3.0	96.9	125.0	187172.1	.334	1122135.0	224427.0	0.00
120.0	3.0	43.7	100.0	60.0	.200	359.7	71.9	0.00
121.0	3.0	102.4	100.0	181.6	.200	1088.7	217.7	0.00

MUNICIPAL SLUDGE PRODUCTION IN CANADA

TOWN	PROVINCE	%POPULATION SERVED	AVERAGE GPCD	POUNDS/DAY	POUNDS/CAPITA/DAY	GALS AT 2%	GALS AT 10%	MGD EXTRA
1.0	4.0	100.0	12.0	300.0	.120	1798.6	359.7	-.03
2.0	4.0	100.0	53.1	376.4	.200	2256.6	451.3	-.10
3.0	4.0	0.0	0.0	0.0	0.000	0.0	0.0	0.00
4.0	4.0	0.0	0.0	0.0	0.000	0.0	0.0	0.00
5.0	4.0	0.0	0.0	0.0	0.000	0.0	0.0	0.00
6.0	4.0	72.7	120.0	500.0	.200	2997.6	599.5	.20
7.0	4.0	38.3	266.7	600.0	.200	3597.1	719.4	0.00
8.0	4.0	0.0	0.0	0.0	0.000	0.0	0.0	0.00
9.0	4.0	0.0	0.0	0.0	0.000	0.0	0.0	0.00
10.0	4.0	0.0	0.0	0.0	0.000	0.0	0.0	0.00
11.0	4.0	0.0	0.0	0.0	0.000	0.0	0.0	0.00
12.0	4.0	79.5	100.0	7000.0	.200	41966.4	8393.3	.50
13.0	4.0	97.4	90.9	880.0	.200	5275.8	1055.2	-.34
14.0	4.0	0.0	0.0	0.0	0.000	0.0	0.0	0.00
15.0	4.0	0.0	0.0	0.0	0.000	0.0	0.0	0.00
16.0	4.0	0.0	0.0	0.0	0.000	0.0	0.0	0.00
17.0	4.0	92.4	114.3	167.0	.095	1001.4	200.3	0.00
18.0	4.0	0.0	0.0	0.0	0.000	0.0	0.0	0.00
19.0	4.0	86.7	61.5	260.0	.200	1558.8	311.8	.12
20.0	4.0	97.5	111.1	1260.0	.200	7554.0	1510.8	-.70
21.0	4.0	122.5	107.1	2800.0	.200	16786.6	3357.3	-.50
22.0	4.0	0.0	0.0	0.0	0.000	0.0	0.0	0.00
23.0	4.0	111.7	67.2	213.4	.143	1279.3	255.9	-.10
24.0	4.0	80.0	76.9	110.1	.085	660.0	132.0	0.00
25.0	4.0	0.0	0.0	0.0	0.000	0.0	0.0	0.00
26.0	4.0	60.4	100.0	98.3	.098	589.5	117.9	-.01
27.0	4.0	0.0	0.0	0.0	0.000	0.0	0.0	0.00
28.0	4.0	0.0	0.0	0.0	0.000	0.0	0.0	0.00
29.0	4.0	79.9	94.3	212.0	.200	1271.0	254.2	-.01
30.0	4.0	83.5	46.5	15023.7	.175	90070.0	18014.0	0.00
31.0	4.0	100.0	125.0	320.0	.200	1918.5	383.7	-.20
32.0	4.0	95.6	100.0	400.0	.200	2398.1	479.6	.10
33.0	4.0	100.0	100.0	1000.0	.200	5995.2	1199.0	0.00
34.0	4.0	130.3	102.3	1564.0	.200	9376.5	1875.3	-.80
35.0	4.0	227.0	100.0	1000.0	.200	5995.2	1199.0	.30
36.0	4.0	100.0	83.3	480.0	.200	2877.7	575.5	-.10
37.0	4.0	97.4	130.2	768.0	.200	4604.3	920.9	.10
38.0	4.0	103.2	100.0	99.0	.020	593.5	118.7	0.00

MUNICIPAL SLUDGE PRODUCTION IN CANADA

TOWN	PROVINCE	%POPULATION SERVED	AVERAGE GPCD	POUNDS/DAY	POUNDS/CAPITA/DAY	GALS AT 2%	GALS AT 10%	MGD EXTRA
1.0	5.0	0.0	0.0	0.0	0.000	0.0	0.0	0.00
2.0	5.0	34.4	51.7	309.6	.200	1856.1	371.2	.32
3.0	5.0	0.0	0.0	0.0	0.000	0.0	0.0	0.00
4.0	5.0	0.0	0.0	0.0	0.000	0.0	0.0	0.00
5.0	5.0	44.1	100.0	121.5	.081	728.4	145.7	0.00
6.0	5.0	0.0	0.0	0.0	0.000	0.0	0.0	0.00
7.0	5.0	0.0	0.0	0.0	0.000	0.0	0.0	0.00
8.0	5.0	0.0	0.0	0.0	0.000	0.0	0.0	0.00
9.0	5.0	100.0	649.8	332.4	.120	1992.8	398.6	-.30
10.0	5.0	114.0	166.7	3600.0	.120	21582.7	4316.5	-5.00
11.0	5.0	101.8	111.1	900.0	.200	5395.7	1079.1	-.50
12.0	5.0	91.8	100.0	192.0	.120	1151.1	230.2	0.00
13.0	5.0	101.7	100.0	440.0	.200	2637.9	527.6	0.00
14.0	5.0	0.0	0.0	0.0	0.000	0.0	0.0	0.00
15.0	5.0	0.0	0.0	0.0	0.000	0.0	0.0	0.00
16.0	5.0	100.0	200.0	180.0	.120	1079.1	215.8	.50
17.0	5.0	100.0	300.0	200.0	.200	1199.0	239.8	-.22
18.0	5.0	0.0	0.0	0.0	0.000	0.0	0.0	0.00
19.0	5.0	0.0	0.0	0.0	0.000	0.0	0.0	0.00
20.0	5.0	100.0	138.8	1989.0	.200	11924.5	2384.9	-1.38
21.0	5.0	0.0	0.0	0.0	0.000	0.0	0.0	0.00
22.0	5.0	0.0	0.0	0.0	0.000	0.0	0.0	0.00
23.0	5.0	32.3	100.0	24.0	.120	143.9	28.8	0.00
24.0	5.0	100.0	103.7	2700.0	.200	16187.1	3237.4	.15
25.0	5.0	0.0	0.0	0.0	0.000	0.0	0.0	0.00
26.0	5.0	71.4	10.0	600.0	.120	3597.1	719.4	-.05
27.0	5.0	100.0	78.1	1920.0	.200	11510.8	2302.2	-.75
28.0	5.0	0.0	0.0	0.0	0.000	0.0	0.0	0.00
29.0	5.0	0.0	0.0	0.0	0.000	0.0	0.0	0.00
30.0	5.0	0.0	0.0	0.0	0.000	0.0	0.0	0.00
31.0	5.0	62.5	100.0	300.0	.120	1798.6	359.7	0.00
32.0	5.0	93.7	173.3	9000.0	.120	53956.8	10791.4	-13.00
33.0	5.0	0.0	0.0	0.0	0.000	0.0	0.0	0.00
34.0	5.0	0.0	0.0	0.0	0.000	0.0	0.0	0.00
35.0	5.0	100.0	166.7	2400.0	.200	14388.5	2877.7	-2.00
36.0	5.0	0.0	0.0	0.0	0.000	0.0	0.0	0.00
37.0	5.0	0.0	0.0	0.0	0.000	0.0	0.0	0.00
38.0	5.0	100.0	184.2	912.0	.120	5467.6	1093.5	-1.40

MUNICIPAL SLUDGE PRODUCTION IN CANADA

TOWN	PROVINCE	%POPULATION SERVED	AVERAGE GPCD	POUNDS/DAY	POUNDS/CAPITA/DAY	GALS AT 2%	GALS AT 10%	MGD EXTRA
1.0	6.0	0.0	0.0	0.0	0.000	0.0	0.0	0.00
2.0	6.0	0.0	0.0	0.0	0.000	0.0	0.0	0.00
3.0	6.0	113.3	100.0	320.0	.200	1918.5	383.7	0.00
4.0	6.0	83.3	100.0	424.0	.170	2542.1	508.4	.52
5.0	6.0	118.4	162.6	246.0	.200	1474.8	295.0	3.05
6.0	6.0	84.3	140.0	999.8	.200	5993.8	1198.8	-.50
7.0	6.0	99.3	83.3	240.0	.200	1438.8	287.8	0.00
8.0	6.0	3.6	56.0	500.0	.200	2997.6	599.5	0.00
9.0	6.0	0.0	0.0	0.0	0.000	0.0	0.0	0.00
10.0	6.0	0.0	0.0	0.0	0.000	0.0	0.0	0.00
11.0	6.0	0.0	0.0	0.0	0.000	0.0	0.0	0.00
12.0	6.0	0.0	0.0	0.0	0.000	0.0	0.0	0.00
13.0	6.0	80.0	40.0	12000.0	.120	71942.4	14388.5	-4.00
14.0	6.0	39.7	*****	500.0	.200	2997.6	599.5	-1.50
15.0	6.0	0.0	0.0	0.0	0.000	0.0	0.0	0.00
16.0	6.0	0.0	0.0	0.0	0.000	0.0	0.0	0.00
17.0	6.0	0.0	0.0	0.0	0.000	0.0	0.0	0.00
18.0	6.0	0.0	0.0	0.0	0.000	0.0	0.0	0.00
19.0	6.0	0.0	0.0	0.0	0.000	0.0	0.0	0.00
20.0	6.0	0.0	0.0	0.0	0.000	0.0	0.0	0.00
21.0	6.0	138.9	240.0	500.0	.200	2997.6	599.5	-.10
22.0	6.0	67.5	55.6	180.0	.200	1079.1	215.8	.01
23.0	6.0	0.0	0.0	0.0	0.000	0.0	0.0	0.00
24.0	6.0	0.0	0.0	0.0	0.000	0.0	0.0	0.00
25.0	6.0	0.0	0.0	0.0	0.000	0.0	0.0	0.00
26.0	6.0	100.0	475.2	294.6	.200	1766.2	353.2	-.60
27.0	6.0	0.0	0.0	0.0	0.000	0.0	0.0	0.00
28.0	6.0	0.0	0.0	0.0	0.000	0.0	0.0	0.00
29.0	6.0	99.0	76.9	404.8	.104	2427.0	485.4	.20
30.0	6.0	0.0	0.0	0.0	0.000	0.0	0.0	0.00
31.0	6.0	0.0	0.0	0.0	0.000	0.0	0.0	0.00
32.0	6.0	0.0	0.0	0.0	0.000	0.0	0.0	0.00
33.0	6.0	0.0	0.0	0.0	0.000	0.0	0.0	0.00
34.0	6.0	94.4	100.0	196.4	.200	1177.5	235.5	.90
35.0	6.0	0.0	0.0	0.0	0.000	0.0	0.0	0.00
36.0	6.0	0.0	0.0	0.0	0.000	0.0	0.0	0.00
37.0	6.0	100.0	125.0	3046.2	.152	18262.5	3652.5	3.50
38.0	6.0	0.0	0.0	0.0	0.000	0.0	0.0	0.00
39.0	6.0	107.7	100.0	840.0	.200	5036.0	1007.2	0.00
40.0	6.0	105.2	151.1	794.0	.200	4760.2	952.0	-.60
41.0	6.0	0.0	0.0	0.0	0.000	0.0	0.0	0.00
42.0	6.0	0.0	0.0	0.0	0.000	0.0	0.0	0.00

MUNICIPAL SLUDGE PRODUCTION IN CANADA

TOWN	PROVINCE	%POPULATION SERVED	AVERAGE GPCD	POUNDS/DAY	POUNDS/CAPITA/DAY	GALS AT 2%	GALS AT 10%	MGD EXTRA
1.0	7.0	96.3	93.1	457.9	.071	2745.0	549.0	.20
2.0	7.0	88.3	*****	343.2	.120	2057.6	411.5	-7.30
3.0	7.0	0.0	0.0	0.0	0.000	0.0	0.0	0.00
4.0	7.0	69.3	227.3	593.4	.270	3557.5	711.5	-.20
5.0	7.0	73.0	109.6	876.0	.120	5251.8	1050.4	.20
6.0	7.0	0.0	0.0	0.0	0.000	0.0	0.0	0.00
7.0	7.0	6.7	100.0	200.0	.200	1199.0	239.8	0.00
8.0	7.0	100.0	258.1	320.3	.052	1920.0	384.0	-.10
9.0	7.0	0.0	0.0	0.0	0.000	0.0	0.0	0.00
10.0	7.0	0.0	0.0	0.0	0.000	0.0	0.0	0.00
11.0	7.0	96.7	155.2	696.0	.120	4172.7	834.5	-.90
12.0	7.0	96.4	148.1	5071.6	.376	30405.0	6081.0	1.00
13.0	7.0	0.0	0.0	0.0	0.000	0.0	0.0	0.00
14.0	7.0	0.0	0.0	0.0	0.000	0.0	0.0	0.00
15.0	7.0	265.8	35.3	175.7	.069	1053.4	210.7	1.94
16.0	7.0	100.0	173.9	162.0	.141	971.2	194.2	0.00
17.0	7.0	101.3	130.6	19523.1	.622	117044.8	23409.0	1.90
18.0	7.0	0.0	0.0	0.0	0.000	0.0	0.0	0.00
19.0	7.0	85.3	600.0	100.0	.200	599.5	119.9	-.20
20.0	7.0	0.0	0.0	0.0	0.000	0.0	0.0	0.00
21.0	7.0	0.0	0.0	0.0	0.000	0.0	0.0	0.00
22.0	7.0	93.0	238.7	6797.9	.208	40755.0	8151.0	.20
23.0	7.0	0.0	0.0	0.0	0.000	0.0	0.0	0.00
24.0	7.0	0.0	0.0	0.0	0.000	0.0	0.0	0.00
25.0	7.0	0.0	0.0	0.0	0.000	0.0	0.0	0.00
26.0	7.0	0.0	0.0	0.0	0.000	0.0	0.0	0.00
27.0	7.0	0.0	0.0	0.0	0.000	0.0	0.0	0.00
28.0	7.0	8.8	116.8	513.8	.200	3080.3	616.1	.20
29.0	7.0	101.9	131.6	1064.3	.117	6380.4	1276.1	1.30
30.0	7.0	42.1	125.0	640.0	.200	3836.9	767.4	-.10
31.0	7.0	93.6	125.6	637.0	.200	3818.9	763.8	.40
32.0	7.0	100.0	100.0	8244.2	.200	49425.7	9885.1	0.00
33.0	7.0	98.5	150.7	19477.4	.291	116771.2	23354.2	2.40
34.0	7.0	5.9	909.1	405.0	.736	2428.1	485.6	.10
35.0	7.0	41.4	317.5	0.0	0.000	0.0	0.0	15.20
36.0	7.0	110.0	159.1	1226.0	.056	7350.0	1470.0	.30
37.0	7.0	85.6	140.4	18952.7	.213	113625.0	22725.0	0.00
38.0	7.0	87.9	35.7	250.4	.089	1501.3	300.3	.20
39.0	7.0	0.0	0.0	0.0	0.000	0.0	0.0	0.00
40.0	7.0	99.4	457.1	700.0	.200	4196.6	839.3	-.80
41.0	7.0	0.0	0.0	0.0	0.000	0.0	0.0	0.00
42.0	7.0	0.0	0.0	0.0	0.000	0.0	0.0	0.00
43.0	7.0	0.0	0.0	0.0	0.000	0.0	0.0	0.00
44.0	7.0	0.0	0.0	0.0	0.000	0.0	0.0	0.00
45.0	7.0	0.0	0.0	0.0	0.000	0.0	0.0	0.00
46.0	7.0	0.0	0.0	0.0	0.000	0.0	0.0	0.00
47.0	7.0	91.0	141.6	11328.2	.341	67915.0	13583.0	-.20
48.0	7.0	100.5	146.9	219.6	.124	1316.3	263.3	17.02
49.0	7.0	59.9	100.0	150.0	.200	899.3	179.9	0.00
50.0	7.0	86.1	32.3	65.0	.021	389.7	77.9	.40
51.0	7.0	0.0	0.0	0.0	0.000	0.0	0.0	0.00
52.0	7.0	0.0	0.0	0.0	0.000	0.0	0.0	0.00
53.0	7.0	0.0	0.0	0.0	0.000	0.0	0.0	0.00
54.0	7.0	100.0	531.9	243.0	.431	1456.8	291.4	-.10
55.0	7.0	49.8	243.9	98.4	.120	589.9	118.0	-.20
56.0	7.0	87.0	294.1	750.6	.088	4500.0	900.0	.50
57.0	7.0	90.2	152.9	5100.0	.120	30575.5	6115.1	-6.50
58.0	7.0	100.0	100.0	52.8	.081	316.6	63.3	0.00

59.0	7.0	223.8	230.8	156.0	.120	935.3	187.1	.50
60.0	7.0	89.3	100.0	282.7	.057	1695.0	339.0	.30
61.0	7.0	100.0	102.7	357.1	.092	2141.0	428.2	.30
62.0	7.0	100.0	100.0	372.6	.200	2233.8	446.8	.30
63.0	7.0	0.0	0.0	0.0	0.000	0.0	0.0	0.00
64.0	7.0	92.9	123.1	1428.5	.220	8564.0	1712.8	.20
65.0	7.0	104.6	105.6	1533.9	.085	9196.0	1839.2	.10
66.0	7.0	94.0	234.0	1687.1	.359	10114.5	2022.9	.60
67.0	7.0	0.0	0.0	0.0	0.000	0.0	0.0	0.00
68.0	7.0	100.0	55.0	332.6	.102	1994.1	398.8	.22
68.0	7.0	100.0	122.8	3811.2	.224	22848.9	4569.8	.41
69.0	7.0	73.9	154.7	261.4	.202	1567.0	313.4	.09
70.0	7.0	82.4	98.8	156.5	.141	938.0	187.6	.13
71.0	7.0	100.0	100.0	64.8	.081	388.5	77.7	0.00
72.0	7.0	98.9	92.5	975.6	.081	5848.6	1169.7	.38
73.0	7.0	78.8	100.0	285.6	.179	1712.5	342.5	.24
74.0	7.0	100.0	100.0	122.2	.081	732.8	146.6	0.00
75.0	7.0	96.9	97.1	5572.8	.054	33410.0	6682.0	2.50
75.0	7.0	100.0	305.7	1966.2	.388	11787.8	2357.6	.45
76.0	7.0	100.0	18.8	1661.8	.013	9962.8	1992.6	.15
77.0	7.0	100.0	90.7	682.8	.182	4093.6	818.7	.06
78.0	7.0	102.9	76.5	273.1	.077	1637.6	327.5	.23
79.0	7.0	100.0	169.5	1966.2	.215	11787.8	2357.6	.45
79.0	7.0	59.8	124.5	2278.5	.141	13660.0	2732.0	1.23
79.0	7.0	100.0	100.0	137.7	.081	825.5	165.1	0.00
80.0	7.0	100.0	30.0	77.3	.039	463.5	92.7	-.06
81.0	7.0	0.0	0.0	0.0	0.000	0.0	0.0	0.00
82.0	7.0	81.3	61.5	58.9	.045	353.2	70.6	-.05
83.0	7.0	0.0	0.0	0.0	0.000	0.0	0.0	0.00
84.0	7.0	100.0	243.5	1891.5	.230	11340.0	2268.0	-.20
85.0	7.0	80.0	125.0	363.2	.227	2177.5	435.5	-.12
86.0	7.0	0.0	0.0	0.0	0.000	0.0	0.0	0.00
87.0	7.0	94.3	100.0	85.6	.015	513.0	102.6	.70
88.0	7.0	0.0	0.0	0.0	0.000	0.0	0.0	0.00
89.0	7.0	0.0	0.0	0.0	0.000	0.0	0.0	0.00
90.0	7.0	65.6	136.4	440.0	.200	2637.9	527.6	-.10
91.0	7.0	94.6	100.0	97.2	.081	582.7	116.5	.20
92.0	7.0	0.0	0.0	0.0	0.000	0.0	0.0	0.00
93.0	7.0	96.6	107.1	1065.1	.190	6385.5	1277.1	.50
94.0	7.0	0.0	0.0	0.0	0.000	0.0	0.0	0.00
95.0	7.0	0.0	0.0	0.0	0.000	0.0	0.0	0.00
96.0	7.0	100.0	200.0	600.5	.060	3600.0	720.0	0.00
97.0	7.0	69.8	153.8	156.0	.120	935.3	187.1	.20
98.0	7.0	98.0	371.8	1022.0	.200	6127.1	1225.4	-1.90
99.0	7.0	104.4	95.5	2948.3	.166	17675.8	3535.2	-.20
100.0	7.0	42.9	6.7	6.5	.004	39.0	7.8	0.00
101.0	7.0	0.0	0.0	0.0	0.000	0.0	0.0	0.00
102.0	7.0	0.0	0.0	0.0	0.000	0.0	0.0	0.00
103.0	7.0	0.0	0.0	0.0	0.000	0.0	0.0	0.00
104.0	7.0	0.0	0.0	0.0	0.000	0.0	0.0	0.00
105.0	7.0	100.0	171.4	9145.9	1.307	54831.6	10966.3	-.20
106.0	7.0	48.2	91.4	656.6	.200	3936.5	787.3	-.30
107.0	7.0	94.1	132.8	20132.8	.315	120700.0	24140.0	1.50
108.0	7.0	0.0	0.0	0.0	0.000	0.0	0.0	0.00
109.0	7.0	75.8	125.0	1300.0	.325	7793.7	1558.8	-.10
110.0	7.0	81.2	166.2	120151.5	.370	720333.0	144066.6	6.00
111.0	7.0	118.5	116.7	1198.8	.200	7187.2	1437.5	.10
112.0	7.0	100.5	109.3	366.0	.200	2194.2	438.8	.70
113.0	7.0	0.0	0.0	0.0	0.000	0.0	0.0	0.00
114.0	7.0	0.0	0.0	0.0	0.000	0.0	0.0	0.00
115.0	7.0	73.3	194.4	432.0	.120	2589.9	518.0	-.70
116.0	7.0	28.6	142.9	426.3	.152	2556.0	511.2	-.10
117.0	7.0	97.5	126.6	2535.0	.321	15198.0	3039.6	1.25

118.0	7.0	18.0	142.9	168.0	.120	1007.2	201.4	.10
119.0	7.0	100.0	246.9	133.7	.110	801.7	160.4	1.20
120.0	7.0	0.0	0.0	0.0	0.000	0.0	0.0	0.00
121.0	7.0	0.0	0.0	0.0	0.000	0.0	0.0	0.00
122.0	7.0	0.0	0.0	0.0	0.000	0.0	0.0	0.00
123.0	7.0	93.4	100.0	159.7	.081	957.6	191.5	0.00
124.0	7.0	116.0	35.7	336.0	.120	2014.4	402.9	-.10
125.0	7.0	0.0	0.0	0.0	0.000	0.0	0.0	0.00
126.0	7.0	99.7	183.3	1557.1	.143	9335.0	1867.0	0.00
127.0	7.0	0.0	0.0	0.0	0.000	0.0	0.0	0.00
128.0	7.0	0.0	0.0	0.0	0.000	0.0	0.0	0.00
129.0	7.0	125.0	164.0	4677.7	.062	28044.0	5608.8	1.20
130.0	7.0	100.0	150.0	3788.0	.379	22710.0	4542.0	-.60
131.0	7.0	0.0	0.0	0.0	0.000	0.0	0.0	0.00
132.0	7.0	96.6	142.9	909.9	.065	5455.0	1091.0	2.50
133.0	7.0	100.0	178.2	449.0	.200	2691.8	538.4	-.10
134.0	7.0	0.0	0.0	0.0	0.000	0.0	0.0	0.00
135.0	7.0	49.1	142.9	84.0	.120	503.6	100.7	0.00
136.0	7.0	104.8	227.3	375.3	.034	2250.0	450.0	-.70
137.0	7.0	90.6	130.4	4093.9	.356	24543.8	4908.8	0.00
138.0	7.0	44.7	142.9	86.0	.123	515.8	103.2	.20
139.0	7.0	97.1	129.1	53269.3	.232	319360.4	63872.1	1.50
140.0	7.0	82.9	100.0	160.0	.200	959.2	191.8	.30
141.0	7.0	72.7	75.0	266.6	.200	1598.3	319.7	.15
142.0	7.0	0.0	0.0	0.0	0.000	0.0	0.0	0.00
143.0	7.0	0.0	0.0	0.0	0.000	0.0	0.0	0.00
144.0	7.0	100.0	100.0	162.4	.120	973.4	194.7	.30
145.0	7.0	100.0	119.6	401.4	.120	2406.5	481.3	.40
146.0	7.0	100.0	125.0	66.1	.028	396.0	79.2	0.00
147.0	7.0	92.9	192.3	156.0	.120	935.3	187.1	-.25
148.0	7.0	59.3	48.1	855.5	.053	5129.0	1025.8	-.02
149.0	7.0	61.5	162.5	1805.2	.226	10822.5	2164.5	.50
150.0	7.0	71.4	92.0	541.3	.108	3245.3	649.1	-.06
151.0	7.0	0.0	0.0	0.0	0.000	0.0	0.0	0.00
152.0	7.0	0.0	0.0	0.0	0.000	0.0	0.0	0.00
153.0	7.0	0.0	0.0	0.0	0.000	0.0	0.0	0.00
154.0	7.0	100.0	100.0	130.8	.081	784.3	156.9	0.00
155.0	7.0	18.8	100.0	3.2	.081	19.4	3.9	0.00
156.0	7.0	50.0	350.0	589.9	.295	3536.8	707.3	.20
157.0	7.0	97.8	100.0	286.2	.065	1716.0	343.2	0.00
158.0	7.0	95.5	152.4	1016.8	.097	6096.0	1219.2	-.30
159.0	7.0	103.6	110.1	872.2	.120	5228.8	1045.8	.30
160.0	7.0	95.9	41.7	144.0	.120	863.3	172.7	-.03
170.0	7.0	64.1	100.0	20000.0	.200	119904.1	23980.8	0.00
180.0	7.0	0.0	0.0	0.0	0.000	0.0	0.0	0.00
181.0	7.0	37.5	86.7	274.9	.092	1648.1	329.6	.09
182.0	7.0	0.0	0.0	0.0	0.000	0.0	0.0	0.00
183.0	7.0	100.3	144.0	416.8	.200	2498.8	499.8	-.20
184.0	7.0	86.7	153.8	140.1	.054	840.0	168.0	.10
185.0	7.0	0.0	0.0	0.0	0.000	0.0	0.0	0.00
186.0	7.0	107.8	140.0	600.0	.120	3597.1	719.4	.10
187.0	7.0	91.1	180.0	1000.0	.200	5995.2	1199.0	-.90
188.0	7.0	76.8	135.4	2939.3	.153	17621.5	3524.3	.40
189.0	7.0	100.0	208.0	702.6	.056	4212.0	842.4	-.80
190.0	7.0	100.0	385.0	227.8	.114	1365.6	273.1	.13
191.0	7.0	100.0	80.0	382.5	.051	2292.9	458.6	-.20
192.0	7.0	100.0	102.6	55.9	.072	335.4	67.1	.12
193.0	7.0	100.0	318.2	84.3	.383	505.2	101.0	-.02
194.0	7.0	100.0	91.7	250.2	.077	1500.0	300.0	0.00
195.0	7.0	88.2	134.5	4683.7	.081	28080.0	5616.0	2.20
196.0	7.0	96.0	120.8	539.3	.112	3233.2	646.6	-.28
197.0	7.0	24.8	125.0	213.0	.070	1276.8	255.4	-.08
198.0	7.0	88.3	339.6	837.8	.158	5022.9	1004.6	-.90

199.0	7.0	80.8	257.7	1863.6	.192	11172.5	2234.5	-1.20
200.0	7.0	96.9	149.8	1990.6	.038	11934.0	2386.8	1.20
201.0	7.0	100.0	126.7	3385.2	.078	20295.0	4059.0	2.50
202.0	7.0	100.0	112.5	167.7	.105	1005.2	201.0	-.09
203.0	7.0	97.3	107.7	12524.4	.175	75086.5	15017.3	.60
204.0	7.0	75.8	150.0	390.5	.195	2341.4	468.3	0.00
205.0	7.0	80.0	150.0	9917.9	.248	59460.0	11892.0	2.00
206.0	7.0	0.0	0.0	0.0	0.000	0.0	0.0	0.00
207.0	7.0	0.0	0.0	0.0	0.000	0.0	0.0	0.00
208.0	7.0	0.0	0.0	0.0	0.000	0.0	0.0	0.00
209.0	7.0	70.8	130.4	11031.3	.240	66135.0	13227.0	.50
210.0	7.0	32.5	90.9	0.0	0.000	0.0	0.0	.20
211.0	7.0	100.0	100.0	2216.3	.185	13287.1	2657.4	.30
212.0	7.0	91.7	127.3	3360.4	.153	20146.0	4029.2	1.20
213.0	7.0	100.0	170.2	20166.1	.053	120900.0	24180.0	15.00
214.0	7.0	100.0	112.2	3500.7	.085	20987.5	4197.5	1.90
215.0	7.0	100.0	76.9	208.2	.040	1248.0	249.6	.40
216.0	7.0	600.0	116.7	7200.0	.120	43165.5	8633.1	-7.00
217.0	7.0	95.2	214.1	2130.0	.120	12769.8	2554.0	-.80
218.0	7.0	0.0	0.0	0.0	0.000	0.0	0.0	0.00
219.0	7.0	0.0	0.0	0.0	0.000	0.0	0.0	0.00
220.0	7.0	103.6	148.8	585.5	.097	3510.0	702.0	-.10
221.0	7.0	100.0	176.5	975.8	.057	5850.0	1170.0	-.50
222.0	7.0	63.7	114.3	562.9	.161	3375.0	675.0	0.00
223.0	7.0	0.0	0.0	0.0	0.000	0.0	0.0	0.00
224.0	7.0	100.0	158.5	8950.5	.149	53660.2	10732.0	2.49
225.0	7.0	0.0	0.0	0.0	0.000	0.0	0.0	0.00
226.0	7.0	67.0	117.6	340.0	.200	2038.4	407.7	.20
227.0	7.0	95.9	171.1	935.2	.200	5606.7	1121.3	.20
228.0	7.0	0.0	0.0	0.0	0.000	0.0	0.0	0.00
229.0	7.0	101.0	71.4	267.2	.095	1602.0	320.4	.40
230.0	7.0	0.0	0.0	0.0	0.000	0.0	0.0	0.00
240.0	7.0	73.4	280.0	300.0	.120	1798.6	359.7	1.40
250.0	7.0	100.0	142.6	981.8	.200	5886.1	1177.2	.30
251.0	7.0	96.9	116.3	1720.0	.200	10311.8	2062.4	0.00
252.0	7.0	0.0	0.0	0.0	0.000	0.0	0.0	0.00
253.0	7.0	67.2	100.0	400.0	.200	2398.1	479.6	2.00
254.0	7.0	100.0	40.0	22.5	.009	135.0	27.0	-.10
255.0	7.0	78.7	87.4	109.8	.120	658.3	131.7	-.08
256.0	7.0	100.7	100.0	624.0	.120	3741.0	748.2	0.00
25.0	7.0	13.4	69.0	34.8	.120	208.6	41.7	.28
258.0	7.0	0.0	0.0	0.0	0.000	0.0	0.0	0.00
259.0	7.0	100.0	168.8	580.5	.068	3480.0	696.0	4.55
260.0	7.0	59.3	114.6	3840.0	.200	23021.6	4604.3	-.60
261.0	7.0	0.0	0.0	0.0	0.000	0.0	0.0	0.00
262.0	7.0	0.0	0.0	0.0	0.000	0.0	0.0	0.00
263.0	7.0	0.0	0.0	0.0	0.000	0.0	0.0	0.00
264.0	7.0	0.0	0.0	0.0	0.000	0.0	0.0	0.00
265.0	7.0	86.0	100.0	1095.9	.274	6570.0	1314.0	.45
266.0	7.0	97.9	120.0	2604.6	.104	15615.0	3123.0	1.50
267.0	7.0	0.0	0.0	0.0	0.000	0.0	0.0	0.00
268.0	7.0	100.0	100.0	2000.0	.200	11990.4	2398.1	0.00
269.0	7.0	112.8	130.8	5742.1	.088	34425.0	6885.0	6.00
270.0	7.0	89.6	120.8	2699.2	.037	16182.0	3236.4	3.30
271.0	7.0	0.0	0.0	0.0	0.000	0.0	0.0	0.00
272.0	7.0	0.0	0.0	0.0	0.000	0.0	0.0	0.00
273.0	7.0	40.3	100.0	172.0	.200	1031.2	206.2	0.00
274.0	7.0	0.0	0.0	0.0	0.000	0.0	0.0	0.00
275.0	7.0	0.0	0.0	0.0	0.000	0.0	0.0	0.00
276.0	7.0	95.1	154.4	4904.4	.361	29402.7	5880.5	1.40
277.0	7.0	85.7	166.7	283.1	.118	1697.2	339.4	.10
278.0	7.0	104.3	200.0	600.5	.060	3600.0	720.0	-.20
279.0	7.0	0.0	0.0	0.0	0.000	0.0	0.0	0.00

280.0	7.0	0.0	0.0	0.0	0.000	0.0	0.0	0.00
281.0	7.0	0.0	0.0	0.0	0.000	0.0	0.0	0.00
282.0	7.0	100.0	104.0	44382.8	.222	266084.0	53216.8	2.20
283.0	7.0	57.8	41.7	144.0	.120	863.3	172.7	1.15
284.0	7.0	0.0	0.0	0.0	0.000	0.0	0.0	0.00
285.0	7.0	0.0	0.0	0.0	0.000	0.0	0.0	0.00
286.0	7.0	0.0	0.0	0.0	0.000	0.0	0.0	0.00
287.0	7.0	100.0	107.4	823.0	.152	4934.4	986.9	-.03
288.0	7.0	100.0	*****	4658.7	1.863	27930.0	5586.0	2.20
289.0	7.0	91.0	83.3	860.1	.143	5156.2	1031.3	-.50
290.0	7.0	90.9	96.5	1243.0	.200	7452.0	1490.4	.20
291.0	7.0	98.4	161.3	1240.0	.200	7434.1	1486.8	-.20
292.0	7.0	100.0	134.3	222.7	.100	1335.0	267.0	.30
293.0	7.0	100.0	224.8	363.6	.105	2180.1	436.0	1.12
294.0	7.0	100.0	46.7	81.0	.054	485.6	97.1	-.07
295.0	7.0	100.0	67.5	282.2	.071	1691.6	338.3	.43
296.0	7.0	100.0	146.2	246.7	.095	1479.2	295.8	.02
297.0	7.0	100.0	207.9	769.6	.200	4613.9	922.8	.70
298.0	7.0	100.0	50.9	349.1	.066	2093.2	418.6	-.27
299.0	7.0	100.0	73.7	248.7	.087	1491.0	298.2	.09
300.0	7.0	100.0	80.6	128.4	.041	770.0	154.0	.08
301.0	7.0	100.0	118.4	129.0	.102	773.6	154.7	.01
302.0	7.0	100.0	132.7	11798.9	.129	70736.6	14147.3	2.90
303.0	7.0	100.0	79.1	772.0	.180	4628.3	925.6	2.16
304.0	7.0	0.0	0.0	0.0	0.000	0.0	0.0	0.00
305.0	7.0	0.0	0.0	0.0	0.000	0.0	0.0	0.00
306.0	7.0	100.0	110.4	57.6	.035	345.6	69.1	.22
307.0	7.0	0.0	0.0	0.0	0.000	0.0	0.0	0.00
308.0	7.0	0.0	0.0	0.0	0.000	0.0	0.0	0.00
309.0	7.0	0.0	0.0	0.0	0.000	0.0	0.0	0.00
310.0	7.0	0.0	0.0	0.0	0.000	0.0	0.0	0.00
311.0	7.0	68.2	180.0	5066.6	.068	30375.0	6075.0	-3.50
312.0	7.0	95.2	100.0	30.0	.008	180.0	36.0	0.00
313.0	7.0	76.6	123.1	1939.9	.298	11630.0	2326.0	1.00
314.0	7.0	85.7	175.0	5884.7	.210	35280.0	7056.0	-1.90
315.0	7.0	100.0	136.2	337719.8	.270	2024699.2	404939.8	29.80
315.0	7.0	100.0	136.7	265732.5	.492	1593120.6	318624.1	16.20
315.0	7.0	100.0	110.0	50543.2	.253	303017.0	60603.4	10.00
315.0	7.0	100.0	48.2	11231.4	.066	67334.3	13466.9	-.20
316.0	7.0	89.1	130.8	1560.0	.120	9352.5	1870.5	-.70
317.0	7.0	27.0	100.0	160.0	.200	959.2	191.8	.42
318.0	7.0	98.4	115.9	162.0	.094	971.2	194.2	-.20
319.0	7.0	0.0	0.0	0.0	0.000	0.0	0.0	0.00
320.0	7.0	70.0	28.6	30.7	.022	184.1	36.8	.01
321.0	7.0	50.6	106.3	3158.5	.395	18935.9	3787.2	-.55
322.0	7.0	0.0	0.0	0.0	0.000	0.0	0.0	0.00
333.0	7.0	0.0	0.0	0.0	0.000	0.0	0.0	0.00
334.0	7.0	99.5	100.0	617.2	.200	3700.2	740.0	.40
335.0	7.0	95.2	205.5	2075.8	.474	12444.8	2489.0	.10
336.0	7.0	100.0	81.3	1100.0	.099	6594.7	1319.0	.60
337.0	7.0	0.0	0.0	0.0	0.000	0.0	0.0	0.00
338.0	7.0	99.9	32.7	428.6	.200	2569.5	513.9	.23
339.0	7.0	0.0	0.0	0.0	0.000	0.0	0.0	0.00
340.0	7.0	26.5	83.3	10277.6	.571	61616.4	12323.3	2.30
341.0	7.0	100.0	137.5	9622.7	.241	57689.9	11538.0	3.00
342.0	7.0	101.9	103.7	748.6	.155	4487.8	897.6	.20
343.0	7.0	100.0	252.1	2608.6	.411	15639.1	3127.8	.40
345.0	7.0	99.3	131.5	44693.5	.403	267946.5	53589.3	-1.10
346.0	7.0	99.7	80.0	643.5	.214	3857.9	771.6	.01
347.0	7.0	100.0	100.0	584.0	.389	3501.0	700.2	.06
348.0	7.0	100.0	131.8	15151.6	.344	90836.9	18167.4	.20
349.0	7.0	53.3	100.0	48.0	.120	287.8	57.6	0.00
350.0	7.0	0.0	0.0	0.0	0.000	0.0	0.0	0.00

351.0	7.0	0.0	0.0	0.0	0.000	0.0	0.0	0.00
352.0	7.0	0.0	0.0	0.0	0.000	0.0	0.0	0.00
353.0	7.0	44.0	103.6	532.6	.097	3193.1	638.6	-.07
354.0	7.0	100.0	100.0	76.5	.081	458.9	91.8	0.00
355.0	7.0	0.0	0.0	0.0	0.000	0.0	0.0	0.00
356.0	7.0	68.0	100.0	181.4	.120	1087.8	217.6	.15
357.0	7.0	16.2	392.2	30.6	.120	183.5	36.7	-.10
358.0	7.0	98.5	59.7	295.2	.088	1770.0	354.0	-.20
359.0	7.0	78.7	143.8	16573.2	.104	99360.0	19872.0	1.00
360.0	7.0	100.0	100.0	6205.0	.103	37200.0	7440.0	2.00
361.0	7.0	86.7	153.8	520.0	.200	3117.5	623.5	.20
362.0	7.0	0.0	0.0	0.0	0.000	0.0	0.0	0.00
363.0	7.0	100.0	193.1	11156.4	.440	66885.0	13377.0	-.40
364.0	7.0	0.0	0.0	0.0	0.000	0.0	0.0	0.00
365.0	7.0	0.0	0.0	0.0	0.000	0.0	0.0	0.00
366.0	7.0	0.0	0.0	0.0	0.000	0.0	0.0	0.00

MUNICIPAL SLUDGE PRODUCTION IN CANADA

TOWN	PROVINCE	%POPULATION SERVED	AVERAGE GPCD	POUNDS/DAY	POUNDS/CAPITA/DAY	GALS AT 2%	GALS AT 10%	MGD EXTRA
1.0	8.0	135.0	100.0	3240.0	.120	19424.5	3884.9	5.00
2.0	8.0	84.6	147.1	462.6	.340	2773.4	554.7	0.00
3.0	8.0	0.0	0.0	0.0	0.000	0.0	0.0	0.00
4.0	8.0	117.2	52.6	380.0	.200	2278.2	455.6	-.10
5.0	8.0	0.0	0.0	0.0	0.000	0.0	0.0	0.00
6.0	8.0	121.8	108.7	1438.7	.125	8625.0	1725.0	1.00

MUNICIPAL SLUDGE PRODUCTION IN CANADA

TOWN	PROVINCE	%POPULATION SERVED	AVERAGE GPCD	POUNDS/DAY	POUNDS/CAPITA/DAY	GALS AT 2%	GALS AT 10%	MGD EXTRA
1.0	9.0	0.0	0.0	0.0	0.000	0.0	0.0	0.00
2.0	9.0	0.0	0.0	0.0	0.000	0.0	0.0	0.00
3.0	9.0	0.0	0.0	0.0	0.000	0.0	0.0	0.00
4.0	9.0	0.0	0.0	0.0	0.000	0.0	0.0	0.00
5.0	9.0	0.0	0.0	0.0	0.000	0.0	0.0	0.00
6.0	9.0	115.4	100.0	620.3	.120	3718.7	743.7	0.00
7.0	9.0	0.0	0.0	0.0	0.000	0.0	0.0	0.00
8.0	9.0	0.0	0.0	0.0	0.000	0.0	0.0	0.00
9.0	9.0	0.0	0.0	0.0	0.000	0.0	0.0	0.00
10.0	9.0	0.0	0.0	0.0	0.000	0.0	0.0	0.00
11.0	9.0	0.0	0.0	0.0	0.000	0.0	0.0	0.00
12.0	9.0	0.0	0.0	0.0	0.000	0.0	0.0	0.00
13.0	9.0	0.0	0.0	0.0	0.000	0.0	0.0	0.00
14.0	9.0	100.0	119.0	2520.0	.120	15107.9	3021.6	7.50
15.0	9.0	100.0	100.0	974.5	.120	5842.4	1168.5	.01
16.0	9.0	0.0	0.0	0.0	0.000	0.0	0.0	0.00
17.0	9.0	0.0	0.0	0.0	0.000	0.0	0.0	0.00
18.0	9.0	85.6	100.0	840.0	.120	5036.0	1007.2	.20
19.0	9.0	100.0	281.3	384.0	.120	2302.2	460.4	-.90
20.0	9.0	80.9	100.0	81.0	.081	485.6	97.1	0.00
21.0	9.0	0.0	0.0	0.0	0.000	0.0	0.0	0.00
22.0	9.0	0.0	0.0	0.0	0.000	0.0	0.0	0.00
23.0	9.0	0.0	0.0	0.0	0.000	0.0	0.0	0.00
24.0	9.0	0.0	0.0	0.0	0.000	0.0	0.0	0.00
25.0	9.0	99.5	428.9	1632.0	.200	9784.2	1956.8	-2.00
26.0	9.0	0.0	0.0	0.0	0.000	0.0	0.0	0.00
27.0	9.0	0.0	0.0	0.0	0.000	0.0	0.0	0.00
28.0	9.0	0.0	0.0	0.0	0.000	0.0	0.0	0.00
29.0	9.0	0.0	0.0	0.0	0.000	0.0	0.0	0.00
30.0	9.0	0.0	0.0	0.0	0.000	0.0	0.0	0.00
31.0	9.0	0.0	0.0	0.0	0.000	0.0	0.0	0.00
32.0	9.0	0.0	0.0	0.0	0.000	0.0	0.0	0.00
33.0	9.0	0.0	0.0	0.0	0.000	0.0	0.0	0.00
34.0	9.0	0.0	0.0	0.0	0.000	0.0	0.0	0.00
35.0	9.0	0.0	0.0	0.0	0.000	0.0	0.0	0.00
36.0	9.0	0.0	0.0	0.0	0.000	0.0	0.0	0.00
37.0	9.0	0.0	0.0	0.0	0.000	0.0	0.0	0.00
38.0	9.0	94.7	27.8	432.0	.120	2589.9	518.0	-.10
39.0	9.0	0.0	0.0	0.0	0.000	0.0	0.0	0.00
40.0	9.0	0.0	0.0	0.0	0.000	0.0	0.0	0.00
41.0	9.0	0.0	0.0	0.0	0.000	0.0	0.0	0.00
42.0	9.0	0.0	0.0	0.0	0.000	0.0	0.0	0.00
43.0	9.0	0.0	0.0	0.0	0.000	0.0	0.0	0.00
44.0	9.0	0.0	0.0	0.0	0.000	0.0	0.0	0.00
45.0	9.0	100.0	25.1	335.3	.120	2010.1	402.0	0.00
46.0	9.0	0.0	0.0	0.0	0.000	0.0	0.0	0.00
47.0	9.0	0.0	0.0	0.0	0.000	0.0	0.0	0.00
48.0	9.0	0.0	0.0	0.0	0.000	0.0	0.0	0.00
49.0	9.0	0.0	0.0	0.0	0.000	0.0	0.0	0.00
50.0	9.0	0.0	0.0	0.0	0.000	0.0	0.0	0.00
51.0	9.0	0.0	0.0	0.0	0.000	0.0	0.0	0.00
52.0	9.0	0.0	0.0	0.0	0.000	0.0	0.0	0.00
53.0	9.0	0.0	0.0	0.0	0.000	0.0	0.0	0.00
54.0	9.0	0.0	0.0	0.0	0.000	0.0	0.0	0.00
55.0	9.0	0.0	0.0	0.0	0.000	0.0	0.0	0.00
56.0	9.0	0.0	0.0	0.0	0.000	0.0	0.0	0.00
57.0	9.0	0.0	0.0	0.0	0.000	0.0	0.0	0.00
58.0	9.0	0.0	0.0	0.0	0.000	0.0	0.0	0.00

59.0	9.0	0.0	0.0	0.0	0.000	0.0	0.0	0.00
60.0	9.0	0.0	0.0	0.0	0.000	0.0	0.0	0.00
61.0	9.0	0.0	0.0	0.0	0.000	0.0	0.0	0.00
62.0	9.0	119.0	100.0	420.0	.120	2518.0	503.6	0.00
63.0	9.0	0.0	0.0	0.0	0.000	0.0	0.0	0.00
64.0	9.0	0.0	0.0	0.0	0.000	0.0	0.0	0.00
65.0	9.0	249.2	177.8	540.0	.120	3237.4	647.5	0.00
66.0	9.0	104.3	133.3	409.9	.046	2457.6	491.5	.30
67.0	9.0	0.0	0.0	0.0	0.000	0.0	0.0	0.00
68.0	9.0	0.0	0.0	0.0	0.000	0.0	0.0	0.00
69.0	9.0	0.0	0.0	0.0	0.000	0.0	0.0	0.00
70.0	9.0	0.0	0.0	0.0	0.000	0.0	0.0	0.00
71.0	9.0	0.0	0.0	0.0	0.000	0.0	0.0	0.00
72.0	9.0	0.0	0.0	0.0	0.000	0.0	0.0	0.00
73.0	9.0	0.0	0.0	0.0	0.000	0.0	0.0	0.00
74.0	9.0	0.0	0.0	0.0	0.000	0.0	0.0	0.00
75.0	9.0	0.0	0.0	0.0	0.000	0.0	0.0	0.00
76.0	9.0	0.0	0.0	0.0	0.000	0.0	0.0	0.00
77.0	9.0	0.0	0.0	0.0	0.000	0.0	0.0	0.00
78.0	9.0	0.0	0.0	0.0	0.000	0.0	0.0	0.00
79.0	9.0	105.6	175.0	800.0	.200	4796.2	959.2	0.00
80.0	9.0	0.0	0.0	0.0	0.000	0.0	0.0	0.00
81.0	9.0	0.0	0.0	0.0	0.000	0.0	0.0	0.00
82.0	9.0	0.0	0.0	0.0	0.000	0.0	0.0	0.00
83.0	9.0	0.0	0.0	0.0	0.000	0.0	0.0	0.00
84.0	9.0	0.0	0.0	0.0	0.000	0.0	0.0	0.00
85.0	9.0	0.0	0.0	0.0	0.000	0.0	0.0	0.00
86.0	9.0	0.0	0.0	0.0	0.000	0.0	0.0	0.00
87.0	9.0	0.0	0.0	0.0	0.000	0.0	0.0	0.00
88.0	9.0	0.0	0.0	0.0	0.000	0.0	0.0	0.00
89.0	9.0	95.1	214.3	1680.0	.120	10071.9	2014.4	0.00
90.0	9.0	100.0	109.2	98.9	.120	592.8	118.6	.11
91.0	9.0	100.0	100.0	388.8	.081	2330.9	466.2	0.00
92.0	9.0	0.0	0.0	0.0	0.000	0.0	0.0	0.00
93.0	9.0	0.0	0.0	0.0	0.000	0.0	0.0	0.00
94.0	9.0	0.0	0.0	0.0	0.000	0.0	0.0	0.00
95.0	9.0	0.0	0.0	0.0	0.000	0.0	0.0	0.00
96.0	9.0	0.0	0.0	0.0	0.000	0.0	0.0	0.00
97.0	9.0	0.0	0.0	0.0	0.000	0.0	0.0	0.00
98.0	9.0	0.0	0.0	0.0	0.000	0.0	0.0	0.00
99.0	9.0	133.7	256.4	40.4	.010	242.5	48.5	-1.00
100.0	9.0	0.0	0.0	0.0	0.000	0.0	0.0	0.00
101.0	9.0	0.0	0.0	0.0	0.000	0.0	0.0	0.00
102.0	9.0	0.0	0.0	0.0	0.000	0.0	0.0	0.00
103.0	9.0	96.5	184.6	780.0	.120	4676.3	935.3	-1.10
104.0	9.0	0.0	0.0	0.0	0.000	0.0	0.0	0.00
105.0	9.0	0.0	0.0	0.0	0.000	0.0	0.0	0.00
106.0	9.0	0.0	0.0	0.0	0.000	0.0	0.0	0.00
107.0	9.0	0.0	0.0	0.0	0.000	0.0	0.0	0.00
108.0	9.0	0.0	0.0	0.0	0.000	0.0	0.0	0.00
109.0	9.0	106.0	25.0	320.0	.200	1918.5	383.7	-.04
110.0	9.0	0.0	0.0	0.0	0.000	0.0	0.0	0.00
111.0	9.0	0.0	0.0	0.0	0.000	0.0	0.0	0.00
112.0	9.0	0.0	0.0	0.0	0.000	0.0	0.0	0.00
113.0	9.0	0.0	0.0	0.0	0.000	0.0	0.0	0.00
114.0	9.0	0.0	0.0	0.0	0.000	0.0	0.0	0.00
115.0	9.0	0.0	0.0	0.0	0.000	0.0	0.0	0.00
116.0	9.0	0.0	0.0	0.0	0.000	0.0	0.0	0.00
117.0	9.0	0.0	0.0	0.0	0.000	0.0	0.0	0.00
118.0	9.0	0.0	0.0	0.0	0.000	0.0	0.0	0.00
119.0	9.0	86.0	172.1	19672.0	.091	117937.5	23587.5	-28.00
120.0	9.0	100.0	106.7	92.5	.062	554.6	110.9	.14
121.0	9.0	0.0	0.0	0.0	0.000	0.0	0.0	0.00

122.0	9.0	0.0	0.0	0.0	0.000	0.0	0.0	0.00
123.0	9.0	0.0	0.0	0.0	0.000	0.0	0.0	0.00
124.0	9.0	0.0	0.0	0.0	0.000	0.0	0.0	0.00
125.0	9.0	0.0	0.0	0.0	0.000	0.0	0.0	0.00
126.0	9.0	0.0	0.0	0.0	0.000	0.0	0.0	0.00
127.0	9.0	100.0	40.0	600.0	.120	3597.1	719.4	-.10
128.0	9.0	0.0	0.0	0.0	0.000	0.0	0.0	0.00
129.0	9.0	0.0	0.0	0.0	0.000	0.0	0.0	0.00
130.0	9.0	0.0	0.0	0.0	0.000	0.0	0.0	0.00
131.0	9.0	0.0	0.0	0.0	0.000	0.0	0.0	0.00
132.0	9.0	0.0	0.0	0.0	0.000	0.0	0.0	0.00
133.0	9.0	0.0	0.0	0.0	0.000	0.0	0.0	0.00
134.0	9.0	0.0	0.0	0.0	0.000	0.0	0.0	0.00
135.0	9.0	0.0	0.0	0.0	0.000	0.0	0.0	0.00
136.0	9.0	0.0	0.0	0.0	0.000	0.0	0.0	0.00
137.0	9.0	100.0	58.8	1020.0	.200	6115.1	1223.0	0.00
138.0	9.0	0.0	0.0	0.0	0.000	0.0	0.0	0.00
139.0	9.0	0.0	0.0	0.0	0.000	0.0	0.0	0.00
140.0	9.0	0.0	0.0	0.0	0.000	0.0	0.0	0.00
141.0	9.0	0.0	0.0	0.0	0.000	0.0	0.0	0.00
142.0	9.0	0.0	0.0	0.0	0.000	0.0	0.0	0.00
143.0	9.0	0.0	0.0	0.0	0.000	0.0	0.0	0.00
144.0	9.0	0.0	0.0	0.0	0.000	0.0	0.0	0.00
145.0	9.0	0.0	0.0	0.0	0.000	0.0	0.0	0.00
146.0	9.0	143.9	157.9	149844.8	.079	898350.0	179670.0	******
147.0	9.0	0.0	0.0	0.0	0.000	0.0	0.0	0.00
148.0	9.0	0.0	0.0	0.0	0.000	0.0	0.0	0.00
149.0	9.0	0.0	0.0	0.0	0.000	0.0	0.0	0.00
150.0	9.0	0.0	0.0	0.0	0.000	0.0	0.0	0.00
151.0	9.0	0.0	0.0	0.0	0.000	0.0	0.0	0.00
152.0	9.0	100.0	97.0	2269.2	.200	13604.3	2720.9	.90
153.0	9.0	0.0	0.0	0.0	0.000	0.0	0.0	0.00
154.0	9.0	0.0	0.0	0.0	0.000	0.0	0.0	0.00
155.0	9.0	0.0	0.0	0.0	0.000	0.0	0.0	0.00
156.0	9.0	0.0	0.0	0.0	0.000	0.0	0.0	0.00
157.0	9.0	0.0	0.0	0.0	0.000	0.0	0.0	0.00
158.0	9.0	106.0	100.0	87.6	.003	525.0	105.0	.90
159.0	9.0	0.0	0.0	0.0	0.000	0.0	0.0	0.00
160.0	9.0	132.2	100.0	1560.0	.200	9352.5	1870.5	1.50
161.0	9.0	0.0	0.0	0.0	0.000	0.0	0.0	0.00
162.0	9.0	0.0	0.0	0.0	0.000	0.0	0.0	0.00
163.0	9.0	0.0	0.0	0.0	0.000	0.0	0.0	0.00
164.0	9.0	0.0	0.0	0.0	0.000	0.0	0.0	0.00
165.0	9.0	0.0	0.0	0.0	0.000	0.0	0.0	0.00
166.0	9.0	0.0	0.0	0.0	0.000	0.0	0.0	0.00
167.0	9.0	0.0	0.0	0.0	0.000	0.0	0.0	0.00
168.0	9.0	0.0	0.0	0.0	0.000	0.0	0.0	0.00
169.0	9.0	0.0	0.0	0.0	0.000	0.0	0.0	0.00
170.0	9.0	0.0	0.0	0.0	0.000	0.0	0.0	0.00
171.0	9.0	0.0	0.0	0.0	0.000	0.0	0.0	0.00
172.0	9.0	0.0	0.0	0.0	0.000	0.0	0.0	0.00
173.0	9.0	0.0	0.0	0.0	0.000	0.0	0.0	0.00
174.0	9.0	0.0	0.0	0.0	0.000	0.0	0.0	0.00
175.0	9.0	0.0	0.0	0.0	0.000	0.0	0.0	0.00
176.0	9.0	0.0	0.0	0.0	0.000	0.0	0.0	0.00
177.0	9.0	0.0	0.0	0.0	0.000	0.0	0.0	0.00
178.0	9.0	0.0	0.0	0.0	0.000	0.0	0.0	0.00
179.0	9.0	0.0	0.0	0.0	0.000	0.0	0.0	0.00
180.0	9.0	0.0	0.0	0.0	0.000	0.0	0.0	0.00
181.0	9.0	0.0	0.0	0.0	0.000	0.0	0.0	0.00
182.0	9.0	0.0	0.0	0.0	0.000	0.0	0.0	0.00
183.0	9.0	0.0	0.0	0.0	0.000	0.0	0.0	0.00
184.0	9.0	0.0	0.0	0.0	0.000	0.0	0.0	0.00

185.0	9.0	110.3	163.9	1220.0	.200	7314.1	1462.8	-1.00
186.0	9.0	0.0	0.0	0.0	0.000	0.0	0.0	0.00
187.0	9.0	0.0	0.0	0.0	0.000	0.0	0.0	0.00
188.0	9.0	0.0	0.0	0.0	0.000	0.0	0.0	0.00
189.0	9.0	0.0	0.0	0.0	0.000	0.0	0.0	0.00
190.0	9.0	0.0	0.0	0.0	0.000	0.0	0.0	0.00
191.0	9.0	0.0	0.0	0.0	0.000	0.0	0.0	0.00
192.0	9.0	0.0	0.0	0.0	0.000	0.0	0.0	0.00
193.0	9.0	0.0	0.0	0.0	0.000	0.0	0.0	0.00
194.0	9.0	0.0	0.0	0.0	0.000	0.0	0.0	0.00
195.0	9.0	0.0	0.0	0.0	0.000	0.0	0.0	0.00
196.0	9.0	0.0	0.0	0.0	0.000	0.0	0.0	0.00
197.0	9.0	0.0	0.0	0.0	0.000	0.0	0.0	0.00
198.0	9.0	0.0	0.0	0.0	0.000	0.0	0.0	0.00
199.0	9.0	70.0	119.0	2100.0	.200	12589.9	2518.0	-.65
200.0	9.0	0.0	0.0	0.0	0.000	0.0	0.0	0.00
201.0	9.0	0.0	0.0	0.0	0.000	0.0	0.0	0.00
202.0	9.0	0.0	0.0	0.0	0.000	0.0	0.0	0.00
203.0	9.0	100.0	240.3	998.6	.200	5986.8	1197.4	-1.20
204.0	9.0	0.0	0.0	0.0	0.000	0.0	0.0	0.00
205.0	9.0	0.0	0.0	0.0	0.000	0.0	0.0	0.00
206.0	9.0	0.0	0.0	0.0	0.000	0.0	0.0	0.00
207.0	9.0	0.0	0.0	0.0	0.000	0.0	0.0	0.00
208.0	9.0	94.7	166.7	856.5	.238	5134.8	1027.0	1.00
209.0	9.0	0.0	0.0	0.0	0.000	0.0	0.0	0.00
210.0	9.0	0.0	0.0	0.0	0.000	0.0	0.0	0.00
211.0	9.0	0.0	0.0	0.0	0.000	0.0	0.0	0.00
212.0	9.0	0.0	0.0	0.0	0.000	0.0	0.0	0.00
213.0	9.0	100.0	46.0	4348.2	.200	26068.3	5213.7	-1.00
214.0	9.0	0.0	0.0	0.0	0.000	0.0	0.0	0.00
215.0	9.0	0.0	0.0	0.0	0.000	0.0	0.0	0.00
216.0	9.0	0.0	0.0	0.0	0.000	0.0	0.0	0.00
217.0	9.0	0.0	0.0	0.0	0.000	0.0	0.0	0.00
218.0	9.0	57.8	32.4	222.0	.120	1330.9	266.2	.02
219.0	9.0	0.0	0.0	0.0	0.000	0.0	0.0	0.00
220.0	9.0	0.0	0.0	0.0	0.000	0.0	0.0	0.00
221.0	9.0	109.7	63.0	635.0	.200	3807.0	761.4	-.20
222.0	9.0	0.0	0.0	0.0	0.000	0.0	0.0	0.00
223.0	9.0	0.0	0.0	0.0	0.000	0.0	0.0	0.00
224.0	9.0	0.0	0.0	0.0	0.000	0.0	0.0	0.00
225.0	9.0	0.0	0.0	0.0	0.000	0.0	0.0	0.00
226.0	9.0	0.0	0.0	0.0	0.000	0.0	0.0	0.00
227.0	9.0	0.0	0.0	0.0	0.000	0.0	0.0	0.00
228.0	9.0	0.0	0.0	0.0	0.000	0.0	0.0	0.00
229.0	9.0	0.0	0.0	0.0	0.000	0.0	0.0	0.00
230.0	9.0	0.0	0.0	0.0	0.000	0.0	0.0	0.00
231.0	9.0	0.0	0.0	0.0	0.000	0.0	0.0	0.00
232.0	9.0	0.0	0.0	0.0	0.000	0.0	0.0	0.00
233.0	9.0	100.0	100.0	269.6	.200	1616.3	323.3	0.00
234.0	9.0	0.0	0.0	0.0	0.000	0.0	0.0	0.00
235.0	9.0	101.7	333.3	144.0	.120	863.3	172.7	0.00
236.0	9.0	0.0	0.0	0.0	0.000	0.0	0.0	0.00
237.0	9.0	0.0	0.0	0.0	0.000	0.0	0.0	0.00
238.0	9.0	0.0	0.0	0.0	0.000	0.0	0.0	0.00
239.0	9.0	0.0	0.0	0.0	0.000	0.0	0.0	0.00
240.0	9.0	0.0	0.0	0.0	0.000	0.0	0.0	0.00
241.0	9.0	0.0	0.0	0.0	0.000	0.0	0.0	0.00
242.0	9.0	0.0	0.0	0.0	0.000	0.0	0.0	0.00
243.0	9.0	111.8	100.0	420.0	.120	2518.0	503.6	0.00
244.0	9.0	100.0	10.0	3600.0	.120	21582.7	4316.5	-.30
245.0	9.0	123.0	100.0	264.0	.120	1582.7	316.5	0.00
246.0	9.0	126.4	154.8	2464.9	.587	14777.8	2955.6	.85
247.0	9.0	0.0	0.0	0.0	0.000	0.0	0.0	0.00

248.0	9.0	81.3	100.0	420.0	.120	2518.0	503.6	.20
249.0	9.0	0.0	0.0	0.0	0.000	0.0	0.0	0.00
250.0	9.0	0.0	0.0	0.0	0.000	0.0	0.0	0.00
251.0	9.0	0.0	0.0	0.0	0.000	0.0	0.0	0.00
252.0	9.0	0.0	0.0	0.0	0.000	0.0	0.0	0.00
253.0	9.0	0.0	0.0	0.0	0.000	0.0	0.0	0.00
254.0	9.0	0.0	0.0	0.0	0.000	0.0	0.0	0.00
255.0	9.0	0.0	0.0	0.0	0.000	0.0	0.0	0.00
256.0	9.0	0.0	0.0	0.0	0.000	0.0	0.0	0.00
257.0	9.0	0.0	0.0	0.0	0.000	0.0	0.0	0.00
258.0	9.0	0.0	0.0	0.0	0.000	0.0	0.0	0.00
259.0	9.0	19.8	411.5	87.5	.120	524.5	104.9	.20
260.0	9.0	0.0	0.0	0.0	0.000	0.0	0.0	0.00
261.0	9.0	0.0	0.0	0.0	0.000	0.0	0.0	0.00
262.0	9.0	0.0	0.0	0.0	0.000	0.0	0.0	0.00
263.0	9.0	0.0	0.0	0.0	0.000	0.0	0.0	0.00
264.0	9.0	0.0	0.0	0.0	0.000	0.0	0.0	0.00
265.0	9.0	0.0	0.0	0.0	0.000	0.0	0.0	0.00
266.0	9.0	0.0	0.0	0.0	0.000	0.0	0.0	0.00
267.0	9.0	0.0	0.0	0.0	0.000	0.0	0.0	0.00
263.0	9.0	0.0	0.0	0.0	0.000	0.0	0.0	0.00
264.0	9.0	0.0	0.0	0.0	0.000	0.0	0.0	0.00
265.0	9.0	0.0	0.0	0.0	0.000	0.0	0.0	0.00
266.0	9.0	0.0	0.0	0.0	0.000	0.0	0.0	0.00
267.0	9.0	0.0	0.0	0.0	0.000	0.0	0.0	0.00
268.0	9.0	0.0	0.0	0.0	0.000	0.0	0.0	0.00
269.0	9.0	0.0	0.0	0.0	0.000	0.0	0.0	0.00
270.0	9.0	0.0	0.0	0.0	0.000	0.0	0.0	0.00
280.0	9.0	0.0	0.0	0.0	0.000	0.0	0.0	0.00
281.0	9.0	0.0	0.0	0.0	0.000	0.0	0.0	0.00
282.0	9.0	0.0	0.0	0.0	0.000	0.0	0.0	0.00

MUNICIPAL SLUDGE PRODUCTION IN CANADA

TOWN	PROVINCE	%POPULATION SERVED	AVERAGE GPCD	POUNDS/DAY	POUNDS/CAPITA/DAY	GALS AT 2%	GALS AT 10%	MGD EXTRA
1.0	10.0	107.3	100.0	600.0	.200	3597.1	719.4	-.30
2.0	10.0	0.0	0.0	0.0	0.000	0.0	0.0	0.00
3.0	10.0	0.0	0.0	0.0	0.000	0.0	0.0	0.00
4.0	10.0	103.6	74.1	324.0	.120	1942.4	388.5	-.14
5.0	10.0	100.0	100.0	200.0	.200	1199.0	239.8	0.00
6.0	10.0	0.0	0.0	0.0	0.000	0.0	0.0	0.00
7.0	10.0	100.0	100.0	220.2	.200	1320.1	264.0	0.00
8.0	10.0	0.0	0.0	0.0	0.000	0.0	0.0	0.00
9.0	10.0	100.0	100.0	190.6	.200	1142.7	228.5	0.00
10.0	10.0	100.0	100.0	194.6	.200	1166.7	233.3	0.00
11.0	10.0	100.0	100.0	222.8	.120	1336.0	267.2	0.00
12.0	10.0	0.0	0.0	0.0	0.000	0.0	0.0	0.00
13.0	10.0	99.2	100.0	595.0	.200	3567.1	713.4	0.00
14.0	10.0	103.8	63.2	1900.0	.200	11390.9	2278.2	.10
15.0	10.0	102.3	100.0	290.0	.200	1738.6	347.7	0.00
16.0	10.0	82.8	83.3	144.0	.120	863.3	172.7	-.10
17.0	10.0	90.7	74.1	210.6	.120	1262.6	252.5	-.13
18.0	10.0	0.0	0.0	0.0	0.000	0.0	0.0	0.00
19.0	10.0	88.9	100.0	240.0	.200	1438.8	287.8	0.00
20.0	10.0	103.8	100.0	240.0	.200	1438.8	287.8	0.00
21.0	10.0	0.0	0.0	0.0	0.000	0.0	0.0	0.00
22.0	10.0	0.0	0.0	0.0	0.000	0.0	0.0	0.00
23.0	10.0	123.7	100.0	960.0	.200	5755.4	1151.1	0.00
24.0	10.0	100.0	100.0	362.0	.200	2170.3	434.1	0.00
25.0	10.0	107.8	100.0	600.0	.200	3597.1	719.4	0.00
26.0	10.0	100.0	47.6	294.4	.200	1765.0	353.0	.03
27.0	10.0	100.0	40.7	147.6	.120	884.9	177.0	.03
28.0	10.0	100.0	22.2	900.0	.200	5395.7	1079.1	-.08
29.0	10.0	272.7	33.3	600.0	.200	3597.1	719.4	0.00
30.0	10.0	100.0	100.0	247.2	.200	1482.0	296.4	0.00
31.0	10.0	100.0	62.5	192.0	.120	1151.1	230.2	.20
32.0	10.0	100.0	100.0	221.0	.200	1324.9	265.0	0.00
33.0	10.0	100.0	46.9	1006.0	.094	6031.3	1206.3	.10
34.0	10.0	100.0	100.0	473.8	.200	2840.5	568.1	0.00
35.0	10.0	0.0	0.0	0.0	0.000	0.0	0.0	0.00
36.0	10.0	93.9	87.0	552.0	.120	3309.4	661.9	-.40
37.0	10.0	98.2	74.1	563.3	.104	3377.0	675.4	.30
38.0	10.0	100.0	64.7	6800.0	.200	40767.4	8153.5	1.80
39.0	10.0	91.4	45.5	264.0	.120	1582.7	316.5	-.10
40.0	10.0	95.2	75.0	433.4	.108	2598.6	519.7	.20
41.0	10.0	92.7	90.5	3738.4	.308	22412.5	4482.5	.40
42.0	10.0	110.4	100.0	234.0	.120	1402.9	280.6	0.00
43.0	10.0	100.0	100.0	260.0	.200	1558.8	311.8	0.00
44.0	10.0	100.0	100.0	94.3	.120	565.5	113.1	0.00
45.0	10.0	80.0	50.0	200.0	.200	1199.0	239.8	-.05
46.0	10.0	90.3	89.3	3360.0	.120	20143.9	4028.8	-1.80
47.0	10.0	38.5	263.2	45.6	.120	273.4	54.7	.30
48.0	10.0	100.0	114.9	46312.4	.313	277652.5	55530.5	13.00
49.0	10.0	100.0	37.0	324.0	.120	1942.4	388.5	.20
50.0	10.0	100.0	100.0	522.8	.200	3134.3	626.9	0.00
51.0	10.0	100.0	89.1	7704.8	.056	46191.6	9238.3	7.78
52.0	10.0	0.0	0.0	0.0	0.000	0.0	0.0	0.00
53.0	10.0	100.0	75.0	3200.0	.200	19184.7	3836.9	.80
54.0	10.0	96.7	86.2	709.9	.245	4256.3	851.2	2.75
55.0	10.0	100.0	41.5	482.0	.200	2889.7	577.9	-.10
56.0	10.0	83.7	162.2	222.0	.120	1330.9	266.2	.70
57.0	10.0	103.1	70.2	285.0	.200	1708.6	341.7	0.00
58.0	10.0	0.0	0.0	0.0	0.000	0.0	0.0	0.00

59.0	10.0	113.3	100.0	349.2	.200	2093.5	418.7	0.00
60.0	10.0	103.3	75.3	1752.9	.188	10508.8	2101.8	-.10
61.0	10.0	90.9	20.0	200.0	.200	1199.0	239.8	-.02
62.0	10.0	100.0	54.8	328.4	.200	1968.8	393.8	-.07
62.0	10.0	82.1	100.0	160.0	.200	959.2	191.8	0.00
63.0	10.0	103.5	100.0	1175.9	.588	7050.0	1410.0	-.20
64.0	10.0	98.3	69.0	2900.0	.200	17386.1	3477.2	.30

APPENDIX 1.2

CANADIAN SURVEY

ONTARIO RESEARCH FOUNDATION

SHERIDAN PARK RESEARCH COMMUNITY

MISSISSAUGA, ONTARIO, CANADA L5K 1B3 • (416) 822-4111 • TELEX 06-982311

Re: Production and Disposal of Municipal Sewage Sludge

Dear Sir,

The Ontario Research Foundation is presently conducting a study of sewage sludge production and disposal in Canada in order to better predict the problem that will be facing us by the end of the century. In order to complete this study, it is necessary to be in possession of the attached information from each Province. Any assistance you or your staff can provide in obtaining this information will be greatly appreciated.

I have also attached a sheet of calculated values for water use and sewage production for your Province based on information contained in the 1976-77 Directory and Environmental Handbook published by Water and Pollution Control. These values are based on calculations done for each municipality in your Province.

I would appreciate it if you could indicate which of these estimates do, or do not correspond to the information that you have on hand.

Your assistance in this matter is greatly appreciated.

Yours very truly,

R.V. Laughton,
Wastewater Treatment Section.
Dept. of Applied Chemistry.

RVL/vw

CALCULATED PRODUCTION VALUES

1. Average water use (gallons/capita/day) ________

2. Percent Province served by treatment facilities ________

3. Pounds of sludge produced per day ________

4. Gallons of sludge produced per day at 2% solids ________

5. Total sewage treated (M.G.D.) ________

6. Number of sewage plants:
   (a) primary ________
   (b) secondary ________

7. Population used for calculations ________

8. Real Population ________

REQUIRED INFORMATION:

1. Regulations governing the disposal of sludge on land (or in water) within your Province.

2. Application required before sludge disposal can take place.

3. Acres of land presently, and expected to be receiving sewage sludge.

4. Present breakdown of sludge processing facilities in the Province.

5. The future plans of your Province in this area.

SECTION I - TABLES

TABLE 1.1 NORMAL QUANTITIES OF SLUDGE PRODUCED BY DIFFERENT TREATMENT PROCESSES*

Treatment process	Normal quantity of sludge			Dry solids	
	Gal/ million gal of sewage	tons/ million gal of sewage	cu ft/ 1000 persons daily	lb/ million gal of sewage	lb/ 1000 persons daily
Primary sedimentation:					
Undigested	2,950	12.5	39.0	1,250	125
Digested in separate tanks	1,450	6.25	19.0	750	75
Digested and dewatered on sand beds	--	0.94	5.7	750	75
Digested and dewatered on vacuum filters	--	1.36	4.3	750	75
Trickling filter	745	3.17	9.9	476	48
Chemical precipitation	5,120	22.0	68.5	3,300	330
Dewatered on vacuum filters	--	6.0	19.3	3,300	330
Primary sedimentation and activated sludge					
Undigested	6,900	29.25	92.0	2,340	234
Undigested and dewatered on vacuum filters	1,480	5.85	20.0	2,340	234
Digested in separate tanks	2,700	11.67	36.0	1,400	140
Digested and dewatered on sand beds	--	1.75	18.0	1,400	140
Digested and dewatered vacuum filters	--	3.5	11.7	1,400	140
Activated sludge:					
Wet Sludge	19,400	75.0	258.0	2,250	225
Dewatered on vacuum filters	--	5.62	19.0	2,250	225
Dried by heat dryers	--	1.17	3.0	2,250	225
Septic Tanks, digested	900	--	12.0	810	81
Imhoff tanks, digested	500	--	6.7	690	69

* Based on a sewage flow of 100 gpcd and 300 ppm, or 0.25 lb per capita daily, of suspended solids in sewage. (U.S. gallons)

Source: Metcalf & Eddy, 1972

TABLE 1.2 ADDITIONAL SLUDGE PRODUCTION WITH CHEMICAL TREATMENT SYSTEMS FOR PHOSPHORUS REMOVAL IN PRIMARY TREATMENT

Sludge Production Parameter		Conventional Primary	Low Lime Addition to Primary Influent	High Lime Addition to Primary Influent	Alum (Al^{+++}) Addition to Primary Influent	Iron (Fe^{+++}) Addition to Primary Influent
Level of Chemical Addition (mg/1)		0	350-500	800-1,600	13-22.7	25.8
Percent sludge solids	mean	5.25	11.1	4.4	1.2	2.25
	range	5.0-5.5	3.0-19.5	2.1-5.5	0.4-2.0	1.0-4.5
1b/MG	mean	788	5,630	9,567	1,323	2,775
	range	600-950	2,500-8,000	4,700-15,000	1,200-1,545	1,400-4,500
gal/MG	mean	4,465	8,924	28,254	23,000	21,922
	range	3,600-5,000	4,663-18,000	16,787-38,000	10,000-36,000	9,000-38,000

Note: 1b/MG = pounds per million gallons (U.S.)
gal/MG= gallons per million gallons

Source: U.S. EPA Sludge Manual, 1974

TABLE 1.3 ADDITIONAL SLUDGE PRODUCTION WITH CHEMICAL TREATMENT SYSTEMS FOR PHOSPHORUS REMOVAL IN SECONDARY TREATMENT

Sludge Production Parameter		Al^{+++} Addition to Aerator		Fe^{+++} Addition to Aerator	
		Conventional Secondary	With Al^{+++} Addition	Conventional Secondary	With Fe^{+++} Addition
Level of chemical addition mg/l		0	9.4-23	0	10-30
Percent sludge solids	mean	0.91	1.12	1.2	1.3
	range	0.58-1.4	0.75-2.0	1.0-1.4	1.0-2.2
lb/MG	mean	672	1,180	1,059	1,705
	range	384-820	744-1,462	918-1,200	1,100-2,035
gal/MG	mean	9,100	13,477	10,650	18,650
	range	7,250-12,300	7,260-20,000	10,300-11,000	6,000-24,000

Source: EPA Sludge Manual, 1974

TABLE 1.4

ADDITIONAL SLUDGE PRODUCTION WITH CHEMICAL TREATMENT SYSTEMS FOR PHOSPHORUS REMOVAL IN SECONDARY EFFLUENT

Sludge Production Parameters		Lime Addition	Alum (Al^{+++}) Addition	Iron (Fe^{+++}) Addition
Level of Chemical Addition (mg/1)		268-450	16	10-30
Percent sludge solids	mean	1.1	2.0	0.29
	range	0.6-1.72	---*	---*
1b/MG	mean	4,650	2,000	507
	range	3,100-6,800	---*	175-781
gal/MG	mean	53,400	12,000	22,066
	range	50,000-63,000	---*	6,000-36,000

* Not measured

Source: EPA Sludge Manual, 1974

TABLE 1.5

TOTAL SLUDGE VOLUMES FROM PRIMARY, SECONDARY AND TERTIARY TREATMENT SYSTEMS

Process	Primary Sludge	Secondary Sludge	Tertiary Sludge	Chemical Sludge	Total Sludge
Standard Activated Sludge (A.S)	1041	833	-	-	1874
AS + Lime	1562	312	-	2082	3956
AS + Alum	1562	312	-	362	2236
AS + Iron	1562	312	-	462	2336
Tertiary Lime	1041	833	104	2082	4060
Tertiary Alum	1041	833	104	362	2340
Tertiary Iron	1041	833	104	462	2440

All units as pounds/million gallons sewage

Source: Knight et al, 1973.

TABLE 1.6 SOLIDS CHARACTERISTICS OF CONVENTIONAL SLUDGES

Sludge Type	% Solids in Raw Sludge*	% Solids if Thickened **	% Solids if Digested **
Separate			
Primary	2.5 - 5.5	8 - 10	10 - 15
Trickling Filter	4 - 7	7 - 10	---
Modified Aeration	2 - 4	---	---
Activated Sludge	0.5 - 1.2	2.5 - 3.0	2 - 3
Combined			
Primary + Trickling Filter	3 - 6	7 - 9	10
Primary + Modified Aeration	3 - 4	---	----
Primary + Activated	2.6 - 4.8	5 - 10	6 - 8

Source: * Metcalf and Eddy, 1972

** Hrudey, 1977

TABLE 1.7

COMPUTER ESTIMATE OF SLUDGE PRODUCTION IN CANADA, 1977*

Province	Average GPCD	Percent Province Served	Pounds Sludge Per day	Pounds per Capita Per day	Gallons at 2% solids	Gallons at 10% solids	Sewage Treated MGD	Towns no Treatment	Primary Only	Secondary	Total Plants	Population for data	Real Populaton
Alberta	106.86	91.07	278,826	0.173	1,671,621	334,324	153.71	7	20	57	77	1,364,181	1,850,000
B.C.	69.17	68.17	139,708	0,096	837,577	167,514	180.46	30	14	32	46	1,870,906	2,502,000
Manitoba	53.73	41.59	233,335	0.084	1,398,888	279,777	90.43	67	12	42	54	1,140,979	1,030,000
New Brunswick	59.54	59.37	35,432	0.104	212,422	42,484	15.41	15	2	21	23	361,274	692,000
Nfld.	74.59	40.73	26,120	0.073	156,597	31,320	28.76	20	9	9	18	254,309	559,000
Nova Scotia	71.57	34.16	21,486	0.070	128,812	25,762	13.32	26	1	15	16	420,511	836,000
Ontario	109.51	61.88	1,405,429	0.120	8,425,834	1,685,167	848.13	102	66	158	224	8,246,901	8,373,000
P.E.I.	68.06	76.44	5,521	0.131	33,101	6,620	4.25	2	2	2	4	36,449	121,000
Quebec	20.62	15.69	206,494	0.022	1,237,970	247,594	369.11	236	21	21	42	4,877,579	6,267,000
Sask.	70.49	83.88	94,250	0.152	568,047	113,609	46.30	11	15	39	54	530,334	941,000
Canada			2,447,101	0.103	14,670,869	2,934,171	1749.58	516	161	396	560	19,103,423	23,231,000

* see also data in Appendix 1 for individual communities

TABLE 1.8 RECALCULATED VALUES FOR TOTAL SLUDGE PRODUCTION IN EACH PROVINCE

Province	Calculated Sludge Production (lbs/day)	Recalculated Sludge Production (lbs/day)
Alberta	278,826	378,123
British Columbia	139,708	186,834
Manitoba	233,335	210,639
New Brunswick	35,432	67,868
Newfoundland	26,120	57,414
Nova Scotia	21,486	42,715
Ontario	1,405,429	1,426,919
P.E.I.	5,521	18,328
Quebec	206,494	265,316
Saskatchewan	94,250	167,233
Canada	2,447,101	2,821,389

TABLE 1.9 COMPARISON OF REAL AND ESTIMATED SLUDGE PRODUCTION FOR FOUR MAJOR ALBERTA CITIES

City	Real			Calculated		
	US gpd	% Solids	Dry tons/ day	US gpd	% Solids	Dry tons/ day
Edmonton	375,000	2.3	35.95	650,416	2.3	62.36
Calgary	312,500	2.0	26.05	343,244	2.0	28.62
Lethbridge	62,500 11,250	2.0) 3.0)	6.62	76.709	2.0	6.40
Red Deer	42,500	-	3.54*	35,971	2.0	3.00

* Assume 2% solids

TABLE 1.10 CANADIAN POPULATION PROJECTIONS TO 2001

Net Migration	Fertility Rate	1976	1986	2001
0	1.8	22,533,590	24,624,410	27,094,790
	2.1	22,671,500	25,317,010	28,841,940
	2.6	22,901,360	26,471,340	31,753,860
100,000	1.8	23,063,860	26,375,580	30,899,850
	2.1	23,204,620	27,104,760	32,780,140
	2.6	23,439,210	28,313,380	35,913,960

Source: Environment Canada - 1976

Table 1.11

Maximum Total Daily Water Use

Year	Maximum Population	Water Use (IGPCD)	Total Daily Water Use (IGPD x 10^6)
1972	22,670,000	125	2833.8
1976	23,439,210	150	3515.9
1986	28,313,380	225	6370.5
2001	35,913,960	350	12569.9

Table 1.12

Sewage and Sludge Production to the Year 2001

Year	Sewage Treated MGD	Sludge Produced (tons/day)
1972	1870.3	1307
1976	2320.5	1622
1986	4204.5	2939
2001	8296.1	5799

Table 1.13

Future Sludge Production for Canada, Sweden and the United States

Tons Dry Solids/Year

	1970	1972	1976	1986	2000
Canada *	-	477,055	592,030	1,072,735	2,116,635
Sweden **	110,000	220,000	275,000	330,000	770,000
U.S.A. **	-	4,950,000	5,500,000	7,700,000	9,350,000

Source: * This study

** Schroeder and Cohen, 1976.

SECTION 1 - FIGURES

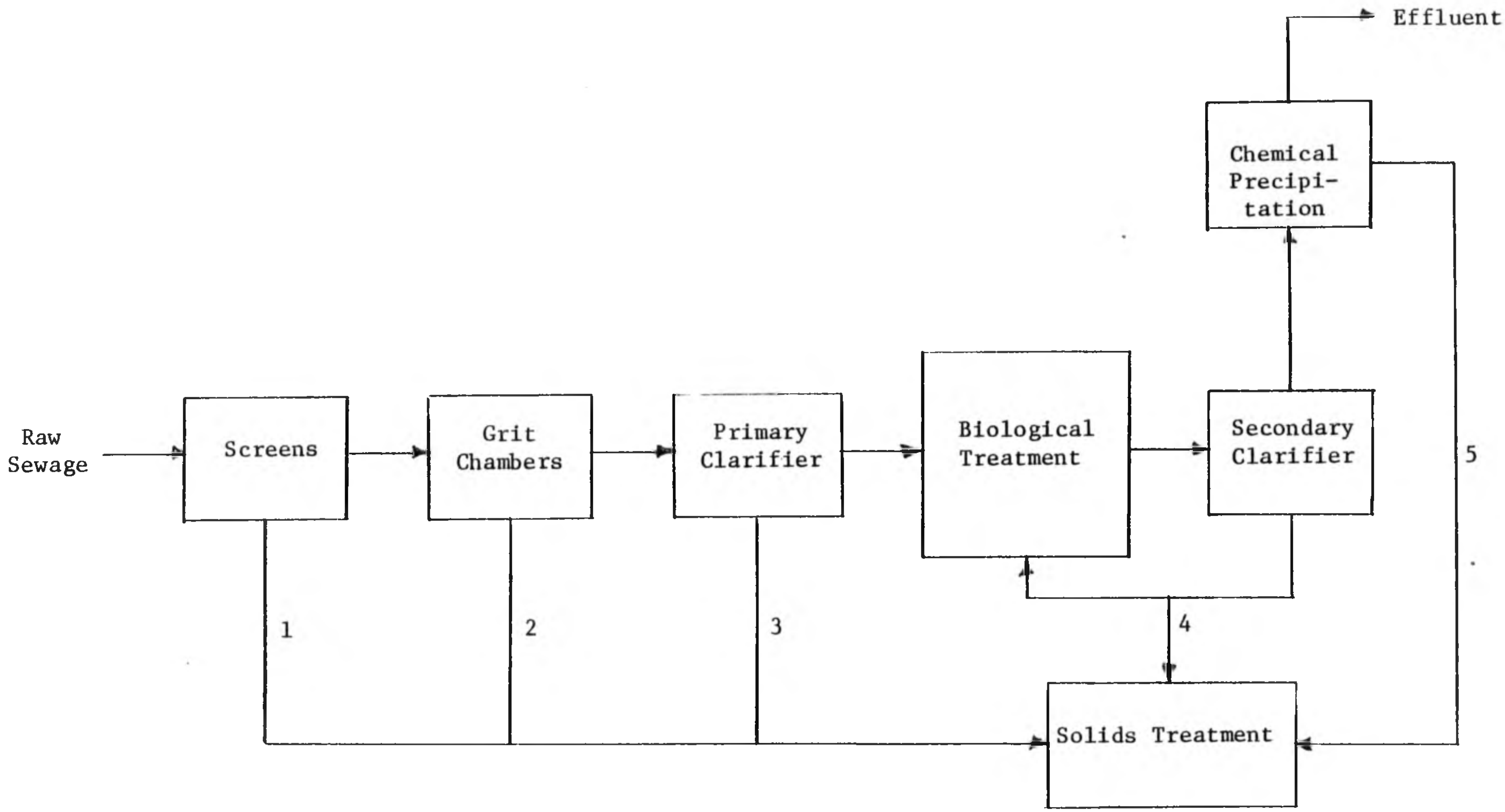

Fig. 1.1 LOCATION OF WASTE SOLIDS IN A WASTEWATER TREATMENT PLANT

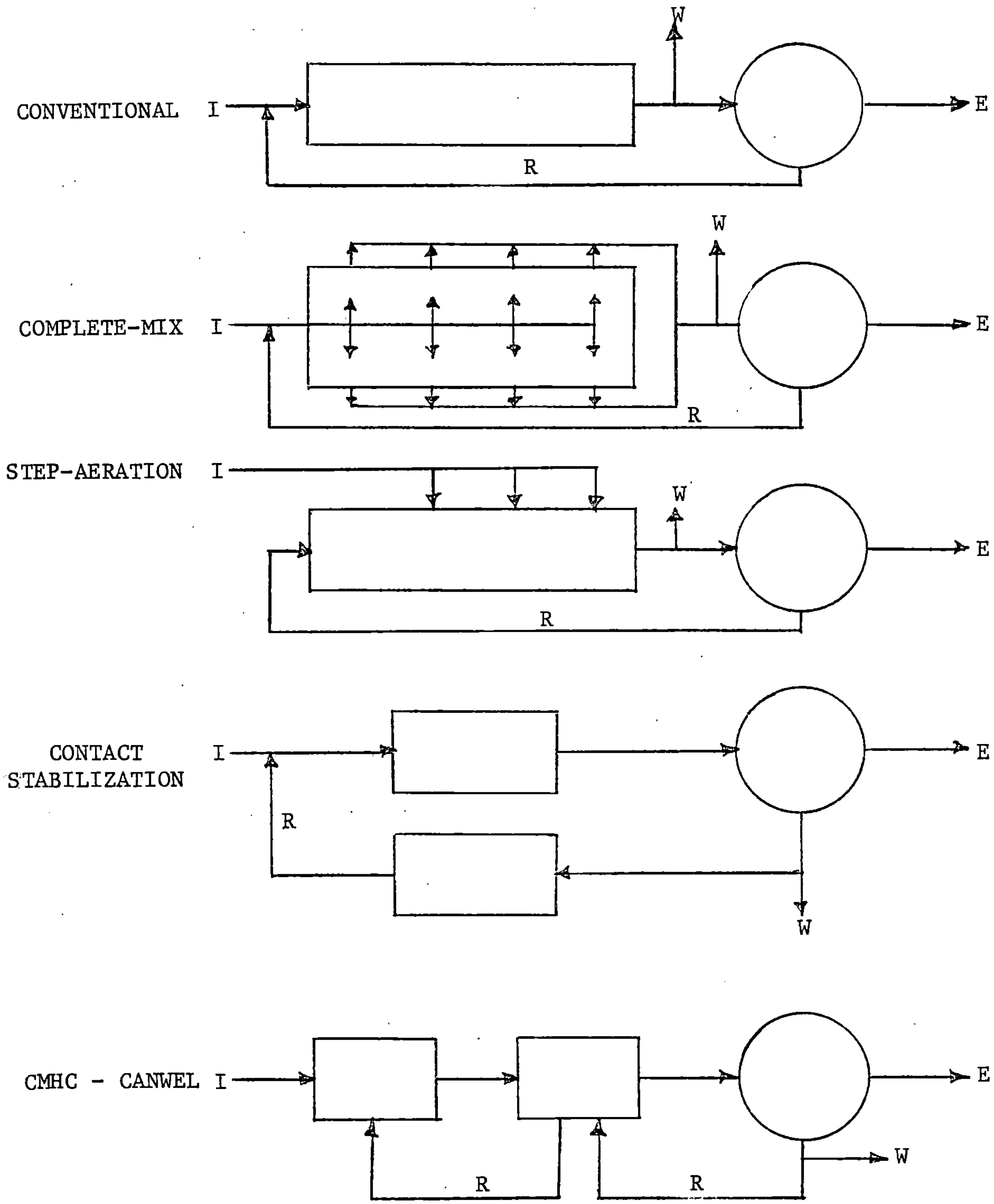

Fig. 1.2 TYPES OF ACTIVATED SLUDGE PLANTS

I = Influent

E = Effluent

W = Waste sludge

R = Return sludge

Biological Reactor

Clarifier

Liquid Flow

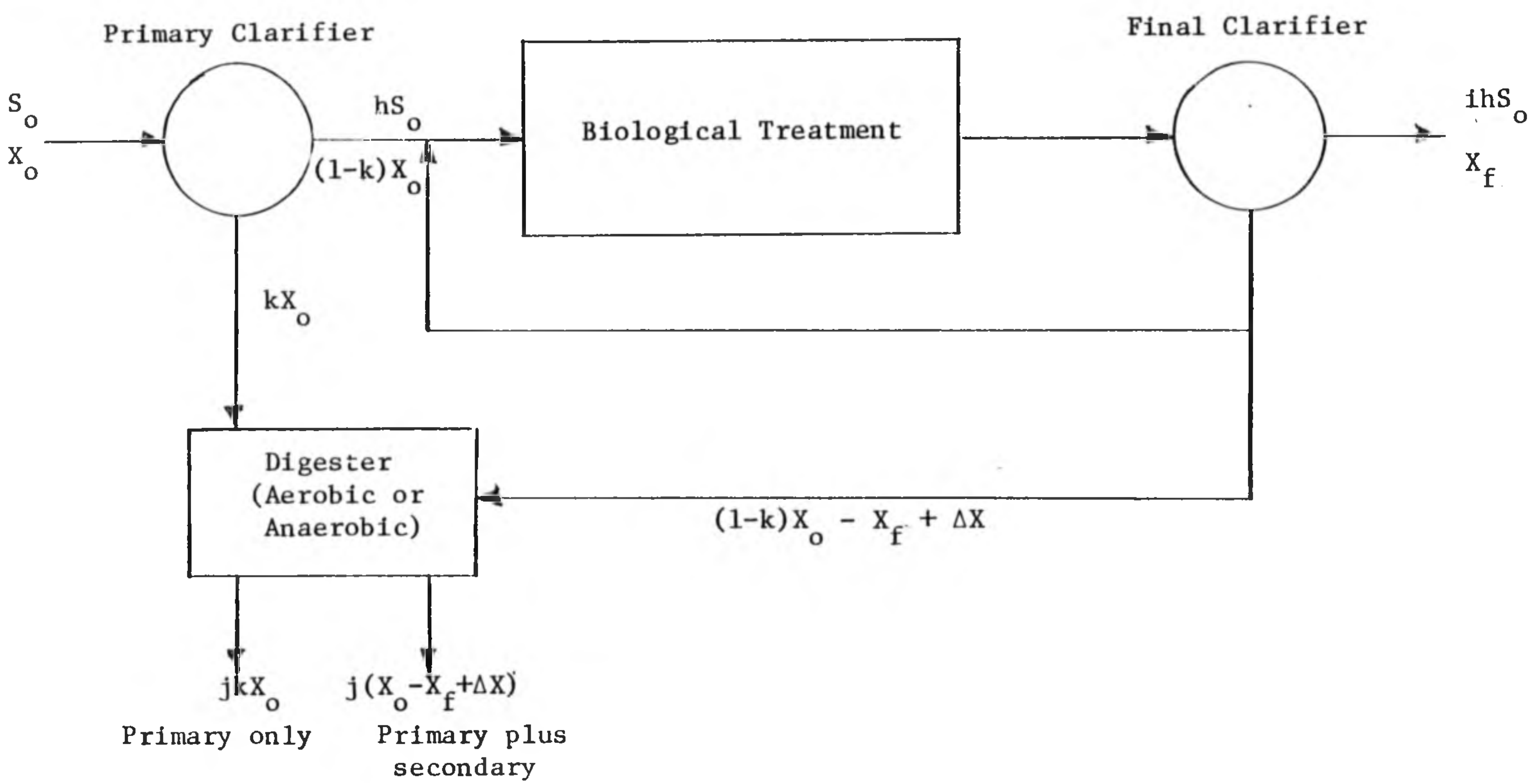

Fig. 1.3 Solids Balance for a Generalized Wastewater Treatment Plant

Source: Vesilind, 1974.

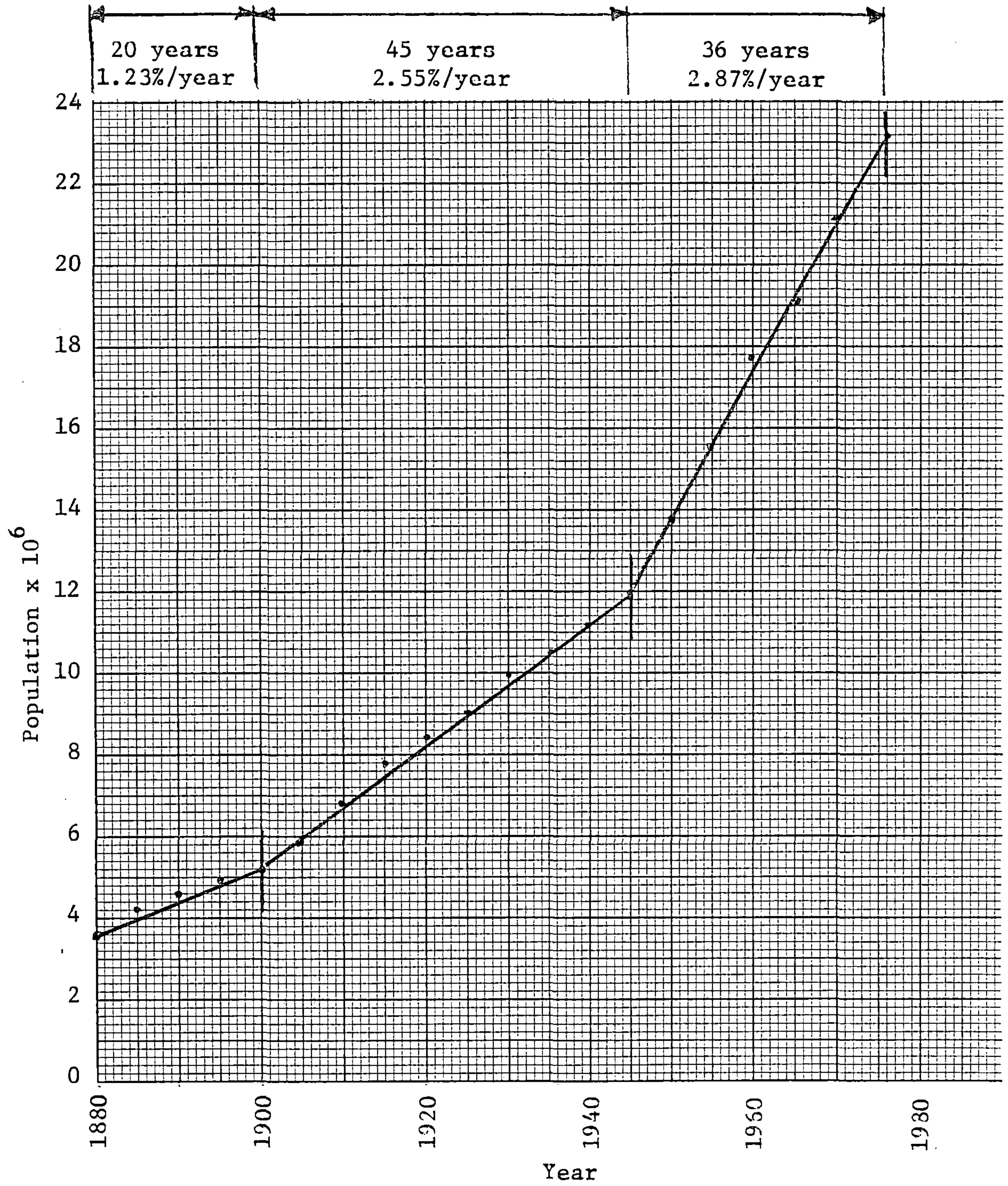

Fig. 1.4 HISTORICAL POPULATION GROWTH IN CANADA

Source: Urquhart _et al,_ 1965

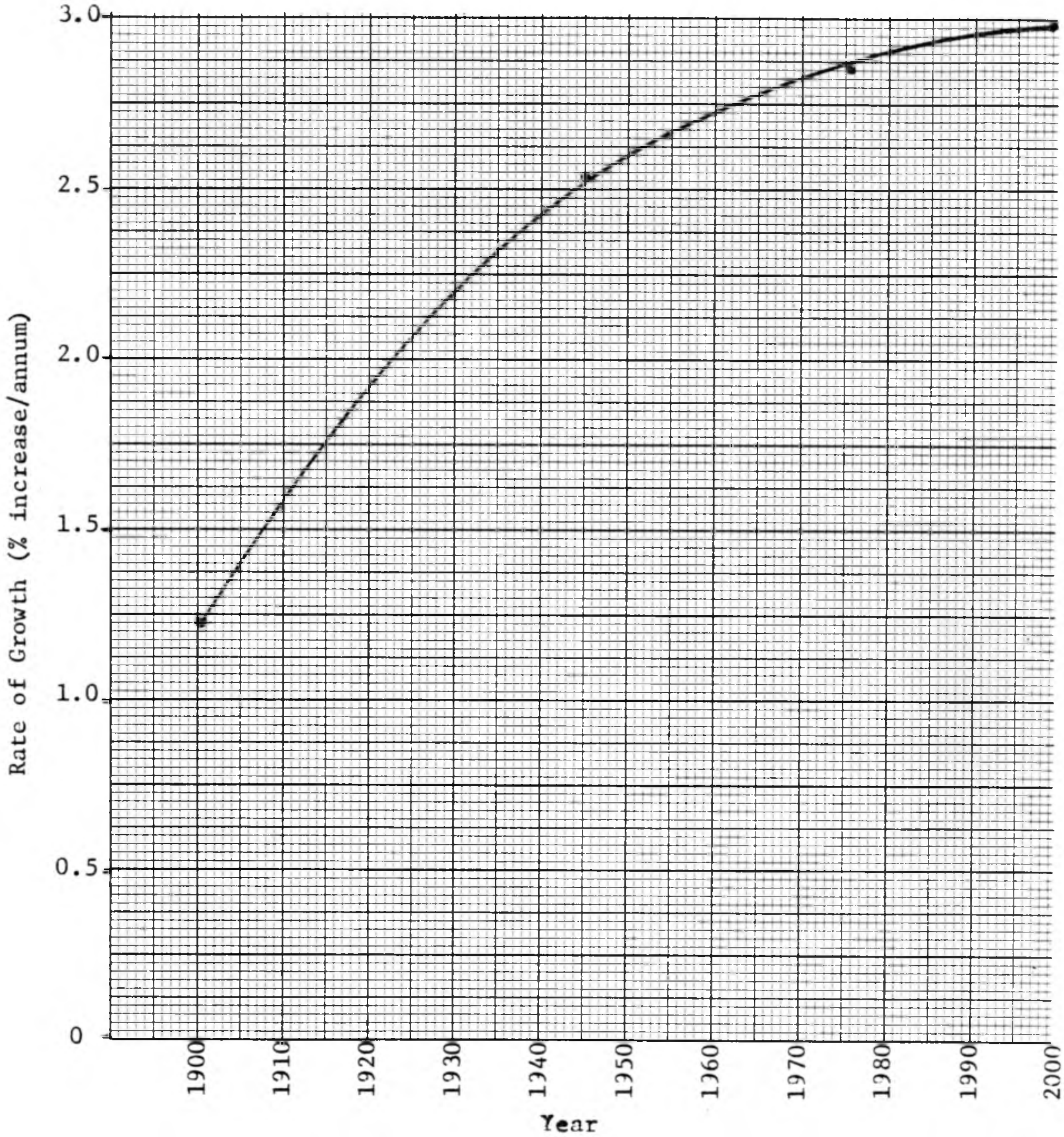

Fig. 1.5 20th CENTURY POPULATION GROWTH RATE CHANGE

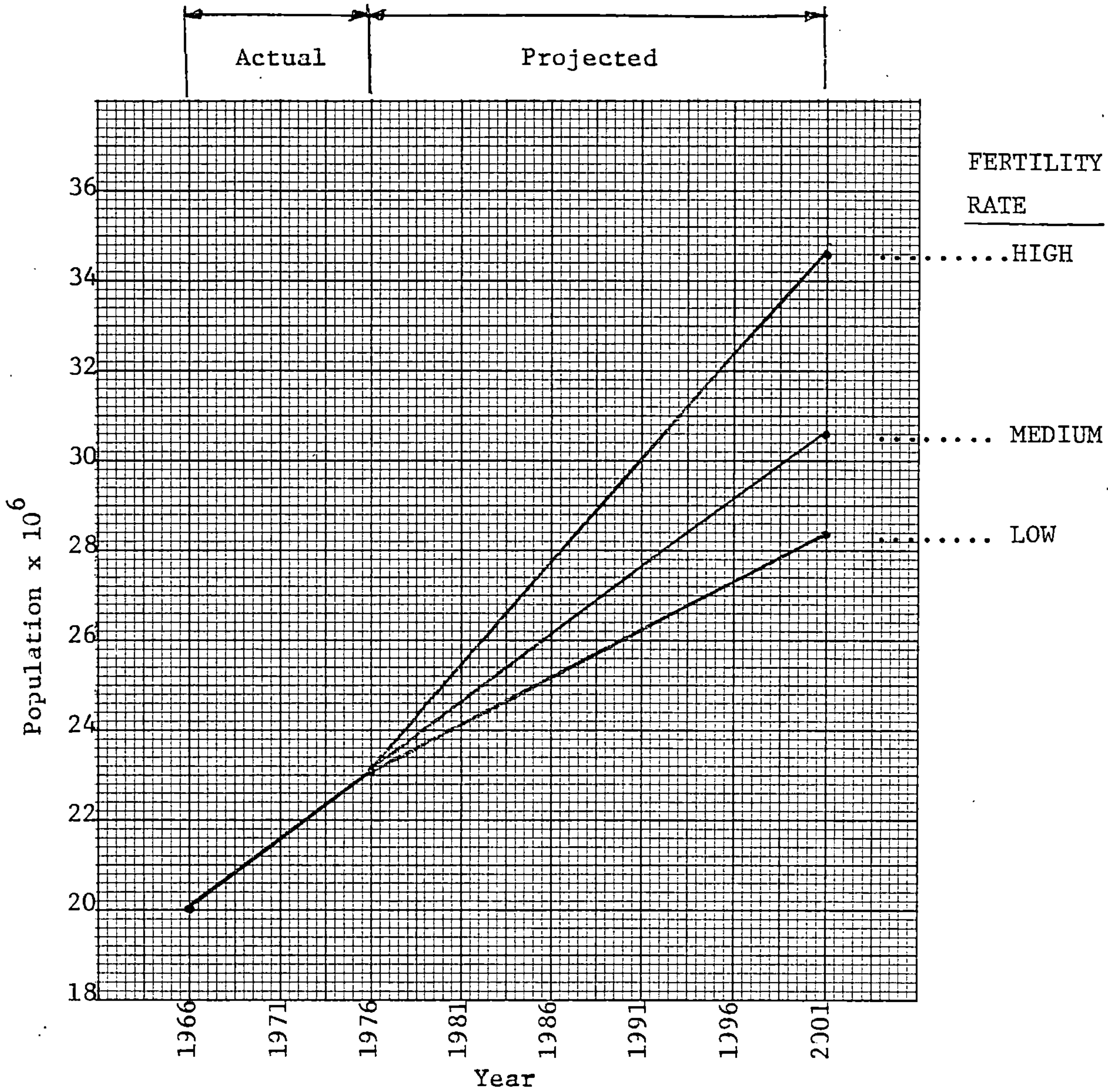

Fig. 1.6 CANADA'S POPULATION PROJECTIONS TO 2001

Source: Statistics Canada 1975, 1976

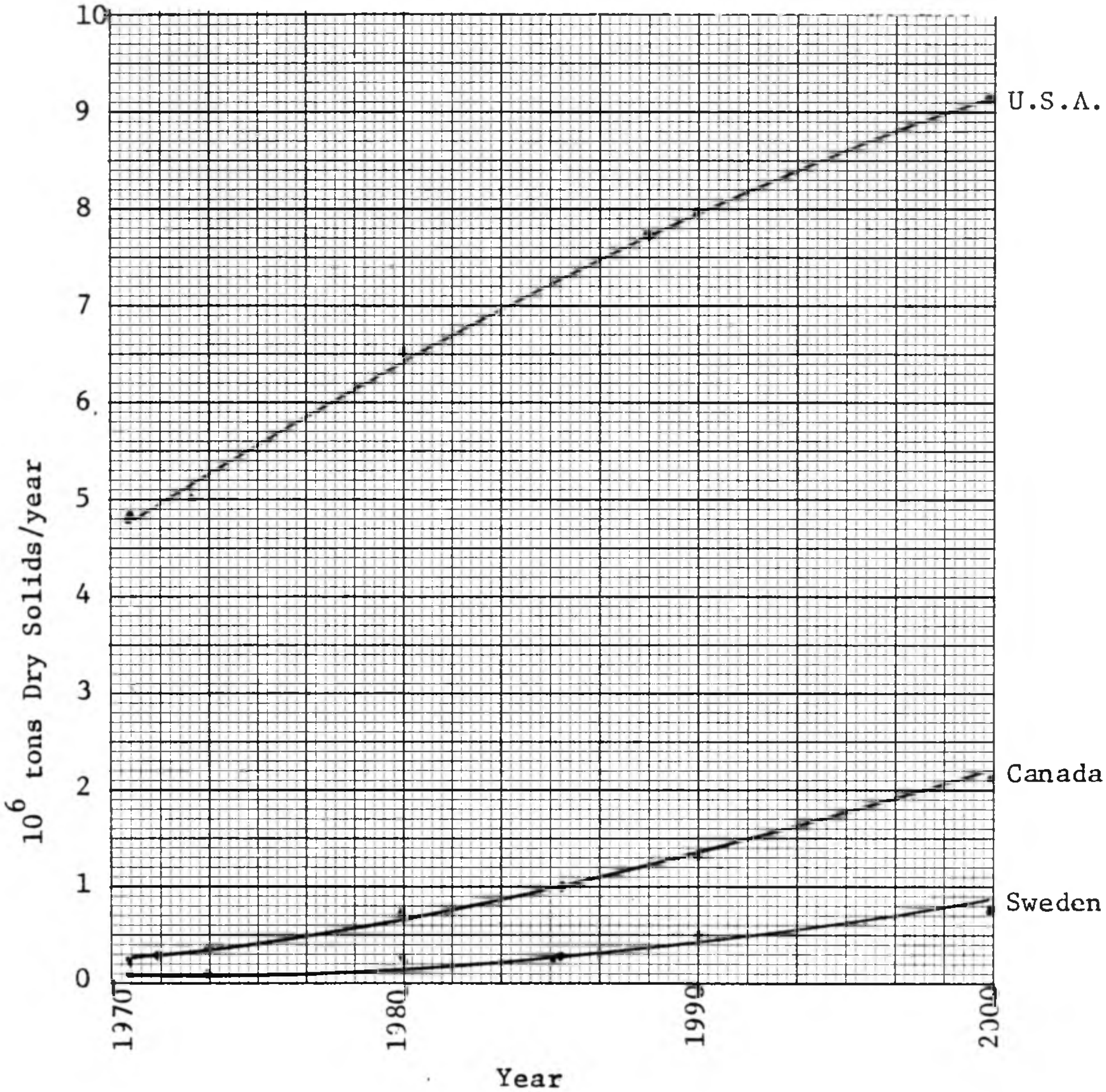

Fig. 1.7 FUTURE SLUDGE PRODUCTION FOR CANADA, SWEDEN and UNITED STATES

Section 2

SLUDGE STABILIZATION

2 SLUDGE STABILIZATION

If sludge is to be disposed of on agricultural lands or into sanitary landfills, it is often necessary to stabilize the sludge prior to dewatering or direct application. Stabilization in this sense means a reduction of pathogenic organisms and odour. By destroying organisms responsible for putrefaction, the odour problem is eliminated. The major stabilization mechanisms discussed in this report are aerobic and anaerobic digestion, composting, heat treatment and chemical treatment such as lime and chlorine.

Each stabilization procedure has advantages and disadvantages, the use of any one process being dependent upon the nature of the sludge to be treated (i.e. primary, secondary, chemical), and the environmental conditions (i.e. too cold a climate). The quantity will determine the economical and final disposal methods (i.e. landfill or land spreading). The Ontario Ministry of the Environment now requires anaerobic digestion before land spreading (DeAngelis, 1977).

Some processes result in a decrease of suspended solids, an increase in dewaterability of the sludge or useful by-products, and thus, these secondary functions may also play a key part in selecting a stabilization process.

2.1 Anaerobic Digestion of Sewage Sludge Anaerobic digestion has been used as a form of sludge stabilization for many years. For centuries now people have been operating cesspools, septic tanks and Imhoff tanks which also allow for a period of sludge retention under anaerobic conditions. This, in essence, is the fundamental principle of this operation. Recently, as the energy crisis has become more alarming, there has been an increased interest in this type of stabilization as it provides a by-product, highly combustible methane gas.

Anaerobic digestion can be applied to most organic wastes such as sewage sludge, municipal refuse, livestock wastes and food processing wastes. A combination of any of these can also be digested anaerobically.

2.1.1 Theory of Operation The process of anaerobic digestion provides decomposition of volatile solids in the sludge through process gasification, liquefaction, stabilization, colloidal structure breakdown and release of moisture (Wyatt et al, 1977). The complex organic substrates forming the volatile fractions are first broken down into organic acids such as acetic, propionic and butyric (EPA, 1974). From this stage the volatile organics are converted to a gas consisting mainly of methane (CH_4) and carbon dioxide (CO_2). Smart (1977) has referred to these two stages as the acid fermentation phase and alkaline fermentation phase. A flowsheet of these stages is given by Andrews (1967) and is shown in Figure 2.1.

The microbes responsible for the two separate phases are not the same. In the first phase the acid formers act on the carbohydrates, fats and proteins, converting them to organic acids and alcohols. Amino acids (protein building blocks) are converted to ammonia at the same time (Kalinske, 1976). From these phase 1 products, the methane bacteria produce methane gas and carbon dioxide. Because the methane producers are slower growing organisms and more sensitive to operating conditions, they generally determine the rate at which the anaerobic digestion will proceed (Andrews, 1967; Kalinske, 1976; Vesiland, 1974; Zajic, 1971).

The sensitive methane producing bacteria found in anaerobic digestion operations are usually in one of the following four genera: (Zajic, 1971)

1. Methanobacterium
2. Methanobacillus
3. Methanosarcina
4. Methanococcus

The exact organisms involved, their operating conditions and their utilized substrates are given in Table 2.1.

The methane producers are especially sensitive to heavy metals, chlorinated hydrocarbons, oxygen, pH, and temperature. These microbes operate most efficiently between 30 and 35° C. There is no activity occurring below 21°C (Kalinske, 1976). The pH range required by the methane producers is 6.4 to 7.2 with an alkalinity in excess of 2,000 mg/1 (Andrews, 1967). Smart (1977) has indicated that a pH range of 6.6 to 7.6 is adequate but optimum conditions include a pH of 7.0 to 7.6. The EPA Design Manual (1974) has given the substances and concentrations of a variety of compounds affecting sludge digestion. As the methane producing step is the most sensitive, it will be most critically affected by these compounds. This guideline is shown in Table 2.2 Boyko et al (1975) report that there were no toxic effects on anaerobic digestion with chemicals associated with phorphorus removal.

2.1.2 Types of Anaerobic Digesters There are two major classifications of anaerobic digesters and four types of reactors available to operate under these classifications. The two major classifications are temperature dependent: (Schroeder et al, 1976: EPA, 1974).

1. Mesophilic (27 - 43°C)
2. Thermophilic (45 - 65°C)

The reactor design classification is based on the number of reactors, mixing and heating involved, recycle of sludges and loading rates. Generally, they are classed into one of four groups: (EPA, 1974).

1. One Stage Standard Rate
2. One Stage High Rate
3. Two Stage
4. Anaerobic Contact

The configuration of these four digesters is shown schematically in Figure 2.2

2.1.2.1 Thermophilic Digestion The thermophilic digestion process is advantageous in that it shows increased pathogen destruction, a better solid liquid separation and a greater conversion of volatile solids to gas (Schroeder, et al, 1976). Poradek (1976) has indicated that although aerobic digestion gives a greater solids reduction, a similar high rate of destruction has been produced by some of the thermophilic reactors in operation. Smart et al (1976), in a full scale study of thermophilic digestion, showed that the thermophilic system readily accepted wide variations in loadings without an upset in operation. The authors have suggested that conversion of existing overloaded mesophilic systems would be feasible and acceptable, despite the slightly higher energy requirements.

The reduced retention times available with thermophilic operations are one of its major advantages. The retention time versus temperature is shown in Figure 2.3.

2.1.2.2 One Stage Standard Rate Digesters The one stage standard rate system has no mixing and thus the sludge compacts in the bottom of the reactor, with the clear supernatant forming on top. Metcalf and Eddy (1972) have indicated that an operation such as this results in less than 50 percent utilization of the reactor volume due to the stratification and lack of mixing. Having a reduced active volume is obviously going to result in a reduced loading attainable.

2.1.2.3 One Stage High Rate Digesters The one stage high rate system differs from the preceding in that the contents are mixed - which provides improved process control, increased volumetric loadings and eliminates in-tank settling. The tank can be mixed by mechanical mixers, recirculation pumps or by bubbling the methane gas produced through the sludge. This type of operation requires post digester thickening by gravity or flotation.

2.1.2.4 Two Stage Digestion The two-stage system shown was developed from the high rate system, so that more gas could be recovered, which normally would escape from a conventional thickener. This unit can be classed as a standard rate or high rate system, depending upon its loading. Many people refer to this system as the typical "high-rate" reactor. However, it is the mixing and control, not the number of reactors which determines the classification. The two stage system has been suggested by the EPA to be especially beneficial for primary sludges or combinations of primary and secondary sludge (EPA, 1974).

2.1.2.5 Anaerobic Contact Digestion The anaerobic contact process operates in a way similar to a conventional activated sludge system in that the microbial population is settled in the second reactor and a portion is recycled to the first reactor. When such a recycle is maintained, there will be an increase in the microbial concentrations in the first reactor resulting in an increased reaction rate. More importantly, this type of operation will ensure that a supply of the highly sensitive methane bacteria are returned to the primary reactor. This will help overcome the problem of "washing out" these organisms which results from their slow growth rate.

A comparison of the conventional, high rate and contact processes design was given by Zajic (1971) and is shown in Table 2.3. Design differences due to types of sludge feeds are given for low rate and high rate digesters in Table 2.4 (Vesilind, 1974).

2.1.3 Chemical Reaction of Anaerobic Digestion Regardless of the system employed, the same basic chemical reactions will occur. Only the efficiency and dependability of the reactions varies. During the digestion process, there will be a destruction of proteins (amino acids) and fats as well as the carbohydrates. The general stages of this operation are given by Zajic (1971) and are illustrated in Figure 2.4.

When the volatile solids are destroyed, the protein portions are reduced to ammonia nitrogen (NH_3-N) which reacts to produce ammonium carbonates which are responsible for increasing the alkalinity (Kalinske, 1976). This reaction provides the buffering capacity for the system which is essential for its operation. The methane, unlike the carbon dioxide, does not undergo any reactions as it is only slightly soluble and is transported quantitatively into the gas phase (Andrews et al, 1970).

Based on a carbohydrate source such as glucose, Vesilind (1974) has given the anaerobic digestion reactions as follows:

1. $$C_6H_{12}O_6 \xrightarrow{\text{Acid Formers}} 3CH_3COOH$$

2. $$3CH_3COOH + 3NH_4HCO_3 \longrightarrow 3CH_3COONH_4 + 3H_2O + 3CO_2$$

3. $$3CH_3COONH_4 + 3H_2O \xrightarrow[\text{Formers}]{\text{Methane}} 3CH_4 + 3NH_4 + HCO_3$$

It is at the second stage that neutralization with the ammonium carbonates must occur, otherwise the low pH will inhibit the methane formers in the third stage.

2.1.4 Design of Anaerobic Digesters When designing anaerobic digesters it is necessary to consider the digestion time and the loading rates to be employed (Kalinske, 1976). Suggested critical solids retention time (SRT) is given as 30 days with a loading of less than 0.075 lb.VSS/ft^3/day for a single stage standard rate. From 0.10 to 0.40 lb. VSS/ft^3/day can be applied with a 15 to 20 day retention for a high-rate system. Andrews (1967) gave standard rate single stage loading rates of 0.04 to 0.10 lbs. VSS/ft^3/day and similar rates as above for high-rate systems. The Ten State Standards call for loading of 0.08 and 0.4 lb. VSS/ft^3/day for standard and high rate respectively.

Solid retention time estimates based on volatile solids concentration and volatile solids load can be estimated from the EPA data shown in Figure 2.5.

Metcalf and Eddy (1972) have suggested that reactors should range from 20 to 115 feet diameter with water depths ranging from 25 to 45 feet. All digesters should have a minimum bottom slope of 1 vertical to 4 horizontal.

2.1.5 Operation of Anaerobic Digesters Owing to the susceptibility of anaerobic digestion to upsets, it is necessary to ensure adequate supervision and maintenance. If the pH cannot be maintained between 6.4 and 7.2, it may be necessary to add lime (Andrews, 1967). If the temperature is not optimum it will be necessary to heat the reactor by external heat exchangers or internal heating coils (Vesilind, 1974). The extent to which heat must be applied may well determine the economics of large exposed digesters in the cold Canadian climate.

The EPA (1974) has suggested the major controlling parameters for anaerobic digestion are temperature, mixing and the solids retention time. In order to keep the reaction at optimum conditions, Andrews et al (1970) have suggested that the following parameters be monitored:

1. Rate of increase of volatile acids (which indicates an increase by acid producers or a decrease by the methane producers);
2. Alkalinity decreases, which indicate a pending failure;
3. pH changes, which occur rapidly following the alkalinity decrease;
4. CO_2 production rates, where a decrease or change in CO_2 indicates a non-uniform feed;
5. Gas composition, where an increase in the CO_2 content usually indicates the onset of failure; and
6. Methane production rates, as it does not participate in chemical reactions and is thus a better indicator of the methane bacteria.

Zajic (1971) indicated that the presence of H_2S in the off gases is a good controlling parameter as it is present only if the digester is operated improperly. Further gas analyses are given in Section 6 of this report which deals with energy recovery.

Gas production rates have been given by Metcalf and Eddy (1972) as 8 to 12 ft^3/lb VSS added or 12 to 18 ft^3/lb VSS destroyed. This averages out to 0.6 → 0.8 ft^3/capita for primary plants and 1.0ft^3/capita in secondary plants.

The bacteria inactivation that is reported by many authors is not due to a lethal environment as often indicated, but is due mainly to unfavourable conditions resulting in a natural die-off over time (EPA,1972). The survival of different species is given in Table 2.5

2.1.6 Advantages and Disadvantages of Anaerobic Digestion Andrews et al (1970) state that anaerobic digestion has advantages over the other stabilization processes in that it:

1. gives a lower production of waste sludge
2. has low power requirements
3. gives methane as a useful by-product
4. digests the sludge well.

Smart (1977) indicates its advantages are also due to economic and aesthetic benefits resulting from:

1. a low volume to be hauled for disposal
2. a cost saving if it is dewatered
3. the destruction of nuisance odours.

Disadvantages of the process are usually associated with the poor stability of the reactions.

The process is not suitable for all sludge handling schemes, for example,it would be inefficient to anaerobically digest sludge prior to incineration or pyrolysis as the digestion would render the sludge relatively non-combustible.

Research and development is continuing in this field at present. However,more work will be required on the effects of cold Canadian climates in exposed operations. Present research studies are now centred around the use of powdered activated carbon as a stabilizing agent and the effect of phosphorus removal chemicals on the operation. To date it has been found that the inorganic coagulants have little effect on the digestion process.

2.2 Aerobic Digestion of Sewage Sludge

Aerobic digestion is a sludge stabilization method which closely resembles the common extended aeration sewage treatment system. This type of treatment process is known for its low sludge production due to the auto-oxidation (self consumption) of microorganisms once the food source has been digested. In aerobic digestion, the process of auto-oxidation is enhanced in order to reduce the quantity of microorganisms and thus decrease the sludge volume.

2.2.1 Theory of Operation When an aerobic digester receives waste activated sludge, the digester is only required to oxidize the microbial cellular material present. If, however, the sludge contains a portion of primary sludge, it will be necessary for the digester to oxidize the biodegradable material first. The cells involved in the biodegration process will only auto-oxidize when the food source becomes limiting. Due to this extra step involving primary sludge digestion, it has been found that aerobic digesters are more competitive for waste activated sludge, especially if it comes from an extended aeration process.

Unlike anaerobic digestion, there is not a specific group of microorganisms involved in the digestion process. The microorganisms present are brought forward from the activated sludge and are capable of both carbon oxidation and nitrification. Most of the cell tissue is aerobically oxidized to CO_2, H_2O and NH_3. Metcalf and Eddy (1972) have indicated that only 75 to 80 percent of the cell tissue can be oxidized. The remaining 20 to 25 percent is inert material.

Although not as sensitive to daily operation conditions, an aerobic digester would be subject to the same inhibitory effects of toxic materials as anaerobic digestion (Smart, 1977). In general, toxicity limits applicable to activated sludge treatment systems would also apply to aerobic digestion.

2.2.2 Types of Aerobic Digesters An aerobic digestion scheme may be very simple incorporating a single batch reactor, or it may be very complex, such as the five stage Petmar Progressive Digester discussed by Poradek (1976). The digesters may be operated on a batch basis, daily fill and draw, or continuously, in which case a clarifier is required for decanting the supernatant. Most aerobic digesters in operation are single or two stage. Thermophilic aerobic digestion might also be a possible alternative (Andrews et al, 1973).

2.2.2.1 Batch Operated Digesters The batch operated digester is best suited for small extended aeration plants which, because they already include some auto-digestion, have only occasional wastage of sludge (Koers, 1977). For this type of operation the digester is loaded, the digestion process is performed and then the liquor is allowed to settle. At this time, the supernatant is returned to the treatment plant and the sludge is sent for further treatment or disposal. One limiting factor of this type of operation, then, is return of the supernatant to the treatment plant in one large flow.

2.2.2.2 Daily Fill and Draw The daily fill and draw digester operates similarly to the batch process in that the mixing is stopped, the sludge is allowed to settle and the supernatant is drawn off. This, however, is a daily operation and the supernatant is displaced by the sludge being loaded into the digester. A separate clarification stage is not required for this operation, thus the whole process may be carried out in one reactor. This has an advantage in that a large surface area is available for the thickening process, usually much more than available from a standby clarifier. Koers (1977) has indicated that this point often makes the daily fill and draw process the most practical and economical.

2.2.2.3 Continuous Operation The continuously operated digester operates like a sewage treatment plant in that incoming raw sludge is continuously replacing supernatant from the digested sludge. To operate this process a clarifier as well as a digester is essential. A recycle of thickened sludge may or may not be included in this process.

The different schemes of aerobic digesters are shown in Figure 2.6 .

The type of digestion operation carried out will depend on the size of the plant, daily sludge production and type of sludge processed. If a continuous process is employed extra tanks are required, however if batch or fill and draw systems are used there will be an increase in operator man-hours and an increase in aeration requirements. Increased aeration is required because the sludge must be resuspended in the digester after it has been allowed to thicken. Resuspending grit and microorganisms requires more air than maintaining mixing.

2.2.3 Chemical Reactions of Aerobic Digestion The aerobic digestion process reduces the sludge volume by reducing the volatile solids content of the sludge. Metcalf and Eddy (1972) report a linear decrease in volatile solids up to 40percent removal,after which the rate of destruction decreases. Maximum removals have been stated at 45 to 70 percent in ten to twelve days at 20°C. This applies to a two stage digester. A one stage digester normally achieves 10 to 25 percent volatile reduction (Ahlberg, 1970). The Petmar process noted above claims a 100 percent reduction in volatiles.

The basic reactions involved in the aerobic digestion process have been described by Vesilind (1974), Wyatt et al (1975) and Koers (1977). The basic reactions are the conversion of all protoplasm and biologically degradable organisms to CO_2, H_2O and NH_3, by aerobic microorganisms. The relation between the two reactions is as follows:

$$\text{Organics} \xrightarrow[\text{microbial cells}]{O_2} \text{New cells} + CO_2 + H_2O$$

$$\text{Cells} \xrightarrow[\text{microbial cells}]{O_2} \text{Digested Sludge} + CO_2 + H_2O + NH_3 + \text{non-biodegradable material}$$

In a more specific form, the biodegradation of a cell, having the formula $C_5H_7NO_2$, is given as: (Koers, 1977)

$$C_5H_7NO_2 + 5O_2 \longrightarrow 5CO_2 + 2H_2O + NH_3$$

If enough oxygen is present, the ammonia is oxidized to nitrate by Nitrosomonas and Nitrobacter as follows: (EPA, 1974)

$$NH_4^+ + 1.5O_2 \xrightarrow{\text{Nitrosomonas}} NO_2^- + 2H^+ + H_2O$$

$$NO_2^- + 0.5O_2 \xrightarrow{\text{Nitrobacter}} NO_3^-$$

Thus, given the added oxygen, the complete oxidation can take place, yielding the following products:

$$C_5H_2NO_2 + 7O_2 \longrightarrow 5CO_2 + 3H_2O + H^+ + NO_3^-$$

If digestion is taking place in a two stage digester, the nitrate may be taken to N_2 gas through anaerobic denitrification. Such reactions could easily proceed in the thickened sludge of the second stage of clarification. It is best to avoid this, if possible, due to the bulking nature of denitrifying sludges.

2.2.4 Design of Aerobic Digesters Unlike many of the sludge treatment processes, the aerobic digestion process does not have set design standards. Most of the information used for design has been derived from monitoring of pilot and full scale plants. Most of the design material available describes the oxygen supply required, the loading rates and required retention times. Basic design criteria presently used are as shown in Table 2.6 (Metcalf and Eddy, 1972: EPA, 1974).

The oxygen requirements for aerobic digestion are most often determined by the air required for mixing, not the air required to maintain the minimum dissolved oxygen. In some cases pure oxygen has been used in combination with mechanical mixing. This gives the added advantage of increased temperatures from increased exothermic reactions (Vesilind, 1974). The EPA (1974) have indicated that pure oxygen systems may be beneficial for thicker sludges having very high oxygen uptake rates.

Kalinske (1976) has given the oxygen requirements of 10 ppm per hour per 1000 ppm volatile solids in the digester. If primary sludge is included, a 50 percent increase in aeration is required. Using compressed air and diffusers, this means an average of 25 to 35 gm O_2 / 1000 ft^3 of digester volume. Kalinske points out that mechanical surface aerations should not be used in areas experiencing freezing temperatures. This would result in excessive ice buildup and heat loss from the large surface area formed.

Ahlberg (1970)in a study of aerobic digesters in Ontario found that standard air flows of 20 cfm/1000ft^3 were inadequate in certain cases. He indicated that up to 50 cfm may be required.

Kalinske (1977) stated that the air requirement of a digester digesting primary sludge is six times that of secondary sludge digestion. The oxygen requirement is increased due to the presence of unoxidized organics as well as the increased difficulty in keeping the sludge in suspension. Kalinske's survey showed that the minimum air requirement is 20 to 30 scfm/1000 ft^3, with an increase to 50 - 60 scfm/1000 ft^3 if the digester is to be shut down for decanting.

Overall, the consensus seems to be a minimum 20 scfm/ 1000 ft^3 for a continuous digester, in excess of 30 scfm/1000 ft^3 if daily fill and draw is used,and in excess of 50 scfm/1000 ft^3 for digesters handling primary sludge that require shut-down for decanting.

An interesting and recent design parameter that has been developed by Koers (1977) is the relationship of the product of temperature and sludge age on volatile solids reduction. This information is especially valuable for cold climates, such as those experienced in Canada. These data, as shown in Figure 2.7, show that optimum solids reduction occurs at the point where the temperature times the sludge age equals 250. Thus, given the temperature which can be maintained in the reactor, the desired sludge age can be calculated.

From this information, it is evident that heat conservation is of extreme importance to aerobic digestion. It would thus be appropriate to evolve systems that include the following:

1. underground tanks
2. common wall tanks
3. diffused air, not mechanical aerators
4. pre-heated air supplies.

In some instances, the costs or present conditions may make it impractical to operate aerobic digesters in Canada, especially in the most northern areas. Abramov (1975) has found that variations of 10°C in cold areas of Russia show a 220 percent decrease in time to stabilization. Similar results can be expected in Canada's climate.

Smart (1977) has estimated that 6,000 to 9,000 BTU's are released per pound of volatile solids destroyed and thus if pure oxygen were used in combination with mechanical mixing, as discussed previously, the self heating of the unit would allow for the operation in the mesophilic or thermophilic zones. In Canada, however, utilization of this principle would be less productive as the heat required in our cold climates would be in excess of the heat produced by the system.

Contrary to the comments of Smart (1977), Matsch and Drnevich (1977) have indicated that operation of a thermophilic aerobic digester is possible in cold climates if:

1. oxygen requirements can be maintained
2. sufficient insulation is employed
3. mainly waste activated sludge is used, and
4. high loading rates are employed.

Matsch et al stated in their report that generally, aerobic digestion is not believed to be competitive with anaerobic digestion because of the cost of power and long retention times employed, especially in northern climates. If,however, the aerobic digester was covered and high purity oxygen was used instead of air, one would be able to overcome these economic disadvantages. Furthermore, it is not only possible to make the operating temperatures independent of ambient temperature but also to elevate the reactor temperature into the range of growth of thermophilic organisms.

The heat available from such a system was described as the difference between the heat of combustion of the sludge and the energy required for all maintenance. As the feed to the system increases, there is therefore an increase in the amount of material removed and thus an increase in operating temperature. This,related to the data from Koers (1977) discussed previously,means there will be a decrease in the required sludge age, thus a decrease in reactor size and a corresponding decrease in these capital costs. Pilot plant testing showed that comparable VSS reduction takes place in such a system at 45 to 50^{o}C over 5 days at 0.024 to 0.14 lb/day/ft^3 as in a normal plant requiring 15 to 20 days. The study also showed that pathogenic organisms were non-detectable after only 5 hours in such a system.

In their conclusion, Matsch et al, indicated that this system has considerable advantages over mesophilic aerobic and anaerobic digestion systems. Advantages cited were the significant reductions in reactor volumes,the production of a pathogen free sludge, the independence over ambient weather conditions and the increase in stability over anaerobic digestion processes.

In conventional aerobic digesters, the determination of detention time, thus reactor volume, will be dependent on the types of sludge digested as well as the temperature at which the reaction is carried out. The minimum reported detention time was 10 days. The greater the concentration of biodegradable organics, the greater the required detention time and thus the greater the volume required.

The EPA (1974) has indicated that upgrading treatment plants to include aerobic sludge digestion is probably one of the easiest methods to ensure sludge stabilization. Almost any type of clarifier or aeration tank may be converted to an aerobic digester as long as adequate mixing is ensured. On unusual shaped basins, they suggest air diffusion for mixing, rather than mechanical aerators.

The EPA have also stated that many plants now using anaerobic digesters could improve performance by incorporating aerobic digestion for waste activated sludge and leaving the anaerobic digestion to stabilize the primary sludge. In the case of small overloaded anaerobic digesters, conversion to aerobic digestion can often remedy the situation.

If clarifiers are to be used for decanting the supernatant, it has been suggested that a maximum loading of 4 to 8 $lbs/ft^2/day$ (40-80 $gal/ft^2/day$) be employed. Many plants found clarifiers unsatisfactory. However, this was usually the result of exceeding the loading or overflow rates.

2.2.5 <u>Operation of Aerobic Digesters</u> For day to day operation, it is necessary to monitor pH, temperatures, dissolved oxygen and specific oxygen uptake rate in order to keep control of the process. Temperature dependence occurs below 20^oC. However, if the solids retention time is in excess of 60 days, temperature dependence is non-existent (Metcalf and Eddy, 1972).

The pH of the mixed liquor is not critical, as in anaerobic digestion, however it should not be allowed to drop below 5.5. A drop in pH is usually associated with an increase in ammonia oxidation, as each pound of NH_3-N oxidized utilizes 7.1 pounds of $CaCO_3$ alkalinity. Thus there is a decrease in the pH.

The operation and control parameter most often used for aerobic digestion is the specific oxygen uptake rate (SUR), which is a measure of the milligrams of oxygen consumed per gram of sludge per hour. In general, a SUR of 0.5 to 1.0 mg/gm/hr indicates a well stabilized sludge. Ahlberg (1970) found that SUR ranges for a one stage sludge digester ranged from 0.5 to 6.3 mg/gm/hr and 0.5 to 2.4 mg/gm/hr for a two stage digester. By monitoring the SUR, it is possible to determine the end point of the stabilization process, or at which point the rate of change of stability is no longer practical.

The last major operational requirement is a minimum dissolved oxygen level of 1.0 mg/l. With the large volumes of air used for mixing, it is seldom found that oxygen levels drop below this point.

The major operational problems that were uncovered by Ahlberg (1970) were depositions in the tanks from inadequate mixing and foaming or ice formation due to temperature fluctuations. One of the common problems with mixing was that the diffusers were placed 1.5 to 3.0 feet off the tank bottoms. Once the air was shut off for decanting, it was difficult to resuspend the material collected in the area below the diffusers. In most cases large deposits of grit collected in this area.

The problem of foaming has been associated with high temperatures. However,high temperatures appear to be a necessary condition for foaming, not the cause. The more serious problem with temperature was the 6 to 8 inch layers of frozen foam and ice appearing in the winter months. This made decanting difficult and observation of the digesters impossible.

In summary, the aerobic digestion process, although not as thoroughly studied as some of the alternate stabilization processes, does have some clear advantages. In most cases of sludge stabilization a clear choice can be made from the type and quantity of sludge to be processed and the local conditions. Aerobic digestion appears to be favoured in the smaller communities, having less than 8 mgd sewage, and preferably having extended aeration or contact stabilization as the sewage treatment scheme.

2.2.6 <u>Advantages and Disadvantages of Aerobic Digestion</u> The actual advantages and disadvantages of this process are listed below. In general, this represents a comparison of aerobic and anaerobic sludge digestion. Note the conflict of advantage number 4 and disadvantage number 5. This would indicate that sludge dewatering capabilities are more dependent on the type of sludge treated and the degree of treatment, rather than on whether aerobic or anaerobic digestion is used.

	Advantages	Reference
1.	Volatile solids reduction equal to anaerobic digestion	(Metcalf and Eddy, 1972) (Poradek, 1976)
2.	Lower BOD in the supernatant	(EPA, 1974) (Metcalf and Eddy, 1972) (Kalinske, 1976)
3.	Odourless, bio-stable sludge for easy disposal	(Metcalf and Eddy, 1972)
4.	Excellent sludge for dewatering	(Metcalf and Eddy, 1972) (Kalinske, 1976)
5.	Recovery of more of the basic fertilizer value	(Metcalf and Eddy, 1972)
6.	Fewer operational problems	(Metcalf and Eddy, 1972)
7.	Lower capital costs	(EPA, 1974) (Metcalf and Eddy, 1972) (Ahlberg, 1970)

Cont'd ....

Advantages (Cont'd)		Reference
8.	Less sensitive to toxicity than anaerobic digestion	(Kalinske, 1976)
9.	No sophisticated monitoring equipment or supervision required	(Ahlberg, 1970) (EPA, 1974)
10.	No danger of gas explosions (ie methane-air mixture)	(EPA, 1974)
11.	Does not generate significant odours	(EPA, 1974)
12.	Pathogenic destruction	(EPA, 1974)
13.	Destruction of grease and hexane soluble compounds	(EPA, 1974)
14.	Can handle a sludge having a low mixed liquor suspended solids	(Smart, 1977)
15.	Requires no supplementary heating	(Smart, 1977)

Disadvantages		Reference
1.	Higher operation and power cost for oxygen production (aeration)	(EPA, 1974) (Metcalf and Eddy, 1972) (Schroeder, 1976)
2.	No by-product recovery (i.e. methane)	(Metcalf and Eddy, 1972)
3.	Poorer thickening of sludge	(Schroeder, 1976)
4.	Unclear design parameters	(EPA, 1974)
5.	Poor dewatering on vacuum filters	(EPA, 1975) (Kalinske, 1976)
6.	Does not handle primary sludge as well	(Smart, 1977)

2.3 Compost Stabilization of Sewage Sludge

Schroeder (1976) stated that composting of sewage sludge is practiced in several U.S. cities. However, the EPA (1974) has indicated that it is no longer widely practiced. Of the 18 compost plants constructed in the U.S. between 1951 and 1969, only a few still operate. Most composting practices are now carried out by individuals for their own use. An overview of the method of composting has been presented by Gotaas (1956).

2.3.1 Theory of Operation Composting has been described by Kalinske (1976) as an aerobic thermophilic organic sludge stabilization process. There are over 30 different recorded or patented methods for composting, consisting of natural and mechanical methods. The four major systems are (1) pile, (2) windrow, (3) enclosed and (4) mechanical air supply. An illustration of a common windrow compost process is shown in Figure 2.8.

The sludge is normally trucked from the treatment plant to a central compost site where it is spread over a layer of bulky material, such as garbage or wood chips. The bulk is necessary to provide a high airflow through the sludge which ensures rapid composting (WPCF, 1973). The EPA (1974) has suggested that a 45 to 65 percent moisture content by weight, is desirable.

The digestion period for composting is approximately 6 weeks by natural windrow digestion, or several days if mechanical aeration systems are used. After digestion, the sludge must be cured by decreasing the reaction rate and reaction temperature for 2 weeks in windrows and 1 week in mechanical plants (EPA, 1974). During the digestion period, the windrows must be turned or mixed daily for 10 days, then more sludge is added and the process is allowed to continue.

Once digestion and airing has occurred, the compost is collected and the wood chips or other bulking agent screened out. Kalinske (1976) indicates that the remaining sludge compost should show at least a 30 percent total solids reduction and a 47 percent volatile solids reduction.

2.3.2 Pathogen Kill Attainable The exothermic reactions taking place raise the temperature in the windrow into the 55-85°C range, which is the temperature at which the thermophilic organisms operate most efficiently (Kalinske, 1976; EPA, 1974). The heat generated by the process is usually sufficient for pathogen destruction. The WPCF (1973) reports the process kills the cysts of protozoans, the ova of parasitic worms and most pathogenic bacteria. However, they do report that Salmonella have been found surviving in the cooler portions of the compost piles. The EPA (1974) reports mechanical systems reaching 60 t0 65°C which achieve total pathogen kills in one day and total spore former kills in one week. Results for various systems are shown in Table 2.7. A detailed survey of pathogen destruction reports by composting has been prepared by Kawata (1977).

2.3.3 Disposal of Compost The final compost product is readily disposed of on land as a soil conditioner or fertilizer. In most instances, the compost is a much better soil conditioner (organic matter) than commercial fertilizers (N.P.K.). If the compost is to be landfilled, the EPA(1974) has found that it requires 20 to 50 percent less space than untreated sludge. The nitrogen content is lower than other treated sludges as most of the NH_3 goes to NO_3 and off to N_2 gas in the aerobic and anaerobic zones of the compost piles.

The major drawback to the process it that there is a lack of market for the product, therefore no revenue is generated and the process is no longer economical. Without market development in this area, the future use of sludge composting would appear to be limited.

2.4 Lime Stabilization of Sewage Sludge

Lime stabilization is presently the most common form of chemical stabilization. The principles involved in the operation have been practiced for years in latrines and outhouses around the world (Kalinske, 1976; Vesilind, 1974).

2.4.1 Theory of Operation

The principle of lime stabilization is to bring the pH above 11.0 at which time there are complex changes in the volatile solid matter and almost total pathogen kill. Once biological life has been stopped, the odour problem is eliminated. The lime can stall the putrefaction process for some time, after which organic decomposition gradually returns. This slower reaction rate means less severe odours.

Although the volatile matter changes in structure, there is no absolute organic destruction as in some of the other stabilization processes (EPA, 1974). Lime stabilization is not permanent in the same sense as other processes either, for the pH will eventually drop, and as the sludge is recontaminated, the sludge once again undergoes decomposition (EPA, 1974).

2.4.2 Pathogen Kill Attainable

Kalinske (1976) has indicated that 2 hours of lime treatment (pH $\geq$ 11.5) can give equal pathogen kill to that achieved with two weeks of aerobic or anaerobic digestion. Vesilind (1974) stated that four hours contact at 15^{o}C and a pH of 11.0 to 11.5 destroyed all of the *Escherichia coli* and *Salmonella typhosa* present, however a few pathogens and spores may have survived. The EPA (1974) have indicated that 30 minutes of an elevated pH to 11.5, gave a pH of greater than 11.0 for the following 24 hours, which resulted in a 100 percent kill of *Salmonella* and *Pseudomonas*, 88 to 99 percent reduction of total counts and in excess of 99 percent kills of fecal coliforms and fecal streptococci.

2.4.3 Disposal of Lime Stabilized Sludge Lime stabilization is also beneficial as it eliminates the need for further chemical conditioning prior to vacuum filtration, centrifugation or discharge to sand drying beds, (Kalinske, 1976). Wyatt (1975) reported that in some cases, lime stabilization can increase filterability of the sludge by a factor of two while maintaining an equal cake moisture content. If quicklime (CaO) is used then the sludge will also be dewatered to some extent ($CaO + H_2O \rightarrow Ca(OH)_2$) with lime as the end product (Vesilind, 1974). Vesilind has also indicated that dewatering characteristics can be increased further if CO_2 gas is bubbled through the solution to produce $CaCO_3$.

Reports by Kalinske (1976) and the EPA (1974) indicate that lime stabilized sludge is also excellent for a sanitary landfill site. The EPA suggests that proper application of alternating thin layers of lime stabilized sludge and soil be used in order to prevent rapid pH drops and corresponding rapid putrefaction and odour generation.

The only problem with lime stabilization is maintaining the high pH once the sludge is spread or landfilled. Vesilind (1974) stated that the lime sludge is definitely not chemically stable and that it is impossible to maintain a high pH with even very high lime doses. The chemical or biological activity will eventually reduce the pH back to a level where organisms can grow. The most recent work indicates that a pH of 12.2 to 12.4 must be initially achieved in order to ensure that the pH will be maintained at a pH of 11 or greater for a two week period (Schroeder, 1976; EPA, 1974). Lime dosages required to achieve a pH of 11.0 for at least 14 days are shown in Table 2.8.

2.5 Chlorine Stabilization of Sewage Sludge

Chlorine stabilization, although an excellent stabilization treatment process is not apt to become one of the more popular treatment methods, due mainly to the difficulties arising from mechanical dewatering of the sludge and disposal of the filtrate.

2.5.1 Theory of Operation The process requires raw sludge, chlorine, a tank and a pressure pump that will handle 45 psi with a 10 to 15 minute retention time (Kalinske, 1976). Minimum chlorine dosages are in the order of 500 mg/l, however any systems now developed require in excess of 2,000 mg/l (Vesilind, 1974; Schroeder, 1976; EPA, 1974). At the 500 mg/l dose of chlorine, the residual chlorine in the supernatant is in the range of 10 mg/l. By doubling the dose, to 1000 mg/l, the supernatant residual exceeds 200 mg/l.

2.5.2 Disposal of Chlorine Stabilized Sludge Although the resulting sludge is well stabilized and easily dewatered on sand beds, it is not so easily treated mechanically. Before vacuum filtration or centrifucation can be used it is most often necessary to condition and neutralize the sludge (Kalinske, 1976). The filtrate pH of 2.0 must be neutralized to a minimum of 4.0 before chemical conditions can be effective.

The major problem, from an environmental standpoint, is that of toxicity from the supernatant or filtrate. The chemical combination of chlorine and sludge organics produces a high level of chloramines and other chlorinated compounds, which are toxic to both sewage treatment microorganisms and animal and plant life in receiving streams. Special treatment of the liquid fraction is thus mandatory prior to discharge. Again, the low pH of this liquid portion also causes problems for biological or physical-chemical treatment.

In applications where sodium hypochlorite is used for stabilization, the problem is less severe in terms of pH adjustment, however, the problem of chloramines and other chlorinated compounds still persists.

2.6 Heat Treatment of Sewage Sludge (LPO)

The use of heat treatment for sludge stabilization compares closely to heat treatment for sludge conditioning. The process, however, is not comparable to "wet air oxidation" even though the same type of equipment is used. The end results of the two processes are very different.

Heat treatment is a well known process for sludge stabilization by pathogen destruction. In many cases, it is a by-product of sludge conditioning prior to vacuum filtration.

2.6.1 Theory of Operation The heat treatment process changes the composition of the organic matter and it can degrade large portions of the volatile solids (Kalinske, 1976). Temperatures employed for heat treatment are normally in the 175 to 205°C range. This can be accomplished by either pasteurization or low pressure oxidation (LPO). In pasteurization, the sludge is heated to a specific temperature for a given period of time, primarily to destroy living organisms. LPO processes maintain the sludge under pressure (180-210 psi) at the same time as the sludge is being heated.

The thermal activity of the heat treatment process (LPO) is responsible for release of bound water from the sludge. At the same time, hydrolysis of proteinaceous materials results in cell destruction. The corresponding release of NH_3-N and soluble organics results in a high strength filtrate or supernatant. Most of the organics released are short chain water soluble carbon compounds (EPA, 1974). Their concentration is generally higher than that coming from aerobic or anaerobic digesters. These compounds are, however, easily treated by biological treatment plants if their load has been allowed for in the initial design. Jones (1975) has reported supernatant BOD_5 as high as 6000 mg/l. Vesilind (1974) reported a BOD_5 of 2500 mg/l.

The LPO unit consists of a reactor vessel, heat exchanger and steam injection system, whereby heat treated sludge preheats incoming raw sludge prior to its mixing with steam. Normal retention times are in the order of 30 minutes. The resultant sludge dewaters well on sand drying beds or vacuum filters. Vesilind (1974) reports that solids contents of 50 percent were easily achieved with heat treated sludge. Brough (1977) reports similar results to that by the Metropolitan Sanitary District of Greater Chicago when heat treated sludge was applied to agricultural lands.

2.6.2 Advantages and Disadvantages The advantages and disadvantages of LPO heat treatment have been given by the EPA (1974).

Advantages

1. excellent dewatering without chemical conditioning
2. innocuous sludge suitable for disposal
3. few nuisance problems
4. the process is suitable for many sludges that cannot be biologically stabilized (ie.toxic elements)
5. reduction in incineration requirements after vacuum filtration
6. reduction in size of vacuum filters and incinerators

Disadvantages

1. high construction and operating costs
2. specialized supervision and maintenance due to high temperature and pressures
3. high carbon and nitrogen loadings back to the sewage treatment plant from the supernatant
4. high cost of expensive non-corrosive materials for construction.

SECTION 2 - TABLES

TABLE 2.1 ORGANIC ACID PRODUCING MICROBES IN ANAEROBIC DIGESTION

Microbe	pH	Temp (°C)	Products	
Bacillus cereus	5.2	25-35	acetic	lactic
Bacillus knelfelkampi	5.2-8.0	25-35	acetic	lactic
Bacillus megaterium	5.2-7.5	28-35	acetic	lactic
Bacteriodes succinogenes	5.2-7.5	25-35	acetic	succinic
Clostridium carnofoetidum	5-8.5	25-37		
Clostridium cellobioparus	5-8.5	36-38	formic, acetic, lactic, ethanol, CO_2	
Clostridium dissolvens	5-8.5	35-51	formic, acetic, lactic	
Clostridium thermocellulaseum	5-8.5	55-65	formic, acetic, lactic, succinic	
Pseudomonas formicans	---	33-42	formic, acetic, lactic, succinic, ethanol	
Ruminocossus flavefaciens	---	33-38	formic, acetic, succinic	

Source: Zajic, 1971

TABLE 2.2 SUBSTANCES AND CONCENTRATIONS CAUSING TOXICITY IN WASTEWATER SLUDGE DIGESTION

Substance	Concentration (mg/l)
Sulphides	200
Soluble Heavy Metals	>1
Sodium	5,000 - 8,000
Potassium	4,000 -10,000
Calcium	2,000 - 6,000
Magnesium	1,200 - 3,500
Ammonium	1,700 - 4,000
Free Ammonia	150

TABLE 2.3 DESIGN FEATURES OF ANAEROBIC DIGESTERS

	Conventional process	High Rate Digesters	Anaerobic contact process
Heated or unheated	Heated, unheated	Heated	Heated
Detention time	>40 days	10 - 15 days	12-24 hours
Loading (lb VSS/ft^3 /day)	0.03-0.05	0.1-0.2	0.1-0.2
Feeding & withdrawal	Intermittent	Continuous or Intermittent	Continuous
Mixing	-	+	+
Feed equalization	-	-	+
Effluent sludge recycle	-	-	+
Degasification	-	-	+

minus (-) not used, plus (+) used

Source : Zajic, 1971

TABLE 2.4 TYPICAL DESIGN CRITERIA FOR LOW-RATE AND HIGH-RATE DIGESTERS (After Burd, 1968).

Parameter	Low-Rate	High-Rate
Solids Retention Time, days	30 - 60	10 - 20
Solids Loading $lb.VSS/ft^3/day$	0.04 - 0.1	0.15 - 0.40
($kg.VSS/m^3/day$)	(0.64 - 1.6)	(2.4 - 6.4)
Volume Criteria ft^3/capita (m^3/capita)		
Primary Sludge	2 - 3 (0.06 - 0.09)	1.3 - 2 (0.035 - 0.06)
Primary Sludge + Trickling Filter Sludge	4 - 5 (0.12 - 0.14)	2.6 - 3.3 (0.075 - 0.085)
Primary Sludge + Waste Activated Sludge	4 - 6 (0.12 - 0.17)	2.6 - 4 (0.075 - 0.12)
Combined Primary + Waste Biological Sludge Feed Concentration, percent solids (dry basis)	2 - 4	4 - 6
Anticipated Digester Underflow Concentration, percent solids (dry basis)	4 - 6	4 - 6

Source: Vesilind, 1974

TABLE 2.5 BACTERIAL SURVIVAL IN DIGESTION

Bacteria	SRT*	% Removed	Remarks
Endamoeba hystolytica	12	< 100	Greatly reduced at 20°C
Salmonella typhosa	20	92	85% reduction at 6-day SRT
Tubercle bacilli	35	85	Not reliable destruction
E. Coli	49	< 100	Great reduction at 37°C

* SRT = Solids Retention Time

TABLE 2.6 DESIGN PARAMETERS FOR AEROBIC DIGESTION

		Metcalf and Eddy	EPA
Detention Times (Days 20°C)			
Activated Sludge		12 - 16	10 - 15
Act. Sludge + Primary	(Combined Operation)	18 - 22	15 - 20
" " "	(Separate Operations)	16 - 18	
Primary Alone			15 - 20
Solids Loading ($lb/ft^3/day$)		0.10 - 0.20	0.024 - 0.14
Dissolved Oxygen Level (ppm)		1 - 2	1 - 2
Air Mixing ($SCFM/1000ft^3$)		20 - 30	20 - 35
If Primary included		--	> 60

TABLE 2.7 HYGIENIC QUALITY OF COMPOST

Treatment Method	Material	Water Content %	Maximum Temp. Achieved (°C)	Hygenic Evaluation	Remarks
			Contour Composting		
Contour Spreading	sludge + solid waste	55	46	not pathogen-free after 5 months	
Windrow Spreading	sludge	60	52	not pathogen-free after 6 months	
Windrow Spreading	solid waste	40-60	> 55	pathogen free after 3 weeks	
Windrow spreading	sludge + solid waste	40-60	> 55	pathogen free after 3 weeks	
			Mechanical Composting		
Rotating drum (Dano Process)	solid waste	45-55	> 60	pathogen free after 6-7 days	Spore free after 1 week of windrow composting
Rotating drum	sludge + solid waste	approx 50	> 60	pathogen free after 6-7 days	Spore free after 1 week of windrow composting
Rotating tower (Multibacto process)	solid waste	40 - 50	> 65	pathogen free after 1 day	Spore free after 1 week of windrow composting
Rotating tower	sludge + solid waste	45 - 55	> 65	pathogen free after 1 day	Spore free after 1 week of windrow composting

Source: EPA, 1974

TABLE 2.8 LIME DOSE REQUIRED TO KEEP SLUDGE AT pH > 11.0 FOR AT LEAST 14 DAYS

Type	Dose (lbs $Ca(OH)_2$ / tons sludge solids)
Primary sludge	200 - 300
Septic tanks sludge	200 - 600
Biological sludge	600 - 1000
Alum sludge (secondary)	800 - 1200
Alum sludge (secondary and primary)	500 - 800
Iron sludge (secondary)	700 - 1200

SECTION 2 - FIGURES

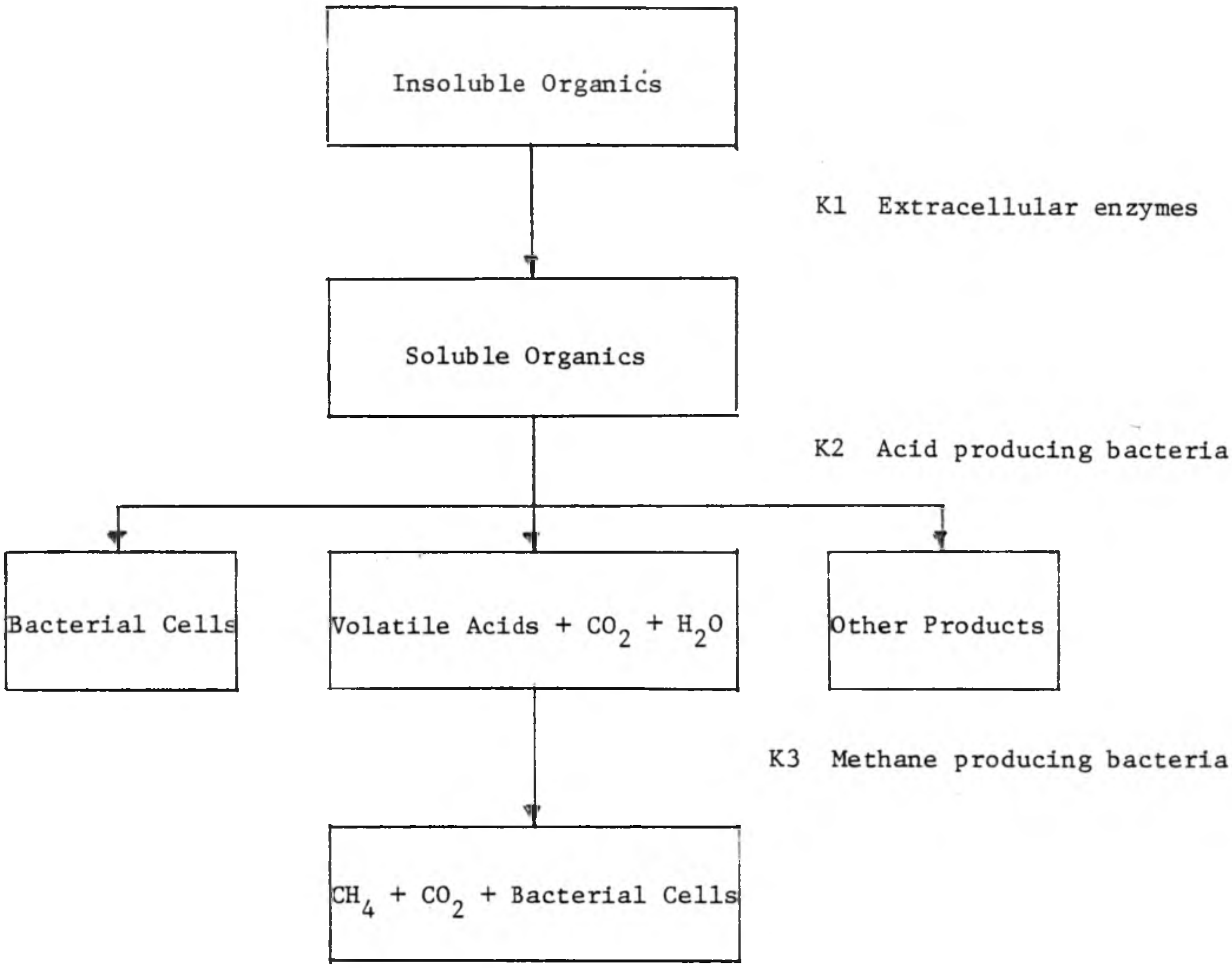

Fig. 2.1 ANAEROBIC DIGESTION OF ORGANIC WASTES
Source: Andrews, 1969

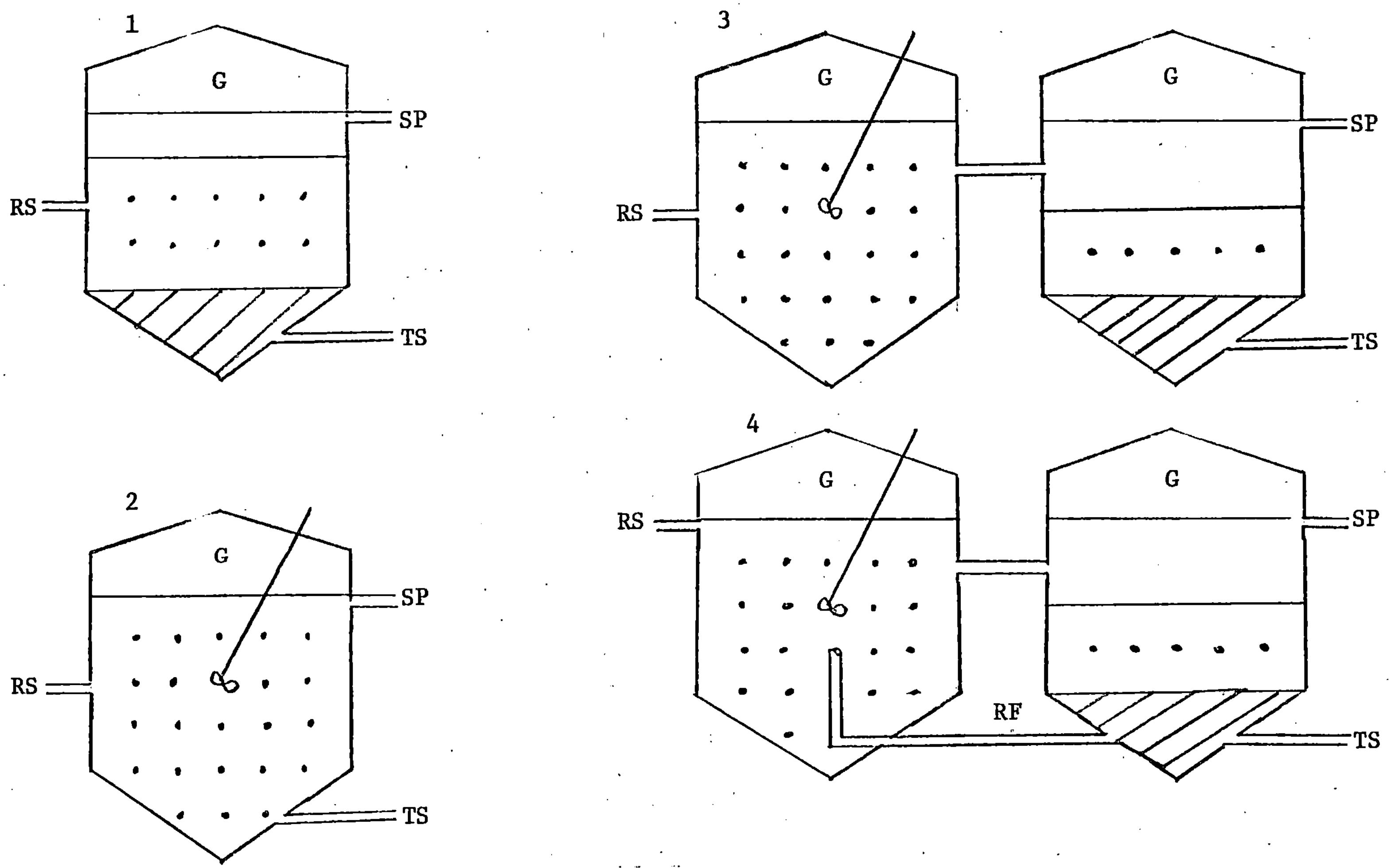

Fig. 2.2 ANAEROBIC DIGESTION PROCESSES

1 One Stage Standard Rate
2 One Stage High Rate
3 Two Stage
4 Anaerobic Contact

RS = Raw Sludge
SP = Supernatant
TS = Stabilized Sludge
RF = Return Feed
G = Gas

Supernatant

Actively Digesting Sludge

Stabilized Sludge

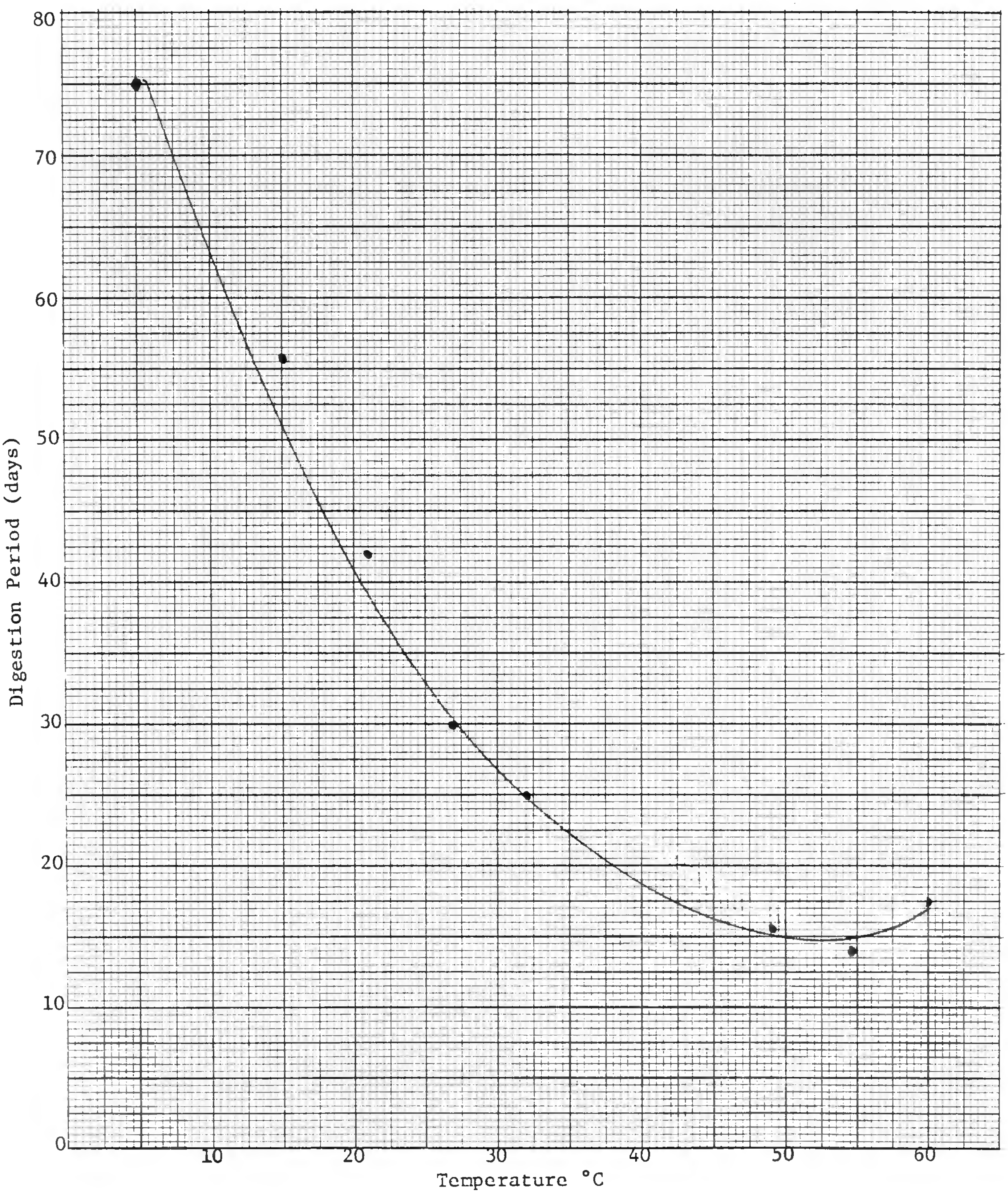

Fig. 2.3 REQUIRED DIGESTION PERIOD FOR VARIOUS TEMPERATURES

Source: Schroeder, 1976

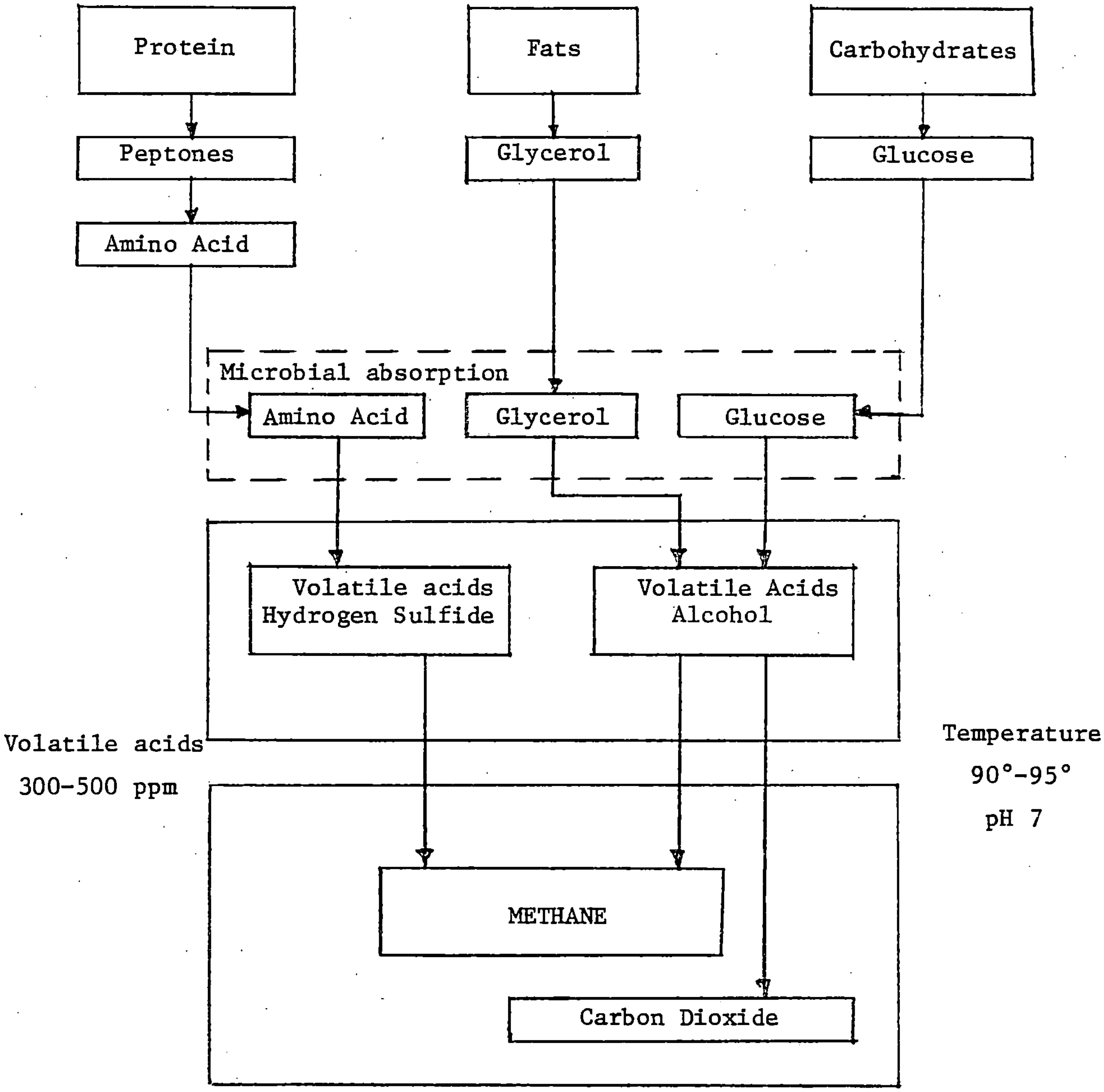

Fig. 2.4 ANAEROBIC BIOCONVERSION OF PROTEIN, FATS AND CARBOHYDRATES TO METHANE AND CARBON DIOXIDE

Source: Zajic, 1971

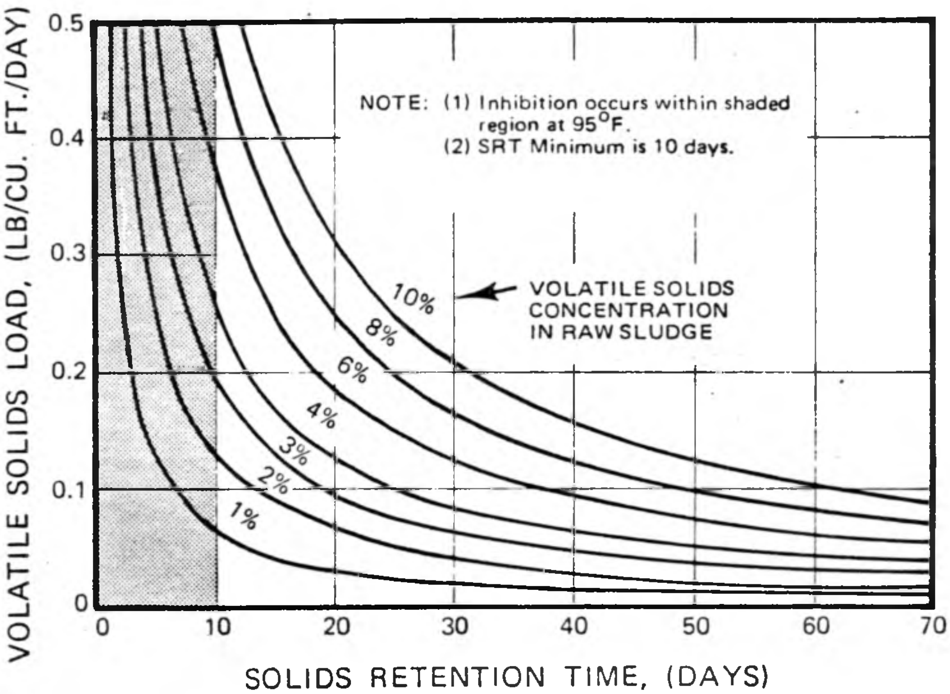

Fig. 2.5 PLOT OF VOLATILE SOLIDS LOADING VERSUS SOLIDS RETENTION TIMES FOR VARIOUS FEED SOLIDS

Source: EPA ,1974

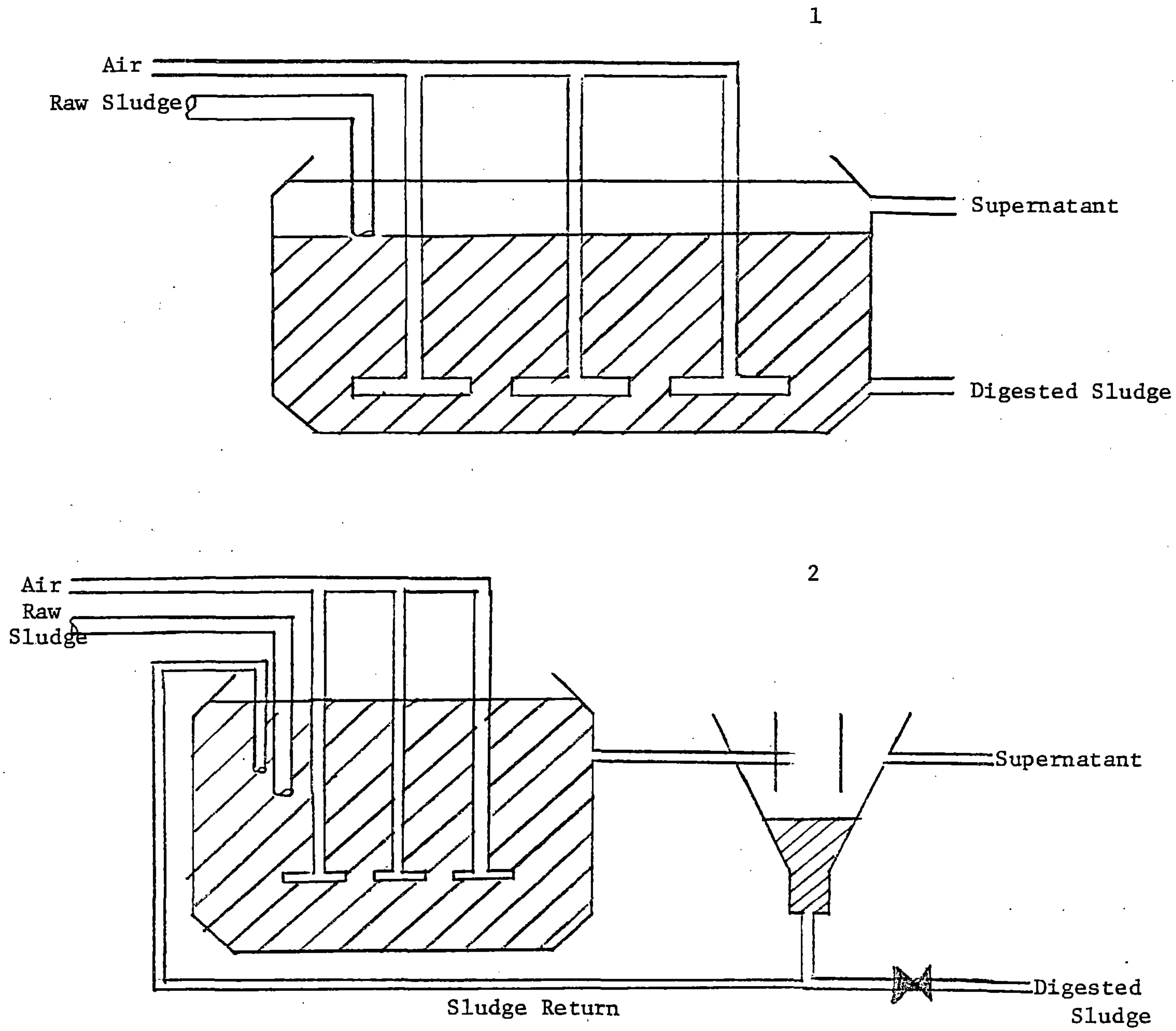

Fig. 2.6 TYPES OF AEROBIC DIGESTERS
Source: Koers, 1977

1. Daily fill and flow.
2. Continuous feed and decant.

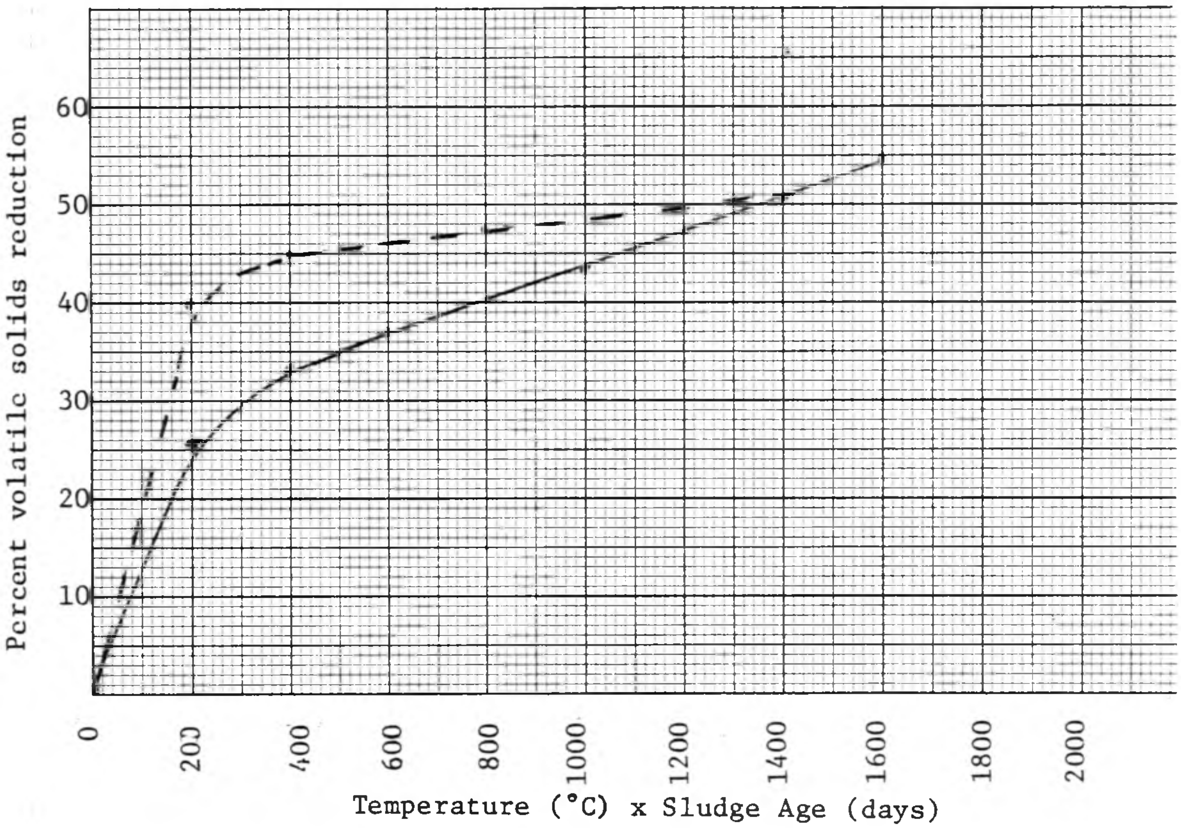

Fig. 2.7 EFFECT OF TEMPERATURE AND SLUDGE AGE ON VOLATILE SOLIDS REDUCTION

Source: Koers, 1977.

——— Experimental

— — — — Full Scale Data

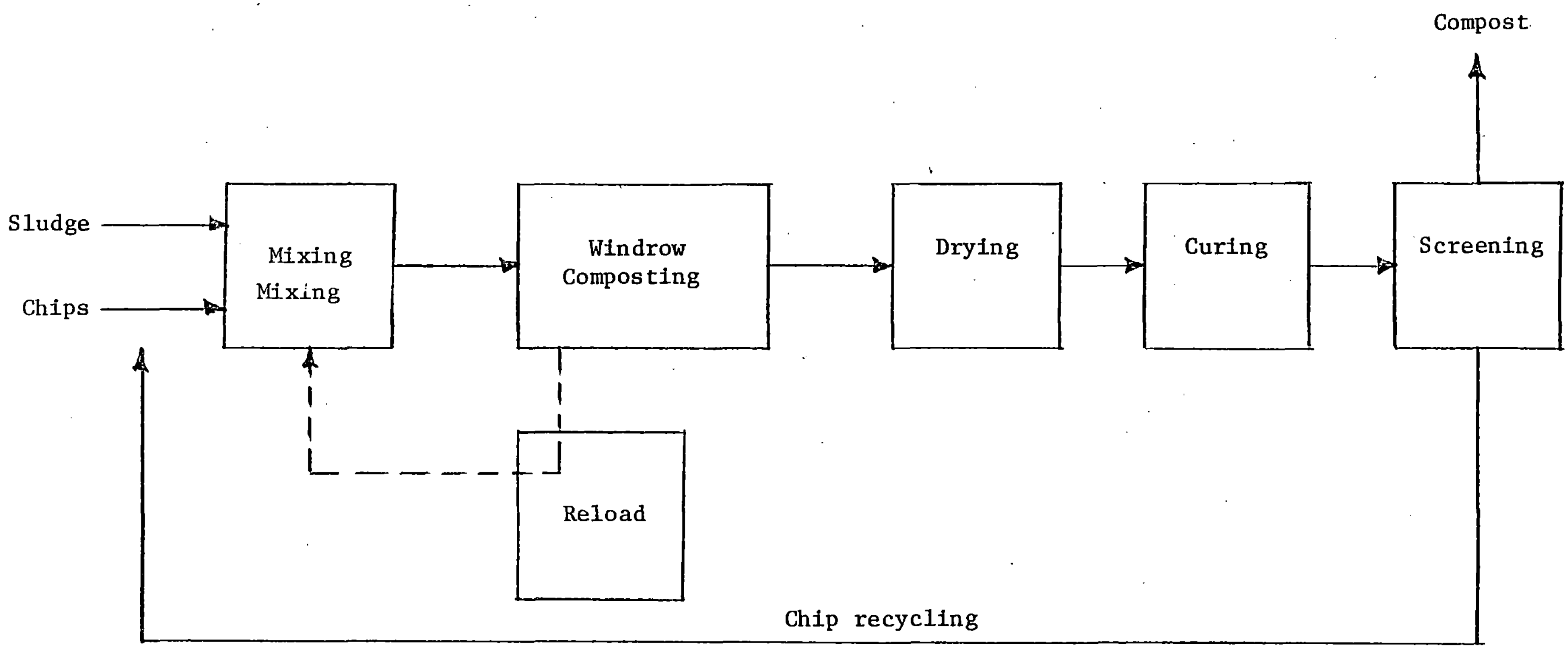

Fig. 2.8 SCHEMATIC OF WINDROW COMPOST
Source: Schroeder and Cohen, 1976

Section 3

SLUDGE DEWATERING

3 SLUDGE DEWATERING

The process of sludge dewatering increases the dry solids concentration of raw or digested sludge in order to make the sludge more suitable for further treatment and/or disposal. The many mechanisms available for dewatering provide different conditions under which the water may be sucked, pressed, drawn or thrown away from the solid portions. Typical dewatering mechanisms are vacuum filters, filter presses, centrifuges, capillary suction devices, belt filters and sand drying beds.

The process selected for dewatering will depend on the economics involved, the amount of sludge to be treated, the transportation method and ultimate disposal plans. For example, a dry 30 percent sludge is suitable for trucking but not for pumping. A dry sludge also has a greater calorific value for incineration. As the dryness of the sludge cake increases, so do the costs involved, either through conditioning costs or increased energy expenditure. For each case there will probably be a best system, and this system must be selected on an individual basis. What is best for one primary or waste activated sludge is not necessarily best for all. An indication of interactions between treatment processes is given by Christensen et al (1976).

Each type of sludge responds differently to the treatment process depending on how the water is held within the sludge. Free water, that is not attached to the sludge, can be removed by settling or gravity thickening. Floc water, which is actually trapped within the separate flocs, can most easily be removed by mechanical dewatering. Floc water cannot be removed by settling. Capillary water, which adheres to each floc particle, can only be removed if the flocs are compressed causing them to change shape. A certain portion of the water, known as particle water, is chemically bound within the sludge and cannot be removed by dewatering processes as described above.

A summary of dewatering methods and uses is provided in Table 3.1.

3.1 Vacuum Filtration Most sludges can be vacuum filtered to some extent. However, in most cases one will only find vacuum filters at the larger installations. The extent to which vacuum filtration can be used successfully is dependent on the characteristics of the sludge. These characteristics are given by Malina (1970) as:

1. the shape and characteristics of the solids in the sludge,
2. the chemical composition of the sludge,
3. the suspended solids concentration,
4. the compressibility of the sludge solids, and
5. the specific resistance of the sludge.

Based on characteristics such as these, Eckenfelder (1970) found that raw sludges were easier to filter than digested sludges and primary sludges were easier to filter than secondary waste activated sludges. Primary sludge filters more easily because of the larger particles in the sludge, which allow for easier passage of the liquid out of the solids. Digested sludge can be dewatered by vacuum filtration. However, this usually increases the required chemical conditioning cost (Wyatt et al, 1975). In most cases where digested sludge is dewatered by this mechanism it is first mixed with primary sludge to increase the bulk content and increase its filterability (Vesilind, 1974).

Kalinske (1976) has indicated that most municipal sludges can be vacuum filtered and that it is beneficial to thicken the sludge prior to filtration. Thickening increases cake quality, as the filtration rate varies directly with the solids input concentration. A maximum ten percent solids input should be selected to minimize problems associated with mixing in conditioning agents and pumping a thick slurry.

3.1.1 Description and Types of Vacuum Filters A vacuum filter consists of a hollow drum, covered with a permeable material, that rotates in a tank with one quarter of the drum submerged in a sludge slurry. A vacuum is applied to the inside of the drum which causes the slurry to be drawn onto the surface. The water is then sucked from the sludge through the cloth and collected in the internal piping. As the drum rotates into the air the vacuum then assists in drying the sludge. The sludge cake is then scraped, lifted or blown off the drum surface before the media re-enters the sludge slurry. A wash cycle for the filter media is often provided before the media re-enters the slurry tank.

A cutaway view of a rotary drum vacuum filter is given in Figure 3.1, with a corresponding schematic of a vacuum filter operation in Figure 3.2.

The EPA (1975) has given three classifications of vacuum filters as the drum, top feed drum and coil. The drum filter is the conventional method as shown in Figure 3.1. The top feed drum filter differs from the drum filter in that a sludge hopper is located above the filter and thus gravity aids in the cake formation. In this type of filter there is no agitation required in a bottom hopper. The coil filter differs from the other two in that the filter media consists of two layers of stainless steel coils in a corduroy fashion that separates after dewatering to lift the sludge off the bottom coil.

Thomas (1974) further describes vacuum filters as either rotary drum, rotary disc, rotary pan or a linear type conveyor. The rotary disc has a vacuum applied to the two faces of a vertical disc, the rotary pan has the vacuum applied on the horizontal surface of a rotary table. The linear type conveyor has the vacuum applied on a horizontal surface through a filter media belt.

3.1.2. Design and Operation of a Vacuum Filter Clark and Viessmann (1969) have indicated that vacuum filters are generally designed to produce a cake yield of 2.5 to 11 pounds/hour/ft.^{2} of filter media. Metcalf and Eddy (1972) have suggested a normal yield of 3.5 pounds/hour/ft.^{2} would occur for a well digested primary sludge.

The most important characteristics to consider when selecting a vacuum filter have been suggested by Malina (1970) as:

1. type of filter medium,
2. size of medium pores,
3. effect of solids loading on filter medium,
4. manner of filter medium support,
5. drainage system used to remove the filtrate, and
6. operating vacuum pressure and time.

The performance of this machine will then be affected by:

1. specific resistance of sludge,
2. cycle times selected for filter, and
3. the initial and final solids content.

The cycle time for a vacuum filter is determined by the rate of drum rotation. The time in any one cycle can be further broken down into the form time and the dry time. The form time refers to the time the drum is submerged in the slurry, while the drying time refers to the period of the drum's cycle in the air. The wash cycle is contained within the drying cycle.

The quality of cake produced by the filter will depend on the cycle time as set by drum submergence and speed of rotation (Vesilind 1974). A thinner but drier cake is produced from less submergence. A drier cake, with a lower filter yield, is achieved at a slower speed. Increasing the drum speed causes an increase in cake moisture content and an increase in cake thickness. Metcalf and Eddy (1972) have stated that the moist cake will separate much easier from the drum than a drier cake.

Generally the sludge yield has also been found to vary directly with the feed solids concentration brought about by thickening. The EPA (1974) has indicated, however, that holding the sludge for any length of time may cause a decrease in filter efficiency. In order to overcome this problem a period of reaeration can be placed between the thickening and vacuum filtration stages.

The largest vacuum filters on the market today can produce around 100 dry tons/day, however, Wyatt et al (1975) have indicated that design should be at 25 to 50 percent of the maximum to account for down time required in most vacuum filter installations.

It is generally agreed that vacuum filters can produce a cake having a solids content of 20 to 40 percent, with most installations not exceeding 30 percent solids. Suspended solids in the filtrate of such filters ranges from 100 to 20,000 mg/l. The solids in the filtrate generally resettle well, with some floating fines.

The solids content of the sludge and the filtrate can be adjusted by conditioning of the sludge prior to filtration. This will then increase the cost of the process but also greatly increase the calorific value of the sludge. At the same time the conditioning decreases the load of solids to the front end of the plant. If incineration is being practiced it may be possible to use the ash as a conditioner, decreasing operational costs (Micale, 1976).

Lime and ferric salts have been the most commonly used coagulants but recently polyelectrolytes have been gaining much wider acceptance. The iron and lime coagulants coat the fine particles, making them larger and more settleable, whereas the polyelectrolytes agglomerate the fine particles, producing a larger more dense particle. Kalinske (1976) has estimated that 400 to 430 lbs/ton of inorganic coagulants can be replaced by less than 20 lbs/ton of polymers. The disadvantage of the polymers is that they do not have the side effect of stabilization experienced with iron and lime coagulants.

Kalinske (1976) has outlined the advantages of polymers, associated with vacuum filters, as follows:

1. significantly smaller requirements for chemical handling equipment and space,
2. decreased production of incinerator ash,
3. lower heat requirements,
4. greater filter yield, and
5. improved safety and cleanliness.

If polyelectrolytes are used in conjunction with vacuum filtration, it has been suggested that a larger mesh filter media can then be used (EPA, 1974). The use of a larger mesh will allow for an increase in the water removal rates and the polyelectrolytes will eliminate the loss of more of the fine solids through the larger mesh.

Operational problems associated with vacuum filters can most often be classified under one of the following (EPA, 1975):

1. improper media selection,
2. failure to thicken sludge,
3. cake release problems, and
4. inadequate sludge conditioning

Typical operating data for 60 operating installations was given by Cheremisinoff _et al_ (1976) and is shown in Table 3.2.

3.1.3 Advantages and Disadvantages of Vacuum Filters. Vacuum filters have generally been used only at large installations because of the high operating and chemical costs associated with this process. High operating costs generally result from the need of a skilled mechanic to maintain the unit, while high chemical costs are associated with conditioning requirements (Vesilind, 1974). Vacuum filters are now being used in more small communities because of improved operator training, the increasing scarcity of land and the difficulty of obtaining unskilled labour to clean drying beds (EPA, 1974).

Vacuum filtration is utilized in most systems where sludge incineration is practiced. Only pressure filtration exceeds vacuum filtration in cake solids and volume reduction. However, this process is only beginning to be utilized to its full extent.

3.2 Filter Presses The use of filter presses is not as widespread in North America as it is in European countries. Only recently have they become a serious contender for waste water sludge treatment. Of the filter presses in operation only a few are fully automatic, the majority being operated on a manual basis.

As most filter presses are operated on a manual batch basis there is a very high labour cost associated with their operation. With the introduction of automation to this process it is expected there will be a cost decrease and thus more units will come into operation. As the energy crisis continues and sludge/garbage incineration becomes more popular, there will probably be an increase in the use of filter presses. As indicated in the section of this report dealing with energy recovery, it is possible to burn sludge without auxiliary fuel once a solids concentration of 35% has been maintained. Filter presses produce the driest cake and are, therefore, most suitable for incineration processes.

In many instances the filter press, by nature of the high pressures involved, can produce a dry cake from sludges which would be difficult to dewater even slightly by any other process. This process also allows for drier cakes with less conditioning of the sludge required.

3.2.1 <u>Description and Types of Filter Presses</u> In a filter press the liquid is forced through a media by a positive pressure, while the solids stay behind. The sludge is pumped between individual filter plates, covered with a filter cloth, until all the spaces between the plates are full. The sludge passes to each frame through a series of interconnecting holes. The filtrate then drains out ports in the bottom of each chamber. As more sludge is pumped, the driving force increases, which causes the sludge to compact and expel water. When the filtrate flow drops to zero, the cycle is complete, the press opens and the dry cake is released (EPA, 1974; Vesilind 1974).

The sludge cake is removed from the press by air blowing or by mechanical means. The failure of a cake to expel properly is the major holdback on commercial application of automatic filter presses. If the cake fails to drop completely, the press will not make a complete seal when the cycle restarts and the sludge will thus pump out onto the floor.

A schematic of a filter press and a group of plate frames is shown in Figures 3.3 and 3.4 respectively.

3.2.2 <u>Design and Operation of a Filter Press</u> To date there is little design experience for filter presses and thus Vesilind (1974) has suggested that pilot scale operation is the best method for design. Pilot tests on a small unit will provide information on pressure cycle time, conditioning required, loading rates, cake yield and media selection.

Generally, sludge is pumped under pressure into the press at 80 to 100 psi for a period of 1 to 3 hours, with a total cycle time of 3 to 8 hours to fill, press, open and clear the system. The cake produced by such a unit can achieve 30 to 50 percent solids from even difficult-to-dewater sludges. Higher yields can be achieved by using the same methods of chemical conditioning as described for vacuum filters. If conditioned properly, all kinds of sludge can be dewatered with a filter press.

The most recent advances in improving the operation of filter presses has been in the development of new media for the press (EPA, 1974). The new types of media available, with a precoat system, ensure greater cake release and thus less problems with automation.

3.2.3 Advantages and Disadvantages of Filter Presses

The major advantages associated with filter presses are the high solids concentration achievable, the clear supernatant formed, the high solids capture and the reduction in chemical conditioning costs (EPA, 1974).

The drier cake is especially suitable for incineration. If the same dryness was attempted with a vacuum filter, the cake would dry and crack and the vacuum would be lost (Malina, 1970). Thus for incineration a filter press appears to be the best dewatering method, if automation can be achieved.

The clear supernatant formed results in a decreased solids loading at the front end of the plant and also eliminates the buildup of fines in the system. The same degree of solids capture is not technically or economically feasible with most other dewatering mechanisms.

Pressure filtration does have drawbacks in that it is presently for manual operations and thus has an associated high labour cost. The filter cloth life is also limited but recent work is improving this limiting condition. Two final disadvantages are the operator incompatability with such a process and the problem of cake delumping.

With an increasing amount of work being done in the field of filter media and automation, there will most likely be a climb in the use of filter presses. Full scale demonstration projects now operating in Canada and the U.S.A. are expected to provide much of this information.

3.3. <u>Centrifugation</u> Although centrifugation of sewage sludge was first attempted in 1902 in Germany, it was not until the 1960's that it became an accepted practice in North America (Vesilind, 1974). The main problems were the machining difficulties experienced during manufacture. Operation difficulties experienced during daily running also inhibited its acceptance. With today's more refined machining techniques and with the advent of chemical conditioning methods the centrifuge is gaining much greater acceptance as a sludge dewatering method.

Basically, centrifugation is a speeded-up settling process whereby the denser solids, in a liquid-solid mixture, are forced out of solution by centrifugal forces. Particles which are less dense than water will not sediment out but will most likely come to the surface. It is for this latter reason that Clarke <u>et al</u> (1965) have suggested avoiding a centrifuge where the density of the solids is less than that of water.

There are many types of centrifuge on the market today, some operating by manual processing and others which can be fully automated. Selection of the proper centrifuge type will depend on the quantity and quality of the sludge to be treated. Sludges that are handled by different types of centrifuge are outlined in Table 3.3.

3.3.1 <u>Description and Types of Centrifuges</u> There are three major types of centrifuges used for sludge dewatering, each somewhat different in design and operation. The three classes are: solid bowl, disc and basket (Dougherty <u>et al</u>, 1970). Additional information on centrifuge types and applications has been given by Frederick, (1974).

3.3.1.1 Solid Bowl Centrifuges The solid bowl centrifuge consists of a solid cylindrical bowl supported between two bearings. One end is conical in shape to act as a dewatering section. The liquid level is regulated by a dam at the opposite end of the conical bowl. Inside the bowl, and rotating at a different speed than the bowl, is a screw conveyor to move the solids through the unit. The liquid, which is loaded into the conical dewatering section, moves towards the dam, while the screw conveyor continuously moves the solids toward the conical section. The dewatering section of the bowl, being of reduced diameter, is not submerged in the pool. This area thus acts as a drainage area for the solids prior to discharge.

The solids-liquid flow may either be concurrent or countercurrent, depending on the unit selected. The countercurrent unit, as described above, is the most widely used in wastewater treatment. The concurrent solid bowl differs in that the solids and liquids pass through the bowl in a parallel flow. The EPA (1974) have indicated that the concurrent solid bowl unit produces a better compaction of solids, as they pass through the entire length of the bowl.

The solid bowl centrifuge has been reported to obtain 70-90% solids recovery with a 20% cake and up to a 35% cake at 100% solids recovery (Vesilind, 1974). With a primary sludge alone the units are capable of maintaining a 20-25% cake at 90-95% solids recovery (Dougherty et al, 1970). With a waste activated sludge, plus chemicals, a 5-10% cake is common. For pure oxygen systems, 10-12% solids have been achieved (Vesilind, 1974). If a primary-secondary mixture is centrifuged, the EPA (1974) has suggested that with proper polyelectrolyte addition, 80-95% solids recovery can be maintained. Asano et al (1977) report an increase from 80 to 99 percent solids recovery with the addition of cationic organic polymer.

There is also a low speed continuous solid bowl centrifuge described by the EPA (1974), where speeds of rotation are less than 1500 rpm. It is suggested that this unit produces less noise and suffers less from wear and tear. It also has lower capital cost and power requirements and higher solids capture. Higher solids capture usually denotes a wetter cake.

A schematic of a countercurrent solid bowl centrifuge is shown in Figure 3.5.

3.3.1.2 Disc Centrifuges The disc centrifuge, as described by Dougherty et al (1970), consists of a number of conical discs stacked on top of one another, each disc acting as a separate low capacity centrifuge. Each disc is separated from the next by a space large enough for solids to pass through, yet small enough that this is only a short distance for the solids to travel. The solids are removed from the liquid fraction as they slide down the underside of the upper disc and pass to the outer perimeter of the bowl. The centrifugal forces concentrate the solids in the outer section of the bowl. The solids slurry then passes out through peripheral nozzles in the shell of the unit.

The disc centrifuge is subject to plugging at the nozzle discharge and between the disc plates. For this reason the EPA (1974) has suggested that this unit would be best for larger flows with more fine solids. The plugging problem also necessitates screening and degritting prior to centrifugation. In many cases the EPA suggested that a disc centrifuge be used for thickening sludge rather than total dewatering.

Vesilind (1974) has indicated that the disc centrifuge operation can be improved by recycling solids back to the feed line. The heavier solids assist in the sedimentation of the lighter feed fraction.

As a less efficient dewatering unit, the disc centrifuge produces solids in the range of 1 to 6 percent. For this reason the disc centrifuge is often used as a prethickening stage before a solid bowl centrifuge or a digester.

Knight et al (1973) have studied the disc centrifuge for thickening chemical sludges from phosphorus removal plants and found that it is competitive. Large units were reported to be capable of thickening up to 350 gpm at 5-6% solids without polymer addition. Hydroclones were suggested as a pretreatment to remove grit which would cause excessive abrasion.

A schematic of a disc centrifuge is illustrated in Figure 3.6.

3.3.1.3 Basket Centrifuges The basket centrifuge is a lower capacity centrifuge more adaptable to batch operations, as would be experienced at smaller plants. This type of centrifuge is relatively new to waste treatment and thus has not been subjected to such intensive scrutiny as the other types. Hagstrom et al (1977) have indicated that a basket centrifuge operation can be fully automated, and as such requires minimal supervision.

The centrifuge is of tubular construction with an imperforated bowl similar to that used for a solid bowl unit. The basket centrifuge sits vertically during operation, the solid bowl lies horizontally. The basket type has a bowl with a much larger diameter and rotates at a much lower speed than the solid bowl unit. This unit also lacks the internal conveyor, thus requiring periodic manual removal of solids.

The feed to this unit enters the rotating basket. Solids are separated and these sediment against the outer wall of the bowl. The centrate then overflows the upper lip of the basket and is discharged. Solids are removed manually from the system once the sludge layer builds to a predetermined level,and the machine is stopped. In some installations the machine speed is only decreased at this stage and the solids are removed by a scraper blade entering the bottom of the bowl.

This unit is used less extensively because it has a much lower capacity than a continuous unit and requires more operator attention. It does, however, have the advantage of higher solids recovery without chemical conditioning (EPA, 1974).

A schematic of a basket centrifuge is shown in Figure 3.7.

3.3.2 Design and Operation of a Centrifuge

The design capacity of a centrifuge is limited by the characteristics of the sludge to be centrifuged, similar to the manner in which a sedimentation basin is limited. Clark et al (1969) have suggested that a centrifuge's capacity is limited by:

1. the maximum settling rate of the smallest particle,
2. the retention time to settle these solids, and
3. the liquid depth through which the solids must pass.

The settling velocity and clarifying capacity of the centrifuge will increase with the larger particle size or greater density. The speed of clarification will increase as the radial acceleration increases, which can be developed by increasing the centrifuge speed or increasing the bowl diameter. Eckenfelder (1970) has indicated that a typical centrifuge would operate in the range of 3500 times the normal gravitational force (G).

Thomas (1974), has stated that the separation efficiency in a centrifuge will depend on this G factor but there must be a design compromise between the rotational speed, which is directly proportional to the G factor, and the wear factor brought about by abrasive solids in the feed.

Dougherty et al (1970) have shown that the performance of a solid bowl centrifuge will vary depending on the centrifugal force (speed-diameter), the liquid level in the drum and bowl conveyor speed differential. For the disc centrifuge the performance characteristics will be more dependent on the centrifugal force, the disc openings and the nozzle size at the ejection ports.

The solids recovery of a centrifuge can be increased by lengthening the retention time in the unit which, for a solid bowl centrifuge, is achieved by increasing the pool volume within the unit.

As Eckenfelder (1970) points out, however, increasing the solids recovery will decrease the cake solids content. The sludge pool, within the centrifuge, usually forms a concentric annular ring on the inner wall, the depth of which is controlled by an adjustable weir plate at the non-conical end of the unit.

Another way the retention time can be increased is by decreasing the feed rate to the unit. Conversely, if the feed rate is increased, only the larger particles are removed and a drier cake is achieved.

In terms of actual unit design, Agranonick, (1975) has stated that the unit's efficiency will depend on the bowl geometric size, as well as the operating conditions. These properties include bowl size and speed, discharge cylinder diameter, feed pipe position and the initial sludge properties as previously outlined by Clark et al (1965).

Vesilind (1974) has indicated that as the bowl diameter, or pool depth increases, there will be an increase in solids recovery and an increase in the moisture content. The angle at which the centrifuge sits is also listed as important, as fluffy solids can be retained longer, thus more are recovered and solids capture increases.

Figure 3.8 shows the effect of changing the percent solids recovery on the cake solids concentration. For any centrifuge it is possible to move up and down this curve by changing operating conditions such as flow rate and chemical conditioning.

If a primary-secondary sludge is to be centrifuged, it should receive some chemical conditioning. Chemical polyelectrolytes increase recovery, but as shown will decrease the cake dryness. If raw sludge is being centrifuged, lime may be added for conditioning as well as odour control. Heat treatment may also be used, however, in most cases units are designed to avoid conditioning and thus reduce operational costs.

Kalinske (1976) has shown that optimum use of centrifuges for sludge dewatering may result from a two stage process utilizing a disc and a solid bowl centrifuge. Utilizing this approach one may obtain the thickening benefits of a disc centrifuge and the dewatering benefits of a solid bowl unit. Still greater efficiency can be obtained with polymer addition between the two stages.

3.3.3 Advantages and Disadvantages of Centrifugation

The advantages outlined for centrifugation over other dewatering methods are (Vesilind, 1974; Kalinske, 1976; Wyatt et al, 1975; EPA, 1974; Cheremisinoff et al, 1976):

1. lower capital cost than vacuum or pressure filters,
2. reasonable operating costs,
3. less mechanical supervision than vacuum filters,
4. odour free system as it is totally enclosed,
5. the units take up much less space,
6. the units normally operate without chemical addition,
7. a wide variety of liquid-solid inputs can be handled,and
8. simple startup and shutdown.

The disadvantages are generally classified as (references as above):

1. heavier maintenance on the internal, conveyor of solid bowl units,
2. less solids capture than vacuum filters,
3. greater moisture content than vacuum filters,
4. a high concentration of suspended solids in the centrate, and
5. high operating and maintenance costs associated with gritty sludges.

3.4 Sand Drying Beds Sand drying beds are used mainly in smaller communities, having smaller treatment systems, where the sludge volume and the cost of land is substantially less than would be found in a metropolitan area. Still, however, it has been reported that 38% of American cities with a population greater than 100,000 use sand drying beds (EPA, 1974). It has been reported by Kalinske (1976) to be the most popular method of sludge dewatering at present.

The practicability of a sludge drying bed will be subject to climatic conditions in many Canadian areas, for the cold northern climate can eliminate the usefulness. Clark et al (1965) have reported that a greenhouse structure can make the process practical in cold northern climates.

The sand drying bed consists of a large, flat, shallow area, underdrained by tiles, upon which the sludge is deposited. Water is removed from the sludge by percolation and evaporation. Land requirements are extreme and will be the limiting factor in many areas. Where they are not, the economics of enclosure in colder areas may also eliminate this mechanism.

3.4.1 Description and Types of Sand Drying Beds Sand drying beds, as illustrated in Figure 3.9, are usually in the order of 20 feet x 20 feet to 20 feet x 100 feet. Eckenfelder (1970) has given optimum internal construction as a 4-9 inch sand layer over an 8-18 inch gravel layer. The underdraining should be 9-20 feet apart, constructed of vitrified clay pipe, having open joints and on a 1% slope. Clark et al (1965) suggest a 4-6 inch sand layer over 8-12 inches of gravel and an underdrain system 6-12 feet apart.

The side walls of drying beds are normally solid, constructed of wood, concrete or packed earth. Concrete sidewalls are normally used where the drying bed will be covered during part of the year. The walls are normally 12 inches high, so they can accept 8-10 inches of sludge.

Recently, paved drying beds have been built so that heavy mechanical equipment can be used to clean the beds (Schroeder et al, 1977). The paved beds allow for removal of the sludge with a higher moisture content because mechanical cleaning can be used (EPA, 1974). Vesilind (1974) has indicated that hard bottom beds such as asphalt or impervious clay are operated by withdrawing a supernatant rather than having an underdrain system.

A normal sand drying bed will initially show one or two days of rapid drainage through the underdrains and thereafter will have two to five weeks of slow dewatering by evaporation. The EPA (1974) has indicated that 45% solids can be achieved in 6 weeks in good weather. If the sand becomes prematurely plugged by fine particles, oil or grease then evaporation will take over earlier and the dewatering process will be slowed (Vesilind, 1974). If pavement or cement is used in place of sand the dewatering will be 25% slower (EPA, 1974).

Kalinske (1976) has stated that the rate of evaporation from a drying bed will be increased in the latter days due to the additional surface made available for evaporation by horizontal shrinkage and cracking of the sludge mat. To achieve dryness beyond this state normally takes one to two months.

3.4.2 Design and Operation of a Sand Drying Bed Area requirements for sludge drying beds in the United States have been given by Eckenfelder (1970) and Metcalf and Eddy (1972). These data are presented in Table 3.4. In most cases beds are designed on a square foot per capita basis. Primary sludge requires the least area while chemically treated activated sludge requires the most. Waste activated sludge requirements are between primary and chemical, and fluctuate higher or lower depending on the degree of primary sludge and chemical sludge that is combined with it prior to drying.

If an enclosed bed is used the area required will be 67-75% of that required for an open bed (EPA, 1974). Enclosure, however, necessitates adequate ventilation for humidity and evaporation control. Failure to ventilate properly will result in a greatly reduced drying rate.

Digested sludge is preferred for drying beds as the digestion process reduces the odour problem, decreases the oil and grease content and generally improves the dewaterability of the sludge. This dewatering process is not capable of removing bound or capillary water, and as digestion releases bound water it will thus increase the total amount of water that can be removed from the sludge. The EPA (1974) has also stated that a digested sludge is apt to have entrained gas bubbles which will cause the sludge to float, leaving a clear liquid to percolate through the soil. The EPA also states that over-digestion may produce too many fines and plug the beds.

Vesilind (1974) has shown that in the design of sludge drying beds one must also consider the water added to the sludge by local rainfall. It has been estimated that 57% of rainfall in an area is absorbed by the sludge and must be accounted for in evaporation calculations. In areas having intensive periods of rainfall, covering the beds may sharply decrease the bed size. Kalinske (1976) has suggested that if this occurs in warm areas it may be advantageous to cover the top of the bed but not the sides.

In addition to the rainfall, the operation of the bed will be governed by the percentage of sunshine, the air temperature, the relative humidity and the wind velocity. Kalinske (1976) has shown that summer drying rates can be three times the fall or winter drying rates. If the humidity is high the surrounding air will be able to accept less moisture. If the wind velocities are higher, on the average, the saturation of the air will be less and the sludge should dry faster.

Like most dewatering processes, the operation can be improved with chemical conditioning. Eckenfelder (1970) has stated that alum treatment can reduce drying times by as much as 50%. Polymer addition has also been found to increase the rate of bed dewatering and the depth of sludge that can be applied. The bed yield has been shown to increase linearly with polymer dosage. Jacke (1972), in a study at a Michigan wastewater treatment plant, showed that a polymer treated drying bed was dry enough to clean after 12 days, while a plain bed of the same sludge took 34 days to dry. Average drying time in ideal weather was 10-14 days with the polymer addition.

Beardsley et al(1976) have stressed that for optimum results the designer should consider the use of chemicals as a requirement in bed drying of sludge. The use of polymer flocculants to treat the sludge prior to bed drying offers the following benefits:

1. increased production,
2. heavier loads without binding,
3. reduced odour due to rapid drainage,
4. application of variable sludges,
5. drier cake, therefore less, and
6. easier unloading as sludge does not crumble.

The final step in sand bed dewatering is removal of the dry cake, a process which is much more time consuming and costly than the mechanized processes. If the beds are sand they must be cleaned manually, otherwise the sand would be too heavily compacted. Operation of heavy machinery on a sand bed will also severely damage the under-drain system. If the bed is packed clay or asphalt only then heavy equipment, such as front end loaders, can be used to remove the sludge. This will reduce cleaning time and costs, but this must be weighed against a wetter sludge or longer drying times experienced with this type of bed.

Beardsley et al (1976) report that two new concepts in sludge drying bed design are being developed and should make the system more practical. The first improvement is a full sand bed with the underdrain system improved so that the clay tile is not crushed by the weight of a front end loader. A strong perforated plastic pipe to protect the tile, in combination with large flotation tires on the loader, should eliminate drain tile destruction. Buckets modified with sludge lifting teeth decrease sand loss. The second system is created by alternating sand and cement strips in the bed. Cement strips, 20 inches wide, placed at wheel distances, support the vehicle and at the same time guide the depth of cut by the loader.

After a sand bed has been cleaned, it has been suggested by Kalinske (1976) to periodically disc the sand and remove the top layer of plugged sand particles. It may be necessary to occasionally resurface the entire bed, which may be a major expense.

3.4.3 Advantages and Disadvantages of Sand Drying Beds

The advantages outlined for sludge drying beds over other dewatering methods are (Kalinske, 1976; Culp, 1974; EPA, 1974):

1. they are simple to operate,
2. operational costs are generally less, and
3. little maintenance is required.

The disadvantages are generally classified as (references as above):

1. large land area required,
2. potential nuisance problem,
3. extreme dependence on weather,
4. require pre-digestion,
5. long dewatering periods required, and
6. the high labour cost for sludge removal.

3.5 Other Sludge Dewatering Mechanisms

Although the previously outlined systems are the most common at present, there are various other systems that can be constructed or which are already on the market. A few of the more common processes are:

1. drying lagoons,
2. belt filters,
3. moving screen concentrators,
4. vibrator screens or filters, and
5. squeegees or capillary suction.

There are also some new innovations in sludge dewatering now being investigated, which may become useful in Canada. An example of this is the use of freezing ,as might be applied in cold northern climates. The freezing process has been discussed by Ali Khan (1976), Yapijakis (1976), and Farrell et al (1970).

3.5.1 Drying Lagoons These units operate in a similar manner to a sand drying bed, but in this case dewatering is accomplished almost entirely by evaporation. The lagoons are on average 2 feet deep, as compared to 8-10 inches for a sand bed. In warmer climates the EPA (1974) has suggested sludge application to a 2.5-4 foot depth.

Lagoons are a low cost, simple method of sludge dewatering but are generally restricted to a well digested sludge that will not create an odour problem. The units require little operator attention and are generally built to accommodate mechanical cleaning.

3.5.2 Belt Filters The belt filter is a relatively simple device that has been used in Europe for many years to treat chemical process sludges. It has recently been adapted for waste activated sludge (Kalinske, 1976; Newman, 1977; Wilkins, 1977).

The unit receives pre-thickened and pre-conditioned sludge on a porous horizontal belt. Pressure is now applied by a series of rollers through a rubber top belt, thus squeezing out the water. The filter can achieve 15-25% solids.

A schematic of a belt filter is shown in Figure 3.10.

3.5.3 Moving Screen Concentrators These units, as described by Schroeder et al (1977), consist of two endless horizontal belt filter screens that provide for gravity dewatering, on the first screen, and compression dewatering, by rollers, on the second screen.

The concentrators start with a 3-6% solids and can produce a 20-30% solids with primary sludge. Conditioning is normally applied at polymer doses of 5-15 pounds per ton.

Advantages of this unit are the low capital, operation and maintenance costs, making it adaptable to small treatment plants. It appears to be a promising alternative to previously described systems.

A variation of this process is the rotary concentrator described by Thomas (1974). These units are horizontal cylindrical cells covered with a nylon fabric filter medium. Feed introduced into the interior is concentrated as the filtrate flows out through the medium. The rotation causes the remaining sludge to form a rolling plug which picks up the new solids and keeps the media clean. Excess solids are discharged over annular end plates. The process can be fully automated.

3.5.4 Vibrating Screens and Filters This mechanism utilizes mechanical or sonic vibration on a screen, filter or roller press to produce 35-40% cake solids. In essence, the vibration intensifies the liquid-solids separation by destroying the sludge structure and reducing its resistance to filtration (Dwinskih, 1975). The dewatering must be carried out on rigid metal screens. Cloth media would dissipate the energy of vibration and the vibration would therefore not reach the sludge.

3.5.5 Squeegees Squeegees are really belt filters, as previously described, which operate by capillary suction rather than pressure. Here a belt sponge extracts the liquid, the liquid then being squeezed from the sponge. The cake is further dewatered by steel rollers.

The unusual feature, as described by the EPA (1974) is the capillary dewatering zone wherein the motive force for dewatering comes from capillary action of the sponge belt.

As with many other processes, optimum operation depends on adequate chemical conditioning.

A schematic of this unit is shown in Figure 3.11.

SECTION 3 - TABLES

Table 3.1

THE RELATIONSHIP OF DEWATERING TO OTHER SLUDGE TREATMENT PROCESSES FOR TYPICAL MUNICIPAL SLUDGES

Method	Pretreatment Normally Provided		Normal Use of Dewatered Cake			
	Thickening	Conditioning	Landfill	Land Spread	Heat Drying	Incineration
Rotary Vacuum Filter	Yes	Yes	Yes	Yes	Yes	Yes
Centrifuge (Solid Bowl)	Yes	Yes	Yes	Yes	Yes	Yes
Centrifuge (Basket)	Variable	Variable	No	Yes	No	No
Drying Beds	Variable	Not Usually	Yes	Yes	No	No
Lagoons	No	No	Yes	Yes	No	No
Filter Presses	Yes	Yes	Yes	Variable	Not Usually	Yes
Horizontal Belt Filters	Yes	Yes	Yes	Yes	Yes	Yes

Source: Wyatt et al (1975)

Table 3.2

TYPICAL VACUUM FILTER OPERATING DATA

LIME & FERRIC CHLORIDE CONDITIONING: Type of Sludge	Chemical Dose Rate % Ferric Chloride	Chemical Dose Rate % Lime	Yield ($lb/ft^2/hr$)	Cake Moisture (Percent)
Raw primary	2.1	8.8	6.9	69.0
Digested primary	3.8	12.1	7.2	73.0
Elutriated digested primary	3.4	0	7.5	69.0
Raw primary + filter humus	2.6	11.0	7.1	75.0
Raw primary + activated sludge	2.6	10.1	4.5	77.5
Raw activated sludge	7.5	0	-	84.0
Digested primary + filter humus	5.3	15.0	4.6	77.5
Digested primary + activated sludge	5.6	18.6	4.0	78.5
Elutriated digested primary + activated sludge:				
(a) Average w/o lime	8.4	0	3.8	79.0
(b) Average w/lime	2.5	6.2	3.8	76.2

POLYELECTROLYTE CONDITIONING: Type of Sludge	Dose Rate	Yield ($lb/ft^2/hr$)	Cake Moisture
Raw primary or raw primary + filter humus	0.2 - 1.2	6 - 20	63 - 72
Digested primary	0.2 - 1.5	4 - 15	66 - 74
Digested primary and activated	0.5 - 2.0	4 - 8	68 - 76

Source: Cheremisinoff et al (1976)

Table 3.3

SLUDGES HANDLED BY CENTRIFUGES

	Centrifuge Type		
	Solid Bowl-Scroll Type	Imperforate Basket Type	Disc-Nozzle Type
Sludge Type	Ground screenings	WAS dewatering	Thickening of waste activated
	Raw primary	Aerobic digested	
	Primary digested	Alum treated	
	Mixed digested	Industrial wastes	
	Combined raw primary/WAS *	Thickening of WAS	
	Heat treated		
	Lime treated		
	Alum treated		
	Pure oxygen		
	Classification		
	Thickening of WAS		
	Industrial wastes		

Source: Chereminoff _et al_ (1976)

* WAS - Waste Activated Sludge

SECTION 3 - FIGURES

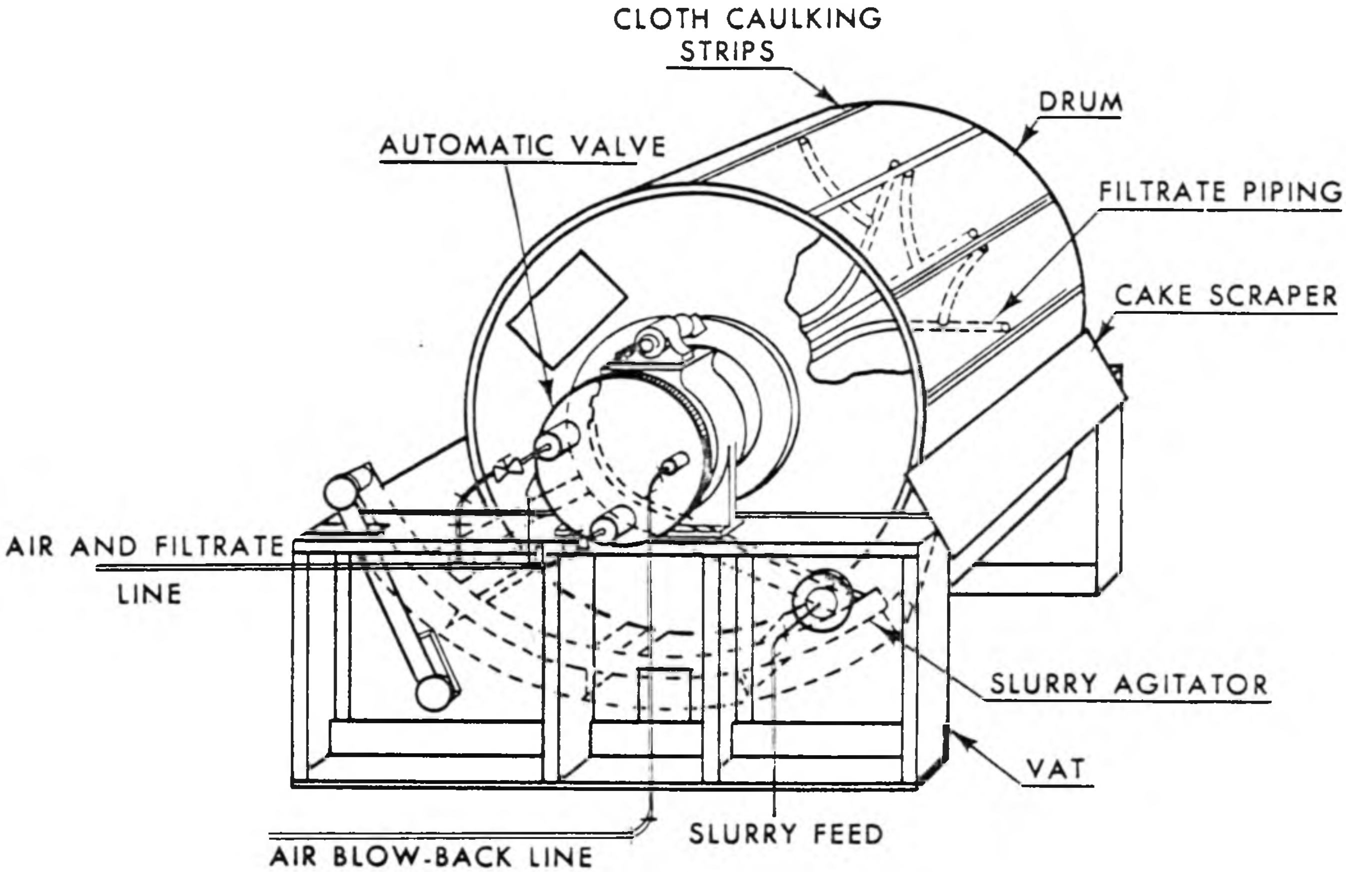

Fig. 3.1 ROTARY DRUM VACUUM FILTER

Source: EPA,1974

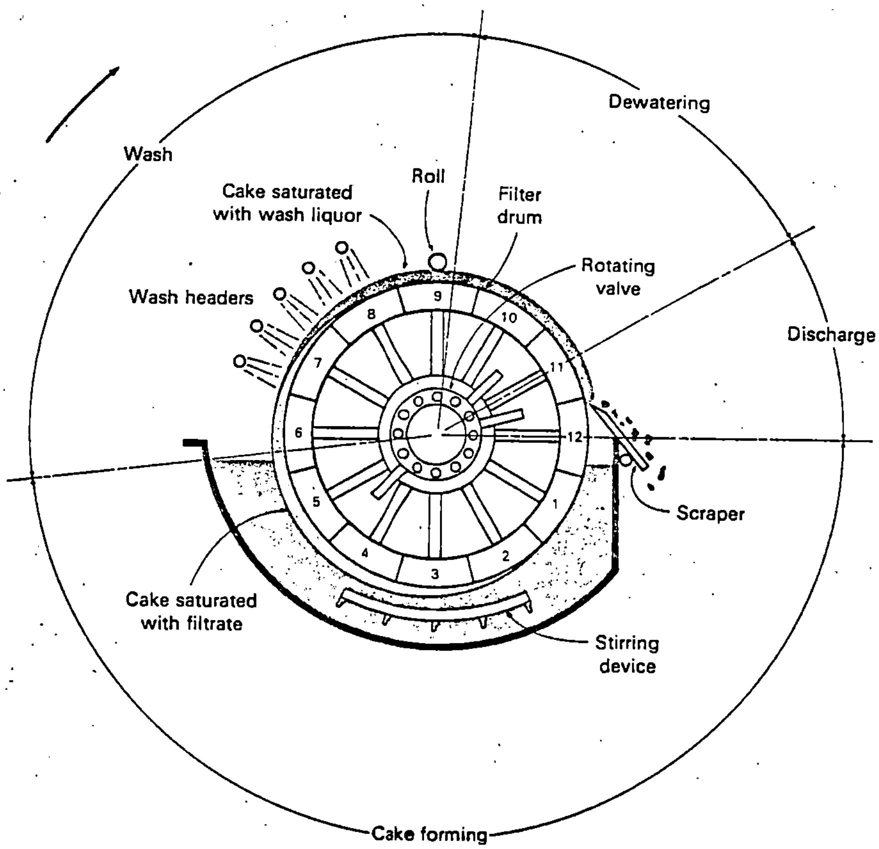

Fig. 3.2 OPERATION OF A ROTARY DRUM VACUUM FILTER

Source: Metcalf & Eddy, 1972

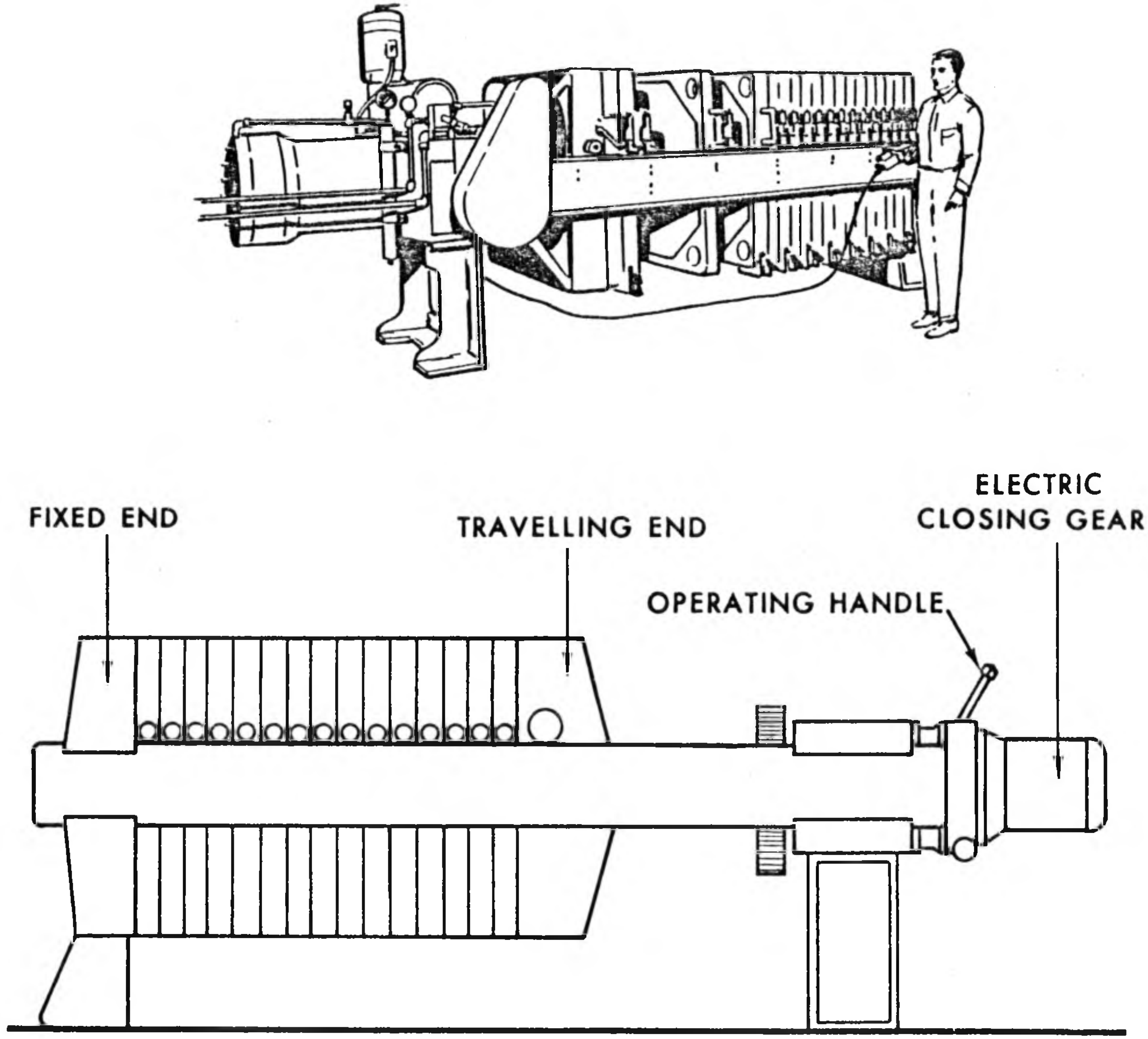

Fig. 3.3 SIDE VIEW OF FILTER PRESS

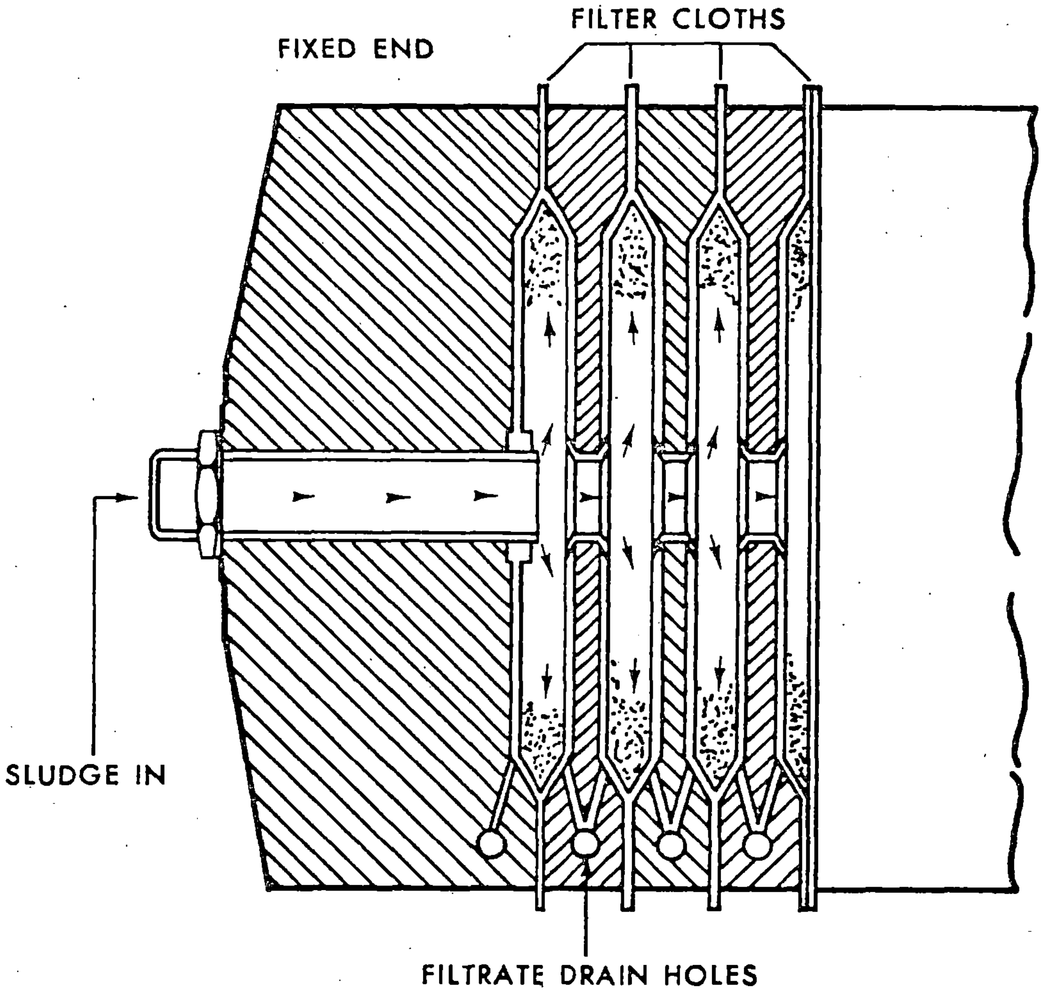

Fig. 3.4 PLATE & MEDIA STRUCTURE OF A FILTER PRESS

Source: EPA,1974

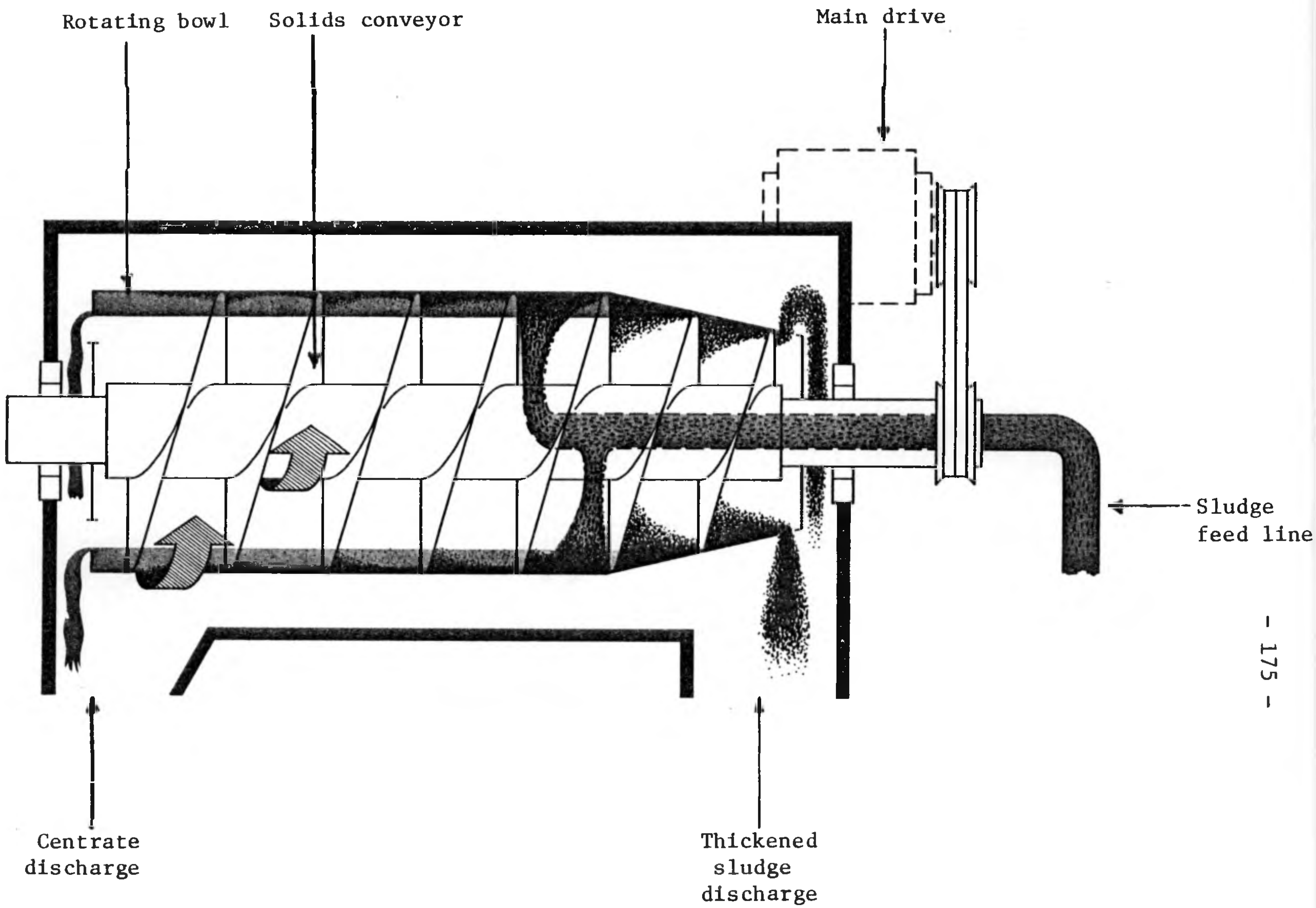

Fig. 3.5 COUNTERCURRENT SOLID BOWL CENTRIFUGE

Source: Pennwalt Corporation Bulletin 1287-B

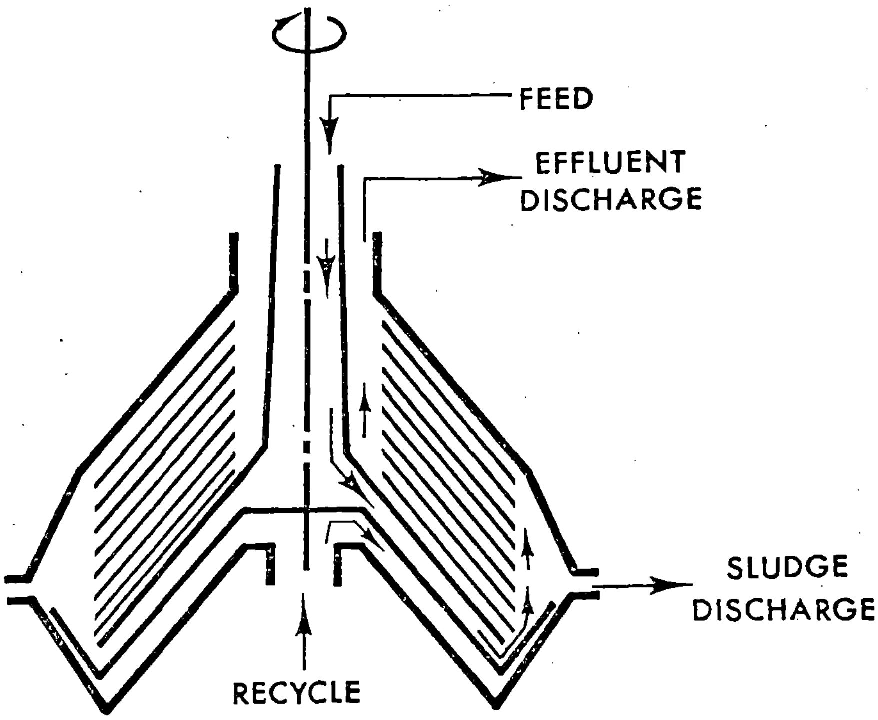

Fig. 3.6 SCHEMATIC OF DISC CENTRIFUGE
Source: EPA, 1974

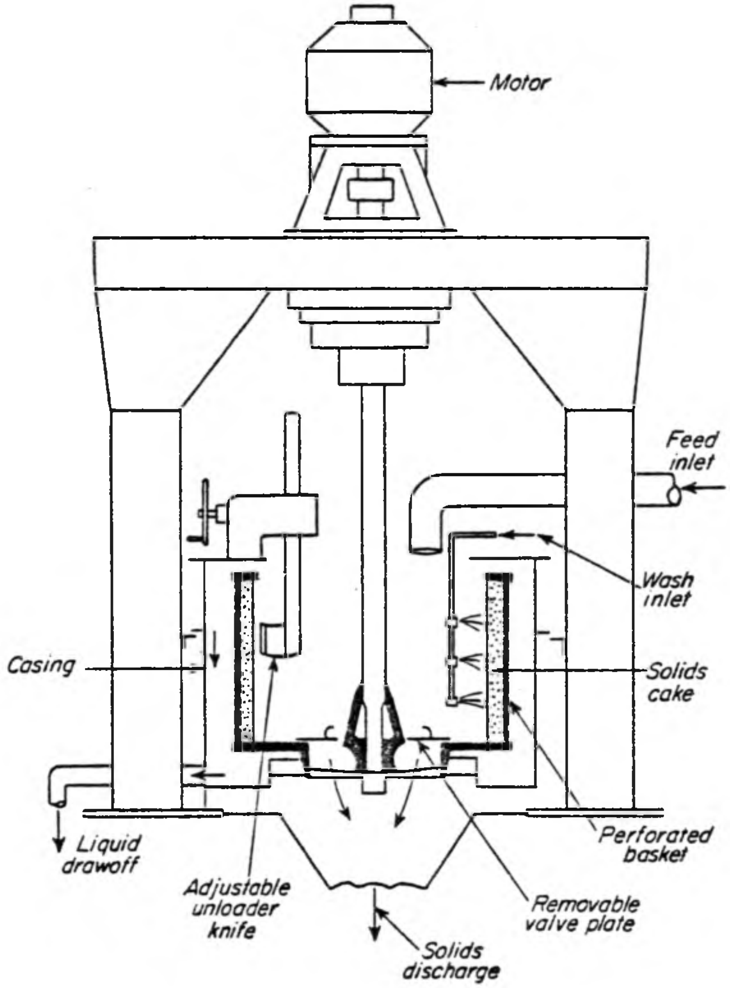

Fig. 3.7 CUTAWAY OF BASKET CENTRIFUGE

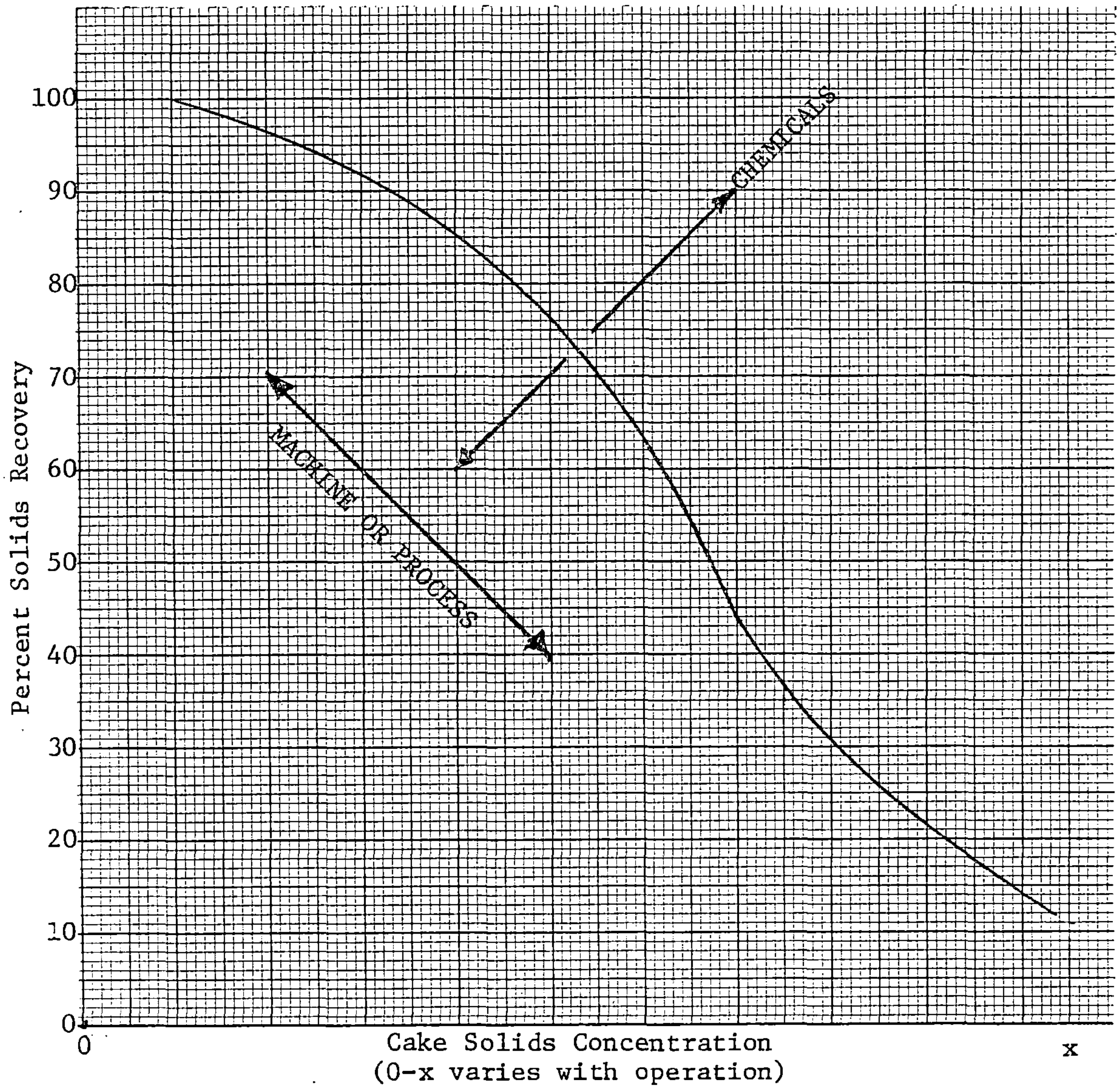

Fig. 3.8 SOLIDS RECOVERY vs CAKE SOLIDS CONCENTRATION
Source: Vesilind, 1974

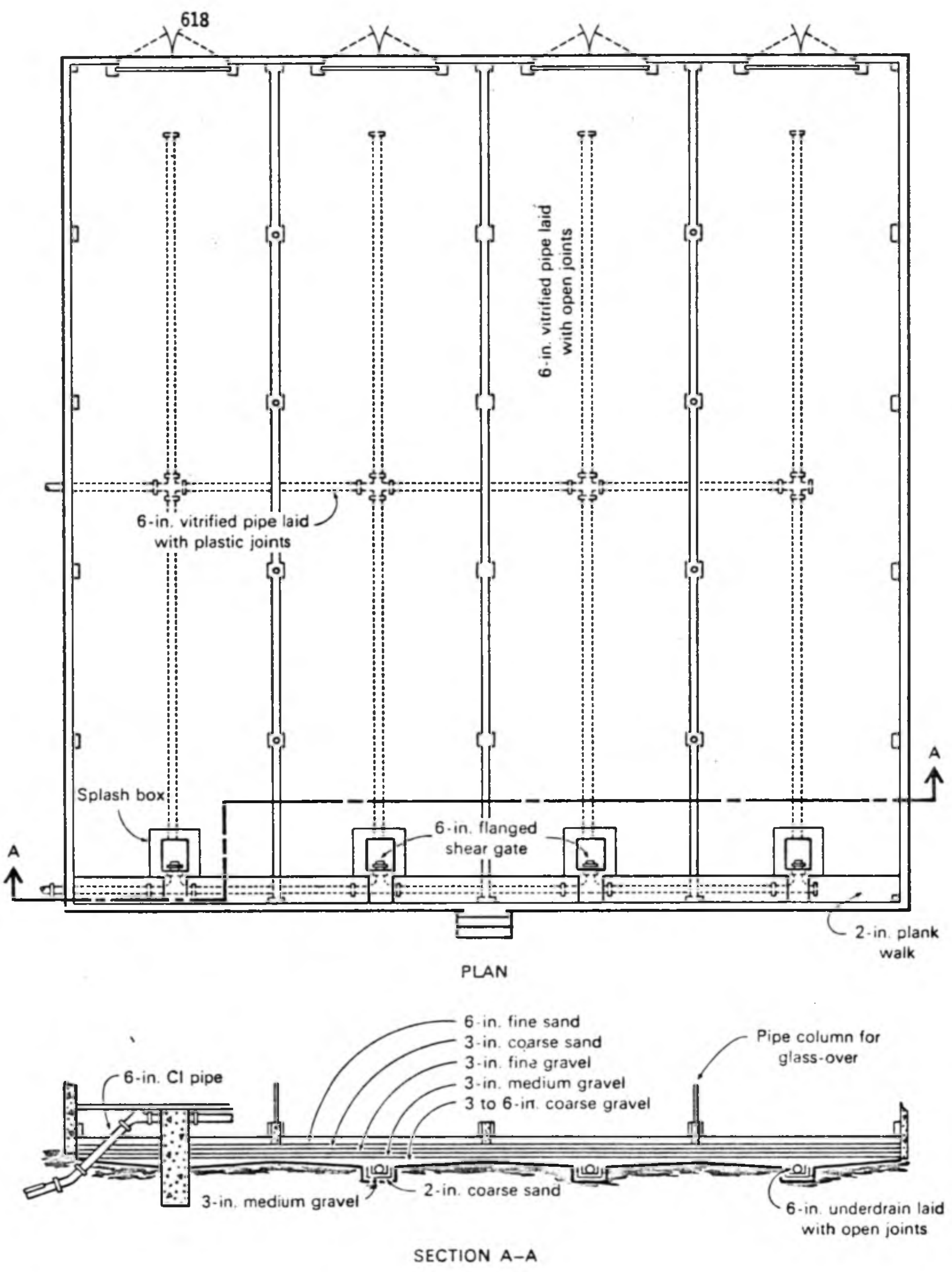

Fig. 3.9 SAND DRYING BED

Source: Metcalf & Eddy, 1972

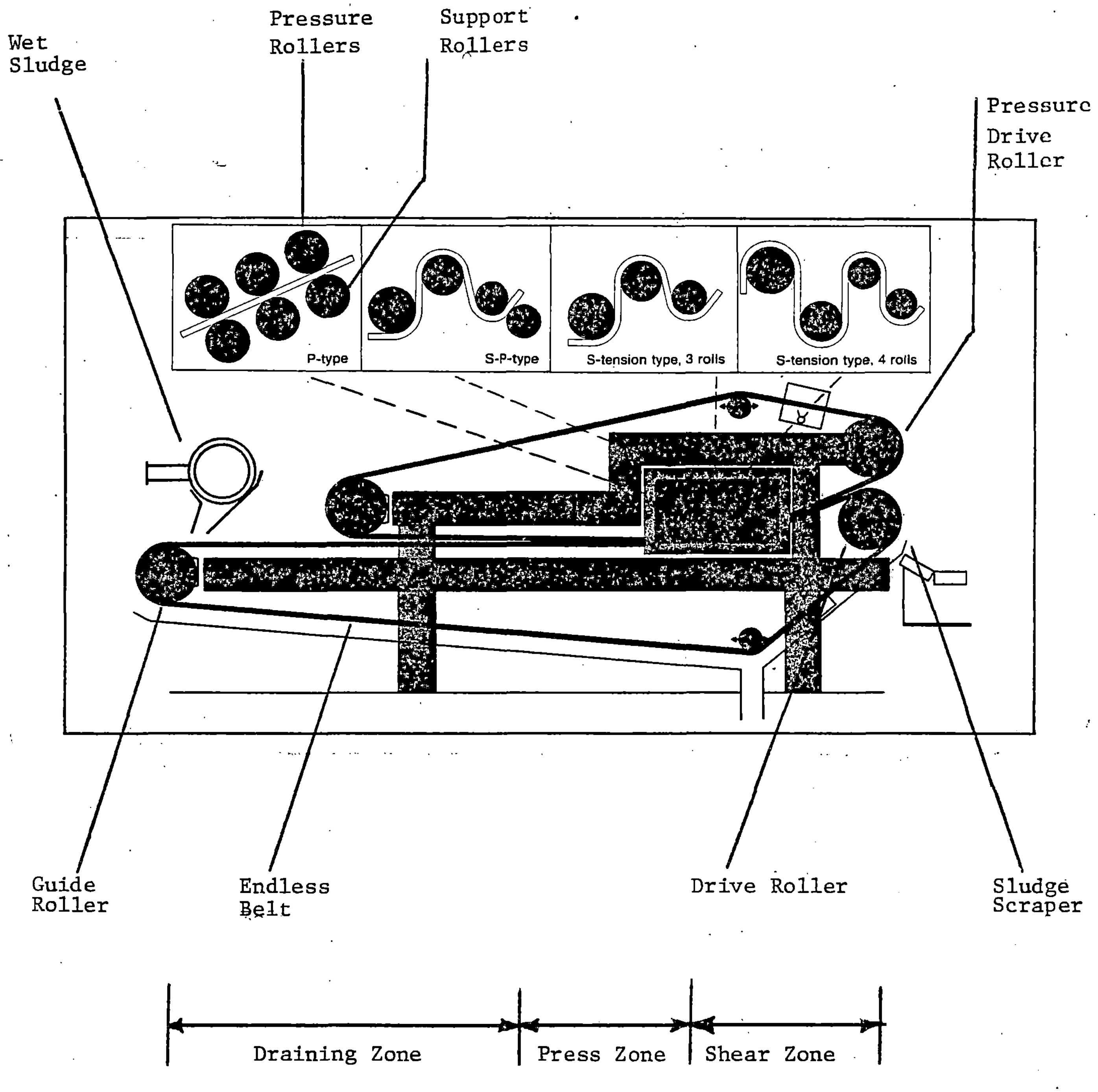

Figure 3.10 BELT FILTER PRESS

Source: Courtesy Control and Metering

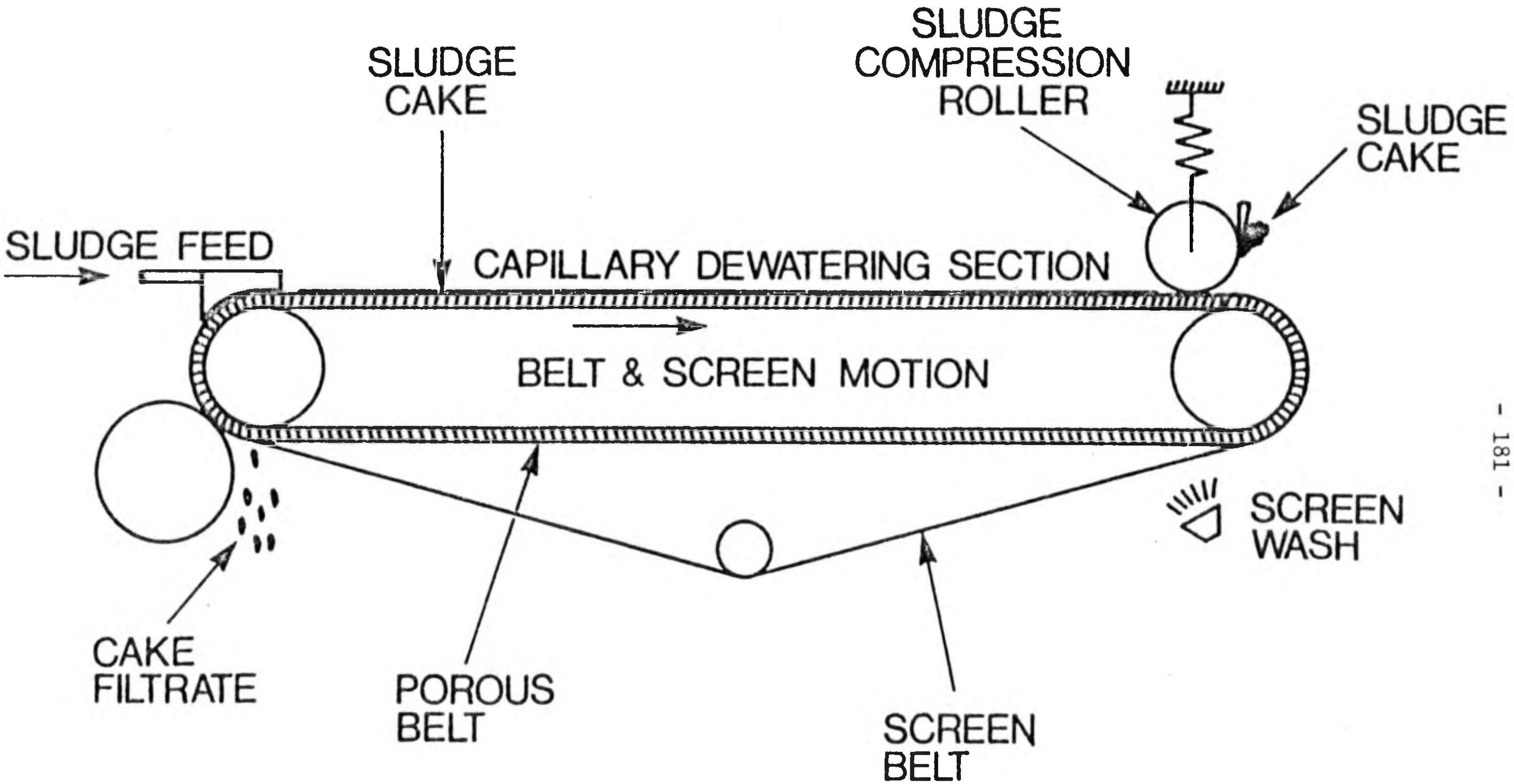

Figure 3.11 CAPILLARY DEWATERING SYSTEM

Source: Schroeder and Cohen, 1977

Section 4

COMBUSTION PROCESSES FOR SLUDGE REDUCTION

4. COMBUSTION PROCESSES FOR SLUDGE REDUCTION

As the volume of sludge to be processed increases, while at the same time land availability is decreasing, we will be faced with an over-abundance of sludge for landspreading and landfilling. In many areas, such as Metropolitan Toronto, the land scarcity is already in existence and sludge reduction has become mandatory prior to final disposal.

Combustion processes also play a role in the destruction and reduction of sludges which are not suitable for sanitary landfill sites or agricultural use. Sludges falling into this catagory would be those which contain high levels of heavy metals or organic pollutants such as PCBs. The combustion process produces biologically sterile sludge which can be safely deposited in landfill sites. In many cases, these processes also allow for material recovery and energy recycling.

The major combustion processes now available in a technology suitable for Canadian development, are incineration, wet oxidation and pyrolysis. Schroeder et al (1977) have indicated that incineration and wet oxidation are now well understood, but pyrolysis is still in its infancy. Technology is advancing so quickly in these areas that there is a type of incinerator oxidation unit or pyrolytic system available for almost every kind of sludge now produced in Canada.

There are advantages and disadvantages in each of the systems, and no one system is standard for all situations. Each process must be evaluated in terms of economic feasibility, availability of technical assistance and by-product recovery expected. Many of these systems are not suitable for small communities, however, centralization is a practical alternative.

Energy recovery from the combustion processes is one of the major advantages of this system over direct land disposal. The nature and quantitiy of energy recovery is variable for each separate case. Fluctuations are the result of quantity and dryness of cake, combustion process utilized and additional heat energy added (i.e. municipal refuse or auxiliary fuel). A more detailed dicussion on energy recovery systems is provided in Section 6 of this report.

Incineration, pyrolysis and wet oxidation have been on the industrial market for quite some time. The use of these systems for sludge disposal generally resulted from an adaptation of an existing industrial combustion process. Incinerators and pyrolysis units have received wide use in municipal refuse disposal and the petroleum industry, while wet oxidation units have been used extensively in extractive metallurgy and industrial waste disposal.

This section of the report briefly outlines each of the major combustion processes and equipment while pointing out the advantages and disadvantages of each system for a variety of municipal sludge disposal situations.

4.1 Incineration Incineration as described by Eckenfelder (1970) is a drying and combustion process in a single or combined unit which reduces the waste to combustion gases and sterile ash. This process is commonly the cheapest method of sludge disposal where suitable land is scarce.

Vesilind (1974) and the EPA (1974) have indicated that sludge must be effectively dewatered prior to incineration if one expects the process to be self-sustaining. It is also suggested that the sludge not be anaerobically digested, as this would reduce the heat value of the sludge. In most applications, the heat value is insufficient to attain self-sustaining combustion and auxiliary fuel is required. Approximations of the heat value can be determined by chemical formulae, such as the Dulong formula shown in Section 6. However, it is suggested that the heat value be determined calorimetrically. Self-sustaining incineration is not usually achieved until the solids content of the sludge exceeds 30 percent.

For incineration to be effective, the feed sludge should have a minimum 25 percent solids content. At this point, the heat derived from the combustion of the sludge just balances the heat demand to evaporate the excess water. Andrews (1967) reports that the fuel value varies approximately with the volatile content of the sludge and at 60 to 70 percent moisture the sludge can burn with little or no fuel. Clark et al (1969) report that raw primary sludge with 30 percent solids will self-combust at 7800 BTU/lb once the process has started. Jones et al (1977) indicate that at this dryness, fuel consumption should be less than two gallons of oil/capita/year, for a $1400^{o}F$ exhaust. LA/OMA (1976) have suggested that it may be beneficial to utilize the light fraction from shredding and air classification of solid wastes to increase the energy content of the sludge.

Initially, enough auxiliary fuel is required to bring the wastes to ignition temperature. Schroeder (1977) has given a definition of ignition temperature as "that temperature at which the heat liberated by the oxidation of fuel is evolved faster than it is conducted away". It is impossible for combustion to occur at less than ignition temperatures. The temperature must first be brought to $212^{o}F$ ($100^{o}C$) to evaporate the water from the sludge and then the temperature is increased to ignition (Eckenfelder, 1970). The economics of an incineration system will depend heavily on the moisture content of the sludge and the corresponding BTU content. As the BTUs decrease, the auxiliary fuel costs increase. Costs can also vary with sludge quantities, types of incinerators and the location of the sewage treatment plant.

Most incineration processes also require an excess of air, the amount depending on the elemental composition of the sludge. Schroeder et al (1977) have outlined the elemental oxygen requirements as shown in Table 4.1. Generally, 50 to 100 percent excess air is required, depending on such factors as sludge mixing. The more excess air used, the greater the amount of auxiliary fuel required, as the air tends to quench the combustion process. Heating the excess air can consume up to 25% of the available heat energy.

Proper control of the process will only allow a minimum of excess air. The effect of excess air and pre-heating the air is illustrated in Figure 4.1 and Figure 4.2, (Cheremisinoff et al 1975).

Kalinske (1976) has stated that the residue ash of an incineration process will be 15 to 45 percent of the original sludge weight. At 25 percent cake feed that ash volume would be 10 percent of the original volume. The volume reduction can be very beneficial where there is a landfill shortage.

The major incineration systems now utilized for sludge combustion are multiple hearth furnaces, fluidized bed reactors and rotary kilns. Each type has its specific operation parameters and advantages. These major processes are described further in the following sections. A summary of the different methods is given in Table 4.2, (Wyatt et al, 1975).

4.1.1 Multiple Hearth Incinerators The multiple hearth incinerator, as illustrated in Figure 4.3, is a steel cylinder containing several hearths constructed out of refractory bricks. The interior of the unit is completely lined with bricks to accommodate the high temperatures experienced. Furnace sizes range from 54 inches to 21 ft 6 inches in diameter and 4 to 11 hearths high.

The hearths are arranged in such a fashion that the sludge descends from the upper hearth to the lower hearths, moving from the inside of the first hearth to the outside of the second hearth. As the sludge reaches the edge of the first hearth, it drops to the second hearth. The movement of the sludge in this manner is aided by the rabble arms, which are teethed rods extending from a central rotating shaft. The rabble arms create grooves in the sludge such that it is continuously mixed and propelled laterally across the hearth.

Thomas (1972) has indicated that the action of the rabble arms is largely responsible for the even combustion experienced with the multiple hearth incinerator. Cheremisinoff et al (1975)have attributed the air cooling of the rabble arms to the higher demand for excess fuel to heat the cooling air. Without air cooling, however, the rabble arms would have a limited lifespan at such high temperatures. The EPA (1974) indicate that an effective area of 130 percent of the hearth can be achieved with the spiral ridges formed by the rabble arms.

The multiple hearth furnace can be divided into three distinct operating zones, separated by height. The top of the incinerator is the drying zone, which represents an incoming sludge of 160^{o}F and an exit air of 800^{o}F. The heat contained in the combustion air effectively dries the sludge. As the sludge descends into the central sections of the unit, the actual combustion begins to take place. At this point, the sludge and air are at 1500^{o}F or greater. The bottom sections of the incinerator allow for cooling of the sludge ash while exchanging heat with the incoming combustion air. In effect the unit acts as a self operating heat exchanger, in that the hot sludge heats the incoming air at the bottom and the hot air heats the incoming sludge at the top (Thomas, 1974; EPA, 1974). Sebastion (1975) reports that the heat exchange operation as such produces a dried sludge in the upper hearths of 48 percent moisture. This drying greatly reduces the auxiliary fuel requirements within the system. Metcalf and Eddy (1972) report that 1800 - 2500 BTUs are required to evaporate each pound of water in the sludge.

To aid in the combustion process, or for use in start-up of a self sustaining sludge, the furnace is fitted with a series of gas or oil burners. Andrews (1967) reports the use of oil burners in the upper hearths also to assist in the drying process. If the sludge is totally self-combustable, the burners can be shut off after start-up. Fuel used in the burners varies from fuel oil and natural gas to residual waste oils and methane from anaerobic digesters.

In order to artificially increase the calorific value of sewage sludge, some municipalities are adding the light fraction of municipal waste to the sludge prior to incineration. In London, Ontario, James F. MacLaren Ltd., are evaluating the addition of newsprint pulp to activated sludge prior to incineration. In a study, described by Morris (1977), funded by CMHC, the City of London has been evaluating the use of newpaper pulp and organic polymers as compared to lime or ferric conditioning. With a fixed polymer dose it has been found that a 27 to 32 percent pulp solids to dry sludge solids is optimum. Operation at less than

35 percent pulp addition shows up as a considerable increase in filtrate suspended solids going from the vacuum filter to the treatment plant. To date there have been no direct savings between lime - ferric conditioning and newsprint-polymer, but there has been a savings of $148,000 per year in auxiliary gas and a 40 percent savings in ash removal costs for a total savings of $180,000 per year. These studies were all carried out on a 6 hearth Nicholson furnace receiving sludge from air floatation thickening and vacuum filtration.

Cheremisinoff et al (1975) report that units are available for operation in the ranges of 500 to 2500 pounds of sludge per hour as dry solids. Shannon et al (1974) indicate that normal sludge loadings are in the range of 7 to 12 pounds of dry solids per hour per square foot of hearth. The actual retention time required for combustion in thse furnaces will depend on the exact nature of the sludge. The combustion time is controlled by the sludge feed rate into the reactor. Vesilind (1974), also reports the use of rabble arm rotation rate as a method of controlling combustion time. The rabble arms control the rate at which the sludge crosses the hearth.

Once the incineration process is completed, the ash is directed out of the furnace and into a cool down area. In most cases, the ash is dumped into a lagoon for quenching. If quenching is practiced, then at some time the lagoon is drained and the ash is loaded into trucks for hauling to landfill. Wyatt et al (1975) report the use of multiple hearth incinerator ash for landfill, filter aids in sludge treatment and in the production of construction grade concrete.

The EPA (1974) and Wyatt et al (1975) have indicated that the multiple hearth incinerator is the most common incinerator for sludge disposal as it is simple, durable and capable of burning a wide variety of materials at various feed rates. Schroeder (1977) reports that these furnaces can handle substantial fluctuations in the feed rate to the system. Schroeder also reports that this type of furnace is advantageous in that no odours are emitted from the system, as the gases are not released from the sludge until 80 to 90 percent of the water is gone, and this occurs only in the lower furnace sections where the temperature is approaching 2000°F. Disadvantages of multiple hearth furnaces that have been reported, are that they are not heat efficient, they can not handle a sticky sludge, and they require careful heating and cooling periods to avoid damage to the fire brick areas, (Cheremisinoff et al, 1975; EPA, 1974). Heat-up and cool-down periods can be as long as 24 to 30 hours.

4.1.2 Fluidized Bed Incinerators The fluidized bed incinerator, as illustrated in Figure 4.4 has been introduced to the sludge incineration field from the petroleum industry. This type of reactor was originally used for catalytic cracking in oil refining. It is now available for sludge incineration in capacities of 220 - 5,000 pounds per hour/dry solids.

The fluid bed incinerator, as described by Schroeder (1977), consists of three major sections, namely the windbox, the fluid bed zone and the disengagement zone. The zones are housed within a fire brick lined cylindrical shell. The windbox is the lower section of the incinerator where the air is admitted at 3.5 to 5.0 psig. The upward rising air fluidizes the sand bed. The fluid bed zone is separated from the windbox by an orifice plate and contains about 3 feet of 0.1 to 0.2 inch select silica sand, (Shannon et al (1974). The top section of the incinerator, referred to as the expanded freeboard or disengagement zone, is an empty space which creates a retention time for the volatile gases, allowing them to combust.

Cheremisinoff et al (1976) indicate that there are three major types of fluidized incinerators. Depending on the preparation of the incoming air, the units are classified as a cold windbox, a hot windbox, or a cold windbox with a waste heat boiler. In the cold windbox, the air is directed upward through the bed of sand. The dewatered sludge and auxiliary fuel are introduced directly into the bed of sand. The hot windbox operates in a similar manner, except that the cold air is passed through a gas/gas heat exchanger. The flue gases are capable of preheating the incoming air to 800 - 1200°F (427 - 650°C).

The use of the heat exchanger increases the thermal efficiency of the unit and provides 20 percent of the required heat. The last unit is a cold windbox in which the flue gas heat is extracted in a waste heat boiler to generate steam, which is then used for heat, power, or rotary equipment. The amount of steam available by this method is indicated in Table 4.3.

The EPA (1974) indicate that an air preheater such as that described above, can reduce fuel costs by as much as 60 percent. The capital costs of such an addition will normally amount to 15 percent of the furnace cost. Because of the high capital cost increase, they suggest that an economic study be completed for each case to determine the feasibility of an air preheater. As the cost and scarcity of fuels continue, it appears safe to assume that an increase in the use of air preheaters can be expected.

If a waste heat boiler is to be considered, rather than a heat exchanger, then Perkins et al (1977) suggest a feasibility study for the project. Generally, this addition is not economical unless the treatment plant is greater than 10 mgd. A study of the quantities and demand for steam should also be made. The steam may be used for process heat, building heat and power generation, or there may be no demand for it at all. In general, it becomes a matter of cost effectiveness of the steam users, for example, the cost of alternate heat sources, on site versus off site steam use and the feasibility of converting steam to electricity. The same fundamental philosophy will apply to any system in which energy recovery is being considered.

If a heat recovery system is to be utilized, then Kalinske (1976) has recommended that a cyclone be used on the flue gases, as this gas is generally very abrasive due to the fly ash and sand content. The EPA (1974) also commented on sand losses, indicating that losses by abrasion and disintegration amounts to about 100 pounds per month for a 100 pound per hour dry solids unit. As the excess air increases, there will be a corresponding increase in sand loss from the system.

Vesilind (1974) has stated that the fluidized bed requires only 20 percent excess air, which is considerably less than that required by a multiple hearth. The air supply to the system, however, must be great enough to expand the bed and give the proper density (EPA, 1974). The EPA also warn that an excess of air will blow the sand and organics out of the flue and thus there will be incomplete combustion. Operation in this manner will not only result in inefficient combustion, but will also deplete the stored heat energy in the sand bed.

The temperature of the sand bed has been reported by Eckenfelder as 1400 - 1500^{o}F (760 - 815^{o}C), which provides for rapid drying and burning of the sludge. Supplemental fuel is supplied to the unit by burners located above or below the windbox grid. Since all gases must flow through the 1500^{o}F zone for several seconds, the effluent gases are sterile and odour free. Because the sand provides a large heat reservoir, this type of incinerator requires less fuel for start-up if the unit has been shut down for short periods, Most installations can be operated on an 8 hour shift with little heat loss during the night period. The sand also provides a greatly improved heat transfer as it contains up to 16,000 BTU/ft^3 as compared to 16 BTU/ft^3 for normal incinerator combustion gases. The fluid bed thus provides an ideal environment for the thermal oxidation of most organic waste materials.

Solids are removed from the fluidized bed by the flue gases exiting out of the top of the incinerator. The gases are normally scrubbed with the effluent of the associated wastewater treatment plant. Hydrocyclones are then utilized to separate the solid/liquid phases.

In a recent study by Perkins et al (1977), it was stated that overall the fluid bed incinerator was thermally efficient despite the high off gas temperatures because of the low excess air requirements. The thermal efficiency of the multiple hearth furnace on the other hand is poor because of the high exhaust temperature required to reduce the hydrocarbon emissions (i.e. PCBs) in conjunction with the 100 to 200 percent excess air requirements.

In a comparison of fuel requirements by Perkins et al (1977), it was found that the multiple hearth, with 100 percent excess air and 1100^{o}F, (593^{o}C), required less auxiliary fuel than a cold windbox fluidized bed incinerator. The requirements were 4.8 x 10^6 BTUs and 5.3 x 10^6 BTUs, respectively. The amount of recoverable heat however, was greater for the cold windbox making the net energy demand less for this system. If no auxiliary fuel is required, the cold windbox definitely has a much less net energy demand.

Several advantages and disadvantages of the fluidized bed system have been reported in the literature. A summary of these points follows (Schroeder, 1977; Cheremisinoff et al 1976; Jones et al, 1977; Kalinske, 1976; Cheremisninoff et al, 1975; EPA, 1974; Wyatt et al, 1975; Metcalf & Eddy, 1972; Vesilind, 1974).

Advantages Include:

1. small excess air is required due to the large degree of turbulence in the furnace,
2. there are no moving mechanical parts,
3. there is rapid and efficient heat transfer,
4. the sand provides a large heat sink,
5. violent boiling of the sand bed provides a uniform temperature throughout,
6. good thermal efficiency is achieved,
7. ash is available for use as a filter aid,
8. the process can handle a liquid sludge as well as a dry sludge,
9. the unit has a lower capital cost in the small community sizes,
10. start-up periods are rapid,
11. the incinerator can be run efficiently on a 4-8 hour day with little reheating,
12. the system operates under low pressure,
13. ash is automatically removed in the flue gas,
14. odour control is automatic at a bed temperature of 800^{o}C,
15. these units can be batch operated.

Disadvantages reported include:

1. a separate system for flue gas solids separation is required,
2. maintenance problems are common with air preheaters,
3. spray nozzles and thermocouples are susceptible to burnout,
4. the size is limited by the ability to feed the sludge cake uniformly,
5. fuel requirements are higher than a multiple hearth as combustion temperature is higher (800^{o}F vs 1400^{o}F),
6. operating costs are higher than the multiple hearth, and
7. problems are associated with the sand media causing scaling and abrasion.

4.1.3 Rotary Kiln Furnaces The Rotary Kiln Furnace is not nearly as popular for sludge disposal as the multiple hearth or fluidized bed. The rotary kiln used is similar to that used extensively in powder metallurgy and similar industries. Basically, the unit consists of a waste feeder, sludge feeder, kiln, burner package and afterburner. A schematic of a kiln unit is as shown in Figure 4.5.

This type of unit is available in sizes handling 40 to 2400 pounds pounds per hour of dry solids. The units are mounted on an inclined plane and are internally baffled to ensure adequate mixing of the sludge. The units rotate slowly via a periphery drive system.

The sludge enters the upper end of the kiln and then flows concurrently with the flow of combustion air. The hot flue gases and ash exit from the lower end of the furnace at, or near, combustion temperature. Auxiliary heat is provided for the system by burners situated at either end of the kiln, or along the sides. Auxiliary fuel requirements will be similar to those for the previously mentioned devices, with fuel requirements dependent on moisture and organic content of the sludge. Because the cylinder is difficult to insulate, Thomas (1972) has indicated that auxiliary fuel requirements will be higher than the better insulated multiple hearth or fluidized bed.

Advantages of the rotary kiln have been listed by Schroeder (1977) as the ability to utilize a wide range of loading rates, the simplicity of design and the relative lack of maintenance required. Disadvantages cited include the inefficient control of excess air, the frequent need for an after burner to eliminate smokey off gases, the tendancy of the sludge to ball up, the high heat loss and the generally poor thermal efficiency.

4.2 Wet Oxidation The process of wet oxidation has been described by Andrews (1967) as a process of oxidizing organic matter to the same end products as incineration while the waste is still in a liquid form. Schroeder (1977) has stated that any combustible substance can be chemically oxidized in an aqueous phase by dissolved oxygen in a specially designed reactor at elevated temperatures and pressure. The process has been suggested for hard-to-dewater sludges or sludges with a solids concentration of less than 5 percent (Kalinske, 1976; Wyatt et al, 1975). The system is efficient for these types of sludge as there is no requirement for dewatering prior to combustion. This process thus reduces capital and operating costs associated with dewatering equipment.

Most of the literature on wet oxidation indicates that it is applicable to sludges in the range of 3 to 6 percent solids. The EPA (1974) have however stated that wet oxidation can treat wastes having up to 99 percent water. Cadotte et al (1976) have shown that above 6 percent solids excess heat is generally produced which can be efficiently and economically recovered. Cadotte et al also state that above 20 percent solids, there is so much heat produced that the system may boil dry. For sludges of this nature, incineration should be evaluated.

In small communities where landspreading is not feasible, Seto and Smith (1975) have suggested wet oxidation should be considered as a viable alternative. Operation of small batch units in these instances would make wet oxidation a more feasible alternative to incineration, especially if incineration of municipal refuse is not practiced. Sommers et al (1976) have indicated that low pressure wet oxidation decreases the use of sludge as a fertilizer, as the nitrogen is effectively removed, and thus use of wet oxidation in conjunction with land disposal is not an efficient alternative. The ash produced is sterile and thus is suitable for landfilling.

Since the wet oxidation process is carried out in a liquid phase, there is minimal air pollution. The gases are automatically scrubbed by the effluent before they escape into the atmosphere. Due to the scrubbing effect, however, two associated problems arise with separating the ash from the liquid phase and treating the liquid phase before discharge. The wet oxidation reactions produce a liquid effluent with a high organic and nitrogen content and this must be re-treated in the sewage treatment plant. If the plant cannot accept the increased load, it may be necessary to pretreat the oxidation effluent before it is recycled to the main plant.

The two major wet oxidation units are the Barber-Colman System and the Zimpro System. The highlights, advantages and disadvantages of each are described in the following sections.

Since the Barber-Colman unit has not been operated to any great extent on a full scale basis, most of the advantages and disadvantages of wet oxidation have been based on the operation of the Zimpro unit. Schroeder et al (1977) have listed the advantages of wet oxidation over incineration as:

1. the feed is not dried or dewatered,
2. the operation is self sustaining at greater than 5 percent solids,
3. the combustion gases are particulate free,
4. the final product is sterile, and
5. the suspended solids of the effluent can be separated easily.

In a separate paper, Schroeder (1977) listed the general disadvantages of wet oxidation as:

1. the liquor must be recycled to treatment,
2. pre-treatment of liquor may be required prior to recycle,
3. odours arise from off gases in lagooning out solids,
4. the units are subjected to frequent shutdowns and maintenance,
5. safety problems arise with high temperatures and pressure, and
6. high capital and operating costs can be expected.

4.2.1 Barber-Colman Wetox The Barber-Colman wet oxidation unit operates at a temperature of 480^{o}F and 600 psi. These values are considerably lower than those utilized with the Zimpro System and as such offer significant advantages. The operation at the lower temperature and pressure is the result of the design of the Barber-Colman reactor.

The Barber-Colman unit is a horizontal chamber divided into a series of mixed compartments. The Zimpro System on the other hand is a vertical unit with no compartments or mixing. Seto and Smith (1975) have indicated that the stirring in each compartment leads to an increase in the effective interfacial area for mass transfer of oxygen. The stirring at 1200 RPM also provides swift eddy currents that delay the escape of air bubbles and maintains the solids in suspension, Rapid mixing also creates turbulent shear conditions which aids in solids breakdown. The compartments within the reactor provide an increase of efficiency and minimum short circuiting in the reactor. Division into compartments also allows the operator to run the reactor under different conditions within each compartment. Unfortunately, the mixers require frequent repacking of the drive shafts, thus increasing operating costs. Installation of the baffled compartments can also increase the capital and operating costs. These added costs must be weighed against the alternative costs of operating at higher temperatures and pressures.

The actual Wetox reactor operates significantly better with 2 gms/litre H_2SO_4 added, and this in conjunction with the pressures and temperatures experienced can lead to excessive corrosion. For this reason, the small units are constructed of titanium and the larger units ($\geq$ 16 tons) are steel, lined with acid resistant bricks.

It has been shown that the more sulphuric acid added, the higher the rate of oxidation and thus the lower chemical oxygen demand in the effluent. Acid also inhibits scaling in the reactor and heat exchanger. Acid addition does however increase the operating costs and the concentration of sulphates in the effluent. The acid also leaches out heavy metals and phosphates in the sludge which will allow these to be returned to the treatment plant. Lime treatment can be added to neutralize the acid and precipitate the heavy metals, phosphates and sulphates. The combined Wetox plus lime treatment is known as the "PURETEC" System and is outlined in Figure 4.6.

Optimum operation of the Wetox reactor is dependent on the temperature, pressure and the rate of oxygen transfer into the liquid phase. The temperature must be high enough to start the liquid combustion. The pressure must be high enough that the effluent air will not carry away the liquid phase. The oxygen transfer rate must be greater than or equal to the oxygen consumption rate. These conditions apply equally as well to operation of the Zimpro unit.

Cadotte et al (1976) have stated that the temperature selected is a trade-off of high temperature and increased contaminant removal balanced against increased corrosion rates and higher operating pressures. Both the latter features cause an increase in the process costs. The operating pressure within the reactor is set by the operating temperature as it must be sufficient to confine the steam.

Once the oxidation process is completed, the vapour and liquid effluent must be discharged from the system. The Barber-Colman System, unlike the Zimpro process, exits the effluent streams separately, that is,a gas and liquid phase effluent.

Seto and Smith (1975) report a vapour/liquid ratio of about 1:2. Each stream is separately withdrawn from the last compartment and fed to a heat exchanger, the heat exchanger thus acting also as a condensing unit for the vapour phase. Alternatively, the vapour phase can be utilized for power generation. The excess heat from the liquid and vapour phase is used to preheat the incoming sludge, prior to injection into the reactor.

Overall, the Barber-Colman unit is simple to operate and quite suitable for sludge combustion. The Barber-Colman unit is cheaper than the Zimpro for sludge disposal in addition to being easier to operate. For small situations,it is also possible to operate a semi-batch reactor, thus eliminating costs associated with high pressure pumping on feeding systems.

The semi-batch system for small scale sludge disposal is as depicted in Figure 4.7. The continuously operating 4-10 unit is illustrated in Figure 4.8

4.2.2 Zimpro High Temperature Wet Oxidation The operation of the Zimpro unit is generally similar to that of the Barber-Colman unit but their respective designs are quite different. The Zimpro unit, as illustrated in Figure 4.9, utilizes a vertical, unstirred reaction tank, whereas the Barber-Colman System has a horizontal, stirred reactor.

The major difference in the operating conditions is an increase in both the operating temperature and pressure of the Zimpro reactor. Kalinske (1976) reports an operating range for the Zimpro reactor from 500 to 700^{o}F and 1000 to 2000 psi. The Zimpro unit also differs from the Barber-Colman process in that the effluent from the reactor is a combination of the liquid and vapour phases. The effluent must thus pass to phase separation. The liquid phase containing the ash goes to a heat exchanger where incoming air is preheated and the oxidized liquid effluent is partially cooled prior to discharge.

In general, the results attainable with the Zimpro process appear to be similar to those achieved with the Barber-Colman apparatus. The selection of the best alternative will most likely be based on the size of the treatment plant and the cost comparison between the two. Both capital and operating costs must be evaluated in such a comparison.

Van Amstel (1971) has clearly stated that the major difference between the two processes will most likely be the mass transfer of oxygen into the reactor liquor. The degree of diffusion limitation of the oxygen, or the extent to which the conversion rate is reduced by oxygen transfer will depend on the temperature, once the temperature exceeds 180^{o}C (365^{0}F). Van Amstel reports that above 290^{o}C (554^{o}F), the conversion rate is largely determined by the rate of oxygen transfer. Unlike the Barber-Colman process, there is no mixing to aid mass transfer and thus a higher temperature must be used to achieve the same level of oxidation. Clark et al (1969) indicate that force feeding, an addition of oxygen above that required for combustion will not accelerate the process. The best alternative, then, is to use the minimum amount of oxygen but assure efficient transfer. The EPA (1974) have also indicated that the air supply must be optimized to assure combustion without the penalty of heating excess air.

Pradt (1972) has provided a graph depicting the dependence of the COD of the effluent based on the operating temperature of the reactor. This plot has been reproduced here in Figure 4.10. Pradt indicates that near complete oxidation of most substances occurs at 320^{o}C (608^{o}F).

As with the Barber-Colman process, the Zimpro process releases carbon and nitrogen into the liquid effluent, and thus this stream requires further treatment prior to discharge. Kalinske (1976), reports ammonia nitrogen levels of 1000 to 1800 mg/l and a BOD_5 of the liquor from 2000 to 10,000 mg/l. Andrews (1967) has indicated that the effluent stream is similar to that of an anaerobic digester, with the BOD_5 composed mainly of volatile organic acids. Kalinske (1976), states that this liquor can be biologically treated, however it may require the addition of phosphorus, as the phosphorus is often removed during the solids-liquid separation process.

If the ammonia nitrogen level is high enough, it has been reported that recovery of ammonium sulphate can be practical (LA/OMA, 1976). This report also suggests the recovery of heavy metals from the wet oxidation filtrate.

Hudgins et al (1973) studied the effect of the Zimpro process on chemically treated sludges and found a minimum 50 percent total organic carbon removal at 260^{o}C (500^{o}F). The work indicated that carbons from the chemical stabilization of sludge act as catalysts in the wet oxidation process. With lime treatment of sludge, carbonate fouling of the reactor was a problem. Where phosphorus removal had been practiced, the phosphorus stabilization was reversed giving a ten-fold increase in filtrate orthophosphate. It was suggested that wet oxidation not be used for lime sludges as the carbonate was stable at operating temperatures and fouling persisted. Sludges containing iron salts from ferric chloride or ferric sulphate showed the greatest catalyses effect with the most rapid oxidation.

As with the Barber-Colman reactor, it was found by Nicholson _et al_ (1966), that at a population of 22,000 or a 2.2 mgd treatment plant, then batch treatment might be more useful. The batch unit eliminates the need for high pressure sludge pumps, heat exchangers and a sludge grinder. It was estimated that a batch process would last 16 to 19 hours on 5700 gallons of sludge.

If energy recovery is a prerequisite of the sludge processing system, then a steam generation or power generation system can also be installed. Again, economics and demand will be a key factor in determining which system to utilize. The two alternative systems as suggested by Pradt (1972) are illustrated in Figure 4.11 and Figure 4.12.

One final note of caution for high pressure Zimpro units. It has been reported in the literature that several accidents have occured from ruptured high pressure steam lines. The installation in Chicago was discontinued for this reason. (Wyatt _et al_, 1975; EPA, 1974). The safe use of pressures greater than 2000 psi in other industrial applications indicates that this is a problem of poor engineering design, rather than the fault of the system.

4.3 _Pyrolysis_ Pyrolitic combustion or "destructive distillation" is described by Cheremisinoff _et al_ (1975), as a combustion process whereby the waste is heated in an oxygen deficient atmosphere resulting in a solid char residue of carbon and ash, condensable liquid and organics and a gas with some heating value. Wyatt _et al_ (1975), indicate that pyrolysis also occurs under pressure as well as in the absence of oxygen. Although not as popular for sludge combustion as incineration and wet oxidation, it is becoming more competitive, especially in light of the fuel value of the waste char. Originally, the process was used in the conversion of coal to coke and in the production of charcoal and methanol from wood and coal gassification (Colosi _et al_, 1976; EPA, 1974). In these processes, the waste is raised to a temperature at which the volatile matter will distill off leaving only carbon and inert materials behind. The carbon and volatiles do not burn because there is an oxygen deficiency, however if combustion is required the volatiles can be burnt off in an excess air secondary chamber.

McIntyre et al (1974), have outlined the four distinct phases of combustion in the absence of air as:

0 - 200°C - organics dehydrate.
- H_2O, traces of CO_2, formic acid, acetic acid and glycerol evolved.

200 - 300°C - organics converted to char as production of above chemicals continued.

300 - 500°C - highly exothermic reactions to produce carbon monoxide, hydrogen, tar, methane, formaldehyde, formic acid, acetic acid and ethanol.

500°C - gas and char react to form a highly combustible end product.

Although the stages described above are those occuring in the destructive distillation of wood, they also apply to the pyrolysis of the cellulose matter in the sludge. A summary of the yields from pyrolysis of dried activated sludge is given in Table 4.4, (Olexsey, 1975).

Wyatt et al (1975) indicated that pyrolysis was being used on a limited basis only and it was generally being used on municipal refuse, not sludge. Results from sludge pyrolysis operations showed that the same end products are achieved but a 70 to 75 percent lower BTU gas is recovered. Folks et al, 1975 (in Dick, 1976) stated that digested sludge produced a char with a low BTU value since the volatiles are removed during digestion leaving a mainly inorganic residue.

A schematic layout of a pyrolysis unit, utilizing sludge drying, has been given by Colosi et al (1976). This is shown in Figure 4.14. A corresponding addition of a waste heat boiler and steam turbine for the above configuration is given in Figure 4.15. Colosi et al suggest that such a unit can be operated to recover usable energy at the site, but generally not enough to show a profit. The authors state however, that addition of an energy recovery system could aid in reducing the overall cost of sludge disposal. In the scheme outlined, the filter press is expected to produce a cake having up to 40 percent solids. As discussed in section 6 of this report, it is often advantageous to consider a centralized unit for a number of treatment plants, thereby increasing the cost benefits of such a system.

Takeda et al (1977) have outlined a sludge pyrolysis system incorporating combined pyrolysis and combustion. In this case, a double hearth incinerator is used. The pyrolysis stage greatly improves the sludge incineration. At 450°C, they report that the bulk density of the feed is reduced by about 50 percent. Colosi et al (1976) have indicated that a multiple hearth unit can be fairly readily converted into a pyrolysis unit, thus allowing for a shift in technology without a shift in equipment.

Wyatt et al (1975) have outlined a pyrolysis system in which the sludge is not used directly. In their scheme, they suggest an anaerobic digester which produces methane which fires a pyrolysis unit for municipal refuse. The heat from the pyrolysis unit is then used to heat the digester. Char produced in the pyrolysis of refuse is utilized as a filter aid in the sludge dewatering step. The char may also be suitable for activated carbon in water polishing or use as an incinerator fuel. If the char is of poor quality it may only be suitable for landfill.

The use of char for the production of activated carbon is to be evaluated at the Huntington Beach Treatment Plant in California (Weismantel et al, 1975). This possibility is also being studied by NASA for a totally integrated system (Poradeck, 1976).

In order to illustrate the advantages of pyrolysis over direct incineration of sewage sludge, Lewis (1975) conducted a thermodynamic analysis of the different processes. In the material and energy balances, as shown in 4.16 through 4.19, the material and heat are accounted for only when they cross the system boundary. Internal recycle loops do not affect the overall heat and material balance. Excluded from the study was any heat and mass transfer operations taking place in the flue gas scrubbers. Included in the evaluation were the inputs and outputs of the systems, which are:

A. Inputs:

1. sludge
2. combustion air
3. auxiliary fuel

B. Outputs:

1. flue gas
2. ash
3. draft cooling air (multiple hearth only)

In comparing the auxiliary fuel use, assuming a 25 percent sludge input, it is evident that the multiple hearth pyrolysis reactor consumes the most auxiliary fuel, and as such is an indication of improper process design. This casts some doubt on the statement by Colosi et al, that the multiple hearth units can readily operate as pyrolysis units. Following this unit in total auxiliary fuel use was the normal multiple hearth, the fluidized bed and finally the pyrolysis reactor. It is assumed here that the multiple hearth incinerator requires an after burner to raise the 800°F (427°C) exhaust to 1400°F (760°C) required for odour and PCB destruction. A summary of the auxiliary fuel uses from Lewis's study is presented in Table 4.5. Note that wet oxidation has not been included in this study because it is not a "dry" combustion process.

Generally, pryolysis of sewage sludge appears to be a viable alternative to incineration and as such is apt to be more predominant in the coming years. Advantages of pyrolysis have been given as (Cheremisinoff et al, 1975; EPA, 1974; Poradek, 1976; Takeda et al, 1977).

1. low temperature pyrolysis minimizes vaporization of heavy metals whereas high temperature incineration increases this,
2. sludge pyrolysis produces hydrocarbons which may be utilized as a new energy source,
3. pyrolysis char may be utilized to produce powdered activated carbon,
4. general air pollution is less from a pyrolysis unit than an incinerator, and
5. other saleable by products can be recovered such as acetic acid, methanol and mixed solvents.

4.4 CMHC CANWEL Process

The solid waste treatment system of the CANWEL Process (Canadian Water Energy Loop) is a starved air incineration process designed to handle garbage production and sludge production for a total community. Sludge production in this case includes reverse osmosis brine, primary screenings and a mixed biological - chemical sludge. In terms of percent loading, the system is a municipal refuse system designed to handle sewage sludge, not a sludge incineration system designed to operate with the addition of municipal refuse. Due to the low air supply to the system, the combustion process proceeds semi-pyrolitically.

The incineration unit, as described by Bruno (1977), shown in Figure 4.20, is a dual chamber design having a primary chamber equipped with a preheat/ waste ignition burner as well as over and under fired air from an auxiliary air blower. The secondary chamber, located immediately above the primary chamber, consists of two sections, one for mixing the products from the first stage combustion with auxiliary air and ignition, and a second section with sufficient retention time to permit completion of the incineration process.

The waste is ignited in the primary chamber in an oxygen deficient environment and thus complete combustion does not occur. The air to the second chamber however, is controlled to provide an excess of oxygen thus assuring complete combustion of the combustible elements arising from the primary chamber.

The solid waste unit can accept sewage sludge as a cake from a filter press or alternatively as a slurry directly from the sludge thickener. When a dewatering system such as a vacuum filter of filter press is used, the sludge and screenings enter the incinerator through the garbage loader. Alternatively, the sludge slurry is injected by a progressing style cavity pump directly into the incinerator. The sludge (and reverse osmosis brine) is injected into the incinerator through special high alumina nozzles fitted into the primary chamber. A dribble flow is thus placed onto the hearth or onto the solid waste load, just inside the charging door. The nozzles and associated fittings have been designed to withstand the corrosion and temperature effects inherent in this area.

The CANWEL Solid Waste System also includes a boiler for generating domestic hot water, a scrubber/condenser for air pollution control, a water preheater for the boiler section, and an evaporator for the reverse osmosis brine. A total view of the system, in conjunction with the wastewater treatment system is shown in Figure 4.21.

SECTION 4 - TABLES

TABLE 4.1

COMBUSTION REACTIONS OF SLUDGE

1.	CARBON + OXYGEN	CARBON DIOXIDE
	$C + O_2$	CO_2
	(1 kg) (2.67kg)	(3.67 kg)
2.	HYDROGEN + OXYGEN	WATER
	$H_2 + \frac{1}{2} O_2$	H_2O
	(1 kg) (7.94 kg)	(8.94 kg)
3.	NITROGEN + OXYGEN	NITROGEN DIOXIDE
	$N + O_2$	NO_2
	(1 kg) (2.28 kg)	(3.28 kg)
4.	SULPHUR + OXYGEN	SULPHUR DIOXIDE
	$S + O_2$	SO_2
	(1 kg) (1 kg)	(2 kg)

Source: Schroeder, 1977

TABLE 4.2

SLUDGE COMBUSTION PROCESSES

Reduction Process	Pretreatment Required	Additional Processing Requirements
Established Processes		
Incineration	Thickening & Dewatering	Landfill Ash
Wet Air Oxidation	Thickening	Treat cooking liquor, landfill ash
Heat Drying	Thickening & Dewatering	Use dried sludge as a soil conditioner
Experimental Processes		
Pyrolysis	Thickening	Utilize by-products of gas, carbon, steam. Dispose of residue
Incineration/ Chemical Recovery	Thickening & Dewatering	Landfill Ash. Recover lime from recalcination or heat in power boilers

Table 4.3

Steam Generation from Incineration

Percent Total Water-Free Organics in Sludge to Incinerator	STEAM GENERATION	
	lb steam/lb water-free organics	lb steam/lb wet sludge
35	2.0	0.7
30	2.6	0.8
25	3.5	0.9
20	5.0	1.0

Source : Chereminisinoff et al, 1976

Table 4.4

Summary of Yields from Pyrolysis

of Dried Activated Sludge

Pyrolysis Temperature °C (°F)	500 (932)	900 (1652)
Yields, Weight Percent of Feed		
Char	57.7	54.1
Gas	5.8	29.3
Tar, Oils, Aqueous	25.3	13.9
Yields, Per Ton of Feed		
Char, lb.	1154	1082
Gas, cu ft	2637	13415
Tar, Oils, Aqueous,gal	57.7	29.6
Ammonium Sulfate, lb.	103.3	73.4
Energy, Million BTU/Ton of Feed		
Char	5.1	4.6
Gas	1.9	5.4
Tar, Oils, Aqueous	4.0	2.6

Source: Olexsey, 1975

Table 4.5

Auxiliary Fuel Use in Dry Combustion Processes

Process	Natural Gas lb/ton of Total Solids	BTU/ton of Total Solids
Multiple Hearth Incineration	349	8,333,750
Fluidized Bed Incineration	284	6,783,475
Pyrolysis Reactor	0	0
Multiple Hearth Pyrolysis	417	9,953,385

Source: Lewis, 1975

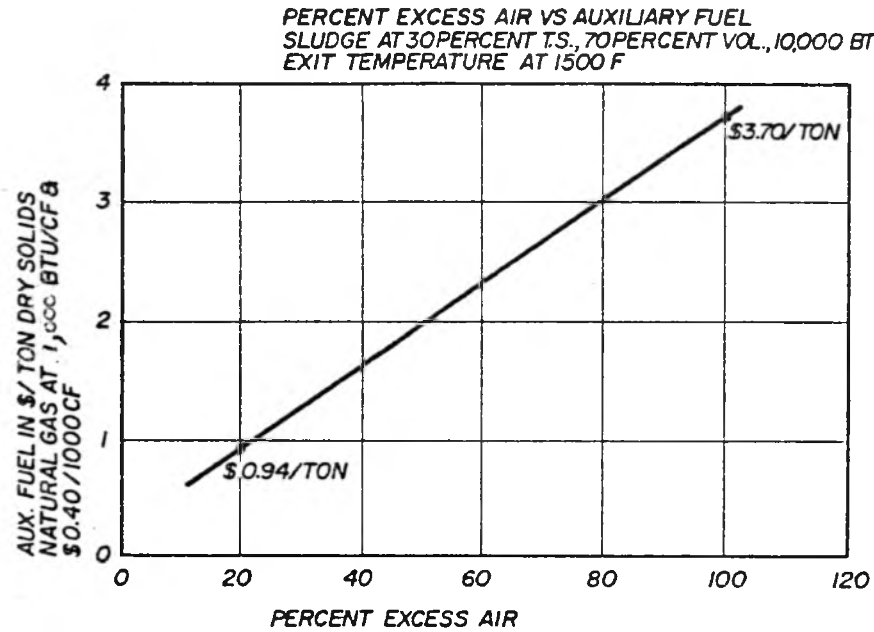

Figure 4.1 Effect of Excess Air on the Cost of Sludge Combustion

Source: Cherimisinoff et al, 1975.

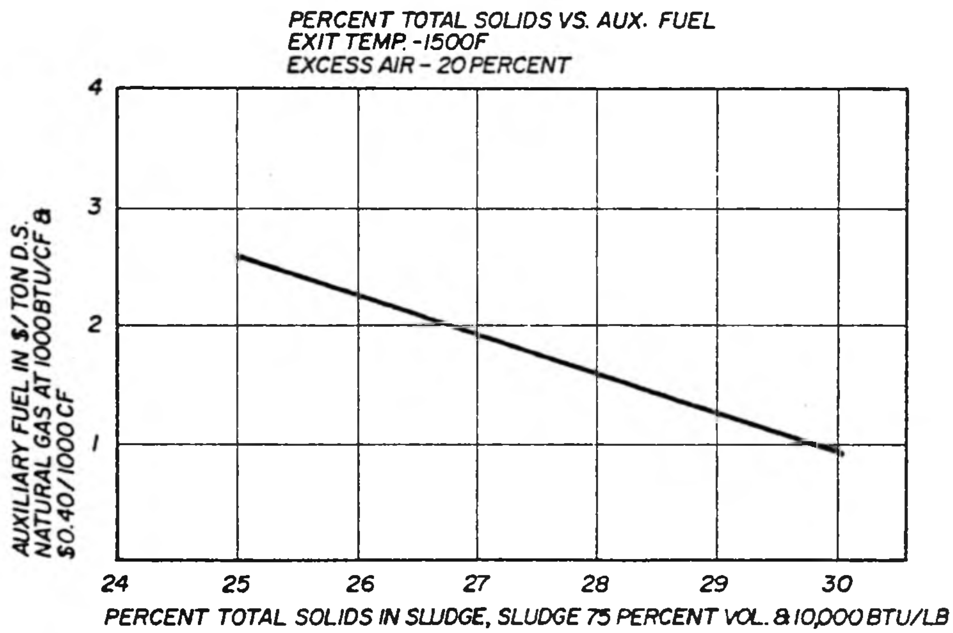

Figure 4.2 Effect of Moisture Content on the Cost of Sludge Combustion

Source: Cherimisinoff et al, 1975.

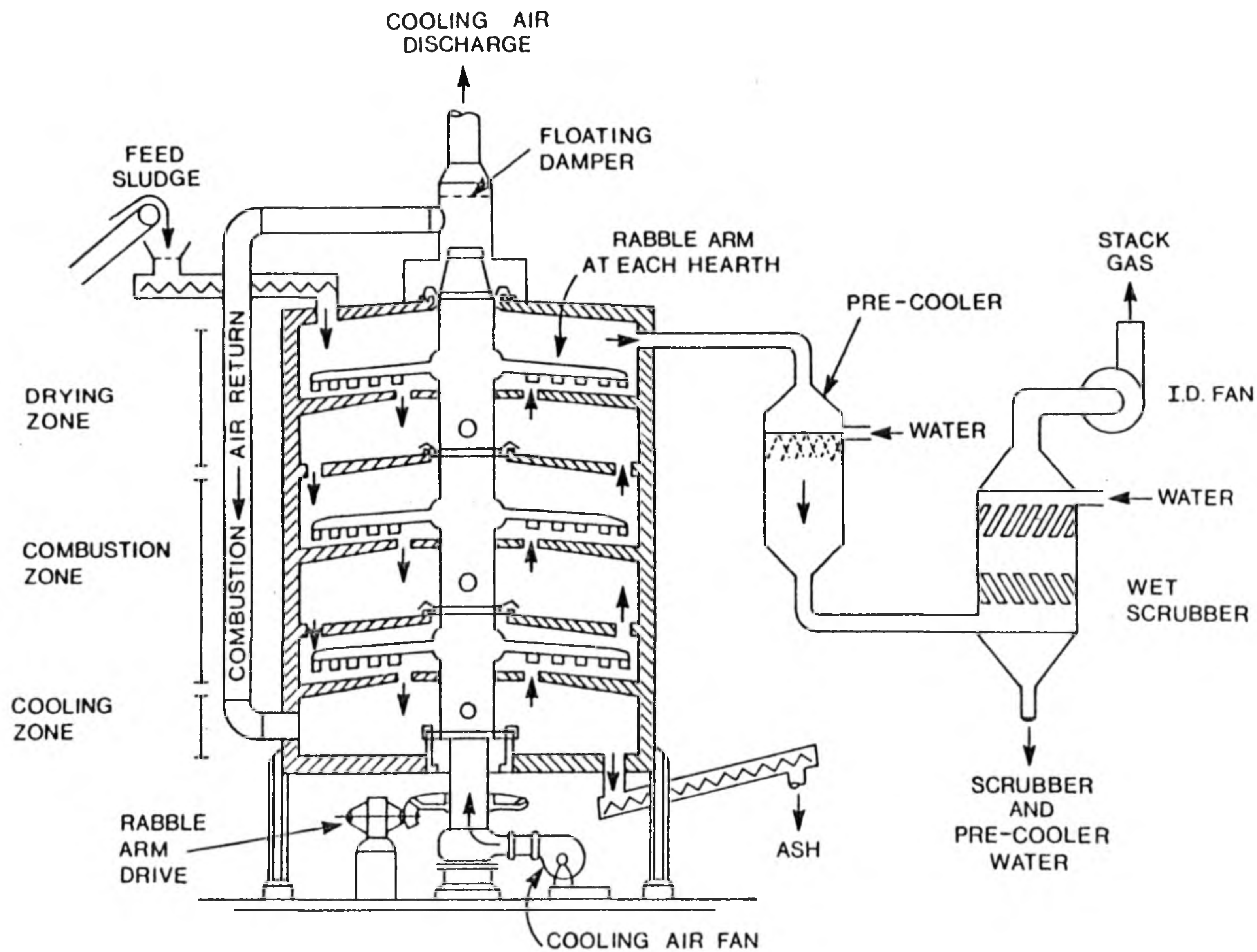

Figure 4.3 Multiple Hearth Incinerator

Source: Schroeder, 1977

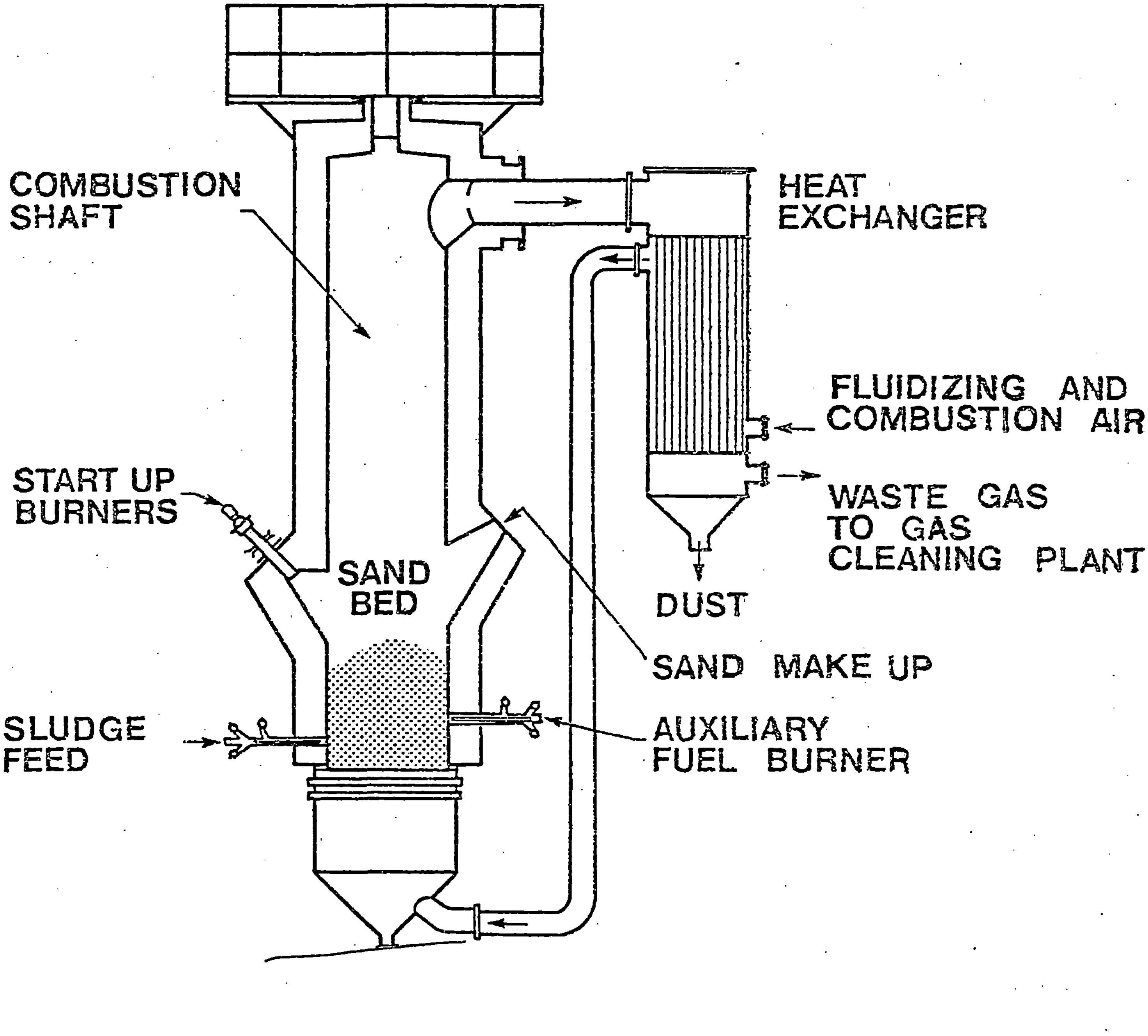

Figure 4.4 Fluidized Bed Incinerator

Source: Shannon, 1974

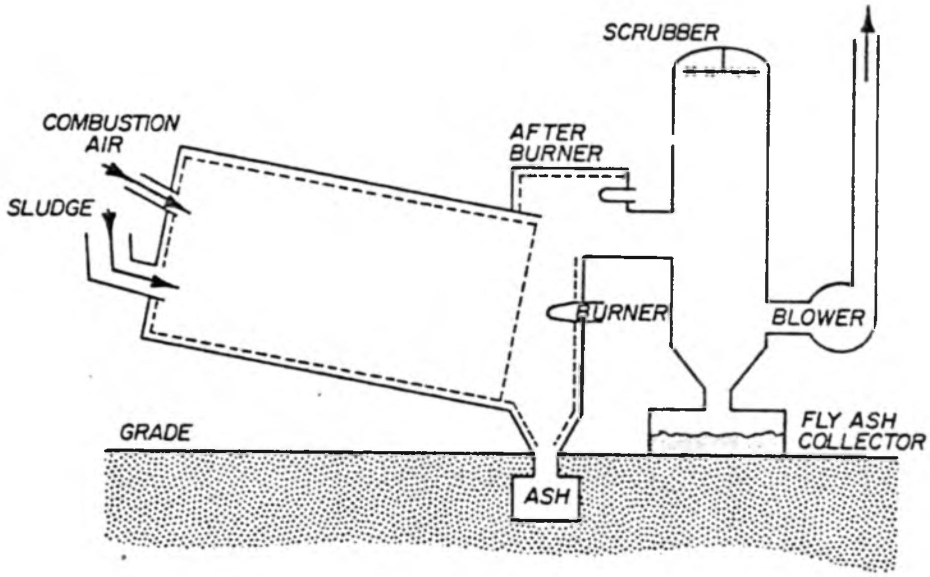

Figure 4.5 Rotary Kiln System

Source : Cheremisinoff et al, 1975

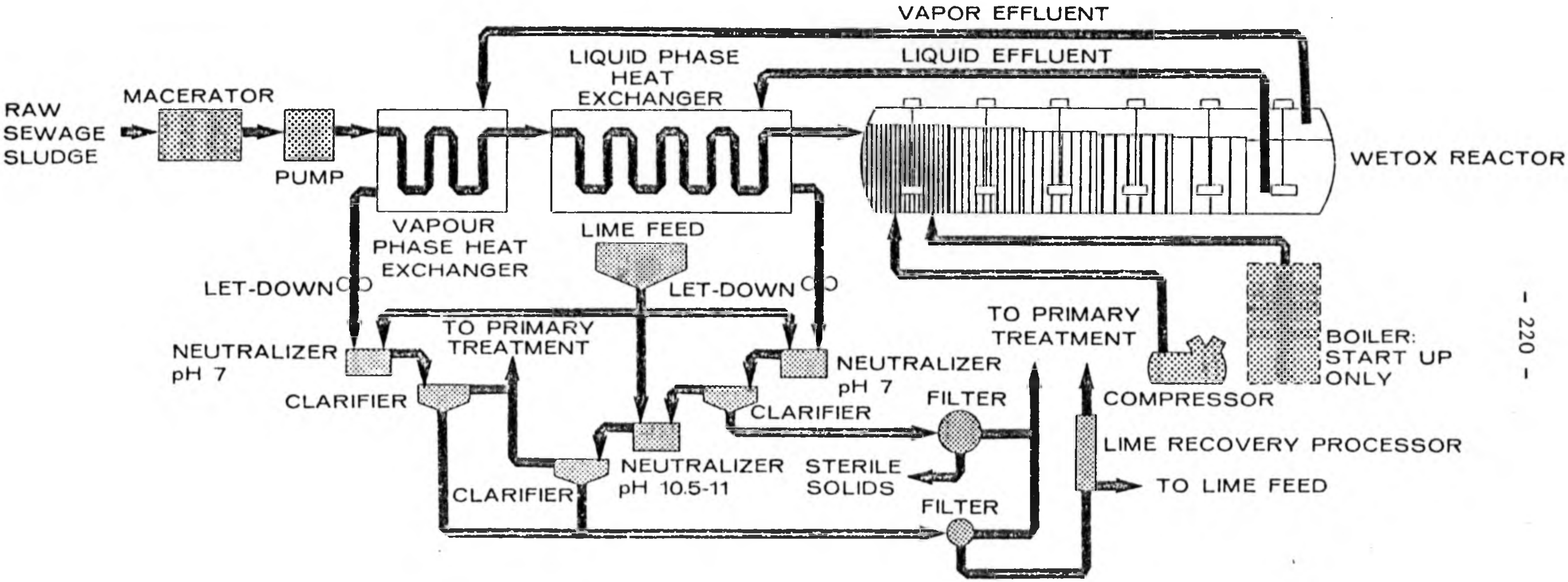

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Figure 4.6 Puretec System (Wetox plus Lime Treatment)

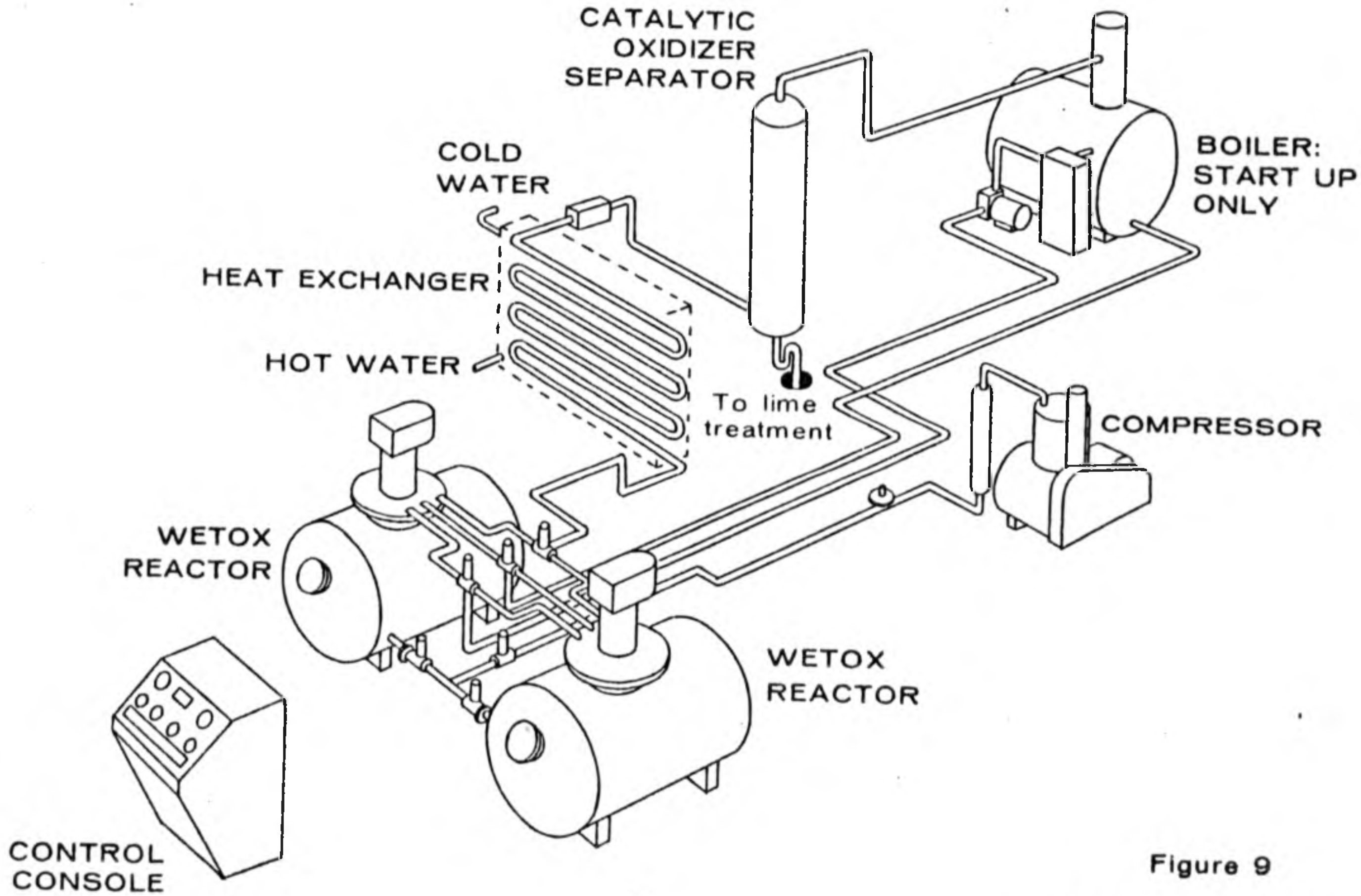


Figure 9

Semi Batch System

Figure 4.7 Semi-Batch Barber-Colman Wetox

Source: Seto and Smith, 1975

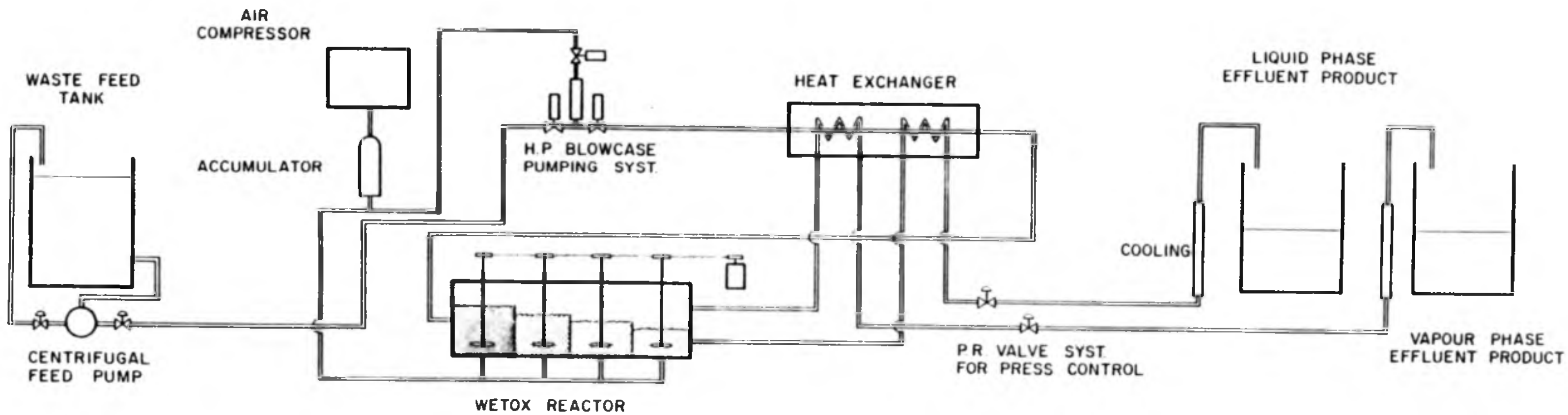


Figure 4.8 4 - 10 Wetox Pilot Plant
Source: Ontario Research Foundation

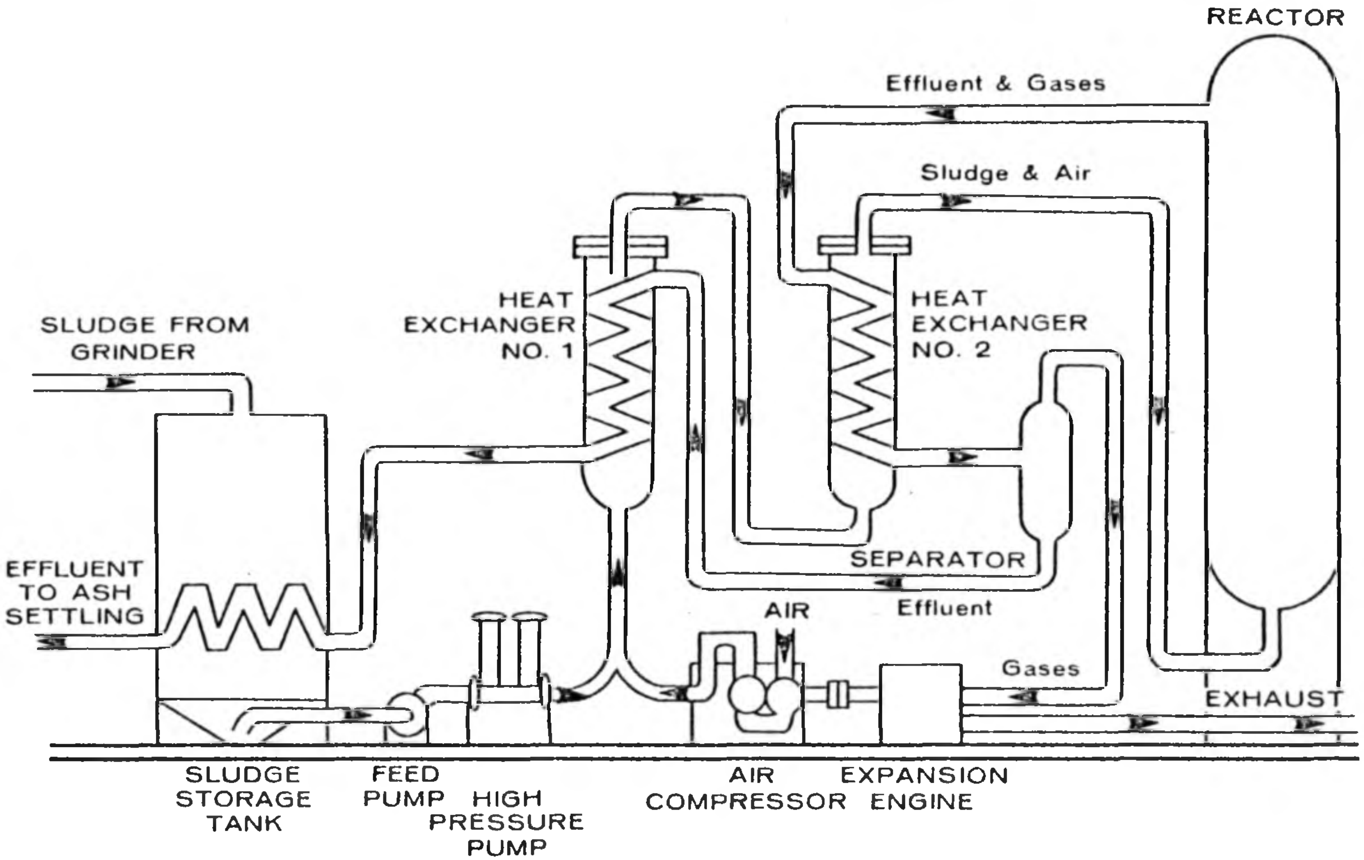


Figure 4.9 High Temperature Pressure Zimpro Wet Oxidation System

Source: Seto and Smith, 1975

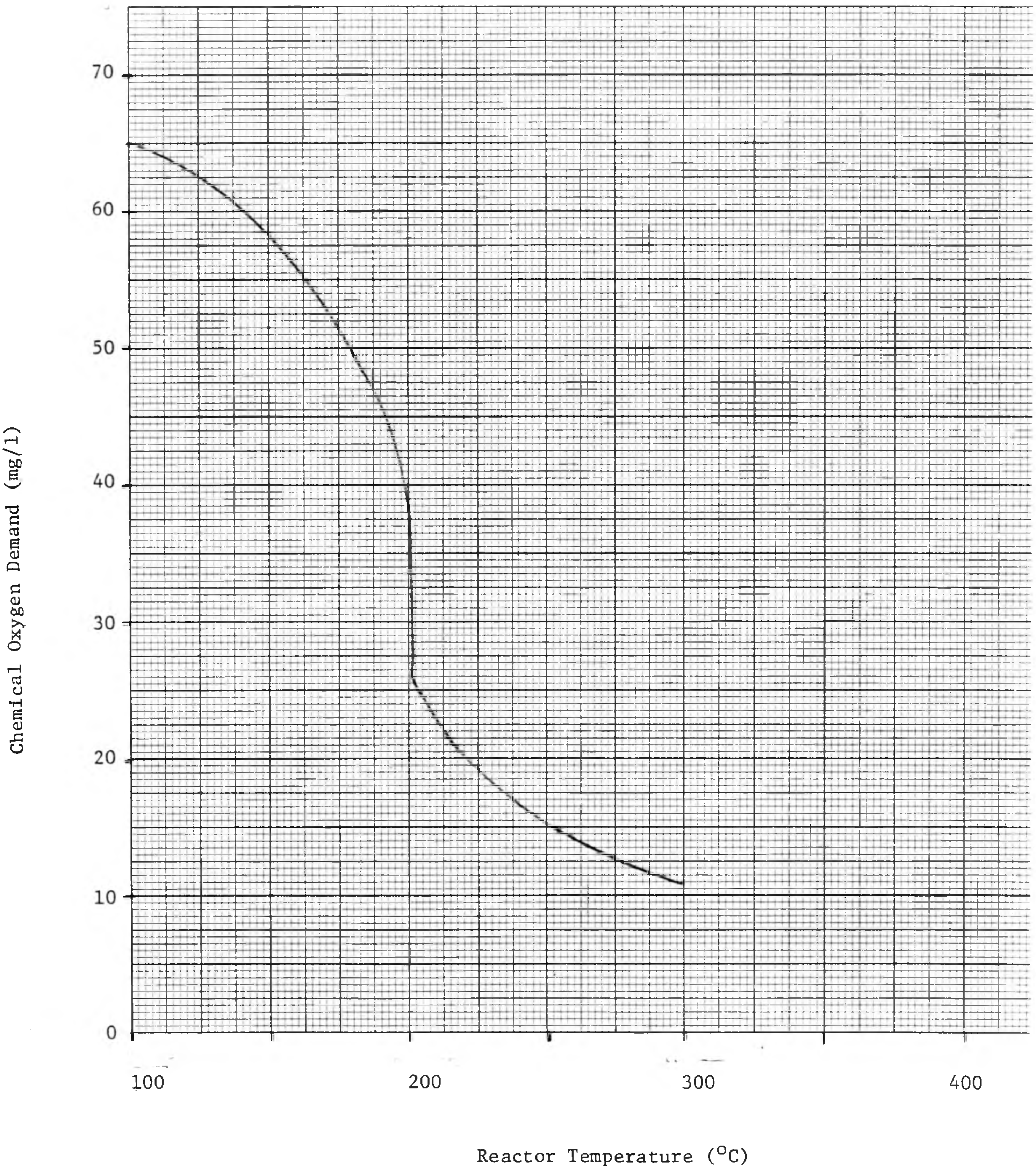


Figure 4.10 Oxidation Versus Temperature of Sewage Sludge in Zimpro Wet Oxidation Reactor

Source: Pradt, 1972

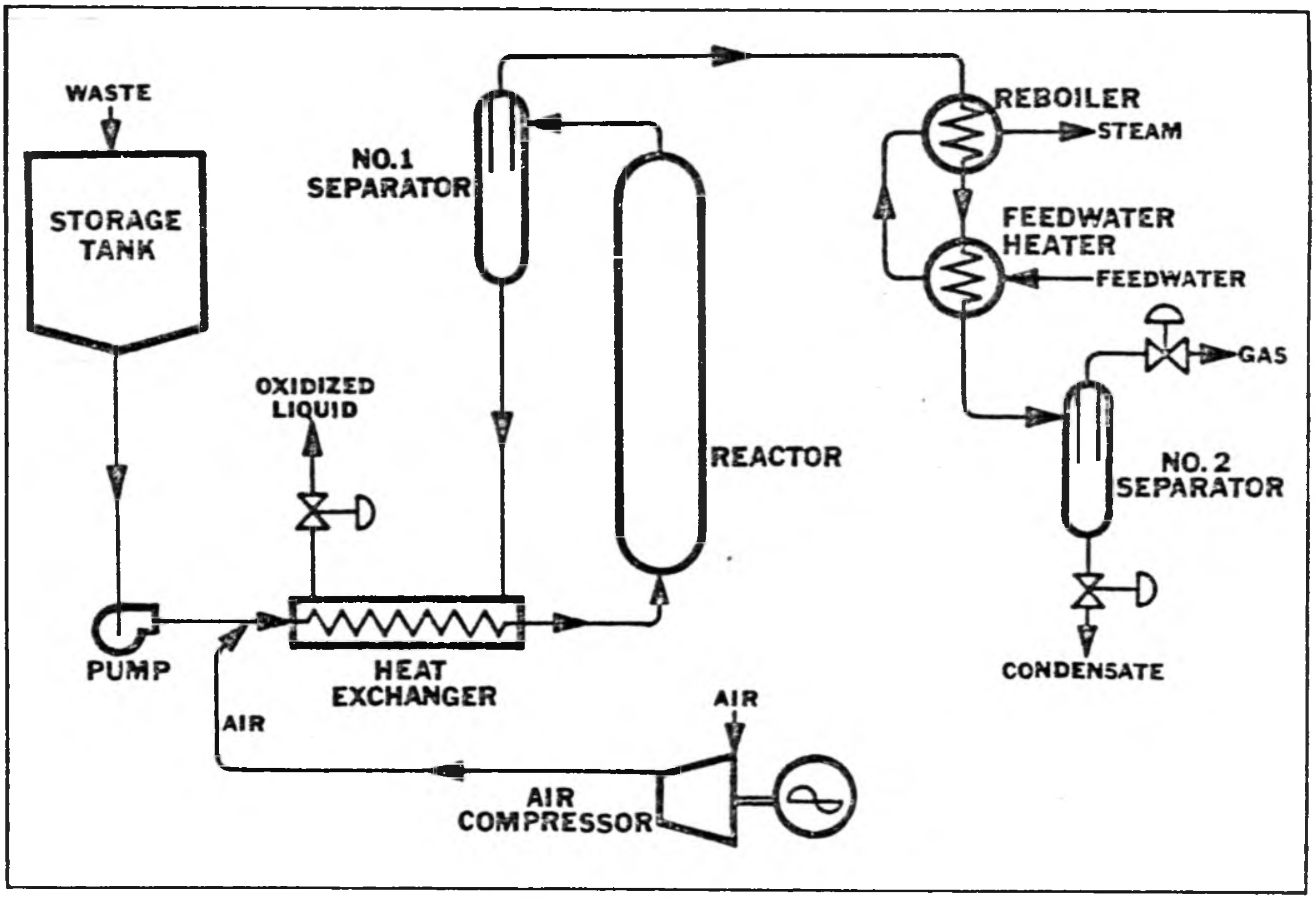


Figure 4.11 Flowsheet of Zimpro for Steam Generation

Source: Pradt, 1972

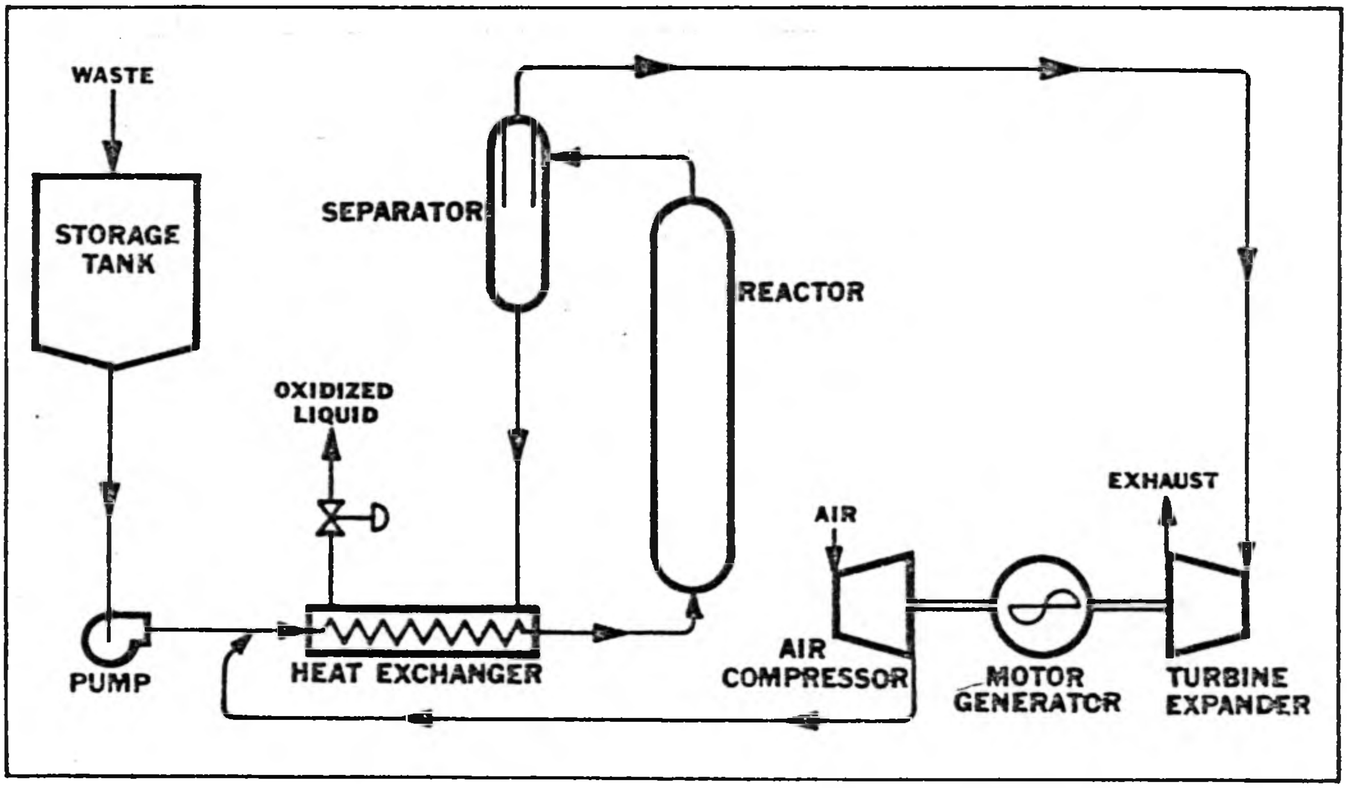


Figure 4.12 Flowsheet of Zimpro for Power Generation

Source: Pradt, 1972

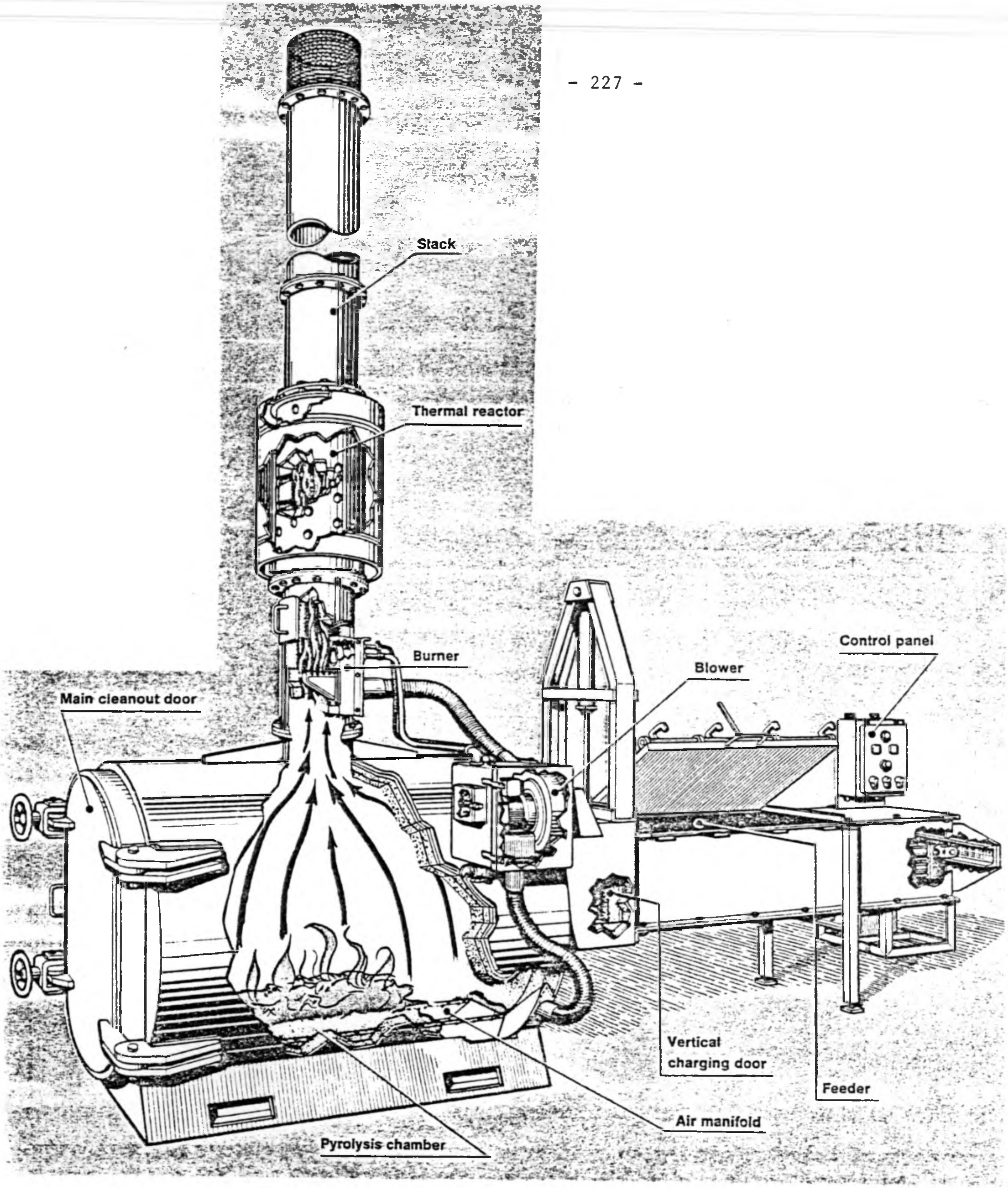


Figure 4.13 Pyrolysis Unit

Source: Courtesy, Kelly Company

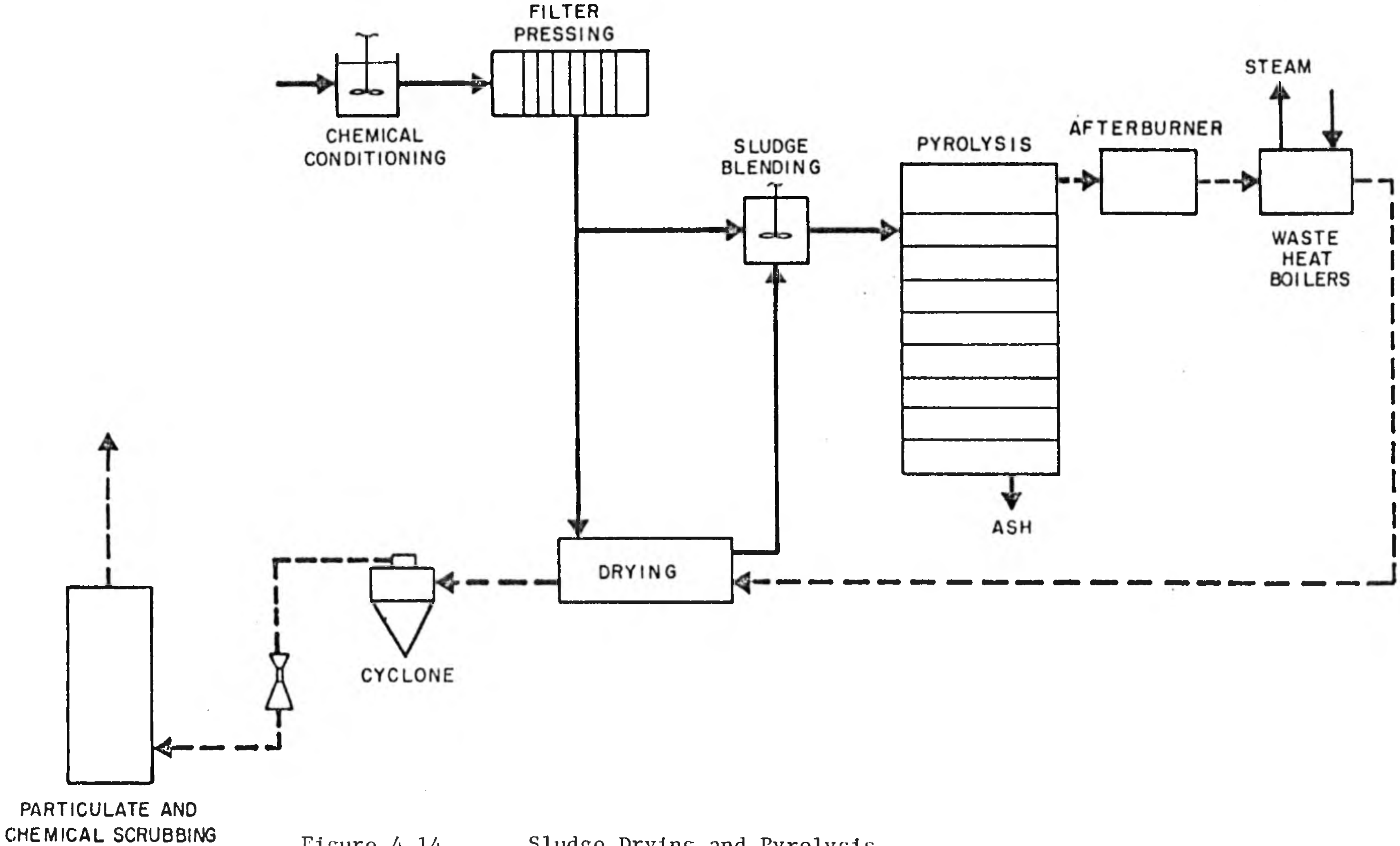


Figure 4.14 Sludge Drying and Pyrolysis

Source: Colosi, et al, 1976

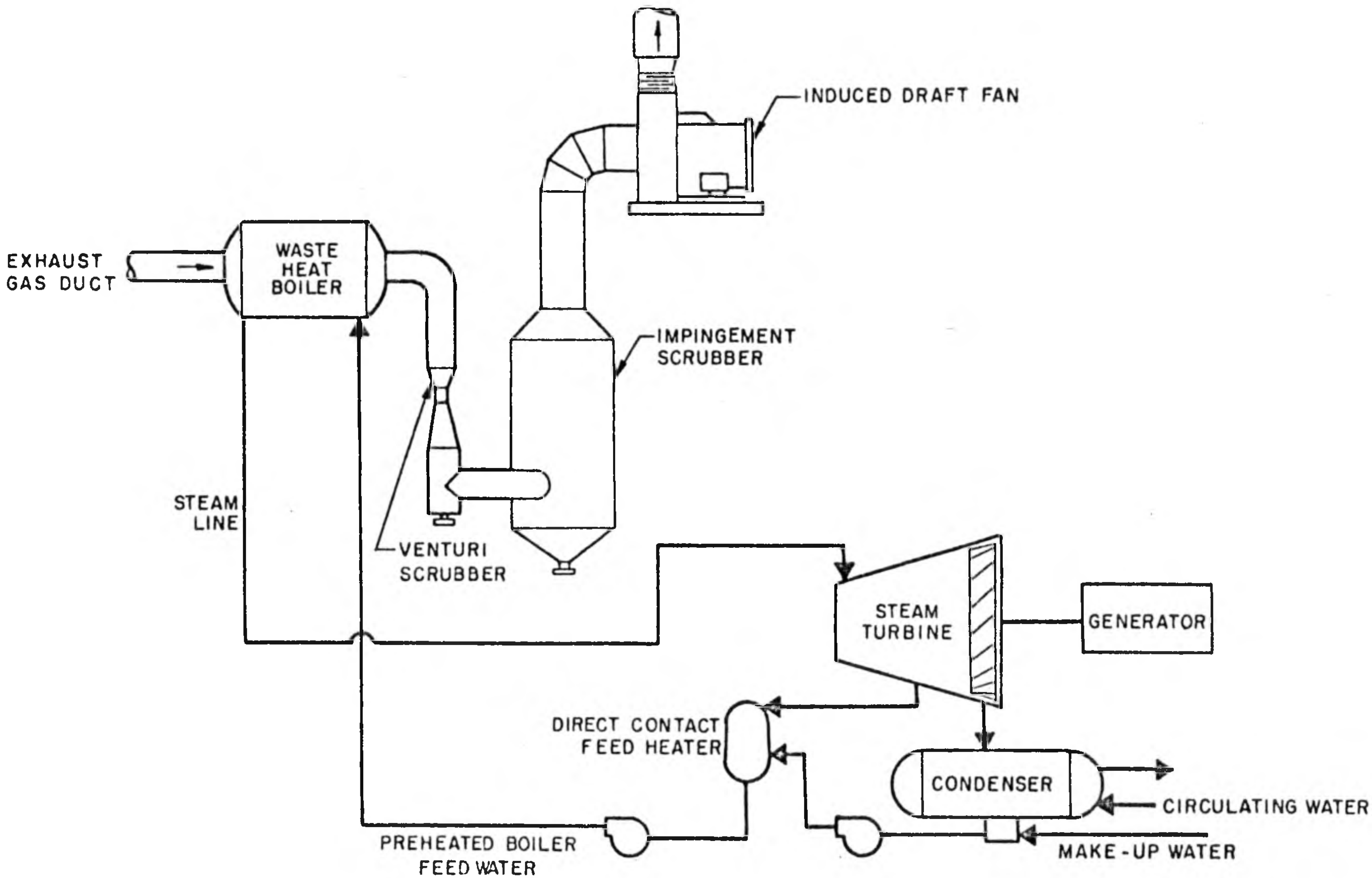


Figure 4.15 Pyrolisis Energy Recovery System

Source: Colosi *et al*, 1976

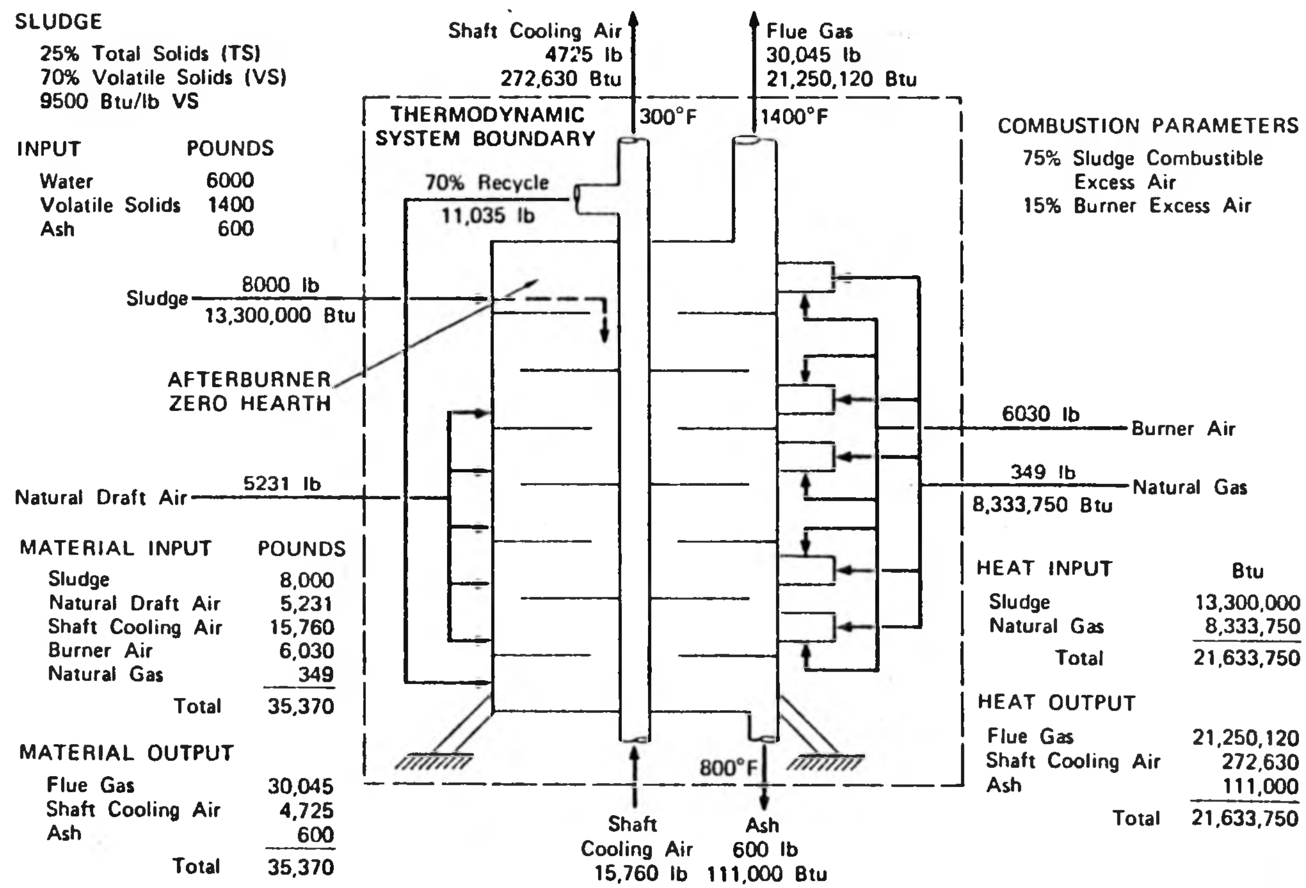


Figure 4.16 Material and Energy Balance for a Multiple Hearth Incinerator

Source: Lewis, 1975

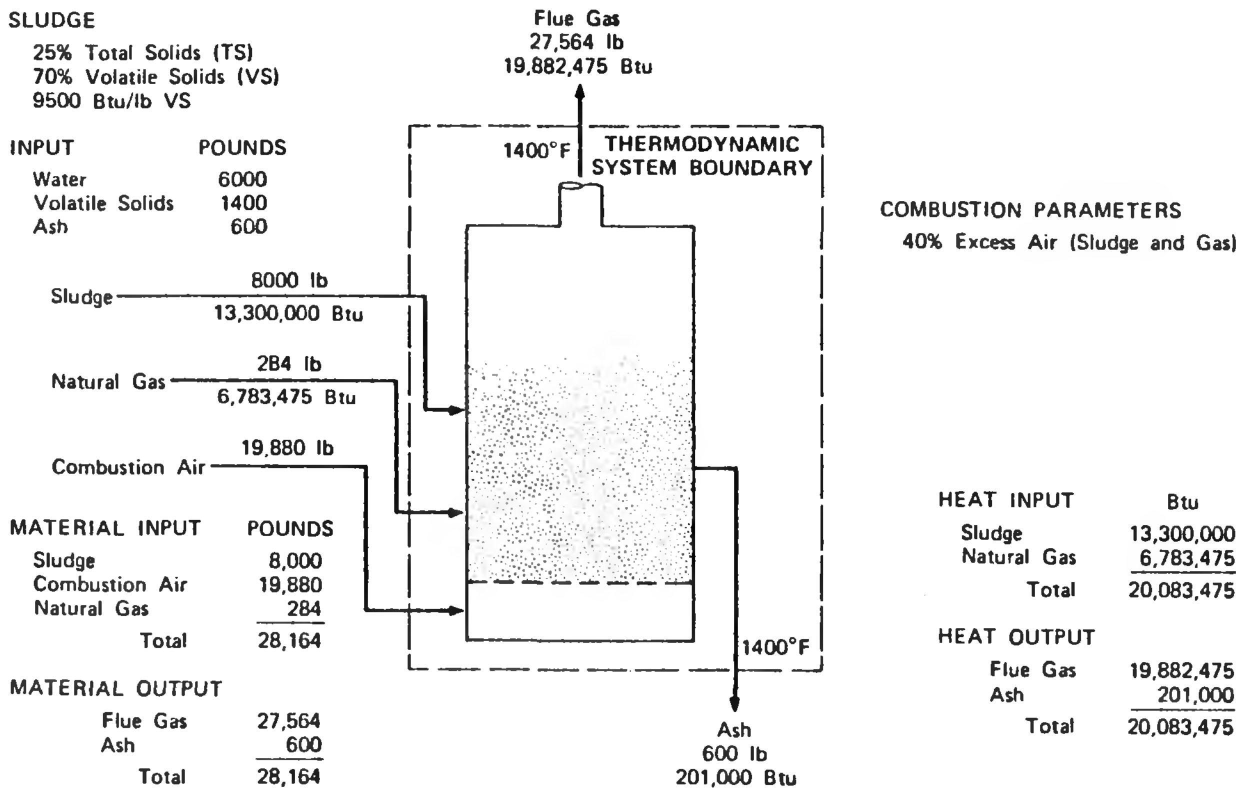


Figure 4.17 Material and Energy Balance for a Fluidized Bed Incinerator

Source: Lewis, 1975

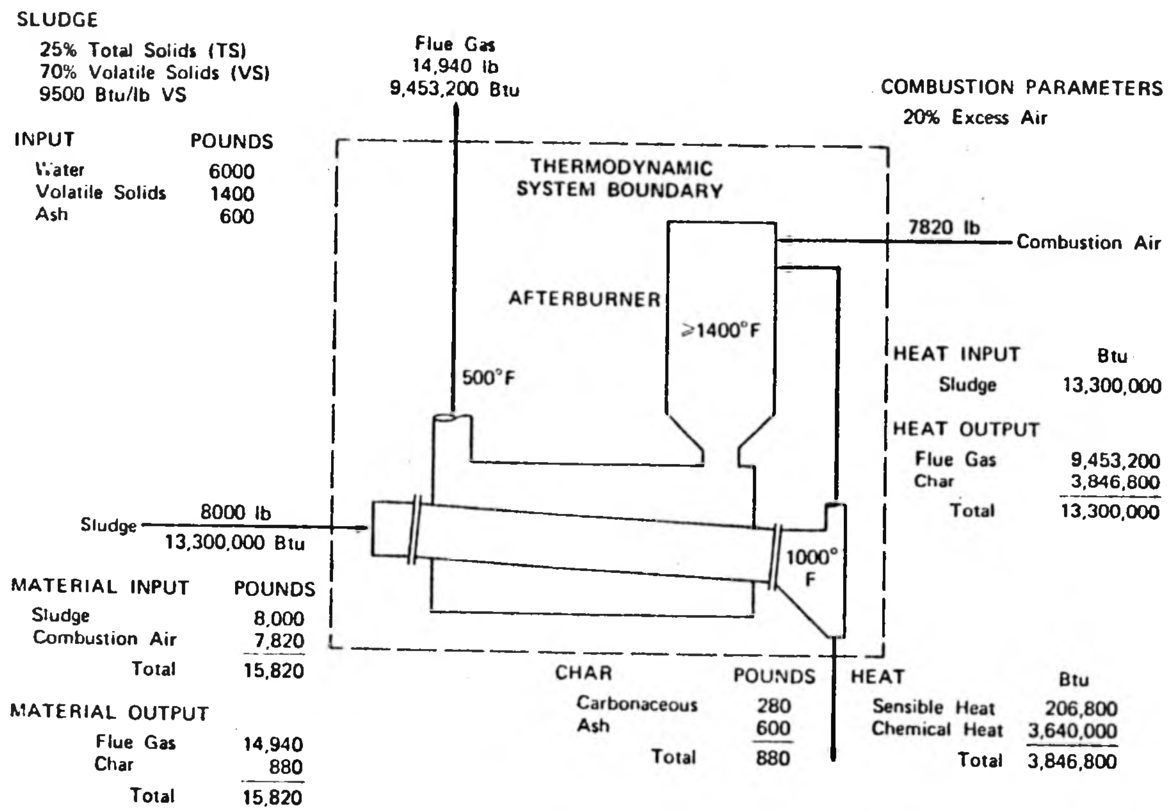


Figure 4.18 Material and Energy Balance for a Pyrolysis Reactor

Source: Lewis, 1975

Figure 4.19

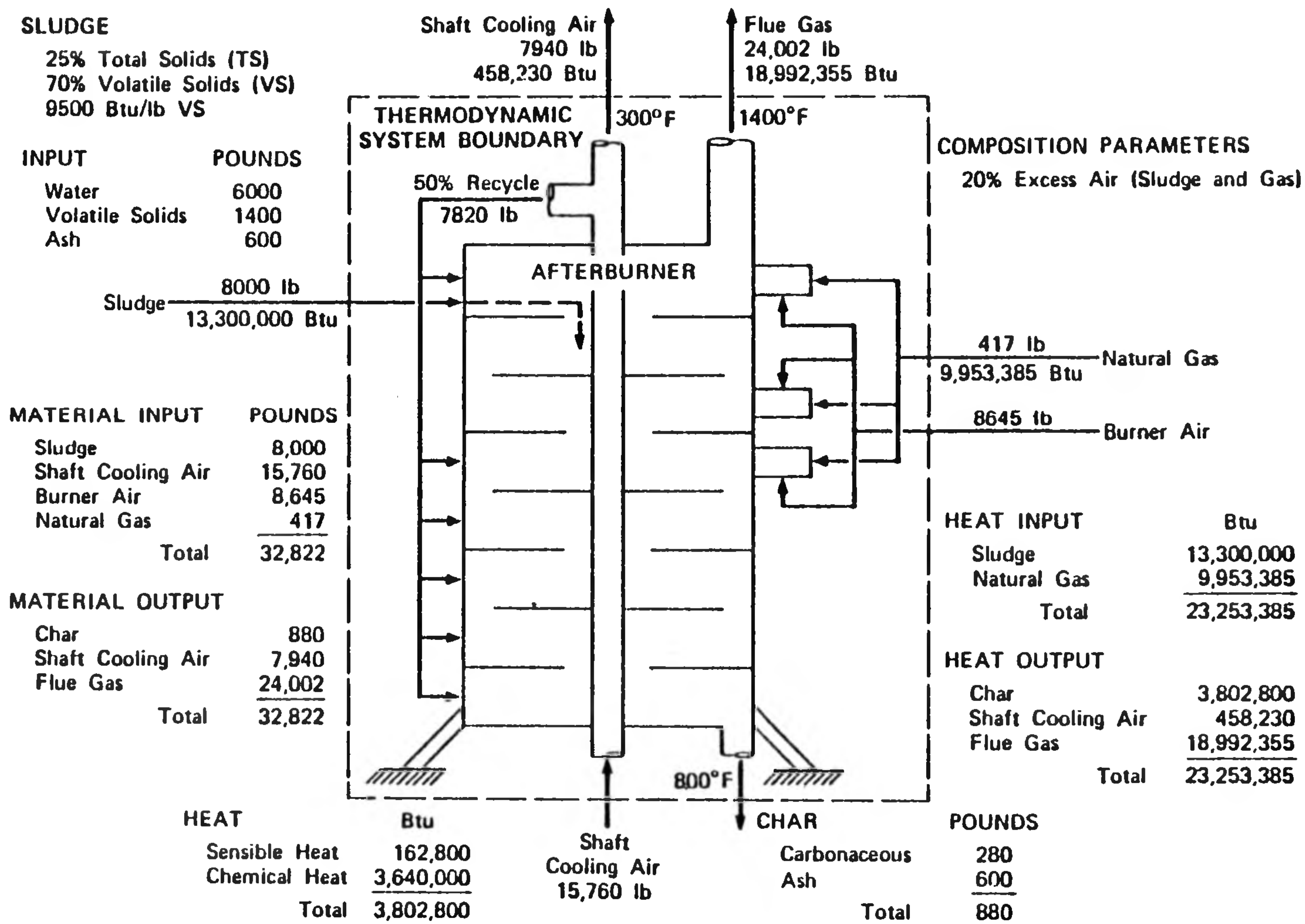


Figure 4.19 Material and Energy Balance for a Multiple Hearth Pyrolysis Reactor

Source: Lewis, 1975

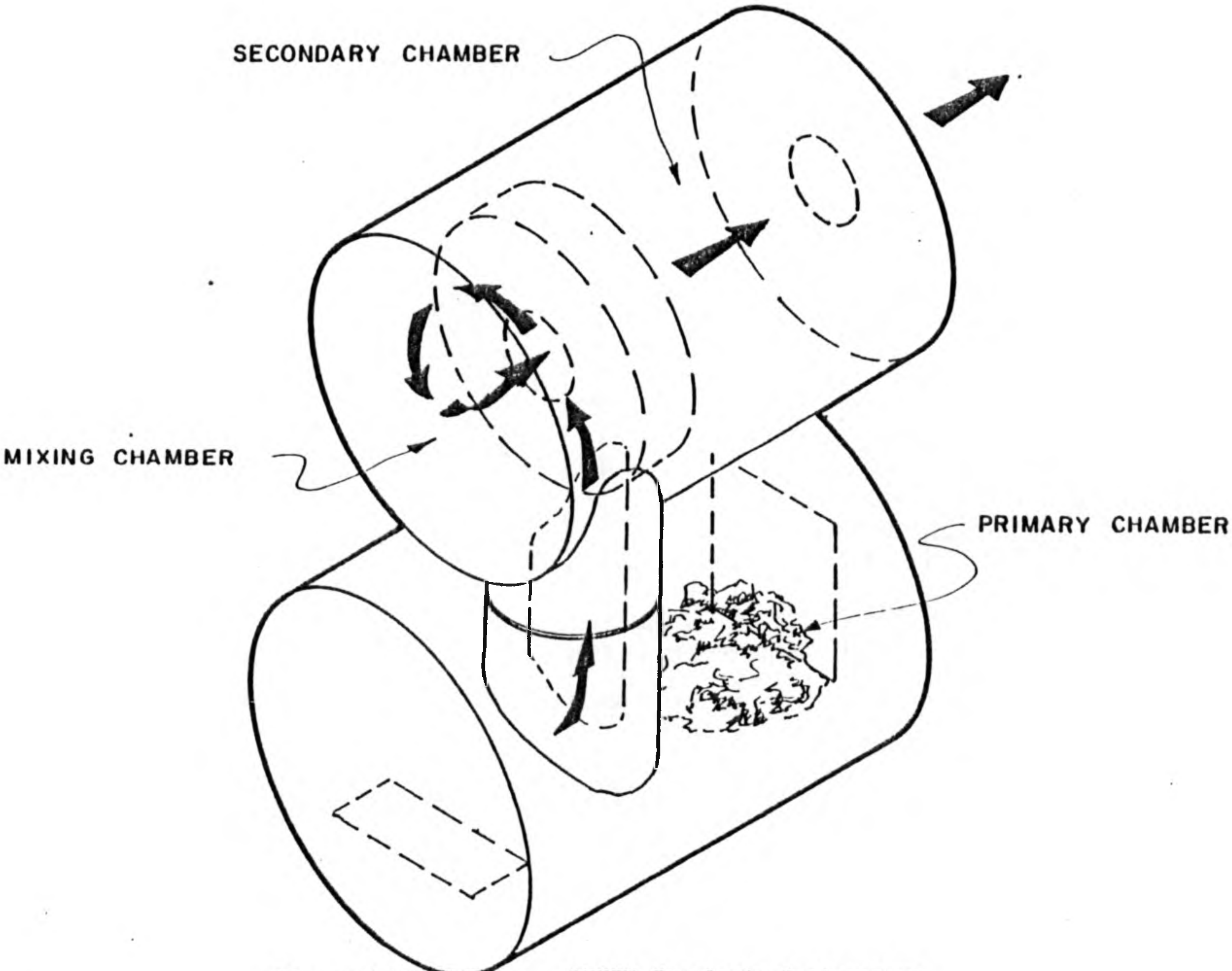


Figure 4.20 CANWEL Pyrolytic Incinerator

Source: Bruno, 1977

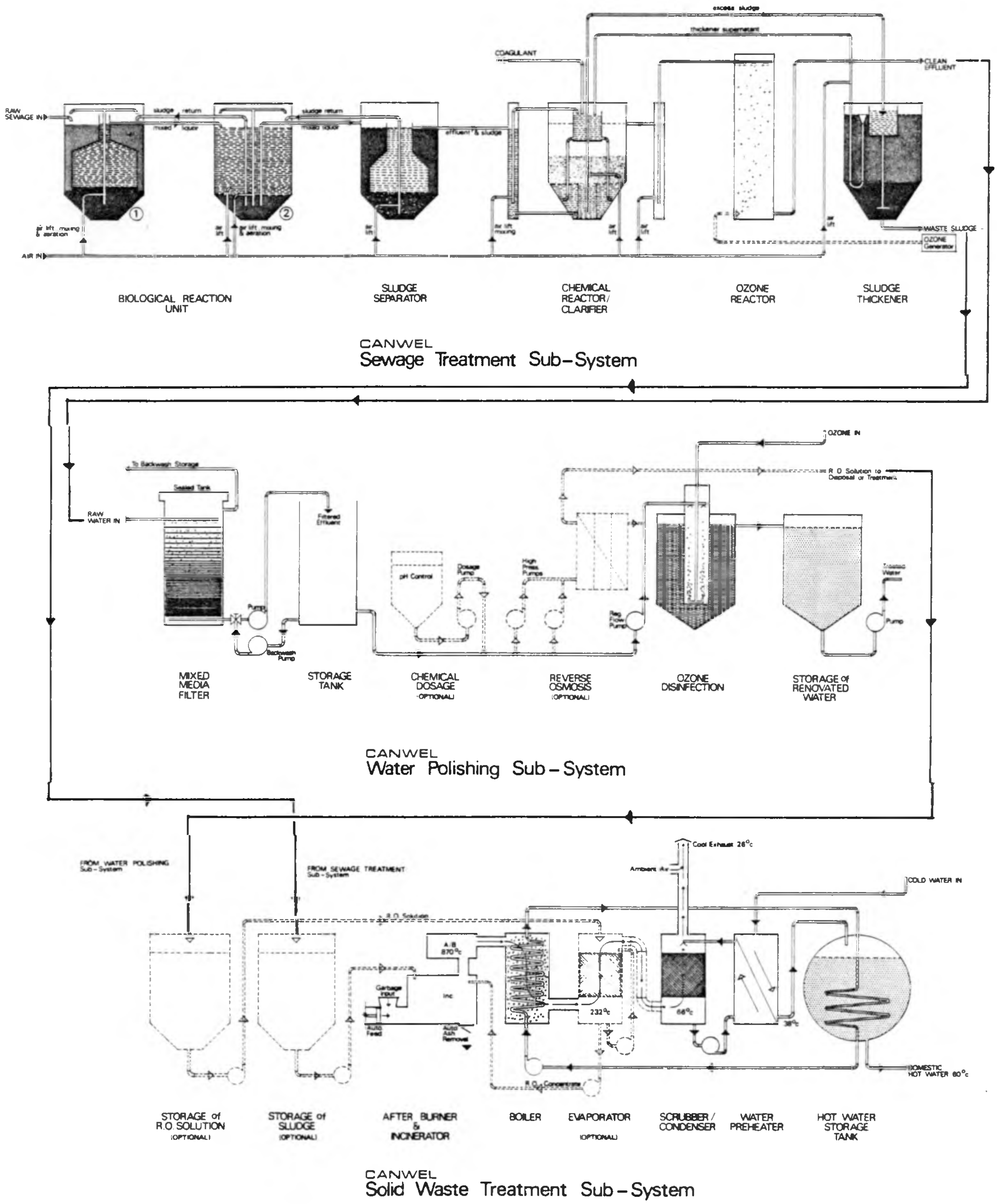


Figure 4.21 Integrated CANWEL Waste Management Process

Source: CMHC, 1977

Section 5

ULTIMATE DISPOSAL OF SEWAGE SLUDGE

5 ULTIMATE DISPOSAL OF SEWAGE SLUDGE

In the past it was quite common to find waste sludge from treatment plants being dumped back into the natural lakes and streams the treatment plants were themselves designed to protect. Deposition of this material creates bottom deposits and excess eutrophication and, in a short period of time, can kill a natural watercourse. The emphasis now is on disposal of the sludge in a safe, aesthetically pleasing, and where possible, a useful way.

The three major ultimate disposal methods now in use are landspreading, ocean disposal and landfilling. Landspreading utilizes the sludge for fertilizer value on agricultural land or for land reclamation in areas not suitable for development. Ocean disposal, like lake and stream disposal, is not really a satisfactory disposal scheme and as such is currently being phased out in most developed countries. Landfilling is probably the most common ultimate disposal method, especially where the final production is incinerator ash.

The choice of a final disposal method will depend largely on the nature and quantity of sludge for disposal, the availability of land, the nature of a town's solid waste disposal, and public feelings toward each method. As more and more research is completed on the effects of landspreading, this method might become more acceptable to the public and gain the widest acceptance for disposal of digested sludge. Where the communities are attempting to recover the sludge value as energy, rather than nutrients, the final treatment and disposal will likely be incineration, pyrolysis or wet oxidation. This would be coupled with ash disposal to a sanitary landfill or land reclamation.

The present outlook of regulatory officials in this area can best be illustrated by a quote taken from a communique with D.P. Caplice, Director of the Environmental Approvals Branch, Ontario Ministry of the Environment. When questioned about ultimate disposal in Ontario, Mr. Caplice stated that:

"Ultimately, it would be desirable in rural communities, to return the sewage sludge to the land for its fertilizer and soil conditioning qualities. However, this is not practical for heavily populated urban areas and there, sludge incineration appears to be the most practical solution, particularly if the incineration process can be modified to reduce the auxilliary fuel requirement and overcome the air pollution potential. Hopefully, some of the more sophisticated processes on the horizon such as pyrolysis will prove to be practical in full scale trials and we may be able to produce fuel oil and gas from the sewage sludges."

The following sections on ultimate disposal outline the operation of each method and the disposal methods that would create the least environmental impact. Selection of a "best alternative" should be possible, based on information in these sections, and information on the local sludge, site availability and public acceptance.

5.1 Disposal of Sludge to Agricultural Lands The application of sewage sludge to agricultural land is looked upon as one of the most desirable forms of ultimate disposal, in that it provides a source of essential nutrients and organic matter for a productive agricultural soil. There are problems associated with this disposal method however, as the sludges often contain toxic materials such as heavy metals, pesticides and pathogens. Research in Canada is now at the stage that these materials can, and have been identified in the sludges. Several full scale and greenhouse experiments have been conducted to determine their effect. (Bates et al, 1977; Cohen et al, 1977).

Based on this work, guidelines for the use of sludge on agricultural lands are presently being developed for land application of sewage sludge in Ontario. (De Angelis, 1977).

5.1.1 Sludge as an Agricultural Supplement

5.1.1.1 Present Practices Several farmers in Canada, Europe and the United States have been using sewage sludge as an alternative to chemical fertilizers with excellent results. Thompson (1975), experimented on his own farm in Iowa with sewage sludge and found that crop yields (corn and soyabean) were equal to, or greater than yields when chemical fertilizers were used. In moving to sludge fertilizer he saved $80 per acre on fertilizers, pesticides and herbicides. The only problem experienced in this project was the odour during land-spreading, however digestion or composting prior to spreading would have eliminated this problem.

O'Neal (1975) looked upon sludge as a very beneficial fertilizer and he took the one extra step, that is he composted the sludge before attempting to market it as a fertilizer. Digestion and lime stabilization were both considered along with composting. However, composting offered a simpler, more economical solution in this case. O'Neal found that the farmers gave an excellent response to this new product, primarily because of the drastically accelerating prices of chemical fertilizers and secondly because they felt sludge would return the organic portion of the soil that had been depleted. Chemical fertilizers added no organic soil conditioner. Sludge was applied at a rate of 25 dry tons/acre at 3 percent nitrogen giving 150 pounds of immediately available ammonia and nitrate and 1350 pounds of organic nitrogen. Breakdown of the organic nitrogen over a five to ten year period was found to reduce the future ammonial requirements. All the farmers involved in this study agreed that sludge was in fact, an excellent fertilizer.

In a land application study carried out in England, it was found that sludge fertilization did not indicate hazards to crops, animals or human life, even after some fields had received a 30 year dose. It was found that the sewage sludge was of greater value than the artificial fertilizers having a similar nitrogen to phosphorous ratio because the variety of trace elements present. Many of these trace elements are essential for plant growth (Claydon et al, 1973).

5.1.1.2 Obtaining Public Acceptance - Case Studies

By far, the most outstanding development project in terms of sludge recycle to agricultural lands is the "Land Reclamation and Recycle Project", often referred to as the "Prairie Plan", developed by the Metropolitan Sanitary Districy of Greater Chicago. The paper by Dalton and Murphy (1973) outlines this project quite well and should be reviewed prior to instigation of such a program. Several brochures are available outlining the development of this project and procedures used to gain public acceptance (Dalton, 1977).

The Prairie Plan's objective was to reclaim stripped mining lands, by recycling the organic matter in stabilized sewage solids. The stabilized solids are applied to the land, tilled into the soil, and farmed on a rotating basis. Approximately 45,000 acres have been strip-mined and this value is increasing at 1200 to 2000 acres per year. The local district conducting the program serves 5.5 million people and produces an estimated 860 dry tons of organic solids each day (Dalton et al, 1973).

In looking for a solids disposal system the district established the following criteria, which are the requirements any community must look at in selecting the best treatment system:

1. The system must conserve both the water and organic material of the solids for beneficial use, with highest preference given to recycling for farm use.
2. The system must be compatible with the environmental standards of both the rural and urban areas, that is, create no land, air or water pollution.
3. The system must be one that solves the problem permanently.

The Prairie Plan itself was the backbone of the public acceptance program. The plan was primarily based on the District's research and demonstration work. The major reason for this plan was that the district initially found it could not move forward with its land reclamation project due to a general lack of public acceptance. The plan was to demonstrate to the public that the land reclamation project was completely engineered and would not cause pollution on the land, in the water or in the air, now or in the future. It would demonstrate that liquid sewage sludge could on a large scale operation, be safely, economically and beneficially applied to the soil while providing the following multiple-use benefits: (Dalton et al, 1973)

1. Reclamation of lands having serious organic deficiencies
2. Development of an agricultural operation returning organic matter to the soil.
3. Provision for recreation, conservation, wildlife preservation and natural science education.

Out of all this, the planners hope that approximately three thousand acres will become grasslands and,

> "the area will be roadless, uninhabited, unbroken by farmsteads, seeded with the native grasses, and supporting once indigenous wildlife. They envision the closest thing possible to the seemingly endless prairies that the first explorers saw." (Watts, 1975).

The project is proceeding well, as buffalo are now once again grazing in this area, while corn and grass crops are flourishing. For Canada's benefit, the restored area has become a well liked and excellent habitat for the Canada Goose.

Not all attempts to use sludge as an agricultural additive were as successful as those previously mentioned. Broaten (1975) was involved in an EPA demonstration project that would:

> "use sludge from a large urban area on a scale great enough to make operational and economic sense; which would seek to optimize agricultural benefits; and which would be carried out with such extensive environmental monitoring that it would convince almost any reasonable observer".

In implementing this project, the EPA undertook to do basic site selection and evaluation work first and then if it looked feasible, to do detailed environmental studies and the project design with total public involvement. Unfortunately, the project never got off the ground. The newspapers picked up the story, and all its associated problems, without ever mentioning resource conservation. Local politicians, backed by the public halted the project in its early stages.

The EPA learnt from this project, and from it developed a logical progression that would avoid the previously encountered problems. These ideas will perhaps be of value to local Canadian groups attempting to initiate agricultural sludge disposal:

1. "In the first attempt, demonstrate the project with an intermediate-sized city. Study not only the disposal scheme itself but also study the public acceptance problem carefully."
2. "Involve local leadership from the start. Special problems exist in each community and special benefits (i.e. tax benefits) may exist within the community."
3. "Obtain the support of allied groups supporting the project. Farm groups, environmental groups and even sports groups may provide the initial support to get the project started."
4. "Try to raise the initial initiative from within local citizens, let them ask for sludge instead of asking where to put it."

A number of other studies have been completed which have evaluated the use of sewage sludge as an agricultural additive: (Smith, 1977; Ardern, 1977; Trout, 1975; Sommers, 1976; Lynam, 1975; Keeney, 1976; Hinsley, 1974; Clark, 1973; Carroll et al, 1975; Ewing et al, 1970; Larson et al, 1974; Webber et al, 1974; Bates et al, 1974). Public acceptance of waste as a resource has been discussed by Brooten (1975), and Forster et al, (1977).

5.1.1.3 Application Practices When applying chemical fertilizers to the agricultural land, practices are usually carried out that obtain the maximum crop yield with the minimum fertilizer input. This practice ensures minimal costs and the least possibility of pollution from surface water runoff. The application of sewage sludge, however, is almost the reverse. Here one attempts to obtain the maximum crop yield while applying the maximum amount of sludge.

In order to obtain the best results from this type of process, Gilley, (1976), has suggested that several factors must be considered:

1. the physical, chemical and biological soil properties;
2. the climate;
3. the type of crop to be grown; and
4. the interactions of these factors with the waste materials.

Although the sewage sludges do contain high levels of nitrogen and phosphorous, they are usually deficient in potassium (as K_2O). A comparison of sludge and conventional fertilizers was given by Donahue et al, (1971)and is shown in Table 5.1.

5.1.2 Heavy Metals in Sewage Sludge The major drawback to the disposal of sludge on land is that it contains high levels of heavy metals that are removed from the raw wastewater. These metals usually arise from industrial effluents which are being combined with municipal sewage prior to treatment. The percentage of heavy metals removed by an activated sludge treatment plant was studied by Oliver et al (1975), and is given in Table 5.2. These values can be used to get an approximation of sludge heavy metal content.

5.1.2.1 Sources of Heavy Metals in Sewage Sludge When the metals initially leave the industrial site, they are usually in dissolved form, however, when the industrial and municipal wastewaters are mixed, there is a considerable conversion of metals into the insoluble state. This reaction can result from a higher pH sewage, phosphorus precipitation, organic complexation and physical adsorption into solid organics, (Oliver, 1975). Those metals which are insoluble can more easily be removed by the treatment process. Metals remaining in the soluble form will pass right through the plant.

Abbott (1972; in Davies, 1972) in a study of heavy metals in raw municipal sewage from industrial cities found that the metals, in almost every case, were from industrial waste discharges exceeding sewer use by-law levels.

If Abbott's data are correct, it highlights the problem of heavy metal discharges from industries into municipal sewers. The real solution to the problem is removal of metals from the waste before they reach the sewers. Legislation or economic incentives are required which will point industries towards metal recovery processes.

Possible sources of heavy metals in municipal-industrial raw sewage are given in Table 5.3.

A considerable amount of work has been completed on the quantities of heavy metals in sewage sludges. Typical values from a number of authors is given in Table 5.4. Considerable variation results from the sources contributing to the plant, the type and efficiency of treatment and the method by which the samples were analysed.

Stover et al (1976) gave a detailed account of sludge analysis for the evaluation of metals. The study indicated that the sludges tested contained a wide variety of sites capable of metal retention. The metal retention was found to be highly variable, depending on the chemical properties of the sludge and the nature of the metal. Retention mechanisms isolated were: ion exchange, sorption, chelation and precipitation.

The same study showed that the predominant forms of lead, zinc, copper, cadmium and nickel were not the same in each sludge. This fact means that each metal will most likely respond differently after incorporation into the soil, thus the exchangeable forms as well as quantities of the metal are required to determine what effect the sludge will have on the plant. This point was also emphasized by Claydon (1973) who stated that "no two sludges are alike and each case must be taken on its own merits".

Brown (1975) found that the metals that are applied to soils with sludge will undergo changes in chemical form over a period of many years. This may be an advantage or a disadvantage depending on the soil characteristics. If most of the metal ultimately reverts to non-useable forms, metal toxicity will not become a problem. If, however, the metals assume chemical forms readily used by the plants, they will have pronounced toxic effects.

High metal levels have also been found in "off the shelf" fertilizers prepared from processed sewage sludge. Van Loon (1972) found that the Milorganite,probably the most well known processed sewage fertilizer, showed cadmium values of 60 ppm, Chromium 5,000, lead 450, nickel 80 and copper 400 ppm. Another common fertilizer, So-Green Turfbuilder 10-6-4 showed levels of 40 ppm for cadmium, 2,500 for chromium, 350 for lead, 70 for nickel, 900 for zinc, 130 for magnesium and 250 for copper.

Bates (1972) stressed that there is no definite evidence that the application of fertilizers containing metals to soils provide a health hazard. Because plants do take up significant levels of metals under some circumstances, there is a potential danger. Precautionary measures should at least be taken.

5.1.2.2 Toxicity from Heavy Metals Webber (1972) has indicated that although there are a variety of heavy metals in the sludges, the major symptoms of toxicity come from the presence of zinc, copper and nickel, with occasional toxicity from other elements such as chromium. Relative toxicity of these elements was discussed by Webber.

Indications are that much higher levels of zinc can be tolerated in an alkaline soil and liming will reduce the harmful effects of zinc on crops. Zinc is readily taken up and translocated within the plant often causing chlorosis of the leaves and stunted growth. Some experience indicates that organic matter can reduce the toxic effects of the metal.

Copper has a toxicity similar to that of zinc in that it is greatly influenced by soil pH, with less of an effect from organic matter. Unlike zinc, however, copper is not as easily translocated within the plant but it can accumulate to high concentrations in the roots.

Nickel toxicity is also reduced by lime and fertilizers but is sometimes increased in the presence of phosphate. It is one of the most toxic of the metals found in sludge.

Claydon et al (1973) suggests that at relatively low dosage rates, the zinc, nickel and copper in the sewage sludge can be easily immobilized in the top soil, providing that the normal soil pH is maintained.

Chromium toxicity to plants was first discovered with sewage sludge experiments. Cationic chromium has little or no toxic effects, except at extremely heavy rates of application. Anionic chromium, however, was much more toxic but as it is easily reduced, it is very seldom found in sewage. Unlike the other metals discussed, the anionic chromium appeared to be more toxic at high pH values, thus liming would increase chromium toxicity.

Claydon et al (1973) while studying the toxicity of lead in the soil found that lead applied to the soil in small quantities will remain relatively immobile, but some types of plants take up more lead than others and this dilution effect should not be ignored. The transfer of lead into the human body is decreased by the high tolerance of lead by ruminants.

There was no evidence from Claydon's studies that cadmium applied through normal applications of sludge should give rise to concern. He stressed however, that the application should be strictly controlled. Lucas (1972; in Davies, 1972) found that cadmium is more apt to enter the human food chain through fish, which eat algae, which are capable of concentrating the cadmium.

5.1.2.3 Application Guidelines - The Zinc Equivalent Channey (1973). put forth recommendations for the application of metal bearing sludges on on agricultural land based upon the "zinc equivalent" (Z.E.). It was suggested that the "metal additions should not exceed a zinc equivalent equal to 5 percent of the cation exchange capacity (C.E.C.) of unamended soils at pH great than, or equal to 6.5."

The zinc equivalent is given as:

$$Z.E. = 1\ Zn + 2\ Cu + 8\ Ni$$

where Zn = ppm zinc
Cu = ppm copper
Ni = ppm nickel.

When applying sewage sludge to agricultural lands, it is suggested that soil pH should be maintained at 6.5 or higher, as metal solubility dereases above 6.0. Soils which are medium to fine textured are more suitable than coarse soils as they have a great adsorption capacity (Gilley, 1976).

Based on the equation, given by Channey, the zinc equivalent for the different sludges shown in Table 4 are given in Table 5.5.

The Zinc equivalent for the Milorganite fertilizer, tested by Van Loon (1972), as discussed previously, is 2640. For the So-Green Turfbuilder, 10-6-4, the zinc equivalent is 1960.

Channey also proposed upper limits of metals in sludges for land applications. These limits are given in Table 5.6.

Long term allowable amounts of sludge using Channey's guidelines are given in Figure 5.1. From this data, the sludge addition as dry tons(metric)/hectare, can be calculated from the equation:

$$\text{TOTAL SLUDGE APPLIED} = \frac{(\text{C.E.C.})\ (36363.6)}{\text{Z.E. of Sludge}}$$

where:

C.E.C. = cation exchange capacity of the soil at the site (mg/100gm)

Z.E. = Z.E. of sludge to be spread

Constant= maximum zinc equivalent divided by slope of Channey's graph. $\left(\frac{8600}{0.154} = 36363.6 \right)$

The United States Environmental Protection Agency limits total sludge application rates according to the equation:

$$\text{TOTAL SLUDGE}\ \left(\frac{\text{Dry Tons}}{\text{Acre}}\right) = \frac{(32{,}700)(\text{C.E.C.})}{(\text{Z.E.} - 200)}$$

Both equations yield similar results.

Webber et al (1974) provided data on a selection of Canadian soils encompassing those classification shown in Figure 5.1. This information is shown in Table 5.7. Based on these two sets of data, it would be possible to determine sludge application rates for these municipalities. It should be noted however, that the soil pH is well below the 6.5 figure recommended for sludge application. Liming of these soils would thus be required before sludge applications could be made.

The major soil zones and regions in Canada are shown in Figure 5.7.

In addition to these requirements, an indication of "desirable soil features", is given by Sweeney (1972). The most important features and management requirements are as follows:

1. A soil that is naturally well-drained; maintains an aerobic environment with less hazard of foul odours and soil clogging which are associated with anaerobic conditions. Good drainage ensures the oxidation of organic matter and nitrogenous compounds in the organic and ammonium forms.
2. The preferred textures include fine sandy loams, loams and silt loams. Gravels and coarse sands have an excessively high permeability and low exchange capacities. In heavy soils (some clay loams and clays) the permeability is too low and they are too slow in drying out.
3. The surface infiltration should be at least moderate, greater than 0.6 inches per hour as found in soils growing hay or pasture crops. The permeability coefficient of

subsoils should be at least 0.2 inches per hour.

4. A level to moderately undulating topography reduces the hazards of runoff and soil erosion; easier spreading of sludges with tankers.
5. The site should be accessible at all seasons; winter spreading would be confined to level or nearly level areas that are well removed from bodies of surface water and stream courses.

Webber (1972) indicated that in addition to basing application rates on the zinc equivalent, it is also necessary to keep the total zinc level in the soil less than 280 mg/kg (ppm)*. This is based on application for a 30 year period. This maximum level means that a maximum of 19 kg/hectare can be added per year, if the soil pH is maintained at pH 6.5 or greater. This value of 19 kg/hectare is based on the following information:

Soil Volume	=	1 Hectare x 150 mm	1 acre x 6 inches
Soil Weight	=	2.24×10^6 kg/volume	2×10^6 lbs/volume
Application	=	250 mg/kg/ppm	250lb/10^6lb.
Yearly Dose	=	$\dfrac{250 \frac{mg}{kg} \times 2.24 \times 10^6 \text{ kg/hec.}}{30 \text{ years}}$	$\dfrac{250 \frac{lb}{10^6 lb} \times 2 \times 10^6 \text{lb/acre}}{30 \text{ years}}$
	=	19 kg/hectare/year	16.7 lbs/acre/year

As an example of sludge application rates based on maximum zinc content, consider the case of Calgary, Alberta which has a zinc content of 1470 ppm (See Table 5.4).

$$1470 \text{ ppm} = \frac{1470 \text{ lbs zinc}}{1{,}000{,}000 \text{ lbs sludge}}$$

* 125 mg/kg acetic acid soluble zinc.

Therefore, at 16.7 lbs/acre/year, the maximum application rate is:

$$\frac{16.7\ \frac{\text{lbs}}{\text{acre}}}{1470\text{lbs}} \quad \text{X } 1,000,000 \text{ lbs sludge}$$

$= 11,360$ lbs/acre

$= \underline{5.68 \text{ tons/acre}}$

Based on the zinc equivalent value, which for Calgary is 3,488 (Table 5.5), the application rate would be as follows:

$$3488 \text{ ppm} = \frac{3488 \text{ lbs.zinc}}{1,000,000 \text{ lbs sludge}}$$

$\therefore$ at 16.7 lbs/acre/year, the maximum application rate is:

$$\frac{16.7\ \frac{\text{lbs}}{\text{acre}}}{3488 \text{ lbs}} \quad \text{X } 1,000,000 \text{ lbs sludge}$$

$= 4,788$ lbs/acre

$= \underline{2.39 \text{ tons/acre}}$

The yearly rate for Calgary, based on total loading, and assuming a loam soil (C.E.C.$\approx$ 15), is found to be similar. The same 30 year addition period is assumed.

Total Application	= 69.6 tons/acre
Period	= 30 years
Annual Rate	= 69.6/30 = <u>2.32 tons/acre</u>

Brown (1975) felt that there is still a need to restrict metal accumulations in sludge-amended soils to moderate levels until research evaluating the long-term effects of sludge on soil productivity has been completed. The questions that still need to be answered to evaluate long term effects are:

1. What mechanism prevents or delays metal toxicity in soils having greater quantities of the metal salt than that causing toxicity conditions?
2. Does the mechanism in (1) function regardless of the metal accumulation in the soil.
3. Does this protective mechanism cease when sludge application is stopped?
4. What are the tolerance levels of various crops to various metals?

Answers to some of these questions will come from work now being completed by Dr. Tom Bates at the University of Guelph. Their continuing 8 year study will begin to show some of the long term effects,

5.1.3 Nutrient Availability in Sewage Sludge Heavy metals alone do not always rule how much sludge can be applied to a specific site. In many cases, the nutrient content (Nitrogen and Phosphorus) will determine the application rates. Nitrogen and phosphorus are of concern because of eutrophication resulting from runoff waters entering the receiving streams.

5.1.3.1 Sources of Nitrogen Pollution Nitrogen runoff occurs from nitrate (NO_3^-) which is leached easily from the soil. Ammonia (NH_4^+) present in the soil is quite rapidly converted to leachable nitrate by soil bacteria. The organic forms of nitrogen do not convert to nitrate as readily, However, over time they too will convert and could be leached from the soil. Not all nitrogen added to the soil will be leached into the runoff waters or groundwater. Much of the nitrogen will be utilized by the plants, some of the ammonia will volatilize and some of the nitrogen will be released as a gas through soil denitrification. It has been estimated that a good corn crop can utilize 150 to 200 pounds or more of nitrogen per acre, and some grasses can use more (EPA Sludge

Manual, 1974). The total balance scheme involving air, land, water and plants is illustrated in Figure 5.2 (Beauchamp et al, 1974).

Brown (1975) stated that sludge disposal farms should not become a serious source of nitrate pollution of the waters if application of nitrogenous materials to the soil is approximately equal to the sum of the nitrogen requirements of the crop and the gaseous losses through denitrification and volatilization of nitrogen from the soil. Brown also pointed out that "the potential for nitrate pollution in a given year depends on the accumulated organic nitrogen in the soil from previous sludge applications as well as the nitrogen in the sludge application during the year under consideration".

The amount of nitrogen that can be handled by an area depends on the mass balance as discussed. This balance itself will not be the same throughout Canada, nor in any area. The balance will change every time there is a change in the soil, the climate, the crop, the yield and the particular farming practices employed. Thus, the determination of application rates becomes increasingly complex and the meaning of a standard rate becomes increasingly obscure.

5.1.3.2 Application Guidelines - Nitrogen Loading The Province of Ontario has developed sludge disposal guidelines based on the nitrogen content of the sludge. The guideline limit has been set at 2247 kilograms of nitrogen per hectare per year (2000 lbs/acre/year), (Woods, 1973). Bates (1972) feels that with the limed soils in Ontario, it could well be the nitrogen content of the sludge that will be the limiting factor. Lime, in this case allows greater applications based on the zinc equivalent, thus increasing the limits.

In general, sludge has a 2.5 percent nitrogen content on a wet basis, or 50 pounds of nitrogen per ton of sludge. Using this value, it would be possible to apply 8,960 killograms of dried sludge per hectare per year, (8,000 lbs/acre).

Beauchamp et al (1974) found that the anaerobically digested sludges contain 0.1 to 0.3 percent nitrogen on a fluid basis, with 2 to 50 percent of the total nitrogen being ammonia-nitrogen.

Given the application rate of 200 lbs N per acre per year, it it possible to calculate the amount of sludge, as tons per acre, if the sludge has been analysed for the percent ammonia-nitrogen, percent organic nitrogen and portion of the organic nitrogen that is taken up by the crops the first year. This latter value has been estimated to be 10 percent the first year and 5 percent in years thereafter.

Larson et al (1974) show results where 11 to 60 percent of the ammonia-nitrogen was lost by volatization during spreading. This, of course, depends on the soil characteristics, the way the sludge is spread and the ammonia content. On the average, they found a 35 percent ammonia-nitrogen content. An example case is as follows:

Ammonia nitrogen (NH_3-N)	= 2.5%	
Organic nitrogen (ON)	= 2.0%	
Volatization loss (VL)	=10.0%	
Available Organic N (AON)	=10.0%	first year.

$$\text{Rate (tons/acre)} = \frac{\text{Allowable Nitrogen (lbs/acre)}}{(\%NH_3\text{-N})(100-\%VL)(2000)+(\%ON)(\%AON)(2000)}.$$

$$\text{Rate} = \frac{200}{(.025)(.9)(2{,}000) + (.02)(.1)(2000)}$$

$$= 4.08 \text{ TONS/ACRE}$$

In all applications in successive years, the amount of nitrogen available must include 5 percent of the organic nitrogen in all previous years. Thus, if an identical sludge is used in the second year, the equation will contain an additional term:

$$\text{Rate} = \frac{200}{4.08 + (\%\ \text{ON})(5\%)(2{,}000)}$$

$$= \frac{200}{4.08 + (.02)(.05)(2{,}000)}$$

$$= 2.92 \text{ TONS/ACRE}$$

Based on these figures, a 30 year addition scheme would be as shown in Figure 5.3. This plot is an exponential curve fit given by the equation:

$$\text{Rate TONS/ACRE} = (4.25)(e^{(-0.04)(\text{Year})})$$

It is quite evident from this information, that a very definite problem is going to exist in the future, for as the amount of sludge generated from any one plant is increasing, the amount that can be spread on a previously spread site decreases.

Consider a hypothetical case of a 100 MGD plant producing 75 tons of dry sludge per day. In the first year they would require 6709 acres for sludge spreading under the 200 lbs/acre/year guideline.

$$\frac{27,375}{4.08} = 6709$$

In the second year, this 6709 acres could only handle 26,279 tons of sludge.

$$(3.917 \times 6709) = 26,279$$

For complete and proper application, they would require an additional 268.6 acres.

$$\frac{27,375 - 26,279}{4.08} = 268.6$$

In the third year, the original 6709 acres could handle 25,226 tons.

$$(3.670 \times 6709) = 25,226$$

The newly acquired 269 acres could handle 1054 tons,

$$(3.917 \times 269) = 1054$$

thus an additional 268.4 acres is required.

$$\frac{27,375 - 25,226 - 1054}{4.08} = 268.4$$

If sludge production rates are increasing annually, the problem complexes. Take the same example with a 2 percent per year increase in production. In the first year, the land requirement for the case just examined would be 6709 acres. In the second year, however, the sludge production would be 27,923 tons, assuming a 2 percent increase.

$$27,375 + (27,375 \times 0.02) \quad = 27923$$

This would require 7112 acres for spreading, as the original 6709 acres will handle only 26,279 tons.

$$(3.917 \times 6709) = 26,279$$

which leaves 1644 extra tons

$$(27,923 - 26,279) = 1644$$

which requires an extra 403 acres

$$(1644 \div 4.08) \quad = 403$$

Thus total acreage required is 6709 plus 403 or 7112 acres.

In the third year, the acreage is again computed as:

$$7112 + \frac{[27,923 + (.02 \times 27,923)] \quad - (3.760 \times 6709 \quad - 3.917 \times 403)}{4.8} = 7523 \text{ acres}$$

an increase of 411 acres.

If these calculations are carried out for the full 30 year period, an exponential curve is developed as shown in Figure 5.4 In this case the curve is described by the equation:

$$\text{Acreage Required} \quad = 6693 \quad [e^{(0.043)(\text{year})}]$$

Thus, a municipality which in 1977 may require only 6709 acres for sludge disposal will require just under 18,000 acres by the turn of the century (2000 AD).

5.1.3.3 Sources of Phosphorus Pollution

Phosphorus levels, like nitrogen can be leached from the soil and enter into the nearby watercourses, thus aiding in the eutrophication processes. Although the soil has an adsorption capacity of 100-2000 pounds per acre-foot, this capacity will be exceeded at some time, thus limiting the lifetime of the disposal site (Gilley, 1976).

In the study conducted by Webber et al (1974) it was found that about 1 percent of the total phosphorus in the anaerobic sludge was in soluble form. The majority is tied up with organics and metals. That phosphorus which is soluble is often transformed to an insoluble form when it reacts with soil calcium. A soil test of 20 ppm phosphorus usually indicates that no more phosphorus is required, and from the digested sludge data, it is expected that up to 1100 kg (2425-lbs) of sludge would be required to achieve this level.

The work showed that as more and more sewage treatment plants begin phosphorus control programs, there will be an increasing amount of phosphorus reaching the land from chemical sludges. A potential hazard to surface water supplies will exist from excessive amounts of this sludge through erosion, runoff and the release of soluble phosphorus under anaerobic soil conditions. The effect of chemicals used in phosphorous removal is discussed by Daniels et al (1975).

Although most studies of land disposal of sewage sludge have dealt mainly with effects on crops and metal toxicity, there has been some work done on the effect of these sludges on the soil itself. Varanka et al (1976) in a study carried out at Chicago found that anaerobically digested sewage sludge applied over a 6 year period resulted in increases of copper, cadmium, chromium, nickel, lead, zinc and phosphorus. The increase in phosphorus was almost 3.5 times. Two-fold increases were also found in carbon and nitrogen. The microbial study made showed significant increases in total bacteria, fungi and actinomycetes. Only azotobacter showed a decrease during the sampling period. Significant increases in the rate of sludge denitrifaction were also observed, most likely due to the denitrified population in the sludge.

5.1.4 Physical Application Practices Once the rate (TONS/ACRE) has been specified, it must be determined at what times this sludge should be applied to the land. Based on the land slope and soil permeability, the Ontario Ministry of the Environment has set regulations as shown in Appendix 5.3. Soil permeability classifications used here are in accordance with the Ministry of Agriculture and Foods, Drainage Guide for Ontario.

In this study by Beauchamp et al, (1974), it was found that difference in the slope appeared to have little effect on runoff loss, particularly during winter months when the soil is frozen and the snow melt is confined to the surface. They did discover, however, that high application rates did increase nutrient runoff.

An estimate of the runoff, that can be expected in different parts of Canada is given in Figure 5.5. The run-off ratio shown in this figure is the ratio of run-off to precipitation. Indications are that runoff accounts for less than 5 percent in the southern prairies and up to 80 percent in the wet hilly regions (Hare et al, 1974). Areas that may be susceptible to run-off problems can be recognized from this figure. For example, Victoria, B.C. would not appear to be a likely candidate for agricultural sludge disposal as they have in excess of 120 inches of run-off or 80 percent of the precipitation. At this rate, the discharge from 1 acre of land would be 3,258,288 gallons per year.

The periods that sludge may not be disposed of because of snow cover can be determined from the snow cover data given in Appendix 5.1. Disposal at this time may be limited by regulations within the provinces or just because vehicles cannot get access to these areas during heavy snowfalls. Further regulations regarding site location and site management are provided in Appendix 5.2 (Woods, 1974)(Clark, 1973).

Considerable work has been done on the problem of run-off from sludge dressed fields (University of Guelph, 1973; Larson et al, 1974; Zenz et al, 1976; EPA, 1974).

In the full scale, four-year study conducted by Zenz et al, 1976, on the Metropolitan Sanitary District of Greater Chicago, the following conclusions regarding run-off were made:

1. The water quality of surface discharges of fields receiving digested sludge application has averaged SS,BOD and fecal coliform levels of 60 mg/l, 6.0 mg/l and 36 counts/100 mls respectively. (Prior to discharge, the values were, 63, 3, 102).
2. The water quality of a major stream which drains the project area is unaffected by surface water discharges from the fields receiving digested sludge.
3. Groundwater monitoring wells showed no evidence of groundwater contamination due to digested sludge application to the soils surface. (NO_2-N + NO_3-N +NH_3-N levels were not significantly different in wells in fields with or without sludge)
4. Virus levels monitored at three surface water points indicate that the virus levels of the surface waters are not influenced by sludge application.
5. No aquatic animals inhabiting the local reservoirs were affected by the sludge disposal system.

The Metropolitan Chicago Project, as described earlier, is perhaps the best example of a well planned sludge disposal project now in operation in North America. The field design and run-off system for this project upon which the preceeding conclusions are based, is shown schematically in Figure 5.6.

A report prepared by the University of Guelph (1973) indicated that winter application of sludge, as opposed to fall application, was associated with a marked contribution of micro-organisms to the run-off water. There was sufficient contamination to adversely effect the receiving waters, Predictions as to what will happen under particular circumstances (time of application, amount of sludge applied, physical state of the environment), they insist is highly speculative.

Whenever an agricultural sludge utilization project is undertaken, it is also necessary to look at the physical design requirements as well as sizing and rate of the unit (land). Such factors that must be considered are:

1. storage facilities required for the sludge when land application is not possible (i.e. spring thaw).
2. layout of the spreading area,i.e. run-off collectors, groundwater collectors, fencing;
3. transportation to the spreading site, i.e. rail, pipeline, trucking.
4. spreading methods at the site i.e. dump trucks, chisel plows, spreaders, spray nozzles.

McMichael (1974), gives a quite detailed look at the different trucking options available for sewage sludge haulers. Also, if regulations are to be followed as in Ontario, permits will have to be acquired (Woods, 1973).

5.2 Disposal of Sludge to Sea (Ocean Dumping) Canada, unlike many of the smaller European countries, does not have a large portion of its population situated along coastlines and thus is less apt to depend on ocean dumping of sludge as a final remedy. Considerable portions of British Columbia, the Maritimes and the Arctic are coastal areas which have this method as an option and thus it must be considered an alternative.

5.2.1 International Regulations During the last decade, the increasing awareness of the need to protect the marine environment has resulted in countries throughout the world banding together to regulate ocean dumping. The Oslo Convention (1972) and the London Convention (1975) were the result of this increasing concern.

The Oslo Convention was developed for, and by, European countries and thus Canada did not participate in these intergovernmental discussions. Signatory countries to the Oslo Convention included, Germany, Belgium, Denmark, Spain, Finland, France, United Kingdom, Iceland, Norway, Netherlands, Portugal and Sweden.

In 1975, Canada participated in the intergovernmental discussions at the London Convention and on November 13th, 1975 ratified this convention, thus agreeing to regulate dumping into marine waters (Brydon, 1977). On December 13th, 1975 Canada proclaimed the Ocean Dumping Control Act, developed in order to fulfil international obligations under the London Convention. The act is dedicated to developing and managing ocean resources to assist in the protection of fisheries and recreational waters.

The Ocean Dumping Control Act, administered by the Environmental Contaminants Control Branch of Environment Canada, controls the dumping of all substances; prohibits the dumping of harmful substances; monitors dumping sites to determine the effects of dumping and establishes criteria respecting the effect of waste substances on the marine environment. This in effect places the regulation of sewage sludge dumping into coastal waterways under this act (Brydon, 1977).

Substances prohibited for disposal, restricted substances and factors to be taken into account in granting sludge disposal permits are given in Appendix 5.3. (Gazette, 1975). Note that many of the compounds listed as restricted substances are often found in sewage sludge and could be prohibitory.

5.2.2 Practical Disposal Guidelines If sludge is to be disposed of into the Marine environment, it should be ensured that the nature of the receiving waters and the sea bed (or river bed) will not be substantially changed. It is also necessary to ensure that no other uses of the sea will be impaired (i.e. fishing, transportation, recreation).

Wood (1973) in his investigation of the effects of the disposal of sludge to sea, outlined the major factors to be considered when employing this practice. These major considerations are outlined below:

A. Commercial activities-
   a) disposal areas must be selected so that material dumped to sea does not accumulate in navigation channels or transport back into the harbours.
   b) no interference with present navigation should result from maneuvers of dumping vessels.

B. Amenity Considerations-
   a) conditions must exist such that unacceptable discolouration of water is rapidly removed and no recognizable or offensive suspended or floating material should reach the coastal areas.
   b) sufficient degradation and dilution must be ensured to remove possible hazards to public health
   c) as with land application, levels of nitrogen and phosphorus

must be controlled in order to control the appearance of decaying or floating algae from excessive growth areas.

C. Marine Biological and Fisheries Aspects-

a) attention must be paid to non-commercial marine organisms as well as commercial fisheries as all form part of the food web.

b) large algae deposits from excessive nutrients may deplete oxygen levels thus choking many fish species.

c) sludge blankets forming on the ocean floor may annihilate benthic organism communities and thus break the food chain.

5.2.3 British and American Practices The Environmental Protection Agency in the United States does allow ocean dumping under a permit system similar to Canada, however, they do not approve of this practice. Every dumper in the U.S.A. is required to actively seek alternatives to ocean dumping even when their wastes have met the published EPA criteria (EPA, 1975; Gross, 1976).

Between 1972 and 1975, the EPA brought all dumping under regulatory control. They have required many dumpers to cease dumping and phase out their activites within the next few years. Only when it is proven that ocean dumping will not cause unreasonable degradation, will the EPA become more selective in permitting such practices. The EPA presently operates 11 disposal sites and do not intend to approve additional locations.

In England, where agricultural land is not as abundant for land disposal, there appears to be more reliance on ocean dumping as the ultimate disposal method. Symes et al (1977) indicate that in the North West Water Authority alone, over 45 percent of the sludge is disposed to sea, as compared to 40 percent to the land. It appears that the major concern there is how to deliver all the sludge to a distribution port, not how else might they dispose of their sludge. Sludge Planning

Groups in England are just now beginning to investigate international reports on the utilization of sewage sludge for agricultural purposes.

5.2.4 Diffusion of Sludge into Ocean Waters If sludge is to be disposed of at sea, it can be accomplished either by submerged outfall (undersea pipeline) or by barging. The system that is chosen depends on the concentration of the sludge, quantity, transportation distance and other sludge characteristics such as sludge floatables.

As ocean disposal relies heavily on the dilution aspect, it is essential that the direction and flow velocity of ocean currents in the area be studied. If currents are not optimum, the result will most likely be shoreline deposition or smothering a small area of the ocean floor with a sludge blanket. The depth at which ocean turbulence occurs is also important. If a submerged diffuser is being used, and there is little mixing, it will be easier for the solids to settle to the bottom prior to dilution. If the sludge has been dumped from a barge, and there is little mixing, then it will be possible for portions of the sludge to produce a density buoyant blanket, i.e. a suspended cloud of toxins.

The choice of ocean disposal is open not only to digested sludge but also to disposal of ashes from sludge incineration or wet oxidation. The nature of the sludge will effect the final outcome. The applicability of different types of sludges and ashes is outlined in Table 5.8 (Wyatt et al, 1975).

Overall, any of the reports dealing with ocean dumping indicate that it is probably one of the least desirable disposal methods and should only be considered when no other route is possible. (La/Oma, 1976; Wyatt, 1975; Seabrook, 1975; Kalinske, 1976; EPA, 1975; Wood, 1973 Colosi et al, 1976). Very few places in Canada would not have alternative methods for sludge disposal and thus this method is not apt to be practiced to any great extent.

5.3 Disposal of Sludge to Sanitary Landfills

Landfilling of digested sewage sludge generally refers to landfilling in combination with municipal refuse such that layers of a sludge-refuse mixture are alternated with a soil cover. Use of a well compacted municipal refuse and a properly dewatered sludge in accordance with accepted landfilling practices should avoid any nuisance conditions or hazards to public health. The EPA (1974) has stated that "a stabilized sludge containing no free water can be satisfactorily disposed in a sanitary landfill either alone or in a mixture of municipal solid waste." The suitability of a sludge for landfilling will depend on the method by which it was produced and the treatment it receives prior to landfilling. Wyatt et al (1975) has provided a list of sludges, their suitability for disposal and their constraints. This information is shown in Table 5.9.

5.3.1 Types of Sanitary Landfills.

All sanitary landfilling operations are similar in that the waste is deposited, covered and compacted. The exact nature of this operation will be dependent on local topographical conditions, the size of the landfill site and the availability of cover material. Wyatt et al (1975) have outlined three different types of landfilling operations which are dependent on these characteristics:

1. The trench method (trench-fill or cut-and-cover method) is used in areas of flat or gently sloping topography. This method generally requires that the site can be trenched with conventional earth-moving equipment and that water-table levels be at least lower than the depth of cut. When completed, the landfill consists of a series of long, narrow cells in parallel rows. Cover material is obtained on site from the excavation of adjacent trenches. The finished grade is usually higher in elevation than the original ground surface.
2. The area method (area-fill or fill-and-cover method) is used in low lying areas, such as tidelands, marshes, or swamps, and in land depressions such as abandoned quarries, ravines, or canyons. Refuse is dumped on the existing ground surface, spread in horizontal layers, and compacted. Cover material is provided by excavation of the earth in front of the working

face of the landfill or, if excavation on-site is not possible, by importation of earth from another location. The finished fill consists of a series of cells in layers and results in a significant increase in the surface elevation of the site.

3. The ramp method (progressive-slope method) is used exclusively in filling natural or man-made depressions (e.g., ravines, canyons, quarries, etc.). Refuse is deposited and spread in layers at an angle against the side of the depression to a design height which can be greater than 15 meters (50 feet). Cover soil is placed on the slope sides and top at regular intervals.

During design and development of a landfill site the use of compacting equipment and future site use must be considered. The nature of sewage sludge, as compared to plain rubbish, will affect the compressability of the fill and will also limit the size and type of equipment used for compacting. The settling of the sludge masses after decomposition will change the surface structure and topography and could obstruct future development of the area. If a landfill site was to eventually become a park, then those areas receiving sludge could settle to a greater extent and create mud holes or swamps.

5.3.2 Selection and Operation of a Sanitary Landfill Site If sanitary landfilling is chosen as the final disposal process it will most likely be because an existing landfill site is in use for the municipal refuse. If, however, a site has not yet been chosen for the sludge and refuse disposal, then the following site characteristics should form a basis for selection (Wyatt et al, 1975):

1. Costs - Land values of the candidate landfill sites should be compared by their present values in the community, potential uses, and possible degradation of neighboring lands.
2. Land Requirements - Sufficient land should be available to meet the volume requirements of the service population for a reasonable number of years.
3. Land Use Compatibility - Candidate sites should comply with local zoning regulations and planning documents.
4. Accessibility - Candidate sites should have two or more all-weather access roads.

5. Character of the Land - The land at the site should not be so rocky or swampy that equipment might be damaged or bogged down when filling operations are attempted. Other natural conditions which should exclude a site from consideration (unless specifically designed for) are:

   (a) hilltops and ridges,

   (b) highly porous areas,

   (c) swamps and marshes (except under a reclamation scheme),

   (d) natural drainage channels,

   (e) wildlife sanctuaries, and

   (f) flood plains.

6. Aesthetic Considerations - It is very important that a sanitary landfill site does not constitute a public eyesore, especially to residents of nearby housing. Odor and machine noise from sanitary landfills can cause aesthetic objections. A distance of at least 300 meters from the nearest highways and other thoroughfares should be maintained unless adequate shielding by natural barriers (land formations, streets, etc.) or man-made structures are present. Sanitary landfills should be located downwind from areas of human activity and residence whenever possible to avoid odor and noise nuisance.

7. Availability of Cover Material - A suitable and adequate source of cover material should be available at the site or at an economical haul distance from the site. The ideal cover material is sandy loam (50-60% sand, 20-25% silt, 20-25% clay). However, any well-graded soil with good composition and low shrinkage properties is suitable.

8. Haul Distance - Landfill sites should be located where they are closest to the sources of refuse within the ranges dictated by other site selection criteria. Where a regional or inter-service landfill is used, it should be located equidistance from all the stations served inasmuch as practicable. Where long-haul distances are made necessary (over about 9 kilometers, 5.6 miles), use of large trailer trucks or railcars as well as transfer stations may become necessary. One large site should be favored over a number of small sites even if the former may require slightly higher haul expense.

Within the province of Ontario, the Ontario Ministry of the Environment has set rigid standards governing maintenance and operation of a landfill site. Regulation 824 of the Waste Management Act, now under the Environmental Protection Act, 1971, has set the following standards:

1. Access roads and on-site roads shall be provided so that vehicles hauling waste to and on the site may travel readily on any day under all normal weather conditions.

2. Access to the site shall be limited to such times as an attendant is on duty and the site shall be restricted to use by persons authorized to deposit waste in the fill area.

3. Drainage passing over or through the site shall not adversely affect adjoining property and natural drainage shall not be obstructed.

4. Drainage that may cause pollution shall not, without adequate treatment, be discharged into watercourses.

5. Waste shall be placed sufficiently above or isolated from the maximum water table at the site in such manner that impairment of groundwater in aquifers is prevented and sufficiently distant from sources of potable water supplies so as to prevent contamination of the water, unless adequate provision is made for the collection and treatment of leachate.

6. Where necessary to isolate a landfilling site and effectively prevent the egress of contaminants, adequate measures to prevent water pollution shall be taken by the construction of berms and dykes of low permeability.

7. Where there is a possibility of water pollution resulting from the operation of a landfilling site, samples shall be taken and tests made by the owner of the site to measure the extent of egress of contaminants and, if necessary, measures shall be taken for the collection and treatment of contaminants and for the prevention of water pollution.

8. The site shall be located a reasonable distance from any cemetery.

9. Adequate and proper equipment shall be provided for the compaction of waste into cells and the covering of the cells with cover material.

10. Where climatic conditions may prevent the use of the site at all times, provisions shall be made for another waste disposal site which can be used during such periods.

11. Where required for accurate determination of input of all wastes by weight, scales shall be provided at the site or shall be readily available for use.

12. All waste disposal operations at the site shall be adequately and continually supervised.

13. Waste shall be deposited in an orderly manner in the fill area, compacted adequately and covered by cover material by a proper landfilling operation.

14. Procedures shall be established for the control of rodents or other animals and insects at the site.
15. Procedures shall be established, signs posted, and safeguards maintained for the prevention of accidents at the site.
16. The waste disposal area shall be enclosed to prevent entry by unauthorized persons and access to the property shall be by roadway closed by a gate capable of being locked.
17. A green belt or neutral zone shall be provided around the site and the site shall be adequately screened from public view.
18. Whenever any part of a fill area has reached its limit of fill, a final cover of cover material shall be placed on the completed fill and such cover shall be inspected at regular intervals over the next ensuing period of two years and where necessary action shall be taken to maintain the integrity and continuity of the cover materials.
19. Scavenging shall not be permitted.

Haulers of sewage sludge in Ontario are also controlled by sections of the Environmental Protection Act. Both the haulers and the sites are certified under Section V of the Act and are issued appropriate certificates when approval has been given (Caplice, 1976). Section 31 of this Act states that no person shall use, operate, establish, alter, enlarge or extend a waste management system or a waste disposal site, unless a certificate of approval or provisional certificate of approval therefor has been issued by the Director and except in accordance with any conditions set out in such certificate.

In selection of the site it is essential that there are no detrimental effects of the site on the water quality, air quality, land quality or the neighbouring public health. Protection of these environments must be assured and accounted for in the design of the landfill site prior to approval. In territories where legislation does not restrict landfill development the same standards should form guidelines for both the developer and the regulatory agencies.

Once the site has been approved a monitoring system should be developed including monitoring groundwater observation wells, surface water, sludge and soil heavy metals, persistent organics, pathogens and nitrates (EPA, 1974). Visual observation of the site by control personnel should also be instituted to control aesthetic pollution at the site.

5.3.3 Environmental Consequences of Landfilling. Detrimental effects on the land quality may arise where the land is developed in such a manner that it becomes susceptible to erosion or where leachate contaminates the surrounding soil. The most objectionable effect is likely to be when the use of the site as a landfill prevents development of the land for other purposes. A summary of environmental effects has been given by Weddle (1975).

Although sanitary landfill sites are generally selected in areas well above the water table, the possibility of runoff and percolation of leachate does exist and should be accounted for. For this reason it is advantageous to incorporate leachate collection systems in landfill sites where high volumes of sewage sludge are to be deposited. Excess water from the sludge cake will leach contaminants from the mixed refuse as well as the sludge solids themselves. With a collection system it is possible to collect and treat the leachate prior to disposal.

Disruption of the water quality will occur when surface and groundwater water supplies are contaminated by leachate or surface runoff. This condition can result in well contamination and/or excessive eutrophication in the receiving streams. Stone (1974) found that the major changes to leachate quality brought about by sludge addition would be a decrease in pH, a possible decrease in BOD_5 and an increase in nitrate-nitrogen.

The amount of leachate reaching the groundwater will depend on the quantity of water absorbed by the soil-rubbish mixture and the soil below the site. The water holding capacities of typical soils and typical solid waste components are given by Stone (1974) and are shown in Tables 5.10 and 5.11 respectively. Calculation of total water holding capacity can be made given the local soil conditions, the nature of the rubbish, the amount of sludge deposited, and local climatic conditions. In terms of total lbs. of water that can be absorbed, Stone (1974) developed maximum and minimum absorption curves for different wastes based on total contact time. These data are illustrated in Figures 5.12 and 5.13 respectively. This information indicates that 0.6-1.8 lbs of liquid could be added for every 1.0 lb of dry weight solid waste before complete saturation is reached. Further work by Stone indicated a 1.74 lb/lb average. Now, given the sludge and solid waste production of a municipality it is possible to calculate whether there is sufficient capacity of the solid waste to absorb the water from the sludge.

Kalinske (1976) has suggested that rainfall percolation should be accounted for in the operation of a sanitary landfill site. Control of this parameter can be maintained by:

1) constructing adequate surface slopes,
2) use of impervious surface slopes,
3) filling of all settlement areas, and
4) planting a cover crop to consume a large volume of rainfall.

If a tight cover material is used to decrease the rate of rainfall percolation then vents should be strategically located throughout the landfill site to allow for escape of the gases produced by decomposition of the rubbish and sludge.

For the immediate area around the site the air quality is apt to be the most critical. The major problems here will most likely be from blowing dust or noxious odours. Blowing debris also results in many instances from inadequate cover material or immediate erosion of cover material by the wind. The addition of sewage sludge should aid in controlling blowing debris as it provides moisture that would normally be provided by direct water addition. To avoid odours from the sludge it is necessary to digest the sludge prior to disposal, by one of the methods suggested in Section 2 of this report.

Health problems in the immediate area of the site could result from the two preceding problems of water and air contamination. The presence of noxious gases, pathogens, dust and smoke could create health problems. Leachate and runoff can create corresponding water pollution problems. Less direct health related problems can result from rodent or insect populations flourishing at the site and spreading to neighbouring areas. Proper covering of the site at the end of each day should reduce this occurrence. Stone (1974) found that the addition of sewage sludge to solid waste provided a deterrent for rodents which would normally be present at the site.

5.3.4 <u>A Survey of Canadian Landfill Practices</u>. Viraraghavan (1973) conducted a random survey of landfill sites in Canada which disclosed the following information about Canadian landfill practices:

1. 31% of the towns prohibit dangerous or noxious chemicals, 19% prohibit septic tank sludge, large dead animals, vehicle and radioactive material, and 31% have no restrictions.
2. 94% accept refuse from private parties, contract haulers or municipal forces.
3. Only 19% of the sites use specially designed compactors, the rest use dozers and front end loaders.
4. 19% of the sites are in residential zones, 56% are in suburban or rural zones, 18% are beyond a half-mile from development, and 87% are more than 250 feet from the nearest dwelling.
5. 31% of the original land use was agricultural, 25% was excavation and 25% was swamp or wasteland.
6. 44% of the proposed land use was recreational, 12% industrial and 44% undecided.
7. 44% of the sites were acquired by purchase, 25% were municipally owned, 6% were privately owned, 6% were leased and 12% of the towns both leased and purchased.
8. 13% of the town sites had 24 months life remaining, 25% had two to four years, 31% had four to six years and 31% had more than six years life remaining.
9. 31% of the sites are on clay soil, 13% on silt or sand, 19% on sand and clay, 13% on clay and gravel.

10. 44% of the sites have depth to groundwater less than 20 feet, 19% greater than 20 feet, and a few less than 10 feet.

11. Only 69% of the towns had engineering surveys completed, 25% had no surveys.

12. Most towns reported a 2:1 or 3:1 compaction ratio (volume reduction) in the site.

13. The amount of daily earth cover varied from 4 to 12 inches, with an average of 6 inches.

14. Population requirements varied from 0.08 to 2.6 acres per 10,000 people, with an average of 0.8 acre.

15. Provincial and/or local regulations do apply and 75% reported compliance with some regulation.

The information derived from this study indicates that proper landfilling practices are not always being observed and problems are most likely to result. Severe ground or surface water contamination is inevitable in many of the areas. Future planning also appears to be lacking and will no doubt develop into a major problem.

If sewage sludge is to be deposited with the municipal refuse, then it will be necessary for the municipalities to follow the guidelines or regulations more closely. The sludge will only increase the load to the sites and increase the chance of air, land or water contamination. With proper planning and development, however, the sites could be constructed safely and in an aesthetically pleasing manner.

5.3.5 Advantages and disadvantages of landfilling sewage sludge

Most of the advantages and disadvantages of landfilling sewage sludge are directly related to the pros and cons of sanitary landfilling of solid wastes. It has the advantages of economics, short start-up time, flexibility, land recovery and being a final disposal method.

Disadvantages of sanitary landfilling are commonly the lack of suitable land in densely populated areas, the poor operation of the sites, gas and odour production, debris scattering and runoff pollution. Most of these problems are the result of poor planning and very poor site attention. Further problems with landfilling may also occur some time after the site is completed as there may be topographical shifts. If the site is planned for future development these shifts could restrict any building on the site.

An advantage that has just recently come to light is the recovery of methane gas from sanitary landfill sites. Carlson (1977) reports a gas production rate of 7.5 MMCFD from a 150 acre site, 40 feet deep. This gas had a mean methane content of 44 percent. Harnessing of gas supplies such as this, on a large scale, could supplement dwindling energy supplies.

Anyone familiar with the development of a landfill site will know that there is normally great public opposition to such a treatment scheme. The major objection is the destruction of some agricultural lands or the thought of such a giant "eyesore." The past histories of landfills in Canada have created this opposition and it will likely be some time before people begin to approve of landfill sites in general. This of course depends on the depth of planning involved in future site developments.

APPENDIX 5.1

CLIMATIC REDUCTION OF LAND APPLICATION OF SEWAGE SLUDGE IN CANADA

Due to the nature of the Canadian climate,much of the land surface that would be available for sludge disposal is snow covered a great portion of the year. The longer the snow cover remains, the larger the storage facilities must be for holding the sludge from winter operations. In certain areas of the country, the duration of snow cover may mean storage costs exceed the costs of an alternative treatment system not requiring agricultural land disposal.

Based on the depth and duration of snow cover, Potter (1965), divided Canada into seven main snow cover regions. These regions are:

1. The Arctic Archipelago
2. Districts of MacKenzie and Keewatin
3. Pacific Coast Region of British Columbia
4. British Columbia and the Yukon
5. The Prairie Provinces
6. Northern Ontario, Quebec and Labrador
7. Southern Ontario, St. Lawrence Lowlands and the Atlantic Provinces.

The Arctic Region, which is north of the tree line, usually has a shallow snow cover of long duration. The snow is of the same duration but of much greater depth in the MacKenzie Region. Moving into the Southern Prairies, the snow cover is of short duration and intermittent because of the actions of the Chinook winds. In the Yukon and British Columbia, the snow cover varies greatly with altitude and exposure, except on the Pacific Coast of British Columbia where snow, brought by individual storms, usually melts soon after falling. Many winters have passed in the Pacific Coast Region with no snow cover at all.

In Eastern Canada, the Northern Ontario Region is similar to the MacKenzie region in terms of duration, but the depths are much greater in the east, usually the deepest in Canada. The Southern Ontario, Atlantic

Region has a much shorter duration and depth than the Northern Region, and this area often experiences melting periods and thus no snow cover at many times.

When melting conditions do arise, several days are required to dry out the soil before vehicles would be able to get onto the land for disposal. Most regions are therefore limited by the time of the first snowfall and the disappearance of the last.

The median date of the first major snow cover and the median date of the last major snow cover are illustrated in Figures 5.8 and 5.9.

In order to illustrate the period of time that land is available for sludge disposal, the median number of days that snow cover is present is shown in Figure 5.10. Days available for sludge disposal are 365 minus this number. The median depth of the snow appearing during these periods is given in Figure 5.11.

APPENDIX 5.2

REGULATIONS

(extracted from: Land Application of Processed Organic Wastes. G.M. Woods, Ontario Ministry of the Environment, May 28, 1973)

Note: Recent Ministry of the Environment Guidelines on the Land Application of Sewage Sludge have been developed but could not be released for publication in this study (DeAngelis, 1977).

INTERIM GUIDELINES FOR DISPOSAL OF SLUDGE BY LAND APPLICATION

NOTE

a) The following pertains to the disposal of sludge which has undergone proper anaerobic or aerobic digestion or other suitable processing, at a municipal sewage treatment plant.

b) It is intended that the method of land application entail the utilization of sludge in the agricultural industry, as opposed to merely disposing of the material.

A. Site Location

A.1 The site should be remote from surface water courses. The minimum distance between the site and the surface water course should be determined by the land slope as follows:

Max. Sustained Slope	Minimum Distance to Watercourse For Sludge Application During May to November Inclusive	For Sludge Application During December to April Inclusive
0 - 3%	200 ft.	600 ft.
3 - 6%	400 ft.	600 ft.
6 - 9%	600 ft.	No sludge to be applied
greater than 9%	No sludge to be applied unless special conditions exist	No sludge to be applied

A.2 The site shall be at least 300 ft from individual human habitations.

A.3 The site shall be at least 300 ft from waterwells.

A.4 The site shall be at least 1,500 ft from areas of residential development.

B. Land Characteristics

B.1 The land slope and soil permeability will determine the time of year that sludge may be applied, as follows:

Maximum Sustained Slope	Soil Permeability **	Allowable Duration of Application Southern Ontario	Northern Ontario
0 - 3%	any	12 months/year	12 months/year
3 - 6%	rapid to moderately rapid	12 months/year	12 months/year
	moderate to slow	10 months/year (May to February)	9 months/year (June to February)
6 - 9%	rapid to moderately rapid	7 months/year (May to November)	6 months/year (June to November)
	moderate to slow	6 months/year (May to October)	5 months/year (June to October)
greater than 9%	any	no sludge application unless warrented by special conditions.	

** Soil permeability classification shall be in accordance with Tables 1. and 2. of the Ministry of Agriculture and Food's publication entitled "Drainage Guide for Ontario"/ The type of soil should be determined with the use of County Soil Maps available through the Ministry of Agriculture and Food.

B.2 The ground water table during sludge application should be not less than 3.0 ft. from the surface for soils with moderate to slow permeability. For soils with rapid to moderately rapid permeability, the ground water table should be not less than 5.0 ft. from the surface.

B.3 Where sludge application is carried out by tank truck, untiled land should be given preference to tiled land. Where tiled land is used, the sludge hauling contractor should request instructions from the landowner, with regard to minimizing the possibility of damage to the tile system.

C. Site Management

C.1 When sludge is applied to agricultural land, the land is to be used only for pasture, fallow or the growing of forage crops. Dairy cattle should be excluded from pasture land. These restrictions on land use shall apply from the date of application until the end of the calendar year during which the sludge has been applied.

C.2 The boundaries of the site shall be marked (e.g. with stakes at the corners) so as to avoid confusion regarding location of the site during sludge application, or during the taking of soil or crop samples. The markers should be maintained until the end of the current or subsequent growing season, whichever is applicable.

C.3 Soil tillage and sludge application, should where possible, follow the contours of the land (to maintain a contour furrow system). Passage of sludge spreading vehicles over the land should be minimized, to reduce compaction of the soil (e.g. the allowable sludge application rate in cu.yards/A/year, could be achieved after one or two passes.

3.4 Special precautions may be required where the possibility of localized surface water run-off problems exist.

D. Sludge Application Rates

D.1 In determining the allowable rate of sludge application for a particular parcel of land, the objective shall be to match as closely as possible the quantity of nutrients removed from the soil by the harvesting of the crop. The allowable rate will thus be determined by the nutrient uptake capabilities of the particular crop under consideration. The sludge hauling contractor shall adhere to the application rate (in cu.yd./A/year) specified in the Certificate of Approval issued by the Waste Management Branch of the Ministry of the Environment. The suitability of sludge application rates may, if required, be monitored by soil analyses and/or crop analyses. The collection of soil or crop samples shall be the responsibility of the Waste Management Branch

D.2 The sludge shall be spread uniformly over the surface of the land.

D.3 The sewage treatment plant operating agency is to keep records of the location of all the sites used for the disposal of its sludge and the sludge quantities disposed of at site, each week (e.g. volume of sludge in cu.yards, and the weight of sludge solids in tons). The operating agency shall ensure that at least every 3 months, samples of the sludge are submitted for through analysis (e.g. total solids, volatile solids, pH, nitrogen, phosphorus, potassium, ether extractables, heavy metals, etc.)

APPENDIX 5.3

CANADIAN RESTRICTIONS ON OCEAN DISPOSAL OF WASTES

extracted from Canada Gazette, Part III,
volume 1, No. 9. Chapter 55.

CANADIAN RESTRICTIONS ON OCEAN DISPOSAL OF WASTES

Schedule I

Prohibited Substances

1. Organohalogen compounds.
2. Mercury and mercury compounds.
3. Cadmium and cadmium compounds.
4. Persistent plastics and other persistent synthetic materials.
5. Crude oil, fuel oil, heavy diesel oil, and lubricating oils, hydraulic fluids and any mixtures containing any of them.
6. High-level radioactive wastes or other high-level radioactive matter that may be prescribed.
7. Substances in whatever form produced for biological and chemical warfare.

Schedule II

Restricted Substances

1. Arsenic and its compounds.
2. Lead and its compounds.
3. Copper and its compounds.
4. Zinc and its compounds.
5. Organosilicon compounds.
6. Cyanides.
7. Fluorides.
8. Pesticides and their by-products not included in Schedule I.
9. Beryllium and its compounds.
10. Chromium and its compounds.
11. Nickel and its compounds.
12. Vanadium and its compounds.
13. Containers and scrap metal.
14. Radioactive wastes or other radioactive matter not included in Schedule I.
15. Substances that by reason of their bulk would interfere with fishing.

Schedule III

Factors to be Taken Into Account in Granting Permits

1. Characteristics and Composition of Substance

(1) Total amount and average composition of substance dumped (e.g. per year).

(2) Form (e.g. solid, sludge, liquid or gaseous).

(3) Properties: physical (e.g. solubility and density), chemical and biochemical (e.g. oxygen demand, nutrients) and biological (e.g. presence of viruses, bacteria, yeasts and parasites).

(4) Toxicity.

(5) Persistence: physical, chemical and biological.

(6) Accumulation and biotransformation in biological materials or sediments.

(7) Susceptibility to physical, chemical and biochemical changes and interaction in the aquatic environment with other dissolved organic and inorganic materials.

(8) Probability of production of taints or other changes reducing marketability of resources (fish and shellfish).

2. Characteristics of Dumping Site and Method of Deposit

(1) Location (e.g. co-ordinates of the dumping site, depth and distance from the coast) and location in relation to other areas (e.g. amenity areas, spawning,nursery and fishing areas and exploitable resources).

(2) Rate of disposal per specific period (e.g. quantity per day, per week, per month).

(3) Methods of packaging and containment, if any.

(4) Initial dilution achieved by proposed method of release.

(5) Dispersal characteristics (e.g. effects of currents, tides and wind on horizontal transport and vertical mixing).

(6) Water characteristics [e.g. temperature, pH, salinity stratification, oxygen indices of pollution - dissolved oxygen (DO), chemical oxygen demand (COD), biochemical oxygen demand (BOD) - nitrogen present in organic and mineral form including ammonia, suspended matter, other nutrients and productivity].

(7) Bottom characteristics (e.g. topography, geochemical and geological characteristics and biological productivity).

(8) Existence and effects of other dumpings that have been made in the dumping site (e.g. heavy metal background reading and organic carbon content).

(9) In issuing a permit for dumping, consideration should be given whether an adequate scientific basis exists for assessing the consequences of such dumping, as outlined in this Schedule taking into account seasonal variations.

3. General Considerations and Conditions

(1) Possible effects on amenities (e.g. presence of floating or stranded material, turbidity, objectionable odour, discoloration and foaming).

(2) Possible effects on marine life, fish and shellfish culture, fish stocks and fisheries, seaweed harvesting and culture.

(3) Possible effects on other uses of the sea (e.g. impairment of water quality for industrial use, underwater corrosion of structures, interference with ship operations from floating substances, interference with fishing or navigation through deposit of waste or solid objects on the sea floor and protection of areas of special importance for scientific or conservation purposes).

(4) The practical availability of alternative land based methods of treatment, disposal or elimination, or of treatment to render the matter less harmful for dumping at sea.

SECTION 5 - TABLES

TABLE 5.1 EXAMPLES OF SOME FERTILIZERS AND THEIR APPLICATION RATES FOR GREENHOUSE SOILS

Fertilizer	N (%)	P_2O_5 (%)	K_2O (%)	For Use as Soluble Fertilizers	In Soil Mixes (Pounds per Cubic Yard)	On Bench Crops (Pounds per 100 sq.ft.)	General Salt Level	Characteristics
NITROGEN								
Ammonium nitrate	33	0	0	Excellent	1/4	1/2	very high	Rapid availability,acidifying
Calcium nitrate*	15	-	-	Excellent	1/2	1-2	moderate	Rapid availability,alkalizing
PHOSPHORUS								
Treble superhphosphate	0	46	0	No	1-2	1-3	low	Moderate availability
Diammonium phosphate*	21	53	0	Excellent	1/2	1	moderate	Rapid availability, acidifying
POTASSIUM								
Potassium chloride	0	0	60	Acceptable	1/4	1/2	very high	Rapid availability
Potassium nitrate*	13	0	44	Excellent	1/4	1/2-1	high	Very rapid availability
ORGANIC								
Activated sewage sludge*	6	3	0	No	1-2	2-4	low	Medium availability
COMPLETE FERTILIZERS								
20-20-20*	20	20	20	Excellent**	1/4	1/2-1	--	Some sources water-soluble
5-20-20*	5	20	20	No**	1/2-1	1/2-1	--	Phosphorous not very soluble

* Provides more than one nutrient

** Suitability for use in soluble fertilization depends upon components. Look for solubility information on fertilizer bags.

TABLE 5.2 METAL REMOVAL EFFICIENCY OF A CONVENTIONAL ACTIVATED SLUDGE PLANT. (OAKVILLE, ONTARIO)

Metal	Percent Removed		
	Primary Treatment	Secondary Treatment	Total Treatment
Aluminum	69	20	75
Barium	*	*	*
Beryllium	*	*	*
Bismuth	3	3	6
Cadmium	60	50	80
Chromium	55	54	79
Cobalt	*	*	*
Copper	33	60	73
Iron	49	55	77
Lead	66	79	93
Manganese	33	6	37
Mercury	60	>62	>85
Molybdenum	*	*	*
Nickel	15	1	16
Silver	*	*	*
Strontium	10	2	12
Vanadium	*	*	*
Zinc	54	50	77

* metal levels too low to determine removal.

TABLE 5.3 SOURCES OF HEAVY METALS IN MUNICIPAL-INDUSTRIAL RAW SEWAGE

Metal	Source
Zinc	Cosmetics, Textiles, Plating
Copper	Water Supply Pipework
Silver	Photographic Work, X-Rays
Cadmium	Plating Industries
Boron	Detergents

TABLE 5.4 VARIATION IN QUANTITIES OF HEAVY METALS IN MUNICIPAL SEWAGE SLUDGE (mg/l)

LOCATION		Aluminum	Barium	Beryllium	Bismuth	Cadmium	Chromium	Cobalt	Copper	Iron	Lead	Mercury	Molybdenum	Nickel	Silver	Strontium	Vanadium	Zinc	REFERENCE
Oakville	A	8500	740	74	42	2500	20	3200	9400	3800	260	1.4	10	780	40	360	10	24000	Oliver(1975)
Oshawa	C	5800	5900	94	13	2700	19	1600	130000	2800	420	2.2	10	1600	52	172	10	7300	"
Woodstock	E	16000	1000	120	150	620	35	1100	59000	5900	17000	2.0	21	82	55	230	25	8500	"
Ingersoll	F	2400	210	180	3.5	300	30	540	250000	150	480	2.5	30	20	10	1000	10	1300	"
N. Toronto		1.6%				21	700		1240	6.9%	1080	24		51	56			.25%	Van Loon(1973)
Newmarket		.14%				2	19		200	.41%	90	1		9	15			760	"
Point Edward		4.4%				5	57		540	.64%	200	4		20	4			710	"
Alum Sludge		6.6%				12	165		539	1.0%	280			10				1050	Cohen (1977)
Iron Sludge		1.1%				22	510		858	6.0%	1480			15				1800	"
Lime Sludge		0.3%				6	40		140	0.6%	129			8				290	"
Calgary						11			845	12400	1470	4.9		41				1470	McCoy(1977)
Lethbridge						8.8			314	12800	162	6.5		19				544	"
Edmonton						14			508	12800	449	2.1		89				850	"
Aurora		1487				.24	194		7.0	122	5.8			2.79				6.8	Bates(1974)
Sarnia		134				2.56	2.87		19.0	1864	86.2			.69				314.5	Bates(1977)
Guelph		71				7.50	132		99.0	750	45.0			3.36				262.5	"

TABLE 5.5 ZINC EQUIVALENTS FOR SOME CANADIAN SLUDGES

SLUDGE	ZINC EQUIVALENT
Oakville	49,040
Oshawa	280,100
Woodstock	127,156
Ingersol	501,460
Newmarket	1,232
Point Edward	1,950
Calgary	3,488
Lethbridge	1,324
Edmonton	2,578

TABLE 5.6 MAXIMUM METAL CONCENTRATIONS IN SLUDGES FOR SOIL APPLICATION

METAL	MAXIMUM PERMISSIBLE CONCENTRATION (ppm)
Zinc	2,000
Copper	800
Nickel	100
Cadmium	.005 of zinc (or 10ppm)
Boron	100
Lead	1,000
Mercury	15

TABLE 5.7 DESCRIPTION AND SELECTED PROPERTIES OF SOILS

Series		Sample Depth (cm)	pH	Organic Matter %	Sand %	Silt %	Clay %	Texture
St. Thomas	Humo-Ferric Podzol	0-30	5.2	1.8	91.9	6.8	1.3	sand
Vaudreuil	Humic Gleysol	2-5	5.1	5.8	72.7	23.7	3.6	sandy loam
Grimbsy	Grey Brown Luvisol	0-15	4.3	0.6	43.7	48.9	7.4	silt loam
Haldimand	Grey Brown Luvisol	0-15	4.8	2.3	11.3	52.3	36.4	silty clay loam
Rideau	Gleyed Eutric Brunisol	8-17	5.3	1.0	5.7	49.1	45.2	silty clay
Wendover	Melanic Brunisol	0-3	5.4	9.4	6.7	47.9	45.4	silty clay

TABLE 5.8

SUITABILITY OF VARIOUS MUNICIPAL WASTEWATER TREATMENT PLANT RESIDUAL WASTES FOR OCEAN DISPOSAL

Residual Waste	Operational Constraints	Institutional Constraints	Alteration of Benthos	Presence of Significant Toxins
Biological Treatment				
Primary Sludges				
Undigested	No	Yes	High	Yes
Thickened	No	Yes	High	Yes
Digested	No	Yes	Moderate	Yes
Activated Sludges				
Undigested	No	Yes	Moderate	Yes
Thickened	No	Yes	Moderate	Yes
Digested	No	Yes	Low	Yes
Sludge Cake	Yes	Yes	Moderate	Yes
Ash				
Wet Oxidation	Yes	Yes	Low	Low
Incineration	Yes	Yes	Low	Low
Chemical Treatment				
Alum Sludge				
Raw	No	Yes	Low	No
Dewatered	Yes	Yes	Moderate	No
Lime Sludge				
Raw	No	Yes	Low	No
Dewatered	Yes	Yes	Moderate	No

Source: Wyatt et al, 1975

TABLE 5.9

SUITABILITY OF VARIOUS MUNICIPAL WASTEWATER TREATMENT PLANT RESIDUAL WASTES FOR SANITARY LANDFILL DISPOSAL

Residual Waste	Operational Constraints	Institutional Constraints	Potential Groundwater Contamination	Methane Production
Biological Treatment				
Primary Sludges				
Undigested	Severe	Yes	High	High
Thickened	Severe	Yes	High	High
Digested	Severe	No	High	High
Activated Sludges				
Undigested	Severe	Yes	High	High
Thickened	Severe	Yes	High	High
Digested	Severe	No	High	High
Sludge Cake	Moderate	No	High	High
Ash				
Wet Oxidation	None	No	Low	None
Incineration	None	No	Low	None
Chemical Treatment				
Alum Sludge				
Raw	Severe	No	Moderate	Low
Dewatered	Moderate	No	Moderate	Low
Lime Sludge				
Raw	Severe	No	Moderate	Low
Dewatered	Moderate	No	Moderate	Low

Source: Wyatt et al, 1975

TABLE 5.10

WATER HOLDING CAPACITY OF TYPICAL SOILS

Material	Fine, sandy loam	Natural humus	Ottawa sand	Charcoal ashes	Clay
Organic content (% dry weight)	4.87	17.65	-	-	5.77
Saturation moisture content (% dry weight)	44.3 40.4 42.5	104.0 87.6 92.0	15.3 15.6 16.1	71.8 71.2 69.5	31.5 32.5 31.0
Average	42.3	94.5	15.7	70.8	31.7

Source: Stone, 1974

TABLE 5.11

WATER ABSORPTION RANGES FOR SOLID WASTE COMPONENTS

Component	Moisture content, percent dry weight					
	Water absorption capability			Total moisture-holding capacity*		
	Maximum	Average	Minimum	Maximum	Average	Minimum
Newsprint		290			290	
Cardboard (solid and corrugated)		170			170	
Other miscellaneous paper	400		100	400		100
Lawn clippings (grass and leaves)	200		60	370		140
Shrubbery, tree prunings	100		10	250		0
Food waste (kitchen garbage)	100		0	300		0
Textiles (cloth of all types, rope)	300		100	300		100
Wood, plastic, glass, metal (all inorganics)		0			0	

* Water absorption plus initial moisture content.

Source: Stone, 1974

SECTION 5 - FIGURES

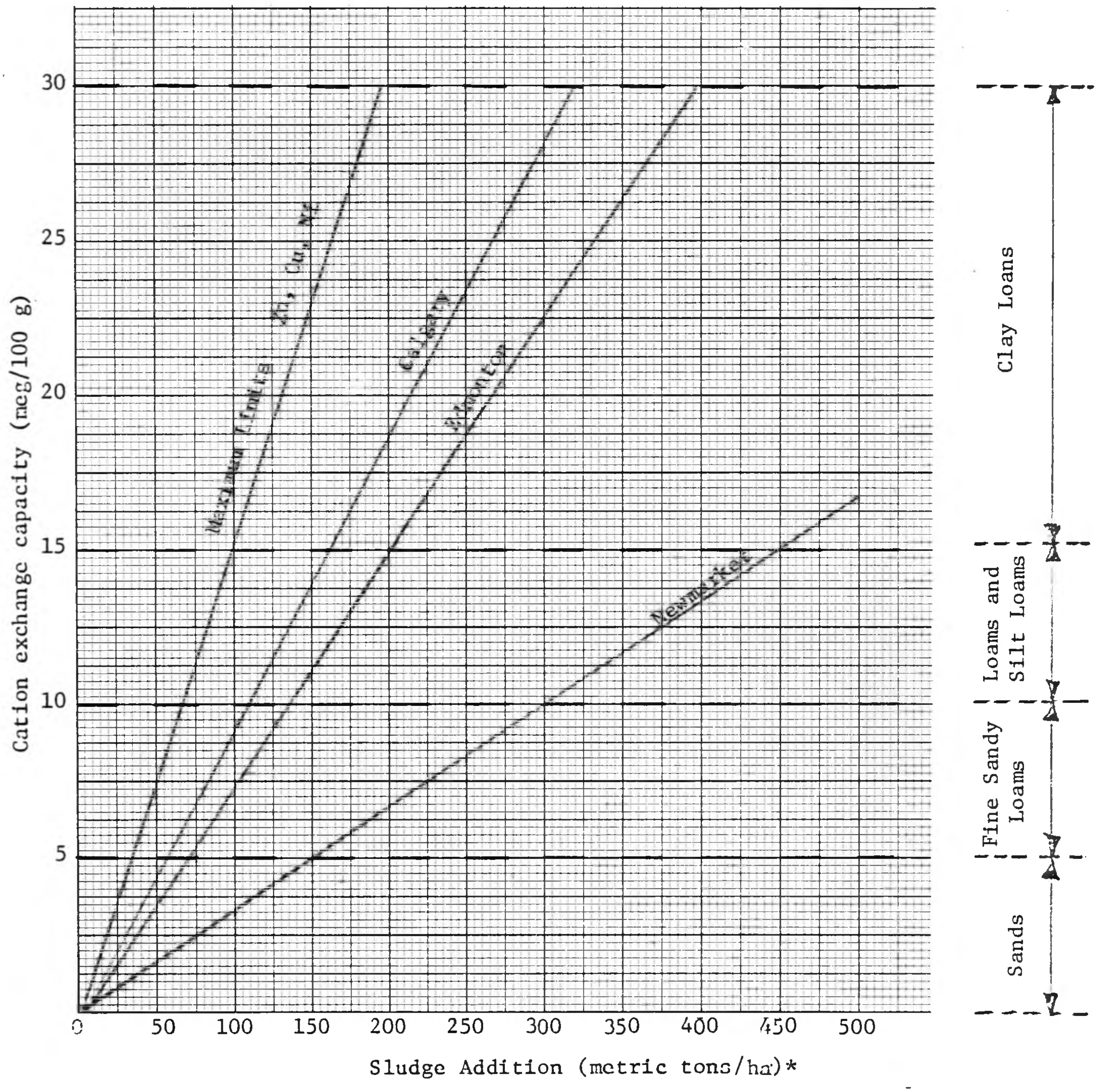


Fig. 5.1 SEWAGE SLUDGE APPLICATION RATES AS A FUNCTION OF SOIL CATION EXCHANGE CAPACITY

Maximum Line: Zn = 2000 mg/1, Cu = 1000 mg/1, Ni = 200 mg/1

* 1 metric ton/Ha = 0.445 Tons/Acre

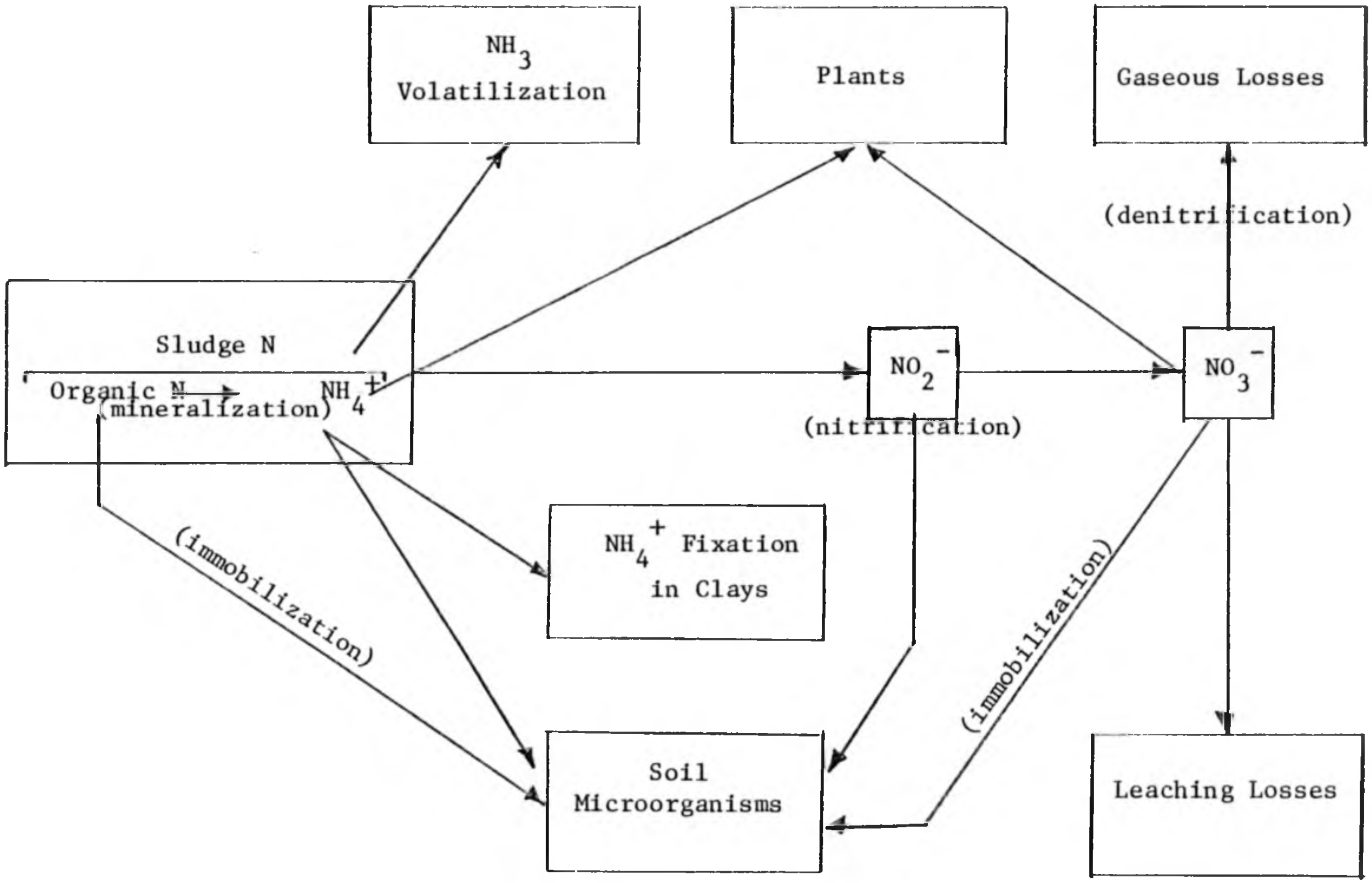


Fig. 5.2 NITROGEN CYCLE ILLUSTRATING THE FATE OF SLUDGE NITROGEN

Source: Beauchany *et al*, 1974

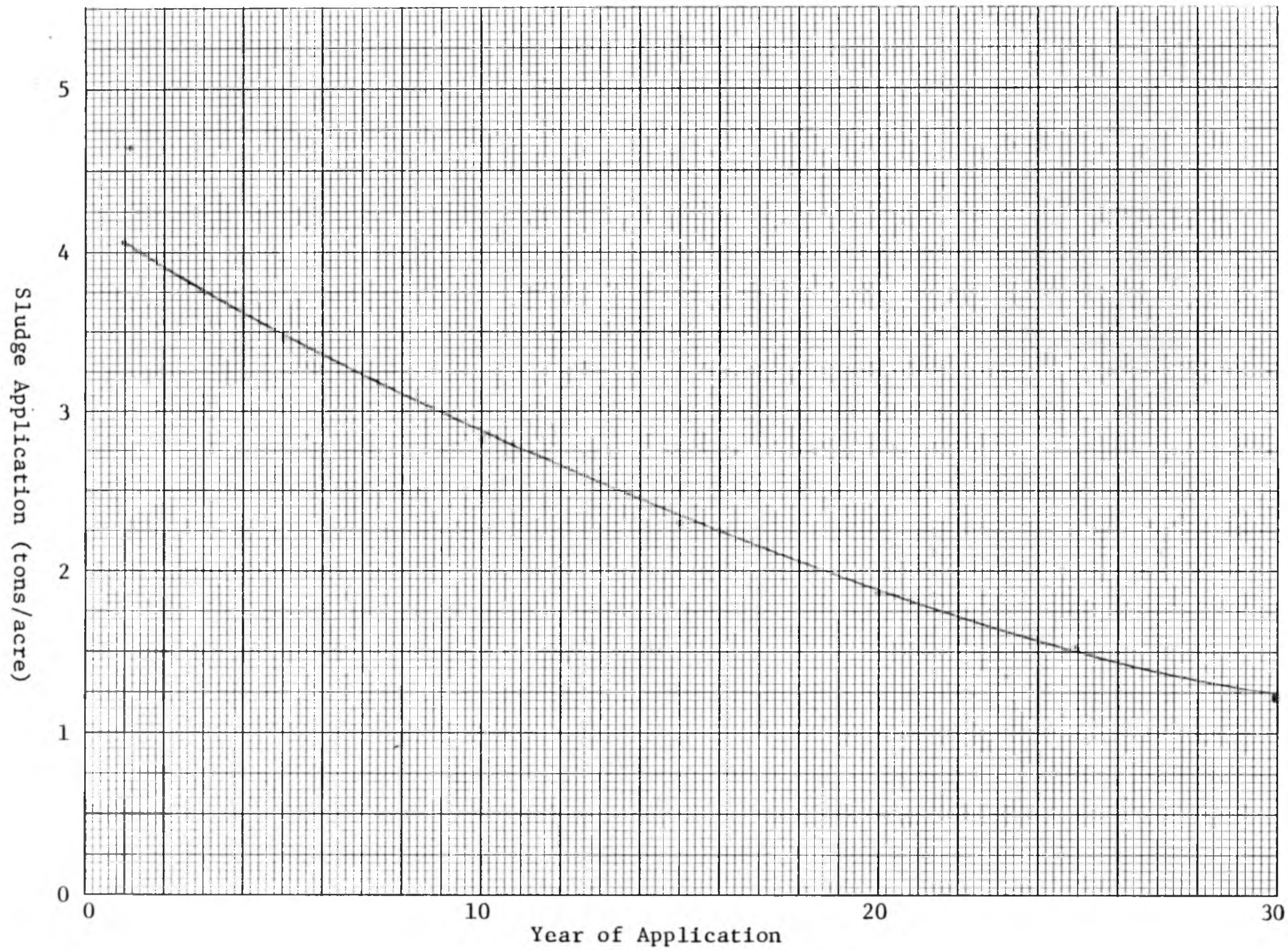


Fig. 5.3 30 YEAR SLUDGE ADDITION SCHEME FOR AN EXAMPLE SLUDGE

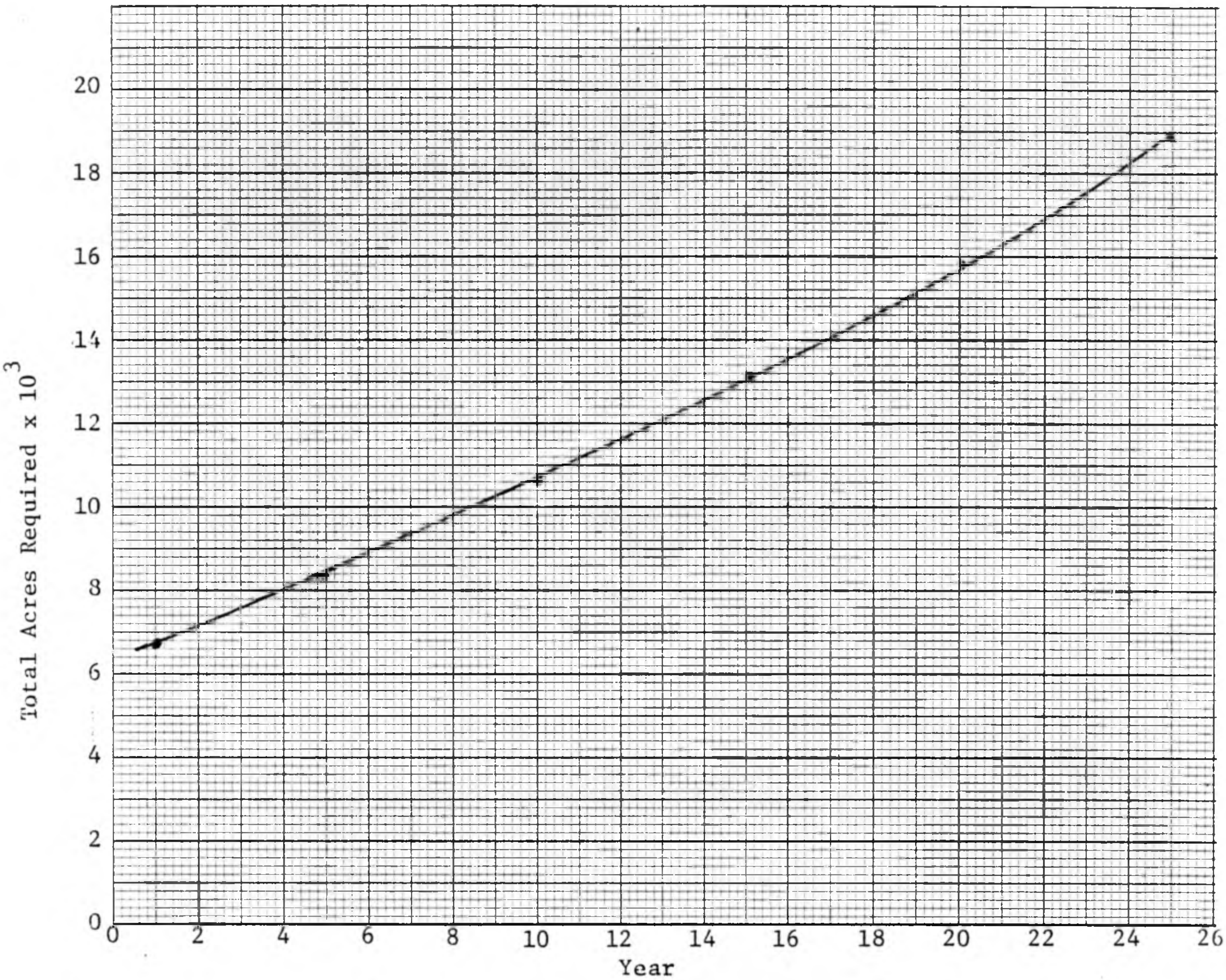


Fig. 5.4 GROWTH IN TOTAL ACREAGE REQUIRED FOR AN EXAMPLE SLUDGE OVER A 25 YEAR PERIOD

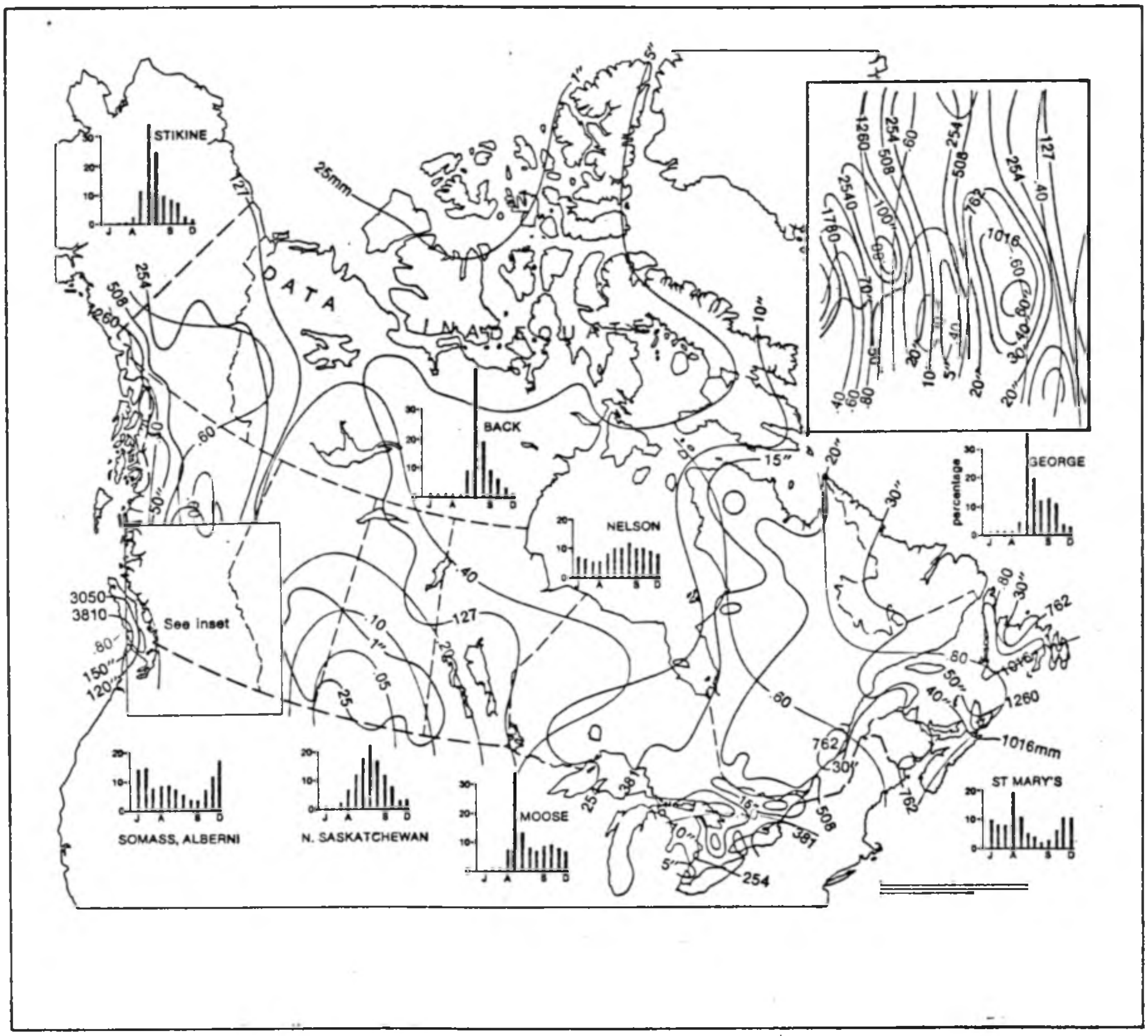


Fig. 5.5 MEAN ANNUAL RUN-OFF AND RUN-OFF RATIO FOR CANADA

Source: Hare _et al_, 1974

Note: Run-off as inches and millimetres.
Ratios expressed as decimal value.

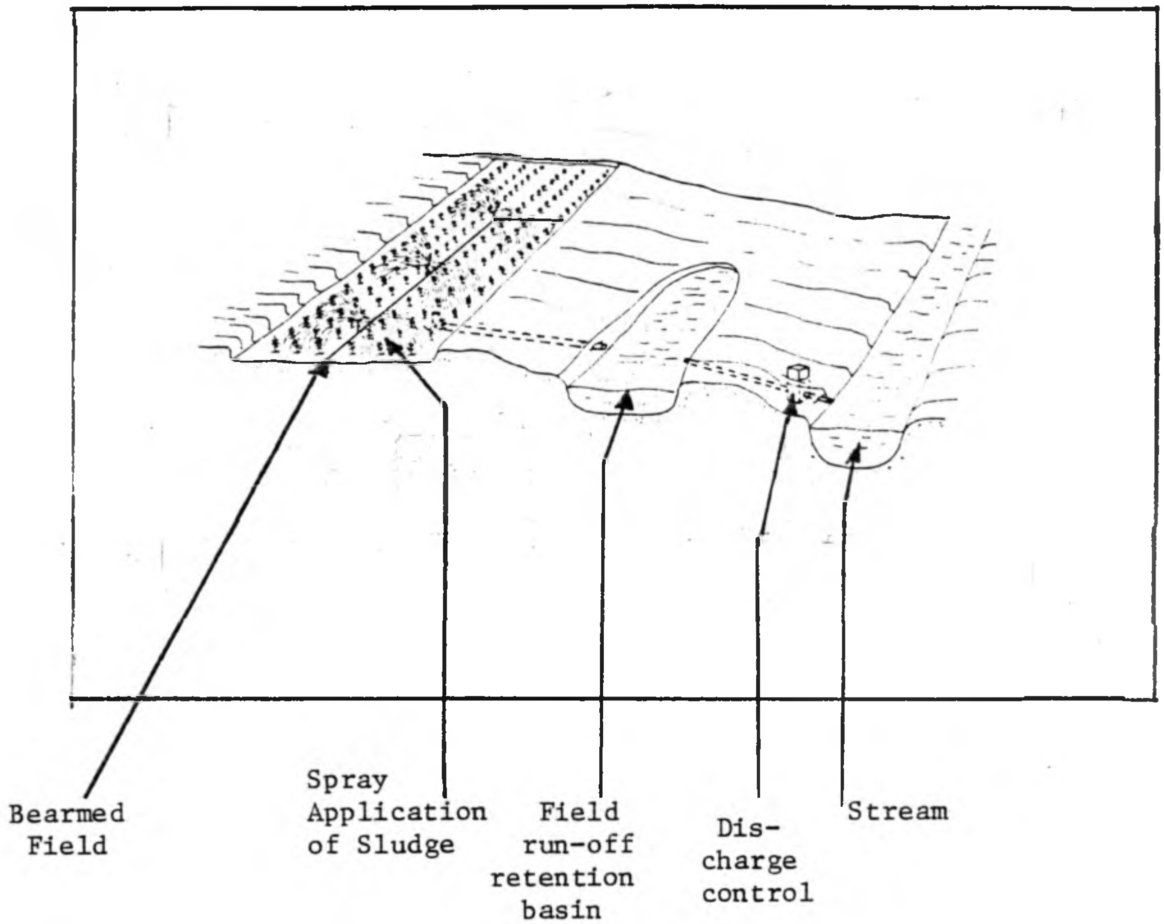


Fig. 5.6 FIELD DESIGN WITH RUN-OFF WATER CAPTURE SYSTEM

Source: Zenz et al, 1976

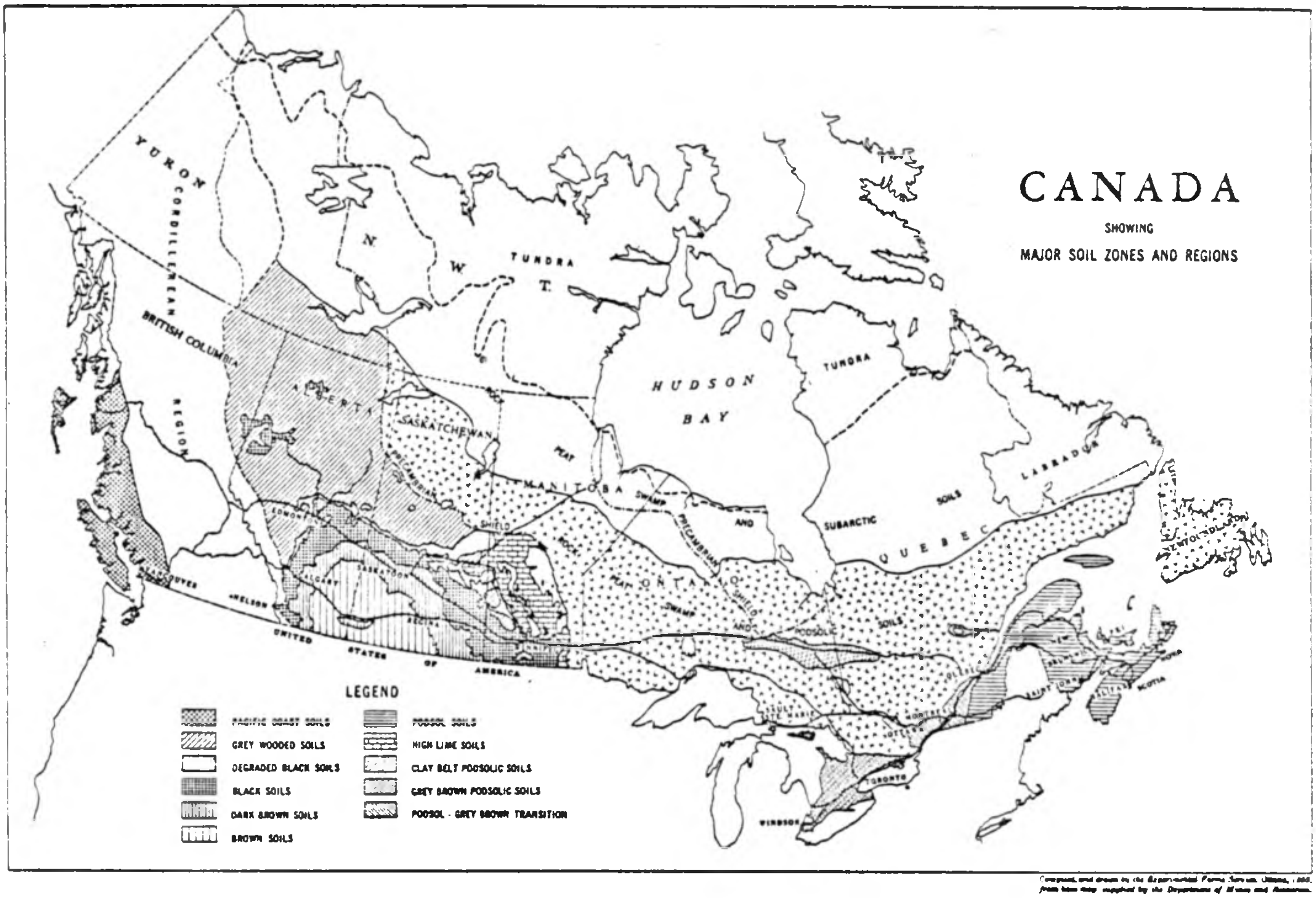


Fig. 5.7 MAJOR CANADIAN SOIL GROUPS

Source: McConkey, 1952

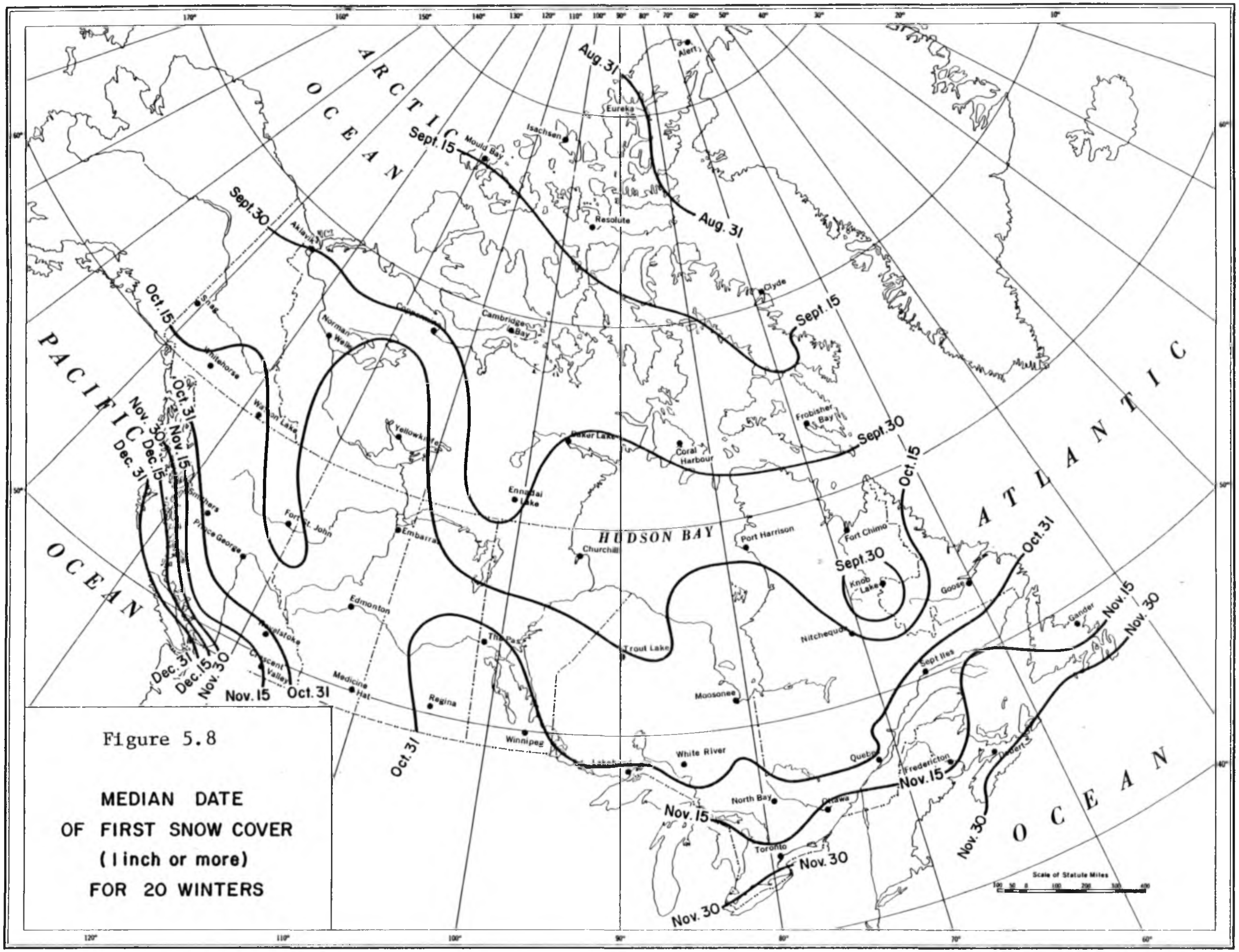


Figure 5.8

MEDIAN DATE OF FIRST SNOW COVER (1 inch or more) FOR 20 WINTERS

Source: Potter, 1965

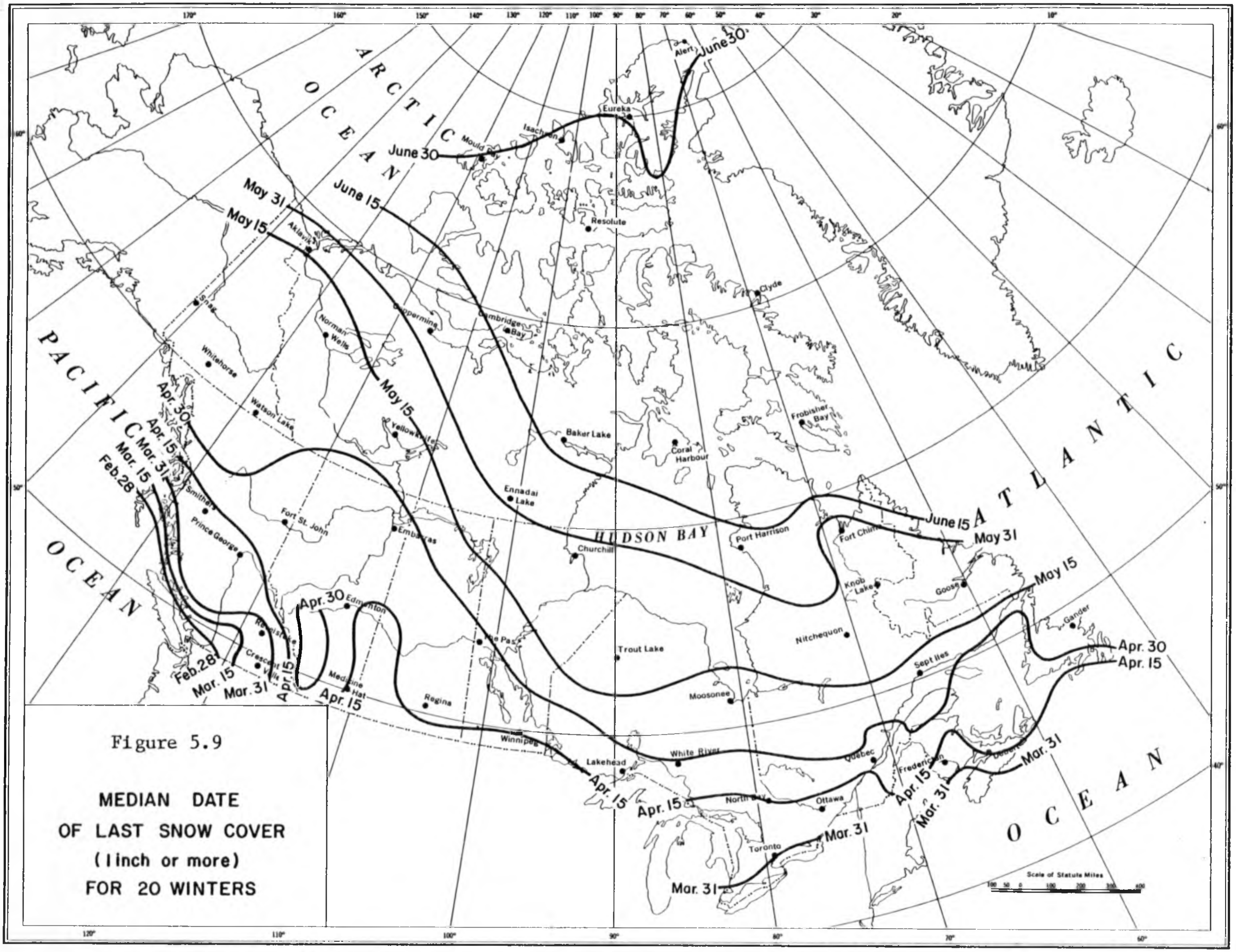


Figure 5.9

MEDIAN DATE
OF LAST SNOW COVER
(1 inch or more)
FOR 20 WINTERS

Source: Potter, 1965

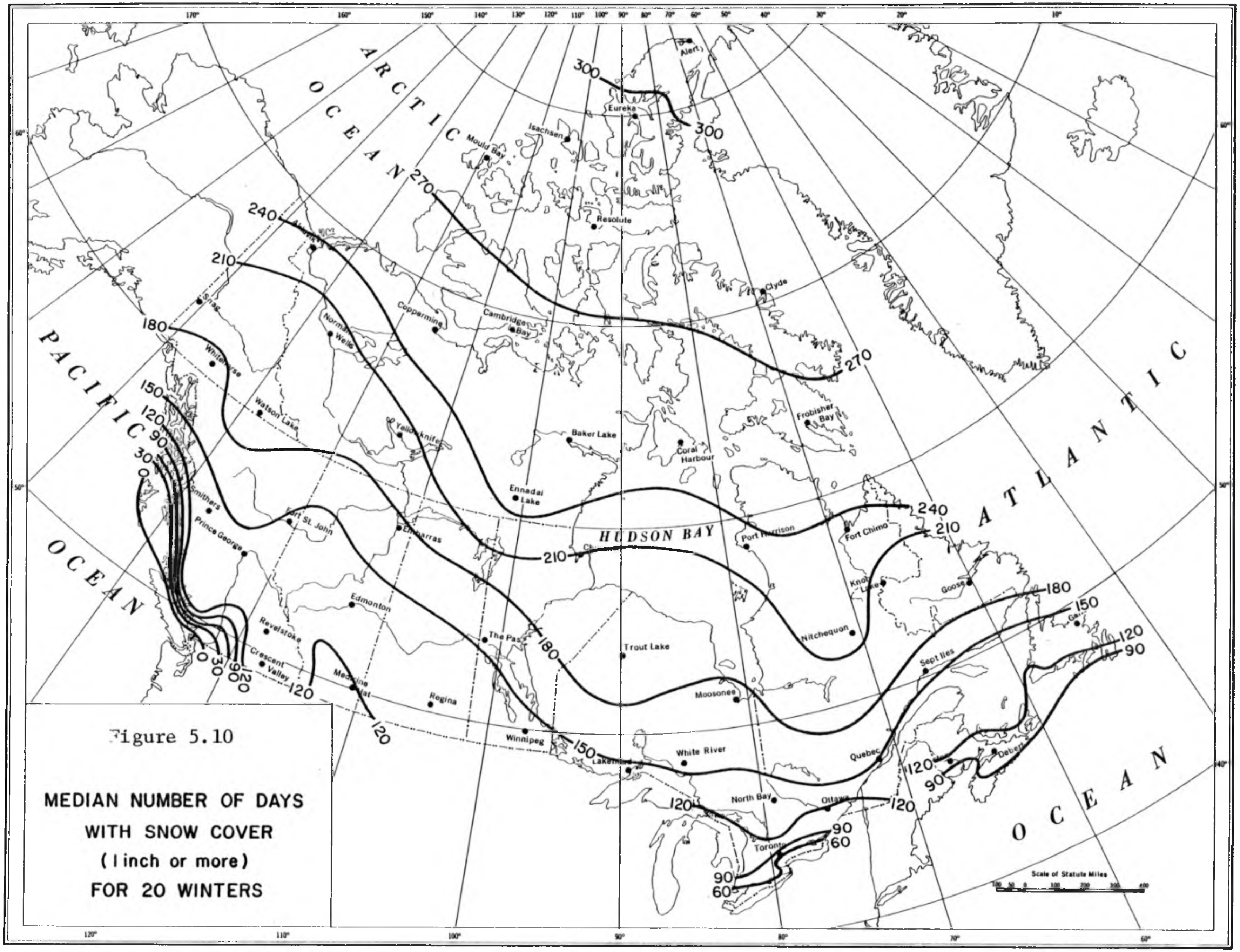


Figure 5.10

MEDIAN NUMBER OF DAYS WITH SNOW COVER (1 inch or more) FOR 20 WINTERS

Source: Potter, 1965

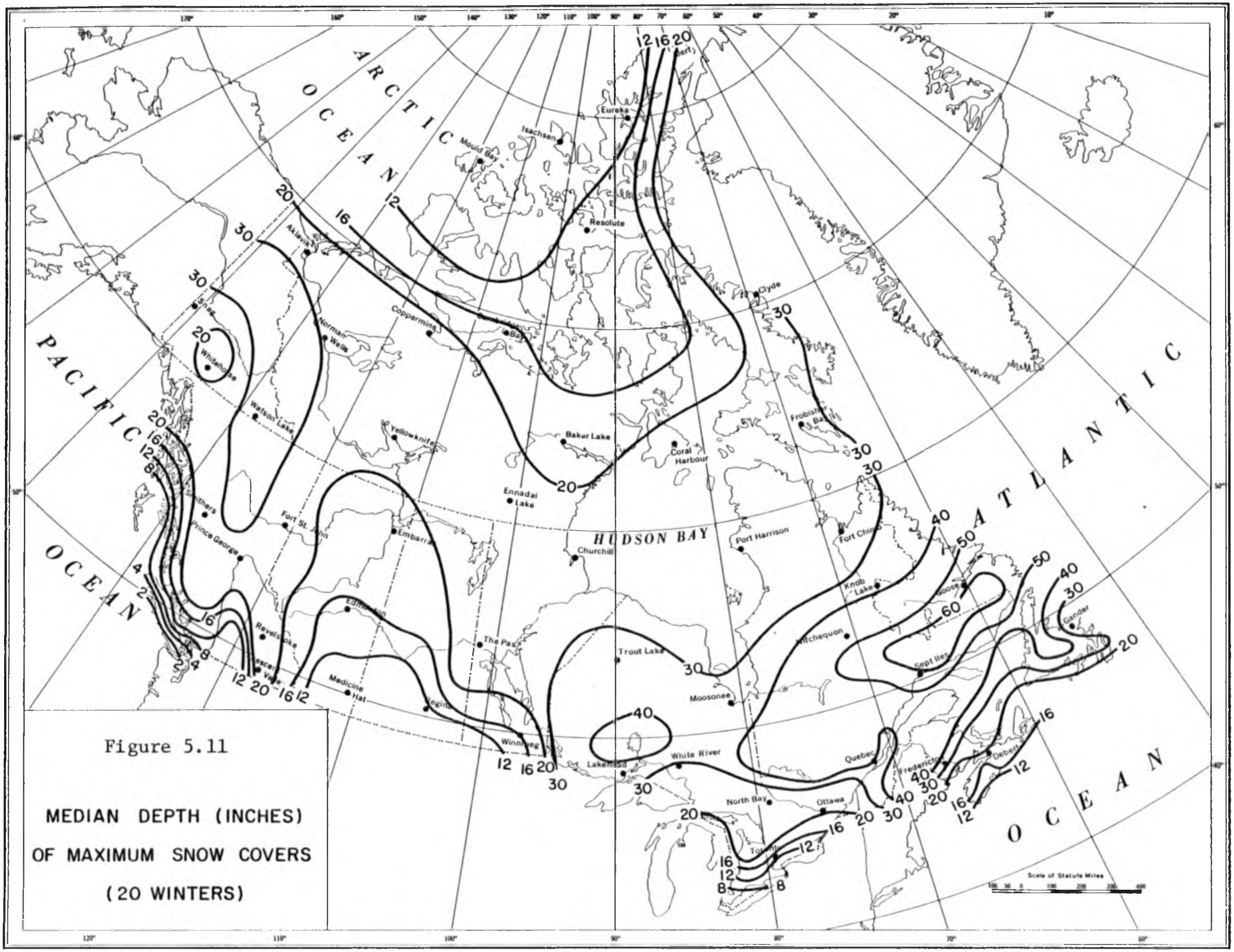


Figure 5.11

MEDIAN DEPTH (INCHES) OF MAXIMUM SNOW COVERS (20 WINTERS)

Source: Potter, 1965

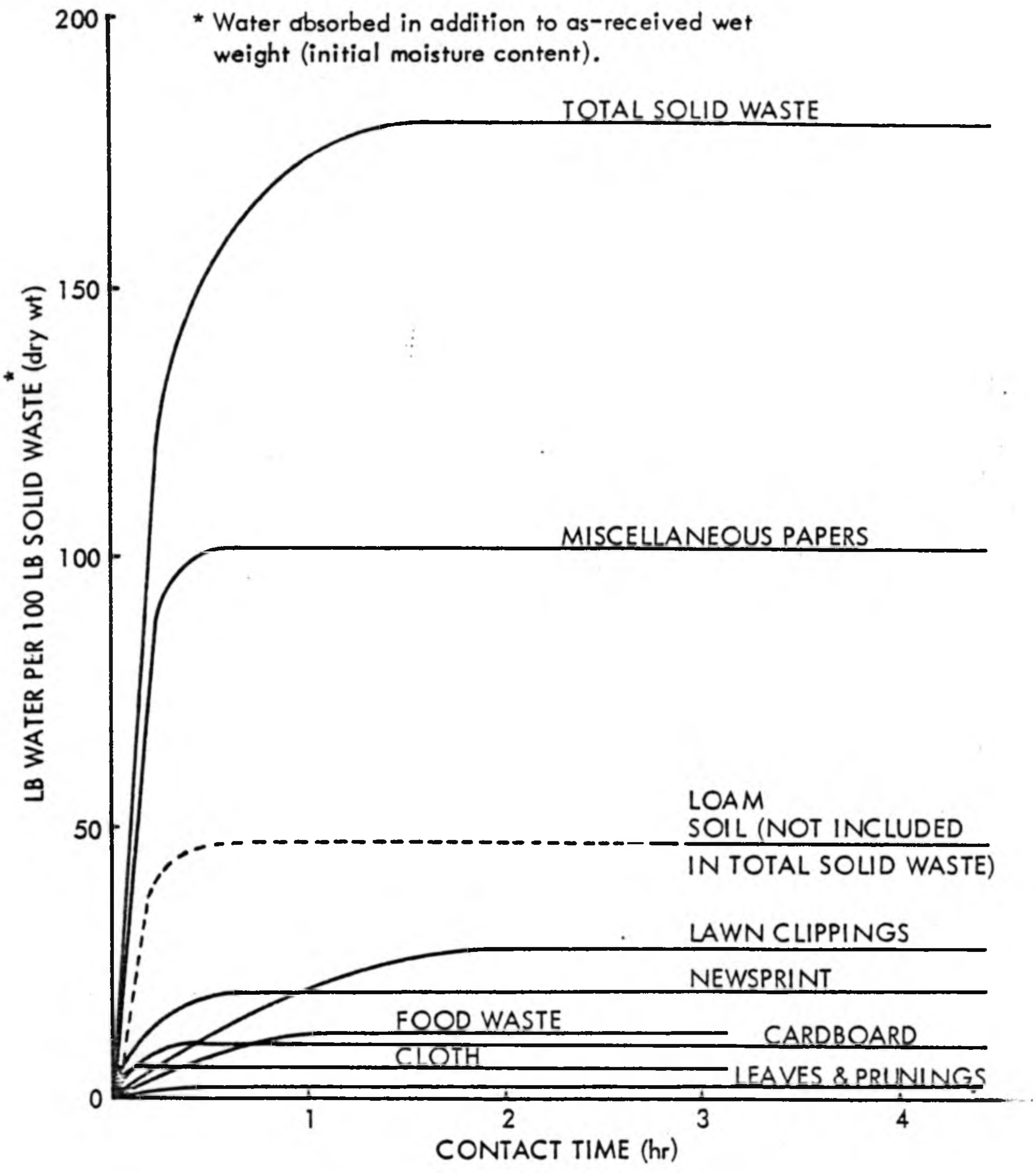


Fig. 5.12 MAXIMUM ABSORPTION OF WATER IN MUNICIPAL REFUSE AND LOAM SOIL

Source: Stone, 1974

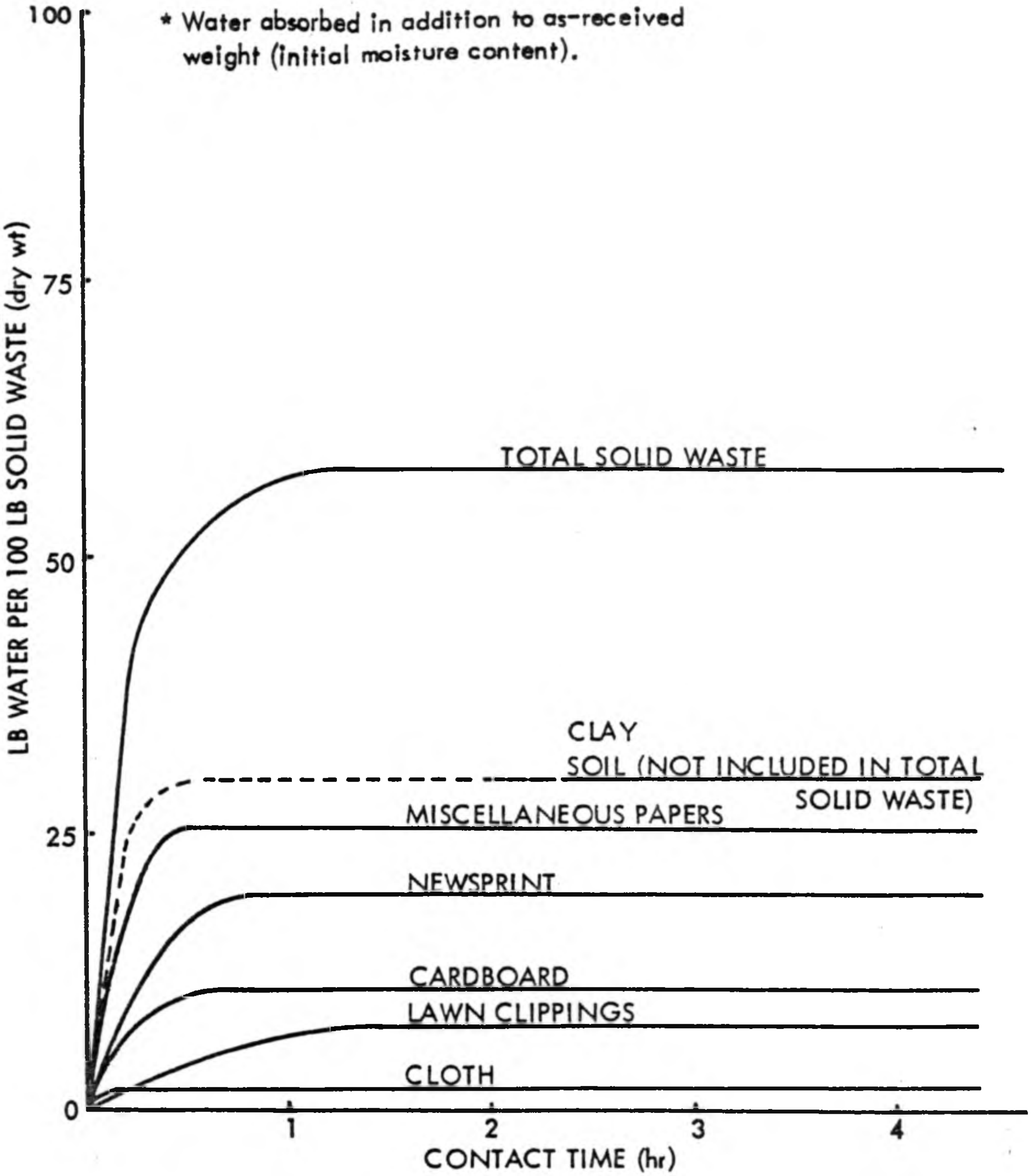


Fig. 5.13 MINIMUM ABSORPTION OF WATER IN MUNICIPAL REFUSE AND CLAY SOIL

Source: Stone, 1974

Section 6

SLUDGE AS AN ENERGY SOURCE

6 SLUDGE AS AN ENERGY SOURCE

As we approach the end of this century, the continually escalating costs of conventional energy production or the presence of severe shortages is going to force the use of alternative energy supplies to those presently used.

6.1 Alternate Energy Sources Two possible major sources of energy exist or will exist by the end of the century:

1. Harnessing natural energy
   - a) wind
   - b) solar
   - c) tidal
   - d) geothermal

2. Re-using waste material:
   - a) incineration
   - b) pyrolysis
   - c) anaerobic digestion.

Although not purely designed or developed for sludge reduction and energy production, the latter three possibilities are possible options for Canadians in order to reduce waste and produce energy concurrently. The extent to which any of these can be used depends on the raw materials supplies (waste), the efficiency and economics of each system, the climate, and the willingness of Canadians to look more towards recycling of matter and/or energy instead of exploitation and waste.

6.2 Canada's Energy Outlook According to the 1975 Canada Year Book, Canadian energy needs are met primarily by oil, natural gas, coal, electricity and nuclear power. The share of each energy source is given as:

Oil	44%
Natural gas	21%
Coal	8%
subtotal	73%
less 7% for electricity generation	7%
subtotal	66%
Electricity	33%
Nuclear	1%
TOTAL	100%

By the end of the century it is expected that 60% of the energy demand in Canada will still be supplied by oil and natural gas. The amount of electricity supplied by hydro-electric installations and thermal generating plants will decrease as the number of nuclear installations increases. The major trends in energy supply and demand are not expected to vary drastically from those indicated in Table 6.1

Environment Canada (1975) estimated that a four fold increase in energy consumption would occur between 1970 and 2000. The data computed from the 1975 Canadian Year Book appears to fall within this projection (Table 6.2) The total energy demand as 10^{15} BTU's is depicted in Figure 6.1

6.3 <u>Development in Canadian Energy Supplies</u> The development of thermal electric generating stations is still being carried out in Canada at present. Coal fields are being developed accordingly. Some of the ongoing Canadian projects are: (Globe and Mail, 1977).

- the development of three large thermal generating systems in Alberta, being carried out by the Calgary Power Ltd. and the Alberta Power Ltd. ;

- the optimization of coal fired electric plants in the Maritimes, being carried out by the Maritime Energy Corporation;
- the development of two large coal fired thermal generating plants, rated at 300 megawatts each, being carried out by the Nova Scotia Power Corporation. Two 100 megawatt units have recently been completed at Wreck Cove,N.S.

Similar hydro-electric projects under development are clearly evident in Manitoba where $300 million per year is being put into developing the full potential of the Nelson River. The massive Limestone Generating Station is expected to begin construction in 1980, with the full development of potential taking another fifteen years. The British Columbia Government plans to spend $1.5 million on the development of the Revelstoke Dam for B.C. Hydro.

Overall, between 1975 and 2005, a total of 134 electrical power developments are projected for Canada, giving an added 80,000 megawatts capacity. The breakdown of these projects is shown in Table 6.3.

The role of coal is expected to increase for direct thermal conversion to electrical power or through liquefaction or gasification. It is believed the Western Arctic area contains immense coal deposits. The majority of the rest is contained in the Western Provinces (Environment Canada, 1975).

Oil development of the prairies underground oil reserves and tar sands is expected to receive increased attention to develop methods to extract more than the estimated 10 percent conventionally available. The Alberta Government is investing in the development of processes that will enable recovery of some of the previously unavailable 90 percent of the oil sands. This would allow current production to continue for 450 years. The Syncrude development in Alberta is expected to begin initial production in mid 1978 with completion expected by 1979.

Similarly in Saskatchewan, the provincial and federal governments have allocated $8 million to aid the development of advanced recovery techniques.as heavy crude reserves in Saskatchewan are dwindling rapidly. It is expected that Western Canadian production of heavy crude will peak in 1978 and decline thereafter (Environment Canada, 1975).

In Newfoundland, three significant flows of natural gas have been found in nine attempts since 1971. Investment in off-shore drilling is expected to increase from $50 million to $100 million in the next year to further increase yields. Conventional Canadian reserves of natural gas should meet the demands to 1980, 1985 if reserves are considered, and 1995 if frontier areas are tapped (Environment Canada, 1975).

Uranium development for nuclear energy is continually growing in Canada as shown by the discovery of two large uranium discoveries in Newfoundland. A new processing mill is being built to handle the 1150-1700 tons of ore per day from these mines. In Saskatchewan, there is some expansion of the Beaverlodge Uranium Mines run by the Eldorado Nuclear Limited.

6.4 Research into new Energy Sources

A few of the provinces are taking immediate steps to investigate the development of alternative energy sources. The government of Alberta plans to spend $25 million on research of solar energy, wind harnessing, wood conversion and coal gasification. The Maritime Energy Corporation is undertaking a similar project to develop solar and wind generating units to augment their present oil fired thermal generation plants. The Ontario government is currently exploring the feasibility of heating downtown Toronto with a refuse-fired central steam plant. Refuse from the new Resource Recovery Plant in Downsview Ontario, is to be used to fire cement kilns for Canada Cement in Woodstock. (Kerr, 1977).

The role of renewable energy sources has recently been receiving increased attention in Canada since the announcement by Energy, Mines and Resources Minister, Alastair Gillespie that: (Water & Pollution Control,April,1977)

1. renewable energy has been awarded the largest share of a $10 million increase in federal energy research and development spending, for the 1977-78 fiscal year;
2. a Renewable Energy Resource Branch has been established within the Energy Policy Section of Energy, Mines and Resources; and
3. a National Advisory Committee on Conservation and Renewable Energy is being created.

The actual breakdown in energy research allocations is $4.4 million for renewable energy, including solar, wind, biomass and the use of heat pumps; $3.7 million for new research into energy conservation and $1.5 million for research on coal, heavy oil and oil sands production. The remaining $640,000 is allocated for energy transportation and transmission. The total federal energy research and development funding will be about $138 million for the fiscal year (WPC, April, 1977).

Throughout Canada, governments, educational institutions and private industry are beginning to focus more seriously on the energy production alternatives. Large municipalities, such as Metro Toronto, are beginning to burn garbage for recoverable heat. Many developers have built and are now testing solar heated houses. The list of ongoing work is unending. However, as with any new technology, there are problems that must be solved to produce a technological and economically feasible energy production system.

6.5 Evaluation of Energy Recovery Processes When evaluating the viability of an energy recovery system for sludge, it is necessary to consider a multitude of factors, namely (Schroeder and Cohen,1977):

1. the relative costs of recovery processes as compared to conventional sludge disposal methods,
2. the market value, and marketing of the recovered product,
3. research and development problems involved with developing a recovery system, and
4. the ability of the process to produce a useable energy by-product (ie purity).

Unlike oil, natural gas and coal, the energy recovery systems of incineration, pyrolysis and anaerobic digestion do not produce an easily storable and transportable fuel source. In order to obtain optimum use, it is necessary to use the energy near the source of production or pay the penalty of decreased efficiency if the energy is transformed to a transportable fuel (ie incineration → steam → electricity). McQueen (1975) has suggested there is a need to look more towards pyrolysis for gasification in order to produce a storable fuel. In many instances, such as experienced in Montreal and Hamilton, steam is being generated from waste reduction but there are no buyers for this steam.
Also, as outlined by Colosi et al (1976), not all communities can generate enough waste, on a regular basis, to make incineration, pyrolysis or anaerobic digestion feasibile. In many cases, it would be essential for a group of small communities to group together and dispose of their wastes at a regional reduction center where a larger, more efficient and more economical operation could be carried out. This would be a similar program to that carried out for municipal solid wastes in Ontario's Resource Recovery Program being carried out by the Ontario Ministry of the Environment. (Ontario Ministry of the Environment, 1975).

6.6 Fuel Sources for Energy Recovery Systems Middleton et al (1976) have shown that there are approximately 15 large Canadian Centers (greater than 200,000 people) which hold 53 percent of the Canadian population and produce 8,500,000 tons of refuse per year. This same population produces in excess of 72,000 tons of sludge during the same period. In terms of energy production, assuming that 75 percent of these communities use pyrolysis, operating at 50 percent efficiency, the energy from solid waste would be approximately 29 x 10^{12} BTU/year and from sewage sludge approximately 400 x 10^9 BTU/year. Conversion values for energy sources are given in Appendix 6.1. Sewage sludge pyrolysis would thus add only 1.38 percent of the energy from garbage.

By 1991, it is estimated that there will be 16 areas of this size in Canada capable of generating 47.5 x 10^{12} BTU/year under these conditions.

6.7 Energy Equivalents of Sewage Sludge Sewage sludge itself has an energy equivalent of up to 14,000 BTU/lb as shown in Table 6.4. Based on a low value of 7,000 BTU/lb and production rates of 0.25lb/capita/day, the energy equivalent would be 1,750 BTU/person/day. At 50% efficiency, an anaerobic digester could produce gas having an energy equivalent of 875 BTU/capita/day, however, Jones (1976) has suggested a typical yield ranges from 500-600 BTU/capita/day. Middleton et al (1976) has given an average value of 580-750 BTU/ft^3 for gases produced by anaerobic digestion.

6.8 Anaerobic Digestion for Energy Recovery Wyatt et al (1975) have given an analysis of gases and BTUs available from anaerobic digestion. These values are shown in Table 6.5

Jones, (1976) gives an example of gas from an anaerobic digester producing 900 BTU/day/capita (0.12 hp-hr @ 1 hp-hr = 7000 BTU), which is capable of producing 75 percent of the sewage plants horsepower requirements, if the digesters are heated with exhaust gases from internal combustion engines or not heated at all. If heating is required by other forms, the energy recovery efficiency will drop below 10 percent.

It is important to note here that the Canadian climate is not the best for anaerobic digester operation. In most cases, the digesters will need to be heated or built indoors, which means there will be an energy demand for heating. In certain areas, the heating demand may make anaerobic digestion inefficient and uneconomical. Further research will be needed to determine the applicability of anaerobic digestion in Canada.

As indicated by Smart (1977), the anaerobic digester temperature has a marked effect on the bacterial metabolism and thus most digesters are operated in the mesophillic 90 - 95^{o}F (32 - 35^{o}C) range. Although some studies have been carried out in Ontario with higher temperatures, little work has been carried out at lower temperatures. These studies have shown, however, that there is little problem with digester heating, providing the boiler and heat exchanger are sized properly. It has been found in these studies that proper design and operation will provide enough digester gas to fuel the boiler, which supplies hot water to the heat exchanger and also heats the building in the winter.

Hitte (1976), has developed technical and economic information for a 1,000 ton per day waste reclamation plant for utilization of municipal garbage (organic waste) in conjunction with sewage sludge in an anaerobic digester. Hitte's experiments show that such a facility could produce 3.6 million cubic feet of methane per day. Solid waste is sorted, the metals reclaimed, then the organics are homogenized and blended with sewage sludge prior to digestion. Such a system as this is advantageous in that it reduces the solid waste disposal problem, provides increased energy recovery and it provides useful by-products such as methane and soil conditioners. Initial capital costs appear to be the major drawback to this system.

Evaluations of anaerobic digester gas for energy recovery have been prepared by Miller (1975) and Kapoor _et al_ (1975) which indicate that utilization of digester gas can offset wastewater treatment plant operating costs, either by direct energy savings or by-product recovery.

6.9 _Incineration for Energy Recovery_ Incineration is also being considered as a highly efficient sludge reduction process because of the energy availability from incinerating sludge or sludge/garbage mixtures. Schroeder _et al_ (1977) can foresee sludge incineration in combination with municipal garbage incineration as he states that:

> "mixing sludge with other combustible urban waste products to achieve autogenous incineration, and incorporation of heat recovery and/or power generation facilities could considerably increase the economic reliability of sludge incineration methods".

The energy available from solid wastes in Canada during the years 1971 - 2000 are given by Payne (1974) in Table 6.6.

These data indicate that by the year 2001, garbage could replace 31 million barrels of oil or 149×10^9 scf of natural gas. Presently it could replace in excess of 11 million barrels of oil or 47×10^9 scf of natural gas. At 7000 BTU/per pound, the sewage sludge could presently replace

$$\frac{16{,}413{,}000 \times 0.25 \text{ lb/cap/day} \times 7000 \ \frac{\text{BTU}}{\text{lb}} \times 365 \ \frac{\text{days}}{\text{year}}}{4.8 \times 10^6 \text{ BTU/Barrel Oil}} = 2.18$$

million barrels of oil. By the year 2001 sludge could replace in excess of 4.2 million barrels of oil per year. A portion of this energy must first be used to dry the sludge prior to combustion.

Many people are sceptical of incineration as an alternate energy producer because it is always a net consumer of fuel. Jones (1976), however, states that once the solids that are to be incinerated are brought above 35 percent, the system is no longer a net consumer of energy, because more heat can be recovered as steam than is required as an auxiliary fuel input. Incineration is a net consumer of fuel because of fuel requirements for start up and the afterburner. This relationship is shown in Figures 6.2 and 6.3. (Jones, 1976).

The optimum operation of an incinerator will then be when dry solids (ie 30%) are incinerated or when sludge is incinerated in combination with a more efficient process, such as incineration of municipal garbage, previously discussed. Once at this value, the fuel consumption drops to less than 2 gallons of oil per capita with a 1400^{o}F exhaust gas. The minimization of auxiliary fuel should be emphasized in the evaluation and design of thermal processing options.

If incineration is chosen as the process for waste reduction and energy recover, the question then arises: What do we do with the recovered energy?. Jones (1976) has given energy recovery efficiencies for different cases such as high temperature steam for industrial processes, and conversion of steam to electric power. The first case of direct use is by far the most efficient, however, it is not often used. Given a 40 percent solids sludge, the energy recovery efficiency would be:

$$\frac{100 \times 600 \ \frac{\text{BTU/capita}}{\text{day}} \times 0.80}{1500 \ \frac{\text{BTU/capita}}{\text{day}}} = 32\%$$

If electricity was generated from the 1500 BTU/capita/day available at about 22 percent efficiency using condensing turbines, atmospheric pressure and steam at 500 psi and 750^{o}F, one could expect an energy recovery efficiency of:

$$\frac{(100) \ \times (600 \text{ BTU Steam/Capita}) \ \times 0.22}{1500 \text{ BTU Sludge/Capita}} = 9\%$$

As the quantity of sludge produced increases towards the end of the century, one would expect a direct increase in the available energy. However, as Chemmoff et al (1976) point out, the heat value of sludge is based on the formula :

$$Q = 14{,}600C + 62{,}000\left(H - \frac{O_x}{8}\right)$$

where Q = BTU/lb dried sludge

C	= % carbon	(52 - 66%)
H	= % hydrogen	(7.2 - 9%)
O_x	= % oxygen	(21 - 38%)

but the value of Q is reduced if any coagulants are used. Q is also reduced by the heat of dehydration if hydroxides are formed (ie. alum sludges). Thus as sewage treatment practices improve by the addition of chemical precipitation (as for phosphorus removal) the heat value, expressed as BTU/lb dried sludge, will decrease. A suggested empirical formula for the heat value of sludge containing inorganic chemicals was given by Fair et al (1968) (in: Vesilind):

$$Q_H = A\left(\frac{100 - Cv}{100 - D} - B\right)\left(\frac{100 - D}{100}\right)$$

where:

Q_H	=	heat value in BTU/lb solids
C_v	=	volatile solids
D	=	dosage of inorganic chemicals used in dewatering the sludge as percent of weight of sludge (D = 0 for organic polymers)
A	=	empirical constant, 107 for activated sludge, 131 for raw primary
B	=	empirical constant, 5 for activated sludge, 10 for raw primary.

Thus, for a small plant (10,000 gpd) wasting 20 pounds of volatile solids per day and consuming 180 mg/l alum we might expect a sludge having a heat value of 10,275 BTU/lb.

6.10 Pyrolysis for Energy Recovery In a comparison of energy recovery between incineration and pyrolysis, Jones et al (1976) found that pyrolysis may be "slightly better or slightly worse" in terms of energy recovery, but overall it may be more beneficial in that it produces a char that can be used as a storable fuel. An analysis of the char produced by a pyrolysis unit, at different temperatures, is given in Table 6.7

In the same study, Jones et al (1976) stated that the multiple hearth and fluidized bed furnaces are comparable with respect to heat recovery, with the fluidized bed being slightly more efficient because of the lower excess air requirement. The fluidized bed furnace however, requires more fuel as it operates at 1400^{o}F and the multiple hearth furnace can operate at 800^{o}F. The authors felt that the fluidized bed incinerators should and probably would become more popular than they have been because of comparable process economics (Jones et al, 1976).

Some work on energy recovery by way of steam production from pyrolysis gas has also been conducted, but char is not recovered in this process (Sussman, 1974).

6.11 Cost Benefits of Sludge Energy Recovery When evaluating the energy alternatives of different sludge disposal schemes, it is necessary to evaluate the energy requirements of the difference processes. As the primary and secondary treatment processes themselves become more advanced, it is quite possible that the quantities of biological and chemical sludge produced will also increase. Increased energy use will thus result from the indirect process, such as production, and the direct processes such as sludge dewatering and transportation to the ultimate disposal site. Garber et al (1975) has stated that:

> "it is not at all certain that the most advanced treatment process will produce the least environmental impact because the resulting increased energy use might very well also increase the net degree of pollution".

If a sludge disposal scheme produces a greater environmental load from excess energy consumption that it would from a simpler, less-energy consuming process, then it is not an environmentally sound process. The net benefits from the increased energy use must be equal to, or great than the environmental costs associated with the less advanced process.

To encourage energy conservation in the design and operation of wastewater treatment plants in Ontario, the Ontario Ministry of the Environment is preparing energy conservation guidelines. The efficient use of all forms of energy will thus become a primary design objective. One of the primary parameters to be facing these new guidelines will be the utilization of more efficient sludge treatment and sludge disposal facilities (MOE, 1977; Zarnett, 1977).

If the increased energy use does not appear to be a benefit for any one community, it is still possible that it may be a benefit for a group of communities in a region. Data adapted from Zarnett (1975), indicates that the energy costs, as BTU's per million gallons of sewage, decrease with increased size. This data is shown in Table 6.8. Thus, a group of communities may find it more economical to operate a central processing unit, providing that the costs of transportation (ie.fuel consumption) do not exceed the savings from operating a communal processing unit. Consider the case of a group of small communities, presently landfilling their sludge, who cannot efficiently operate independent energy recovery systems. Their most desirable scheme would be to construct a central energy recovery system, such as an anaerobic digester or pyrolysis unit, such that they, as a unit, become net energy producers.

Garber et al (1975), in a study of the Los Angeles area, found that pumping their sludge 100 miles to desert drying beds for subsequent pick up and landfill would require 16 times as much energy as the present ocean dumping practices 7 miles at sea. If chemical treatment and mechanical dewatering were to be practiced, the energy requirements would be 35 times as great. The authors realized that there will be a trade off between environmental pollution or destruction from each of these processes. They have suggested looking at anaerobic digestion for the area to provide energy to at least cover the energy requirements for a process such as mixing, solids handling and heating. Such an operation as this will minimize energy requirements while at the same time reducing the volume of sludge for ultimate disposal.

APPENDIX 6.1

HEAT VALUES OF FUEL SOURCES AND ENERGY EQUIVALENTS

Appendix 6.1

Heat Values of Fuel Sources		Reference
Oil	4.8×10^6 BTU/barrel	
Natural Gas	1000 BTU/ft^3	
Electricity	3413 BTU/kwh	Merlin
Coal	13,540-14,550 BTU/lb	Kirkpatrick
Garbage	4,600 BTU/lb	Payne
Raw Sludge	10,000 - 14,000 BTU/lb	Eckenfelder
Digested Sludge	5,300 BTU/lb	Eckenfelder
Activated "	9,000 - 10,000 BTU/lb	Eckenfelder
Anaerobic Digester gas	580 - 750 BTU/ft^3	Middleton

Conversions

1 BTU = 0.29305×10^{-3}kwh

1 kwh = 3.41×10^3 BTU

1 megowatt= 1000 kw

1 gigawatt= 10^6 kw

1 ton refuse = 1 - 1¼ barrels oil = 5250 scfm methane
= $4.8 - 5.25 \times 10^6$ BTU

1 hp-hr = 7000 BTU

SECTION 6 - TABLES

TABLE 6.1 ENERGY SUPPLY AND DEMAND IN CANADA

	1963	1963 BTUx10^{15}	1974	1974 BTUx10^{15}
Petroleum (10^3bbl/day)				
Production	785.5	1.38	1,988.0	3.48
Imports	497.5	.87	891.5	1.56
Total Supply	1,283.0	2.25	2,879.0	5.04
Consumption	998.1	1.75	1,745.9	3.06
Export	265.1	.46	1,083.2	1.90
Total Demand	1,263.2	2.21	2,839.1	4.96
Natural Gas (10^9ft^3)				
Production	843.3	.84	2,438.8	2.44
Import	6.8	.01	9.2	.01
Total Supply	850.1	.85	2,448.0	2.45
Consumption	491.5	.49	1,469.0	1.47
Export	359.6	.36	960.2	.96
Total Demand	851.1	.85	2,429.2	2.43
Coal (10^3 tons)				
Production	10,452	.29	23,261	.65
Import	14,741	.41	13.636	.38
Total Supply	25,193	.71	36,897	1.03
Consumption	23,456	.66	27,261	.76
Export	1,054	.03	11,600	.32
Total Demand	24,510	.69	38,955	1.09
Electricity (10^6 Kwh)				
Production	121,238	.41	262,272	.90
Import	2,884	.01	2,162	.01
Total Supply	125,122	.43	264,434	.90
Consumption	121,509	.41	247,555	.84
Export	3,613	.01	16,879	.06
Total Demand	125,122	.43	264,434	.90

Source: Canada Year Book, 1975

Note: For conversion to 10^{15} BTU's see Appendix 1.

TABLE 6.2 CANADA's ENERGY DEMAND 1970 - 2000

10^{15}BTU

	1970	1980	1990	2000
Petroleum	2.9	4.5 - 5.1	6.0 - 9.4	8.2 - 13.5
Natural Gas	1.1	2.0 - 2.5	2.0 - 5.4	2.4 - 7.7
Coal, Coke	.3	.3	.3	.4
Electricity	.7	1.4	2.4	3.9
Total	5.0	8.8 - 9.3	14.2 - 18.5	20.2 - 25.5

TABLE 6.3 ELECTRIC POWER DEVELOPMENT IN CANADA 1975 - 2005

	Hydro	Fossil	Nuclear	Total
Quebec	4	*	10	18
Manitoba	5			
B.C.	23		*	33
Alberta	7	13	*	
Ontario		10	14	26
Maritimes		*		

* development expected but numbers not given

Source: Adapted from Environment Canada, 1975

TABLE 6.4 HEAT CHARACTERISTICS OF SEWAGE TREATMENT PLANT WASTES

Source	Percent Combustible	Percent Ash	BTU/lb (Ford)	BTU/lb (Eckenfelder)
Grease & Scum	88.5	11.5	16,750	--
Raw Sewage Solids	74.0	26.0	10,285	10,000-14,000
Fine screenings	86.4	13.6	8,990	--
Primary Sludge	--	--	7,820	--
Activated Sludge	--	--	6,540	9,000-10,000
Digested Primary Sludge	59.6	40.4	5,290	5,290
	33.2	69.8	4,000	--

Source: Eckenfelder, 1970
Ford, 1970.

TABLE 6.5 CHARACTERISTICS OF SLUDGE GAS FROM ANAEROBIC DIGESTION

Constituent	Values from Various Plants - Percent by Volume 1	2	3	4
CH_4	42.5	61.0	70.0	75.0
CO_2	47.7	32.8	30.0	27.0
H_2	1.7	3.3	*	.2
N_2	8.1	2.9	*	2.7
H_2S	*	*	.01-.02	0.1
Ho (BTU/ft^3)	459	667	728	716
dv (air)	1.04	0.87	0.85	0.78

DV ≑ volumetric density compared to air * negligible

Source: Wyatt *et al*, 1975

TABLE 6.6 ENERGY CONVERSION PROJECTION FOR CANADA, 1971-2001

	1971	1981	1991	2001
Average Heating Value (BTU/lb)	4600	4800	5100	5400
Efficiency of Boiler & Grate (%)	66	67	68	69
Specific Steam Rate (lb steam /lb refuse)	3.0	3.2	3.3	3.7
Usable Urban Refuse (10^6 tons, 85% total)	7.62	12.23	18.54	26.69
Energy Produced (10^{12} BTU)	46	79	129	149
Energy for Sale (75% above)	35	59	97	149
Total Energy Use (10^{12} BTU)	5300	9200	14,800	20,800
Energy use for Home Heating (10^{12}BTU)	900	1100	1300	1500
Per Capita Refuse Generation	2.99	3.64	4.44	5.41

TABLE 6.7 PROXIMATE ANALYSIS OF PYROLYSIS CHAR AT VARIOUS TEMPERATURES

	900°F	1200°F	1500°F	1700°F
% Volatile Matter	21.81	15.05	8.13	8.30
% Fixed Carbon	70.48	70.67	79.05	77.23
% Ash	7.71	14.28	12.82	14.27
BTU per pound	12,120	12,280	11,540	11,400

Source: Wyatt *et al*, 1975

TABLE 6.8 ENERGY USE IN SLUDGE TREATMENT AND DISPOSAL

PLANT TYPE	BTUs/MILLION GALLONS (MG)					
	1 MGD	%	10 MGD	%	100 MGD	%
PRIMARY						
Sludge Dumping	2,184	0.42	2,184	1.03	2,184	1.66
Gravity Thickeners	34,806	6.74	6,961	3.28	1,044	.97
Anaerobic Digester						
mixing	286,641	55.54	72,343	34.11	23,136	17.58
heating	60,058	11.64	41,768	19.69	26,890	20.44
Vacuum Filtration	35,489	6.88	36,854	17.37	28.903	21.97
Multiple Hearth Incineration	96,912	18.78	52,005	24.52	49,411	37.56
TOTAL	516,090	100	212,115	100	131,568	100
ACTIVATED SLUDGE						
Sludge Dumping	9,077	.84	9,077	1.56	9,077	2.19
Gravity Thickeners	34,806	3.21	6,961	1.20	1,044	.25
Air Flotation Thickeners	238,867	22.05	207,473	35.71	160,109	38.69
Anaerobic Digester						
mixing	361,713	33.39	113,973	19.62	38,287	9.25
heating	60,058	5.54	41,768	7.19	26,890	6.50
Vacuum Filtration	194,506	17.96	118,069	20.32	113,461	27.41
Multiple Hearth Incineration	184,269	17.01	83,603	14.39	65,006	15.71
TOTAL	1,083,296	100	580,924	100	413,874	100

Source: Adapted from Zarnett, 1975

SECTION 6 - FIGURES

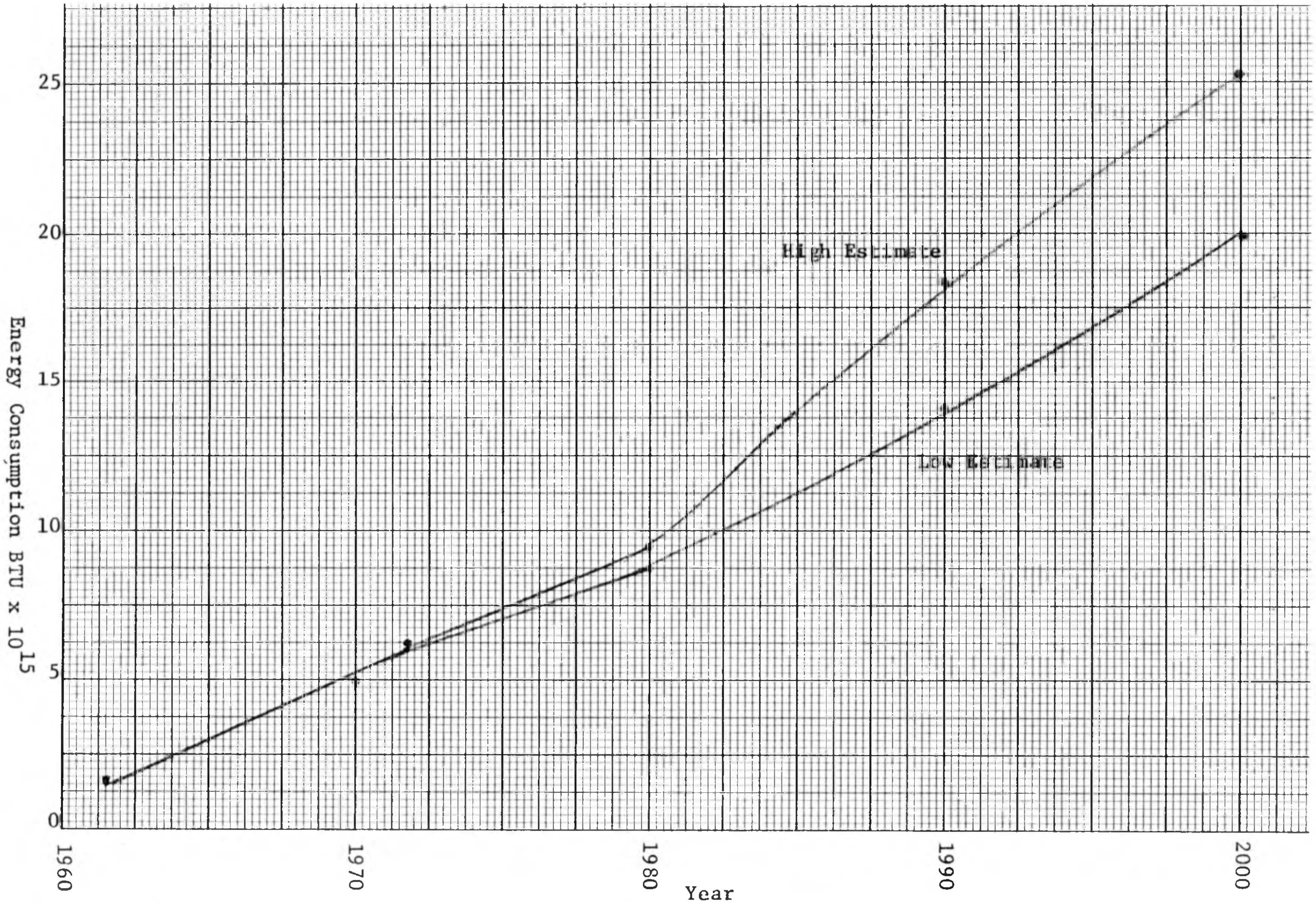
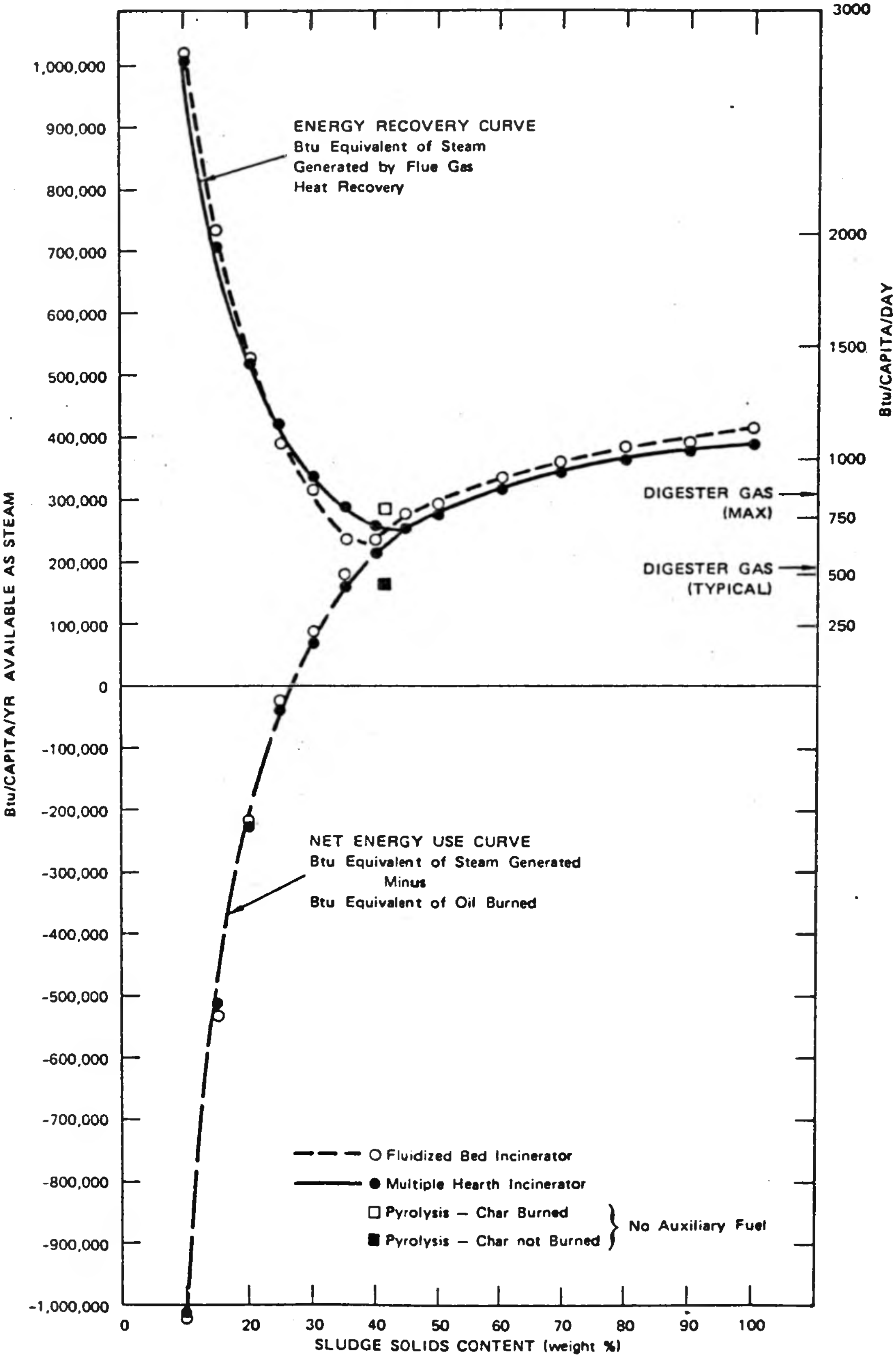


Fig. 6.1 CANADA'S TOTAL ENERGY DEMAND 1960-2000



NOTE: 1400° F incinerator exhaust gas temperature, 500° F boiler exhaust gas temperature.

Fig. 6.2 ENERGY RECOVERY AND USES FOR INCINERATION AND PYROLYSIS VERSUS SLUDGE SOLIDS CONTENT

Source: Jones, 1976

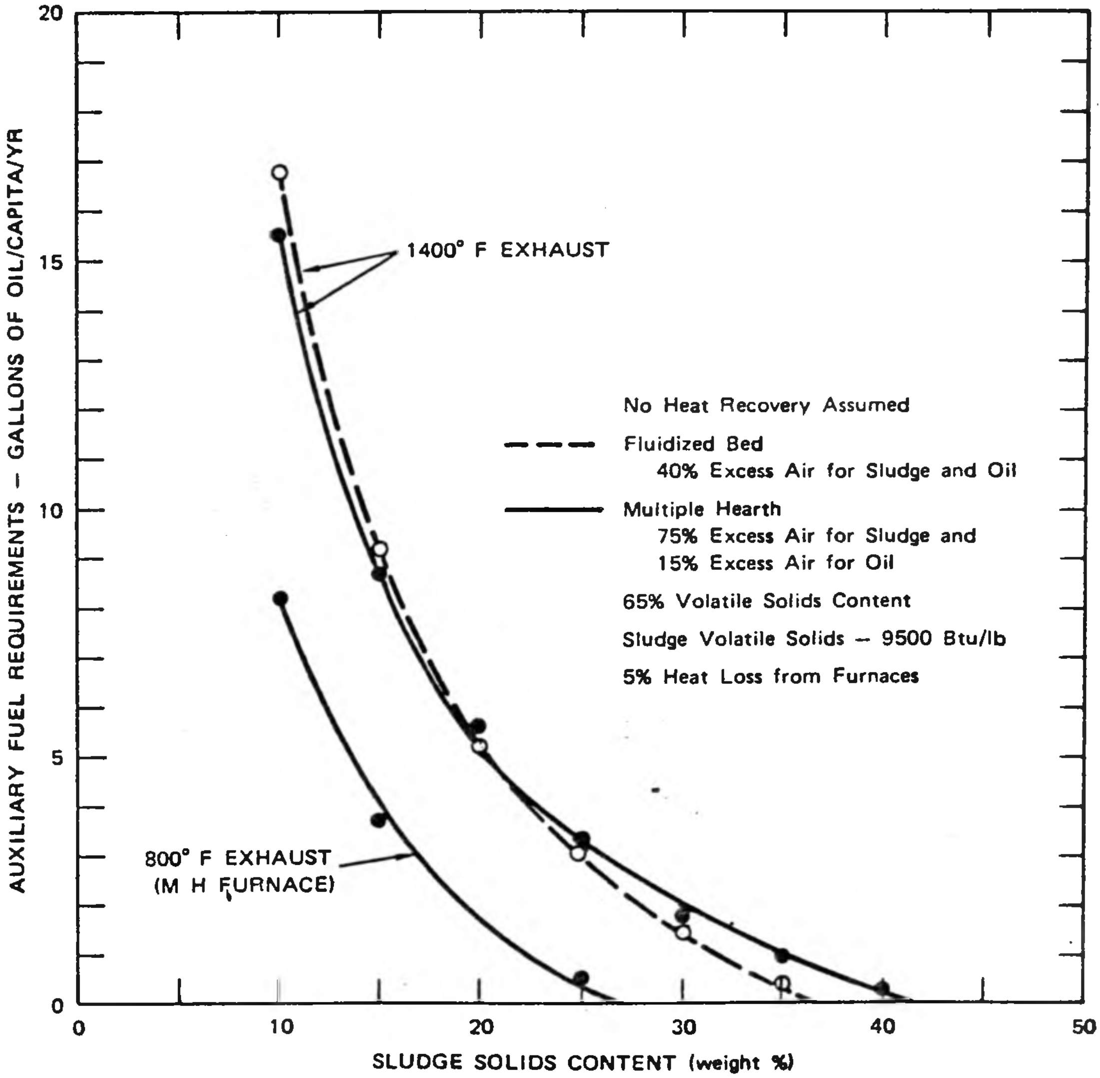


Fig. 6.3 AUXILIARY FUEL REQUIREMENTS FOR INCINERATION VERSUS SLUDGE SOLIDS CONTENT

Source: Jones, 1976

Section 7

COSTS OF ALTERNATIVE SLUDGE DISPOSAL SCHEMES

7. COSTS OF ALTERNATIVE SLUDGE DISPOSAL SCHEMES

Black et al (1974) summed up Canadian sludge disposal practices effectively when he stated "Canadian practice has generally resulted in the selection of the most inexpensive method, often with little consideration given to the environmental impact of the ultimate method of disposal". Now, however, as sludge disposal is becoming an ever increasing problem, it will be necessary to investigate more closesly the trade off between sludge disposal costs and the achievable environmental benefit.

7.1 Elements of Sludge Disposal Costs The cost of any one sludge disposal scheme will depend on:

1. characteristics of the sludge, such as
   - a) solids content
   - b) coagulant content
   - c) corrosive chemical content;
2. volume of sludge to be treated;
3. land costs, if spreading or landfilling;
   - a) outright purchase price
   - b) cost of preparation, i.e. leachate collection system.
4. energy prices and availability for heating, dewatering, incinerating, etc.;
5. distances to final disposal sites and method of transport, i.e. pipeline, rail truck.

In addition to considering the costs associated with disposal and environmental impact, it may also become practical to consider the cost reduction coming from by-products of a sludge disposal scheme.

Examples of practices resulting in recoverable costs are:

1. incineration or pyrolysis giving a net energy output such as steam generated electrical power;
2. landfilling which results in reclaimed land such as recovery of strip mining areas;
3. composting and/or land spreading, which improves the nutritive value of agricultural lands.
4. Flash drying which produces a saleable fertilizer.

The costs of operating the sludge treatment and disposal section of a sewage treatment plant generally represents at least 25 percent of the total plant operating costs and can account for up to 50 percent of total operating and maintenance costs. In terms of capital costs, sludge handling adds from 20 to 50 percent to the costs of the treatment plant. There is a decrease in the percentage of added costs as the plant size increases (Jones, 1976).

As the costs of sludge treatment will vary greatly as previously indicated, only estimated costs can be provided. Estimated costs for the individual treatment steps and select combinations of these steps, in terms of operating costs, capital costs and unit costs are given in Table 7.1 and Table 7.2 respectively. These values are all reported as the 4th Quarter,1976 U.S. dollar value. Where possible, values are given for plant sizes of 10, 100 and 500 million gallons per day. Total costs which include transportation costs will vary depending on the distance travelled to the ultimate disposal site.

Costs of individual processes in sludge processing are also given in Appendix 7.1. This material is extracted from the United States Environmental Protection Agency "Sludge Treatment and Disposal Manual".

A computer evaluation of sludge handling and disposal costs has been prepared by Smith et al (1975), which indicates costs of 261 alternative schemes based on possible combinations of twelve unit systems, type of sludge treated and mass of sludge produced. This analysis gives capital costs, total treatment cost and sludge handling costs for each system.

If a regional Sludge Disposal System is to be considered, then reference should be made to the report by Silveston (1976) which covers, in some detail, the use of computer aided planning in a regional sludge disposal management plan. When a large number of disposal alternatives are to be considered the program can be used in conjunction with standard engineering practice to develop and select the most economic disposal scheme. Utilization of a computer program such as this offers the planners an opportunity to evaluate a larger number of alternatives with greater precision. Selected alternatives can be checked against the computer selection. The program, as described, determines the most economically competitive alternatives for a sludge management scheme, irrespective of environmental consequences. Final decisions should also include environmental consequences as discussed in Section 8 of this report.

Houck (1977), has indicated that in small plants especially, the transportation costs may be a significant portion of the total sludge costs. It has been found that there is little variation in the required initial investment up to the 10 MGD size. The operating costs associated with any transportation scheme are proportional to the sludge production, but are not significant until the 30 MGD size has been reached. In most cases, it is the transportation distance which is more important as it affects both capital and operating costs.

As indicated by Campbell (1977), much of the data on costs contained in the literature is far from explicit in detailing exactly what costs are included. Missing information will render a comparison between two processes meaningless. This is especially true when costs are based on total capital investment curves and operation and maintenance curves. Total annual cost for a system based on this method is a sum of the operating and maintenance costs plus the total cost of the installation, amortized over a specified period at the prevailing interest rate. Estimates of typical values used in this analysis is given in Table 7.2.

7.2 Costs Associated with Transportation to Sludge Disposal Sites

The transportation costs, forming part of the total sludge disposal cost, will depend on the mode of transportation used as well as the distance travelled. The more economical methods of moving the sludge to the final disposal site will be pipeline or rail transport, followed by trailer tankers and trucks. Barging sludge for ocean disposal can also be considered for British Columbia and the Maritime Provinces. Although trucking the sludge will be more costly, it does allow for delivery directly to the site. In many cases, if the sludge is trucked to the site, the same vehicle can then be used to spread the sludge or ash.

7.2.1 Pipeline Transportation Although pipeline transport will have the least operating and maintenance costs, it will have high capital costs, and depending upon the terrain in which the pipeline is laid, it may have exceedingly high environmental costs, as well as high construction costs. Pipeline transport also has limitations in that it can be used only for transporting a sludge slurry.

The change in the fluid characteristics of the sludge will change with the solids concentration, thus affecting the economics of the pipeline design. Raynes (1970) has indicated that below the 5 percent solids concentration, the economics of sludge disposal are similar to that of water transport. The costs are expected to increase in inverse proportion to the solids concentration from 0 to 5 percent solids. For solids concentrations in excess of 5 percent, there is such an increase in friction head losses that dilution of the sludge often provides an economic advantage. If pipes over 10 inches are used, then friction losses at 5 percent solids, or greater, are much less and dilution is not required. Dilution in transportation by pipeline has the economic disadvantages of increased pumping requirements, larger holding tanks required and a less concentrated solution for land spreading.

Whenever pipelines are used, there will be some portion of the costs associated with receiving depots where the sludge can be loaded onto spreaders for final disposal.

Figure 7.1 shows the installation costs of a pipeline as a function of tons of dry solids per day and location of the pipeline. Figure 7.2 illustrates the remaining capital costs as a function of distance pumped. Figure 7.3 gives the annual direct operating costs as a function of distance pumped. Direct operating costs include power, labour, supplies and maintenance. Figure 7.1, 7.2 and 7.3 are based on last quarter, 1975 dollars and are taken from Wyatt et al (1975). All figures are based on pumping a 3.5 percent solids slurry at a 0.95 pipeline operating factor.

7.2.2 Transportation by Rail Transportation of sludge by rail is similar to hauling coal or ore and although it is not presently a heavily practiced method, it may become increasingly important in the near future, just as rail transportation of municipal solid wastes has become increasingly important in the past few years.There may be economical benefits to hauling solid wastes and sludge together to the disposal site. As Wyatt et al , (1975) suggests, there would be many ways to reduce costs, such as transporting dewatered sludge in empty coal cars on their return trip to mined areas.

Information from Canadian National Railways (Simms, 1977) indicates that rates will vary, if filed with the CTC, depending on such factors as the quantity shipped, whether the municipality has its own cars, what type of loading and unloading is required, and the distance transported. Attemps to obtain actual dollar values from CN, given specific cases, have so far been futile.

7.2.3 Transportation by Trucks Costs of trucking sewage sludge will depend on distances and quantities shipped and the amount carried per load. Conventional 5 axle trailer tankers carry approximately 5000 gallons, 3 axle trailers carry 2500 gallons and 2 axle trailers carry 1200 gallons. If the sludge has been dewatered or incinerated, only dump trucks could be used, which means there will be extra costs associated with loaders, unloaders and spreaders. Dumpers can haul up to 22 tons if five axle, 10 tons if 3 axle and 7.5 tons if 2 axle. Hauling costs associated with these different size trucks are given by McMichael (1974)

	$ - Mile
Liquid Sludge	
5 axle, 5000 gallons	.40
3 axle, 2500 gallons	.35
2 axle, 1200 gallons	.23

	$ - Mile
Dewatered Sludge	
5 axle, 22 ton	.40
3 axle, 10 ton	.35
2 axle, 7.5 ton	.23

Costs for round trip hauling of sludge from three sizes of treatment plants (1 MGD,10 MGD,100 MGD) at 2.5 and 5.0 percent solids, are given in Figures 7.4 and 7.5. Costs for the three difference truck sizes are also given. In computing these costs, McMichael (1974) has included the cost of storage lagoons, sludge hauling and interest charges on the land where the sludge is to be spread. It is also assumed that each plant generates 1630 gallons of sludge per million gallon of sewage which is spread at 15 dry tons/acre/year.

Depending on the province and the local road conditions, there will be a limit on the maximum allowable size of tanker, based on a full load weight, (Figure 7.6). If the same vehicle is used to spread the sludge as to haul it, then there will be a maximum weight which can be supported on the land where the sludge is to be spread.

The cost of sludge storage lagoons is included in the cost of ultimate disposal since the ground will be snow covered, or frozen, for 150 to 200 days a year. Land spreading cannot be carried out during this period.

The costs of tank trucks transportation, neglecting spreading and storage charges is given by Wyatt et al, (1975). as is shown in Figure 7.7. Transportation costs for dump trucks hauling dewatered sludges and incinerator ash are given in figures 7.8 and 7.9 respectively.

Capital and operating costs for tankers hauling liquid sludge and dewatered sludges are given in Figure 7.10 and Figure 7.11. Liquid sludge concentrations are 1.0 to 4.0 percent solids and dewatered sludges are 15 to 50 percent solids. In Figure 7.10, the pound per day values are based on a 2.5 percent solids. The solids form can vary over a range without significantly changing the actual cost (Ettlich, 1976).

The original data used to construct Figures 7.10 and 7.11 was given by Ettlich, (1976) and was based on the following assumptions:

1. most economical truck size and type
   a) tankers for liquid sludge
   b) ram or dump for dewatered sludge
2. trucking eight hours per day
3. fuel cost $0.60 per gallon (diesel)
4. operating and maintenance labout $8.00/hour, $0.25 per mile for truck
5. 6 year, 7 percent amortization
6. indirect costs 25 percent of operating and maintenance costs.

Cost equations derived from this data have been developed and are as follows:

<u>Tankers Carrying Liquid Sludge</u>

Capital Costs (1,000 dollars) = $3.72\ (\text{lbs/day})^{0.32}$

Capital Costs (1,000 dollars) = $2.25\ (\text{gpd})^{0.32}$

Operating and Maintenance costs (1,000/year) = $1.33\ (\text{lb/day})^{0.30}$

Operating and Maintenance costs (1,000/year) = $0.86\ (\text{gpd})^{0.30}$

<u>Dumpers Carrying Dewatered Sludge</u>

Capital Costs (1,000 dollars) = $1.65\ (\text{yd}^3/\text{day})^{0.32}$

Operating and Maintenance Costs+ (1,000/year) $0.86\ (\text{yd}^3/\text{day})^{0.30}$

Specialized trucks are now available for disposal of sludge on agricultural lands. One firm, "Big Wheels", reports that up to 100,000 gallons of sludge a day can be applied with one of these specialized units. The unit can provide above or below ground disposal in cake or slurry form (Pauly, 1976; Water and Sewage Works, January, 1976; Public Works, November, 1976). A unit of this type is now in operation in Mississauga, Ontario.

7.2.4 Cost Comparison of Transportation of Sludge A comparison cost for pipeline, tank truck and rail transport is given by Riddell *et al*, (1966) (in: Glayona and Eckenfelder), which although shows 1966 dollars, does show a relative comparison. This is illustrated in Figure 7.12. The data is based on a population of 100,000 which would produce approximately 12.5 tons of sludge per day.

A similar type of analysis for different quantities of sludge transported by truck, barge and rail was constructed for Ettlich's data and is shown in Figure 7.13. Operating and maintenance cost comparisons are shown in Figure 7.14.

SECTION 7 - TABLES

SLUDGE TREATMENT SCHEMES					Unit Cost $/TON			Capital Cost 10^3 $/TON		
					10 MGD	100 MGD	500 MGD	10 MGD	100 MGD	500 MGD
Low Pressure Wet Oxidation	Vacuum Filtration	Incineration	Ash to Landfill		96	45	27	224	126	70
High Pressure Wet Oxidation	Vacuum Filtration	Ash to Landfill						215	140	79
Anaerobic Digestion	Chemical Conditioning	Vacuum Filtration	Landfill(truck or rail)		109	70	51	210	154	113
Anaerobic Digestion	Vacuum Filtration	Landfill or Land spread			104	65	49	231	144	132
Anaerobic Digestion	Landspread Truck or Pipeline				104	55	43	201	144	144
Anaerobic Digestion	Barging	Ocean Disposal			114	22	19	108	62	58
Vacuum Filtration	Incineration	Ash to Landfill (Truck)			114	69	57	447	202	130
Chemical Conditioning	Filter Press	Sludge Incineration	Ash to Landfill (Truck)		88	49	32	187	74	56
Chemical Conditioning	Vacuum Filter	Sludge Incineration	Ash to Landfill (Truck)		106	65	44	187	91	51
Chemical Conditioning	Filter Press	Flash Dryer	Fertilizer for sale		127	78	54	206	91	56
Aerobic Digestion	Flotation Thickener	Chemical Conditioning	Vacuum Filtration	Landfill or Land	117	67	45	131	91	56

Table 7.1 Unit Costs and Capital Costs for Various Sludge Treatment Schemes

TABLE 7.2 - COSTS OF INDIVIDUAL SLUDGE TREATMENT PROCESSES FOR 10, 100 and 500 MGD PLANTS

Sludge Treatment Process	Unit Cost Range $/Ton	Capital Cost 10^3 $/Ton			Operating Cost $ / Ton		
		10	100	500	10	100	500
Pyrolysis	160						
Wet Oxidation	45-48						
Fluid Bed Inc.		115	94	72	19.9	9.6	6.4
Centrifuge	16-25	26		27	25.9	12.8	8.8
Chemical Treatment		22	13	10	4.4	3.0	2.9
Heat Treatment	38	115	69	43	39.8	15.1	8.8
Multiple Heart Incineration	35-127	94	54	37	9.6	5.2	3.2
Pressure Filtration		43	22	19	10.8	5.2	3.2
Vacuum Filtration	18-30	27		13	6.4	1.8	.8
Aerobic Digestion		33		16	15.1	4.8	2.2
Anaerobic Digestion	18-48	108	65	40	3.4	2.7	2.0
Landspread	23-48						
Sand Bed Drying	29-57	83	79		29.9	21.9	23.9
Composting	73-90						
Flotation	9.6-24	30		14	6.8	2.2	.8
Gravity Thickening	2.4-8	19	10	7	4.4	1.0	.4

SECTION 7 - FIGURES

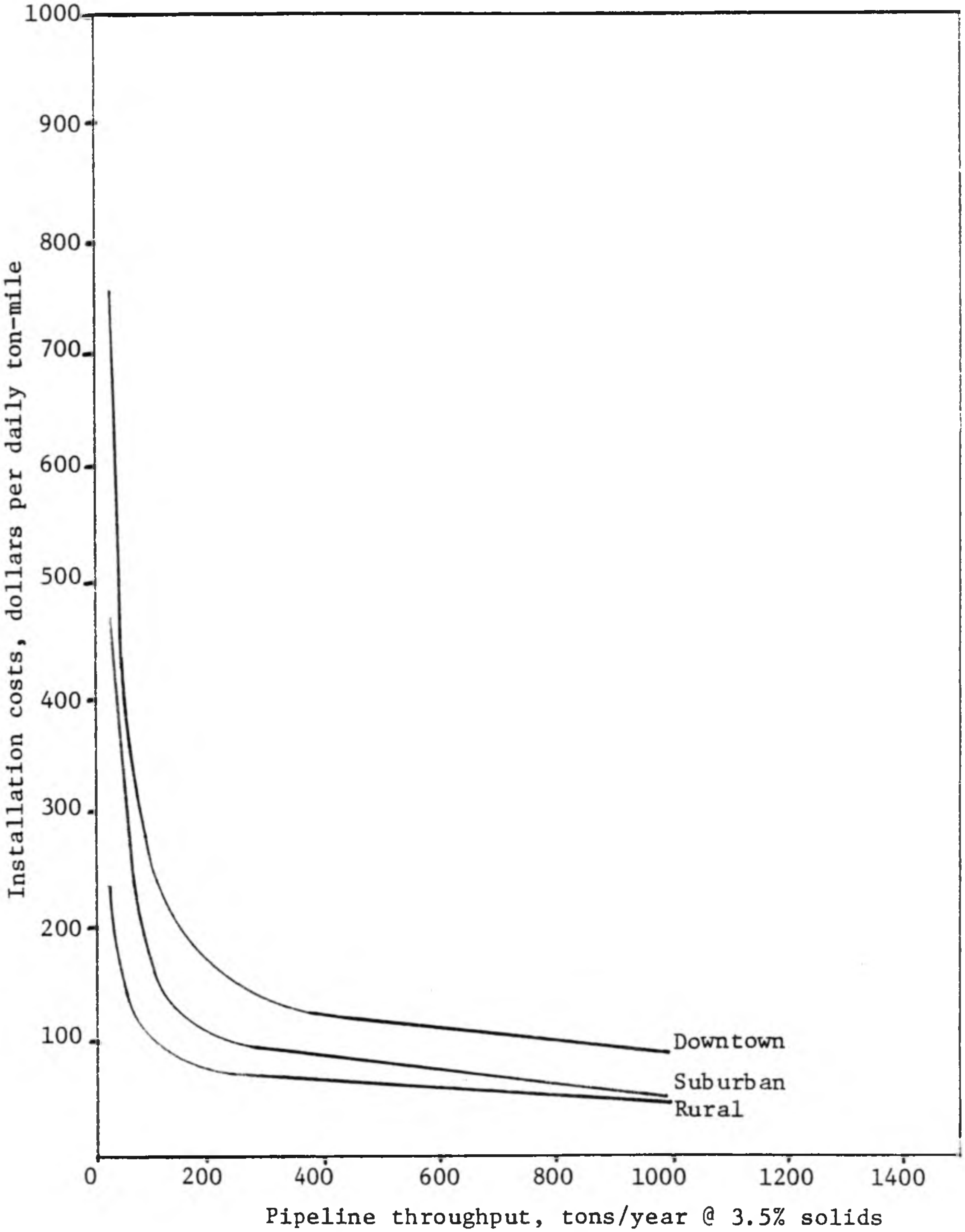


Fig. 7.1 ECONOMICS OF PIPELINE TRANSPORTATION OF DIGESTED SLUDGE

Source: Wyatt *et al*, 1975

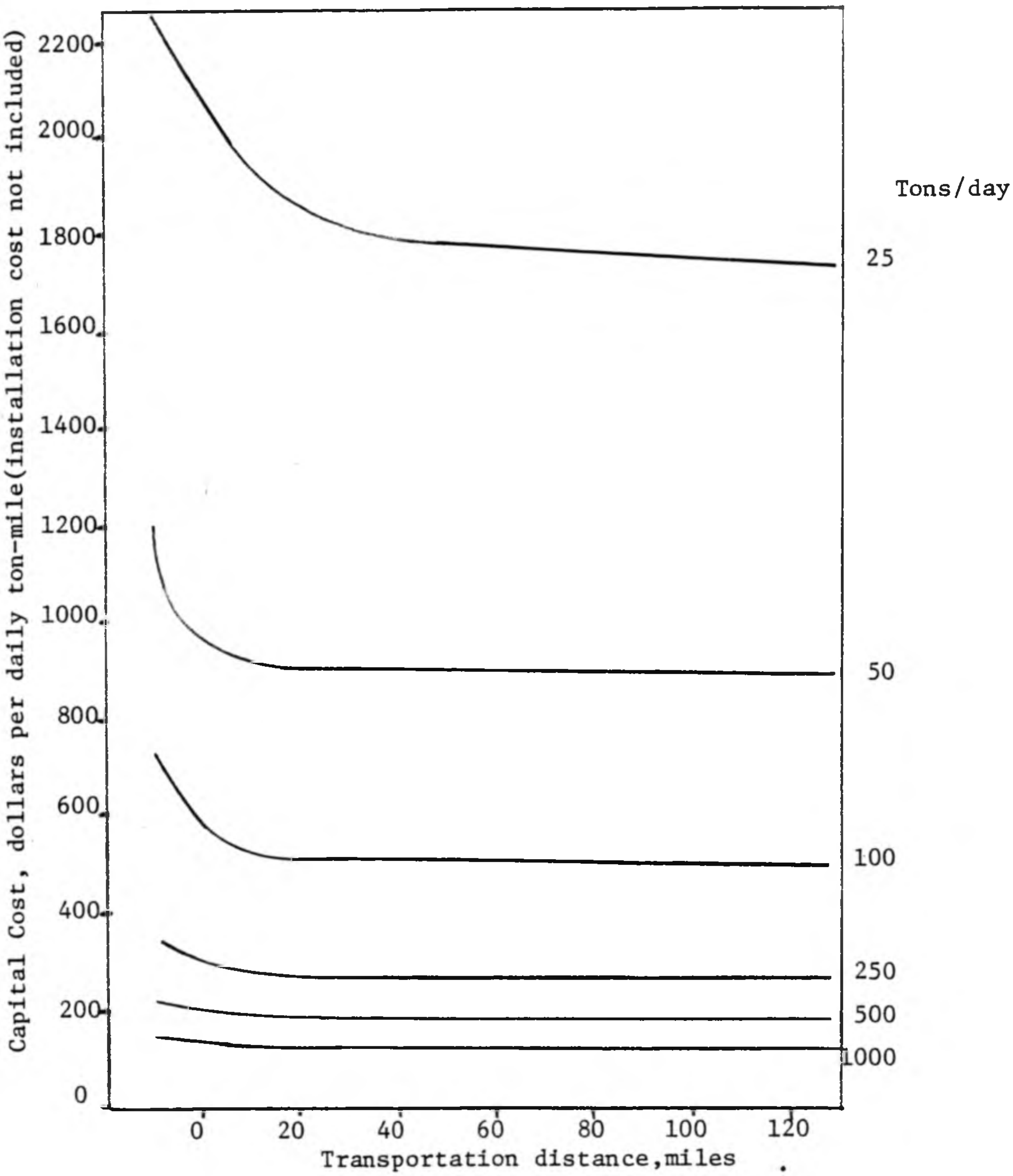


Fig. 7.2 CAPITAL COSTS OF PIPELINE TRANSPORTATION OF DIGESTED SLUDGE, @ 3.5% SOLIDS

Source: Wyatt et al, 1975

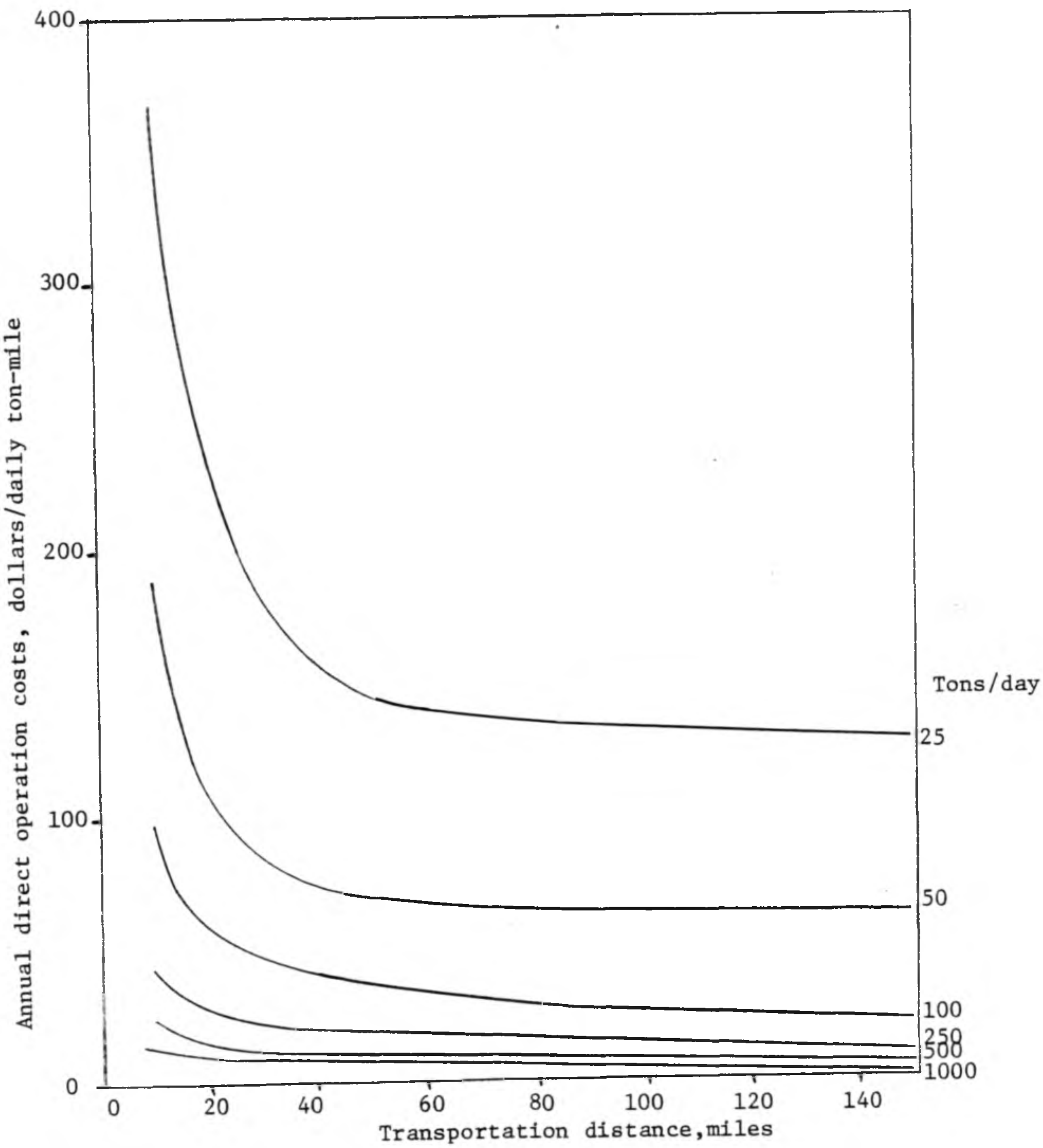


Fig. 7.3 DIRECT OPERATING COSTS OF PIPELINE TRANSPORTATION OF DIGESTED SLUDGE @ 3.5% SOLIDS

Source: Wyatt et al, 1975

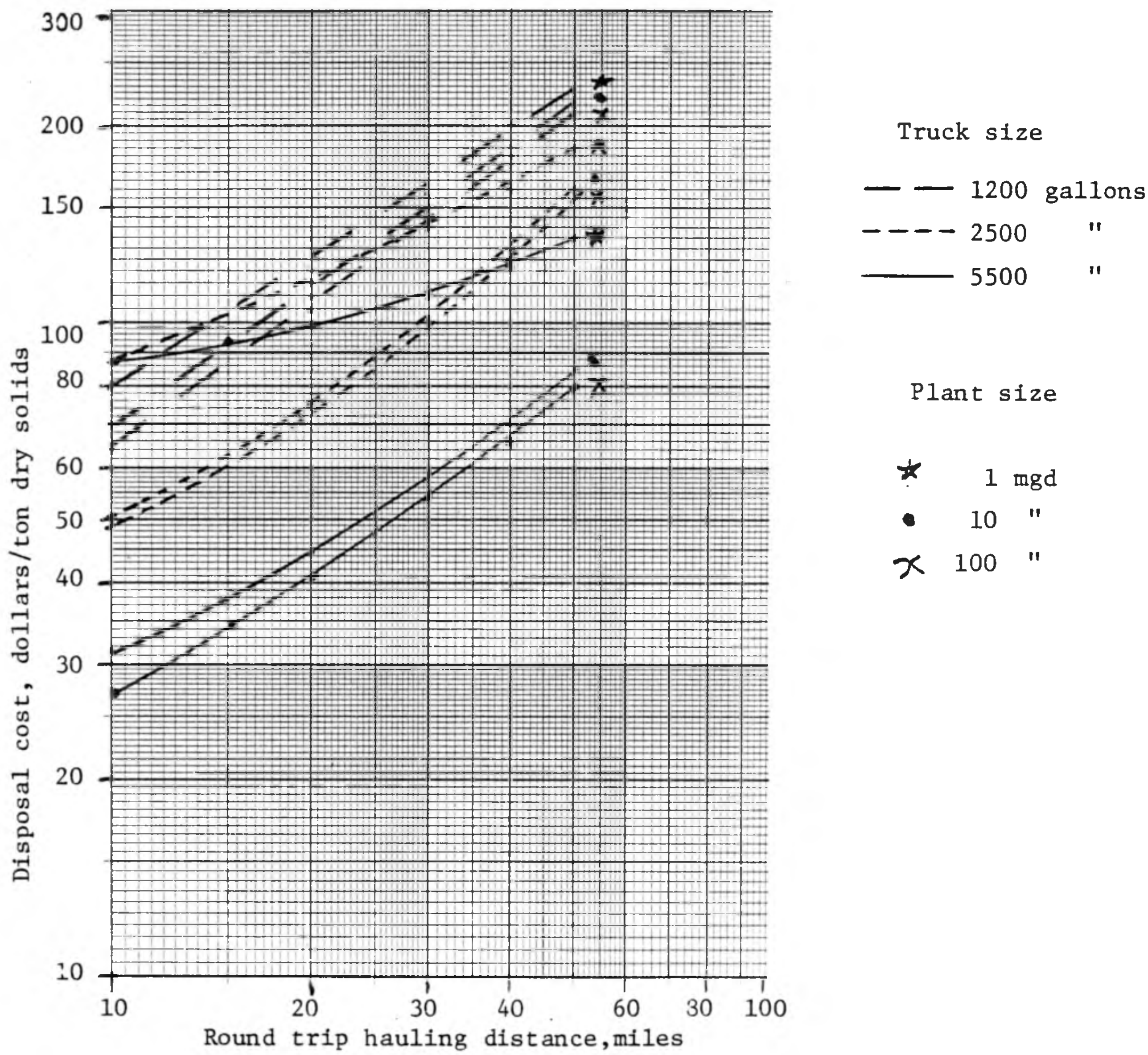


Fig. 7.4 COST OF LIQUID SLUDGE DISPOSAL BY LAND SPREADING @ 2.5% SOLIDS
Source: McMichael, 1974

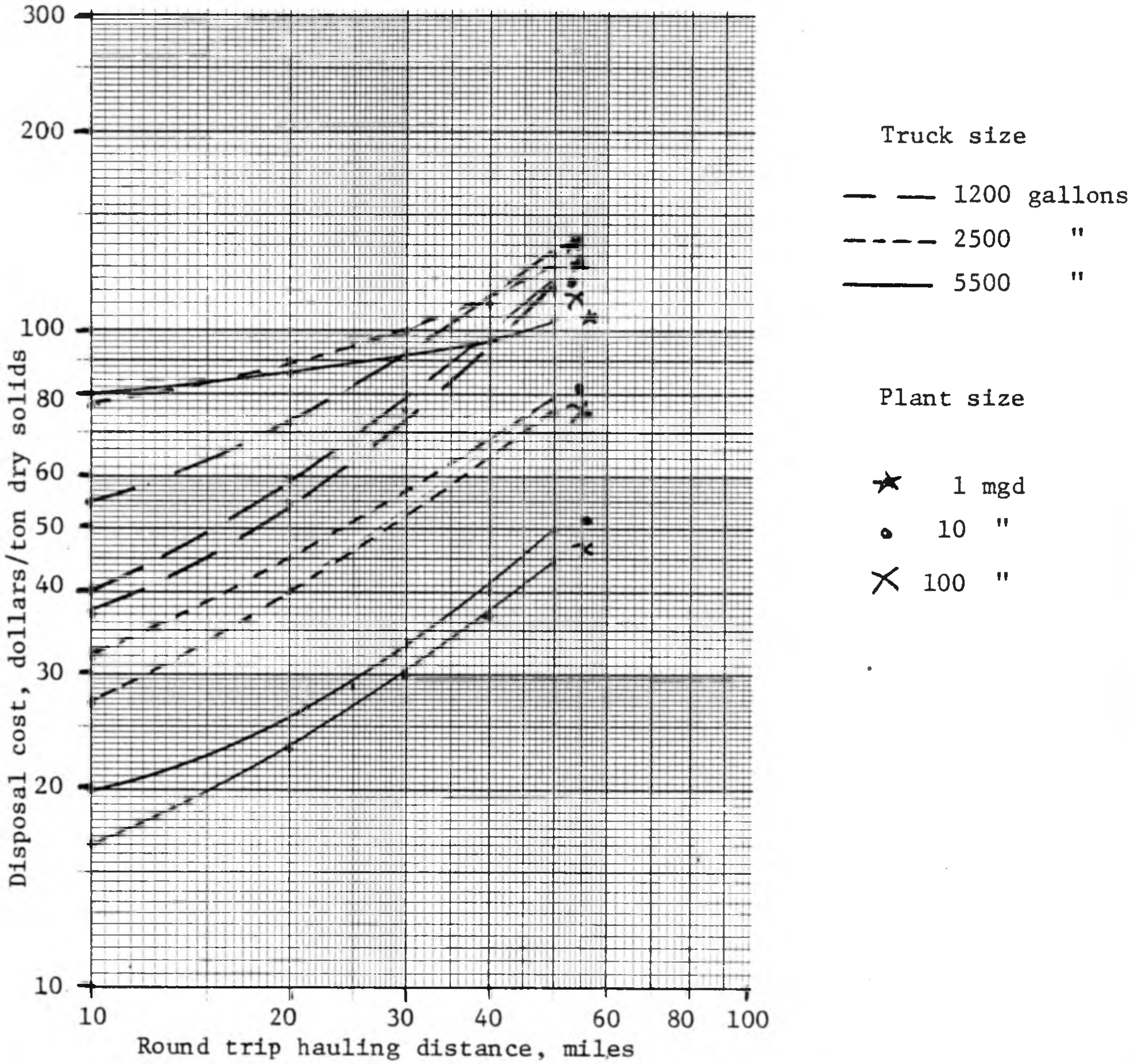
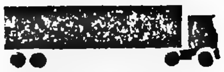
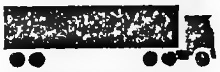
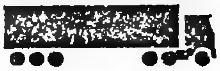
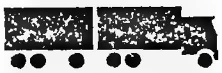
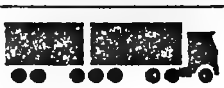


Fig. 7.5 COST OF LIQUID SLUDGE DISPOSAL BY LAND SPREADING @ 5.0% SOLIDS

Source: McMichael, 1974

	NFLD.	N.S.	N.B.	P.E.I.	QUE.	ONT.	MAN.	SASK.	ALTA.	B.C.	Y.T.
OVERALL Length Single Powered Vehicle (ft)	40	40	35	40	35 N	35	40	35N	40F	35 N	35
LENGTH Combination (ft)	65	65	65	65	65	65	65	65	70	65C	70
MAXIMUM WIDTH (inches)	102	102	102	102	102	102	102	102	102	102	102
MAXIMUM HEIGHT (feet)	13½	13½	13½	14½	13½	13½	13½	13½	13½	13½	13½
NUMBER OF TRAILERS ALLOWED	2	2 R	2	*	2	*R	2Q	*	2	2 A	2W
MAXIMUM AXLE LOADS (lb) — Single Axle (except front)	18,000	20.000 G	20,000 E	20,000	22,000 J	20,000	20.000 W	20.000 W	20.000 W	20,000	20,000
MAXIMUM AXLE LOADS (lb) — Tandem Axles	32.000M	35.000 G	40.000 E	35.000 M	38,000 J	40,000	35.000 W	35.000 W	35.000 W	35,000 B	40,000 M
4-wheel truck: 2 axles 	28,000	30.000 L	30,000	30.000 L	41,000 J	30,000 H	30.000 W	28.000 32,000 W	30.000 W	32,000 T	32,000 M
6-wheel truck: 3 axles 	44,000 T	45.000 L	60.000 E	45.000 L	57,000 J	45,000 H	45.000 W	42.000 47.000 W	45.000 W	47,000 T	52.000 M
4-wheel tractor and 2-wheel semitrailer: 3 axles 	46.000 T	50.000	50,000	50.000 L	58,000 J	50,000 H	50.000 W	46.000 50.000 W	50.000 W	52,000 T	52,000 M
4-wheel tractor and tandem semitrailer: 4 axles 	60.000 T	65.000	65,000	65.000 L	72,000 J	65,000 H	65.000 W	60.000 65.000 W	65.000 W	67,000 B	72,000 M
6-wheel tractor and 2-wheel semitrailer: 4 axles 	62,000 T	65.000	65,000	65.000 L	72,000 J	65,000 H	65.000 W	60.000 65.000 W	65.000 W	67,000 T	72,000 M
6-wheel tractor and tandem semitrailer: 5 axles 	78,000 T	80.000	80,000	80.000 L	88,000 J	80,000 H	82.000 W	74.000 82.000 W	80.000 W	82,000 T	92,000 M
6-wheel tractor and 3-axle semitrailer: 6 axles 	76,000 T	80.000	113.000 E	80.000 L	Special Permit	89,000 H	82.000 W	74.000 82.000 W	81.000 W	90,000 U	110,500 M
4-wheel truck and 4-wheel full trailer: 4 axles 	84,000 K	70.000 L	70.000 E	70.000 L	78,000 J	70,000 H	70.000 W	64.000 70.000 W	70.000 W	72.000 T	72,000 M
4-wheel truck and 6-wheel full trailer: 5 axles 	78,000	80.000	85,000 E	80.000 L	94,000 J	85,000 H	85.000 W	74.000 85.000 W	85.000 W	87,000 T,V	87,500 M
6-wheel truck and 6-wheel full trailer: 6 axles 	94,000 T	80.000	100,000 E	80.000 L	110,000 J	100,000 H	100.000 W	74.000 100.000 W	100.000 W	102,000 T,V	106,000 M
4-wheel tractor, 2-wheel semitrailer and 4-wheel full trailer: 5 axles 	82.000	Maximum gross weight on any combination, 80,000 lb. G	90,000 E	Maximum gross weight on any combination up to 110,500 lb based on number of axles and spacing	100,000 J	90,000 H	90.000 W	74.000 90.000 W	90.000 W	92,000 T,V	Trailer combinations permitted, with gross weight restricted on designated highways.
4-wheel tractor, tandem semitrailer and 4-wheel full trailer: 6 axles 	96.000		105,000 E		118,000 J P	105,000 H	105.000 W	74.000 105.000 W	105.000 W	97,000 T,V	
4-wheel tractor, tandem semitrailer and 6-wheel full trailer: 7 axles 	Maximum gross weight on any combination, 112,000 lb.		120.000 E		115,000 J P	120,000 H	110.000 W	74.000 110.000 W	110.000 W	110,000 T,V	
6-wheel tractor, tandem semitrailer and 4-wheel full trailer: 7 axles 			120,000 E		121,000 J P	120,000 H	110.000 W	74.000 110.000 W	110.000 W	110,000 T,V	
6-wheel tractor, tandem semitrailer and 6-wheel full trailer: 8 axles 			125,000 E		126,000 J P	135,000 H	110.000 W	74.000 110.000 W	110.000 W	110,000 T,V	

Key to Abbreviations

*—Limited by length of train only.
A—If gross weight of combination is in excess of 24.000 lb.
B—Based on axles spaced between 42 in. and 53 in.
C—On specified highways.
E—Must meet regs. on axle spacing and tire type and size. GVW above 80,000 lb permitted only on certain highways.
F—Max. WB 35 ft; no restriction on overall length.
G—Single axle tolerance, 1,000 lb; tandem axle, 2,000 lb.
H—This is a maximum practical gross weight based on 10,000 lb at steering axle. Must also meet Ont. regulations ('71) on axle spacing and tire size: 4 ft tandem spacing and 8 ft triples spread used in examples.
J—Must meet regs. on axle spacing and load per inch of tire width. Front axle max. weights: straight trucks, 19,000 lb; combinations, 12,000 lb.
K—Designated highways.
L—Based on 10,000 lb at steering axle, but subject to increase where front axle and tires designed for greater weight. In N.S., eff. Jan. 1, 1976, illegal to have steering axle weight in excess of rated capacity.
M—Must meet regs. on axle spacing and tire sizes. In Nfld. increase over 32,000 lb determined by axle spacing.
N—Buses, 40 ft (3 axles).
P—Distance from centres of the leading rear axle of the tractor and rearmost axle of the train should be at least 52 ft. For each complete foot below this figure deduct 1,000 lb from permissible gross weight.
Q—One full trailer only but this may be towed behind a semi if within 65 ft overall.
R—Max. length of semitrailer 45 ft. (except car carriers in Ont.).
T—Based on 12,000 lb on steering axle and provided vehicle meets requirements for tires and axle spacing.
U—Three axles on one vehicle prohibited unless one is a steering axle, or articulates in the manner of a steering axle.
V—Provided vehicle has two drive axles and a gross weight to horsepower ratio not greater than 300 lb per one hp.
W—On designated highways only. Must meet regs. on axle spacing and load per inch of tire width (500 lb). Front axle loading of 10,000 lb assumed. Max. axle loading 20,000 lb single, 35,000 lb tandem. In Alberta, tolerance of 1,000 lb allowed within maximum gross weight.

For detailed regulations governing specific vehicles, and for route restrictions, contact provincial licensing authorities.

Fig. 7.6 CANADIAN SIZE & WEIGHT REQUIREMENTS FOR COMMERCIAL VEHICLES

Source: Reprinted with permission from Bus & Truck Transport, September 1976

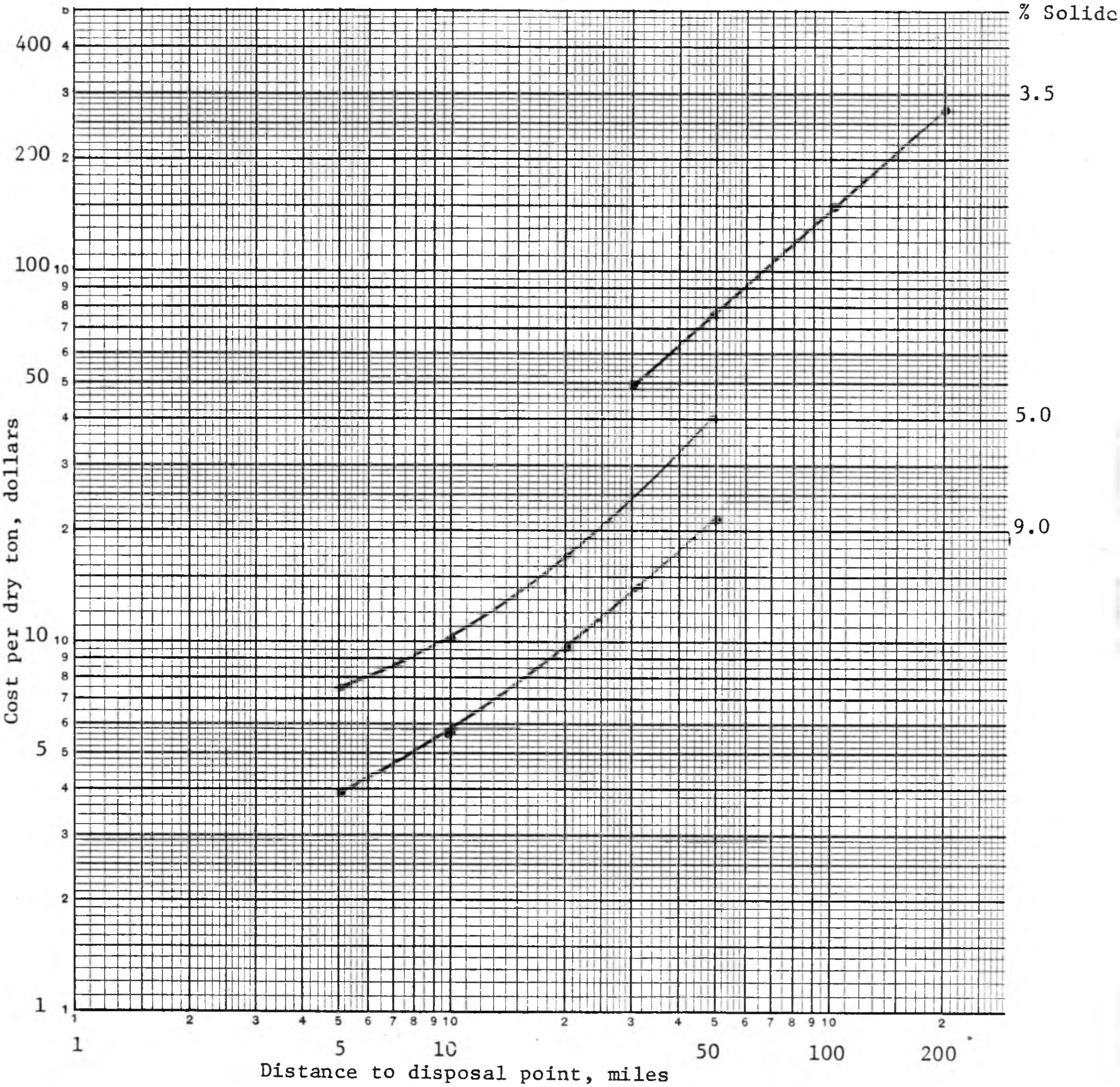


Fig. 7.7 COST OF TRUCKING SLUDGE TO DUMP

Source: Wyatt et al, 1975

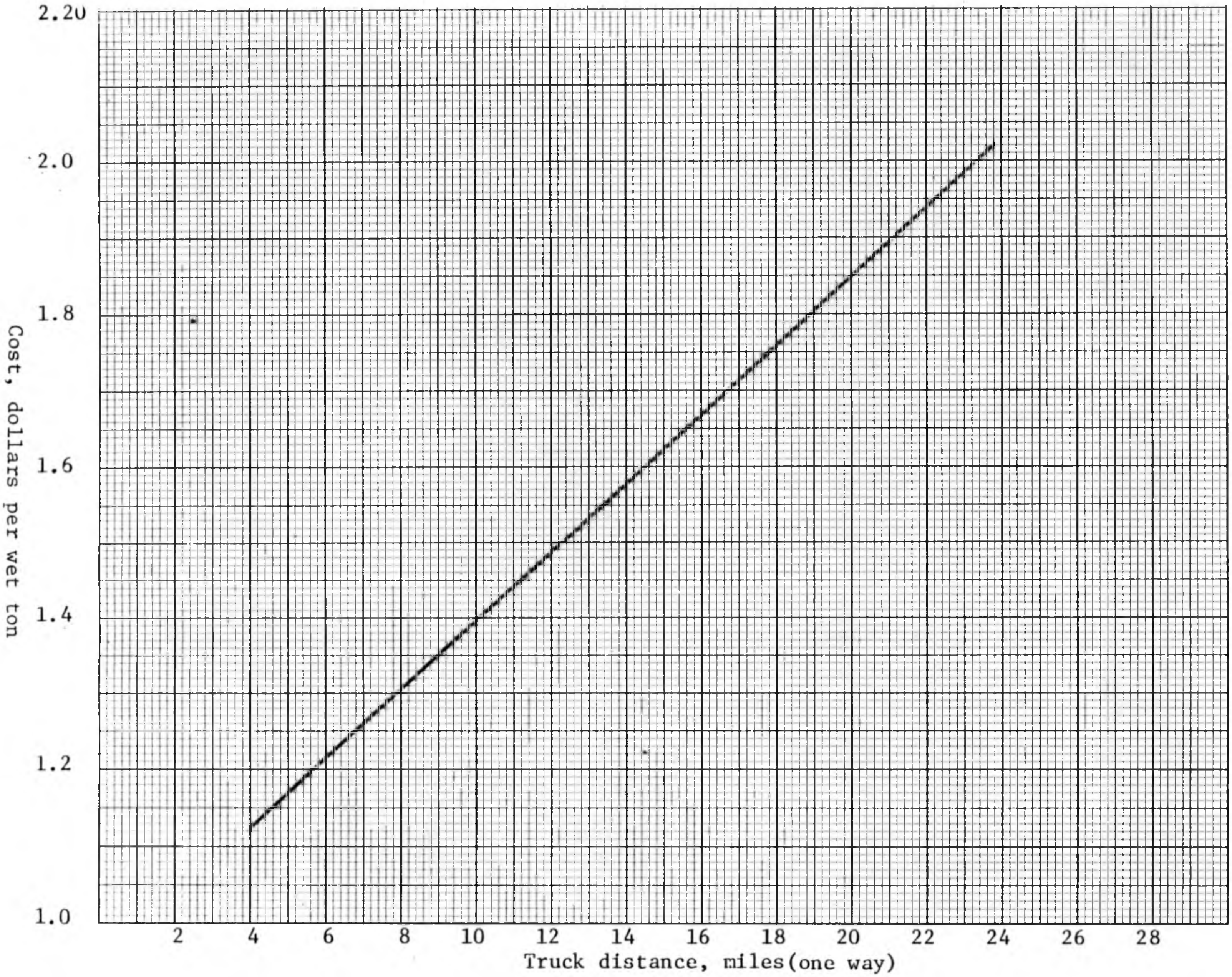


Fig. 7.8 COSTS OF TRUCKING DEWATERED SLUDGE FOR 30 to 70% SOLIDS (Chicago MSD)

Source: Wyatt _et al_, 1975

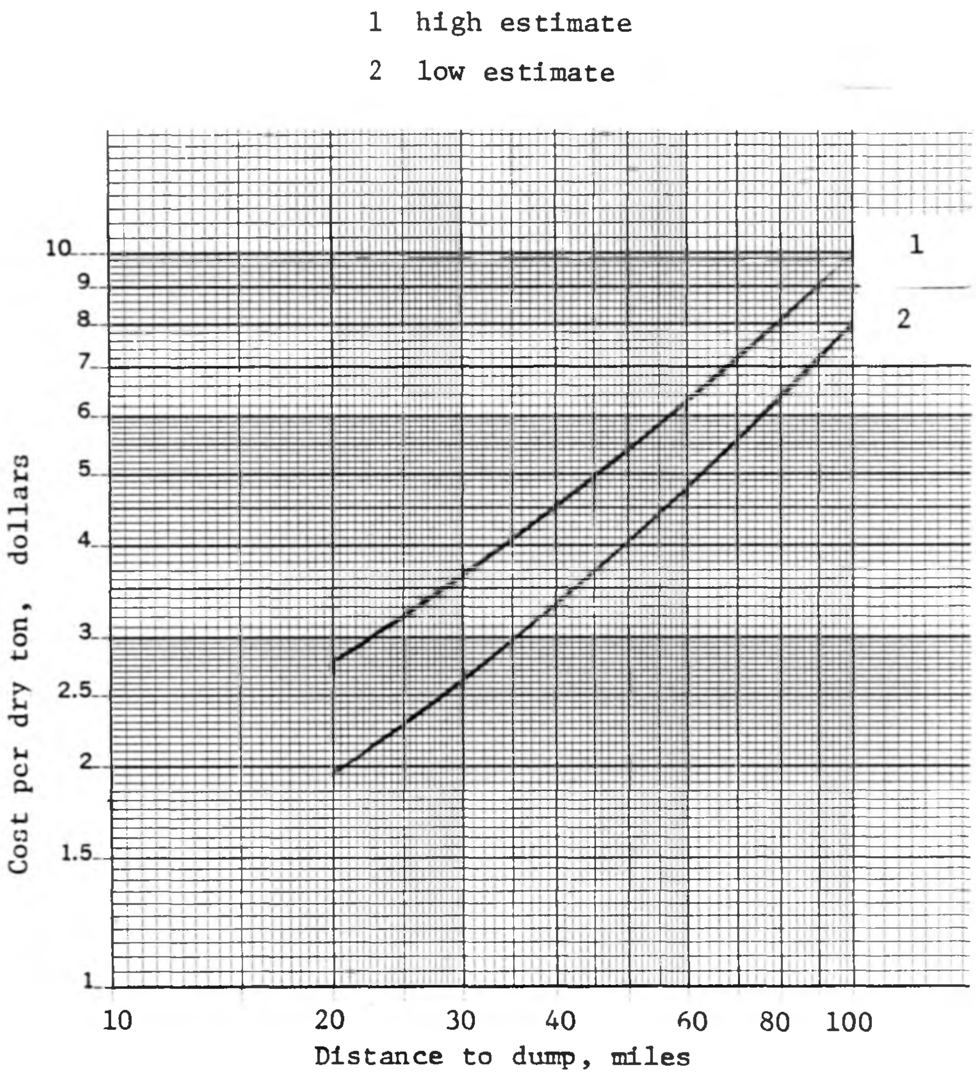


Fig. 7.9 COST OF DUMP TRUCK TRANSPORTATION OF SLUDGE INCINERATOR ASH

Source: Wyatt et al, 1975

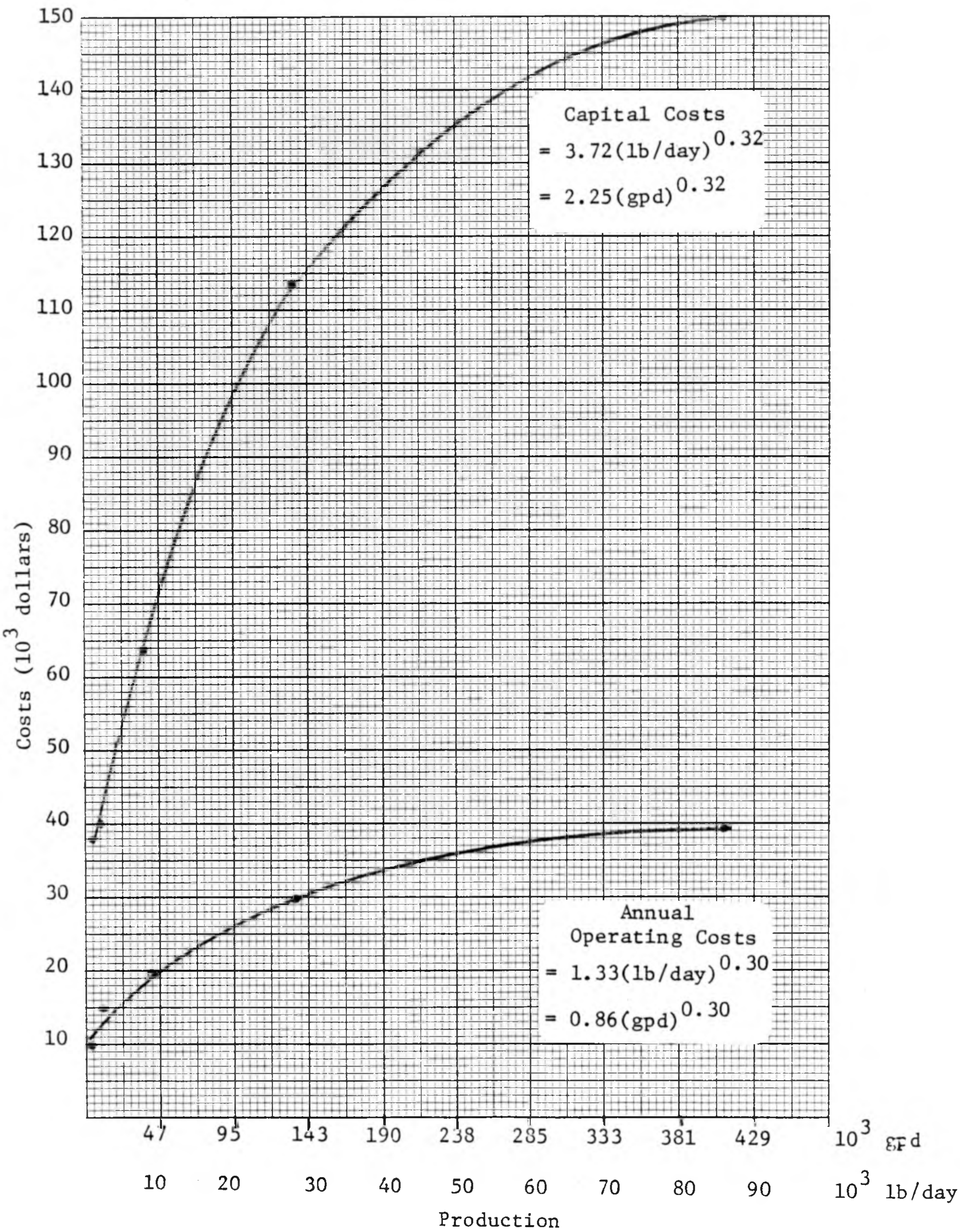


Fig. 7.10 CAPITAL AND OPERATING COSTS FOR HAULING LIQUID SLUDGE

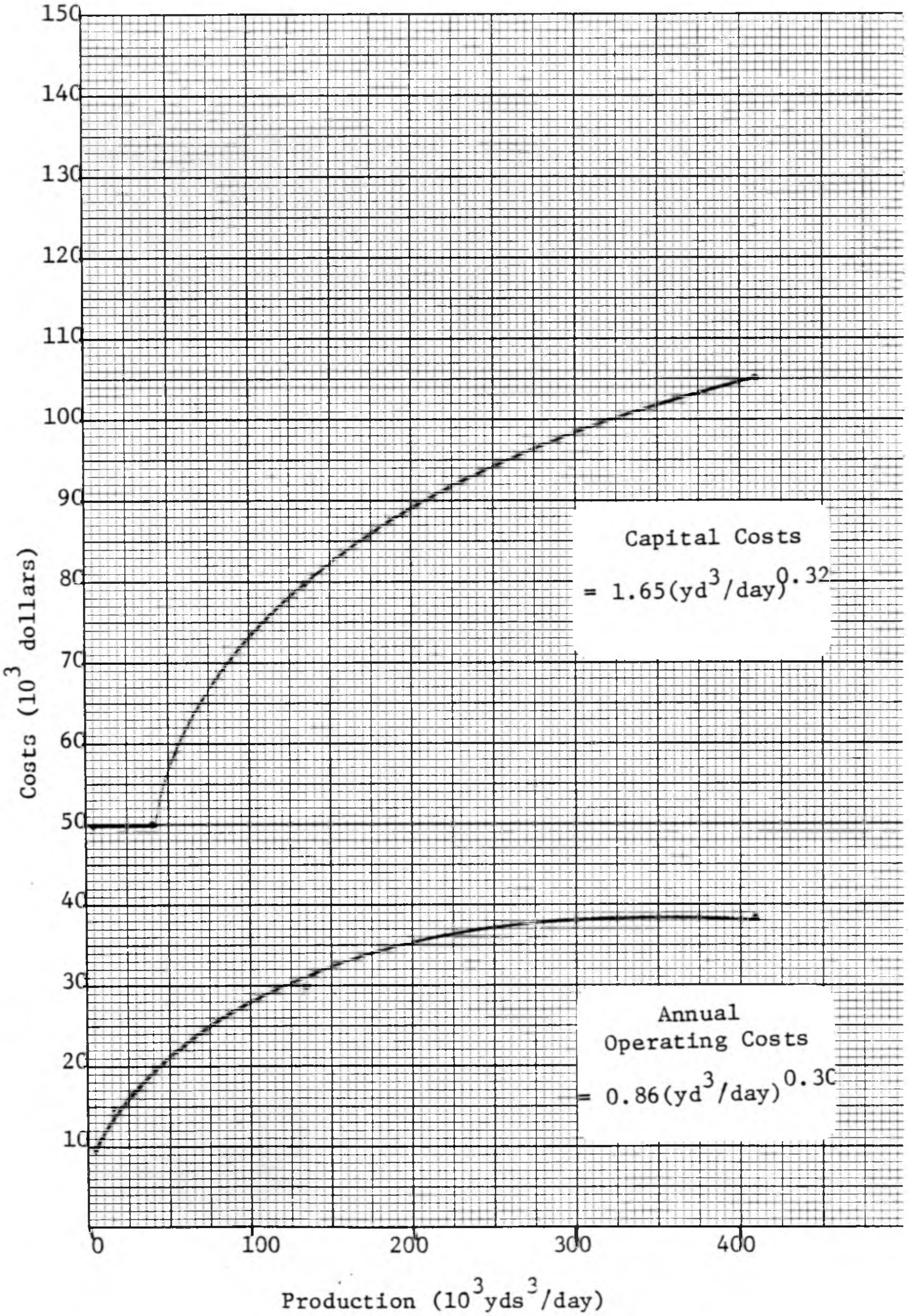


Fig. 7.11 CAPITAL & OPERATING COSTS FOR HAULING DEWATERED SLUDGE

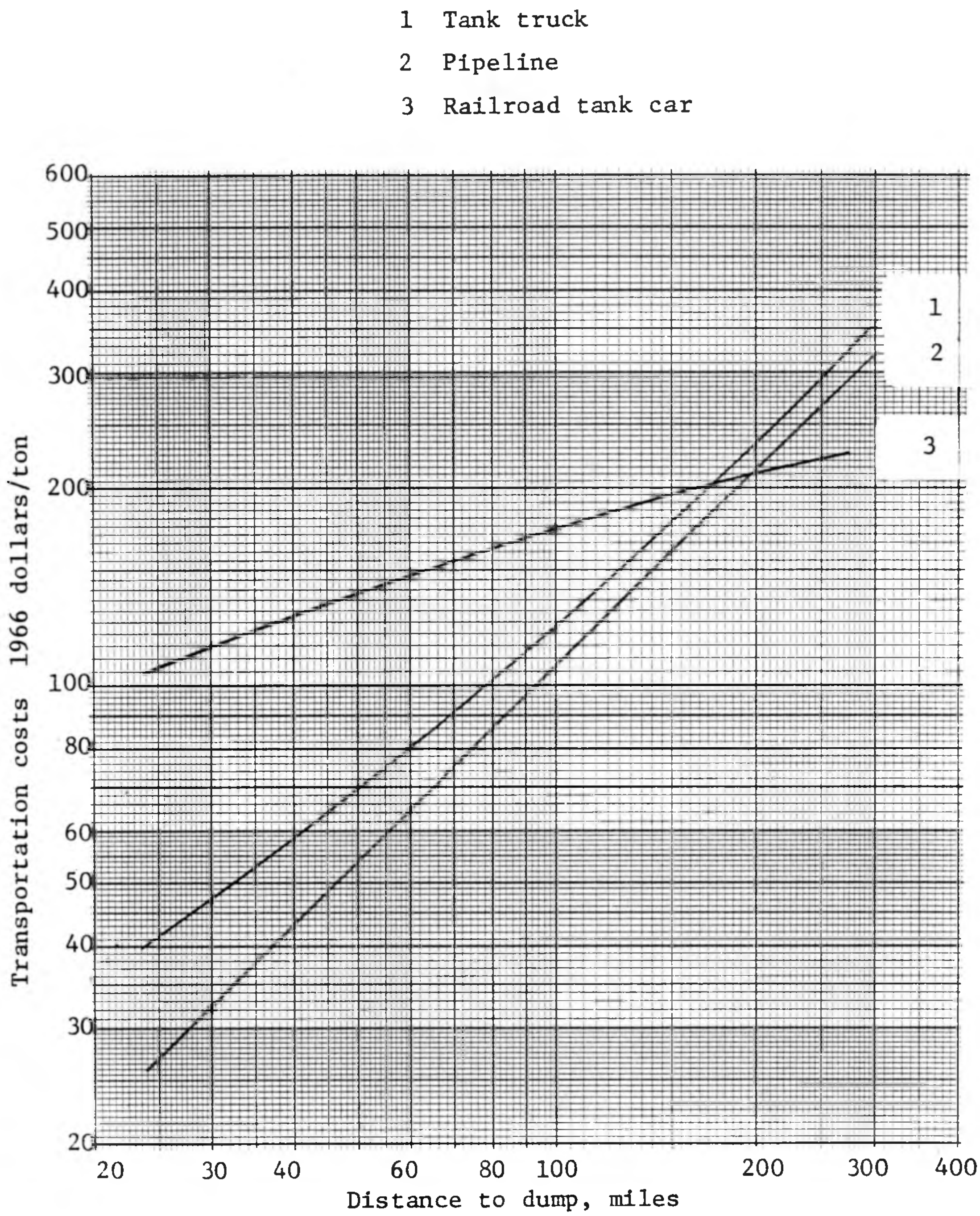


Fig. 7.12 COST OF TRANSPORTING SLUDGE FROM A CITY OF 100,000 PEOPLE

Source: Riddele et al, 1966

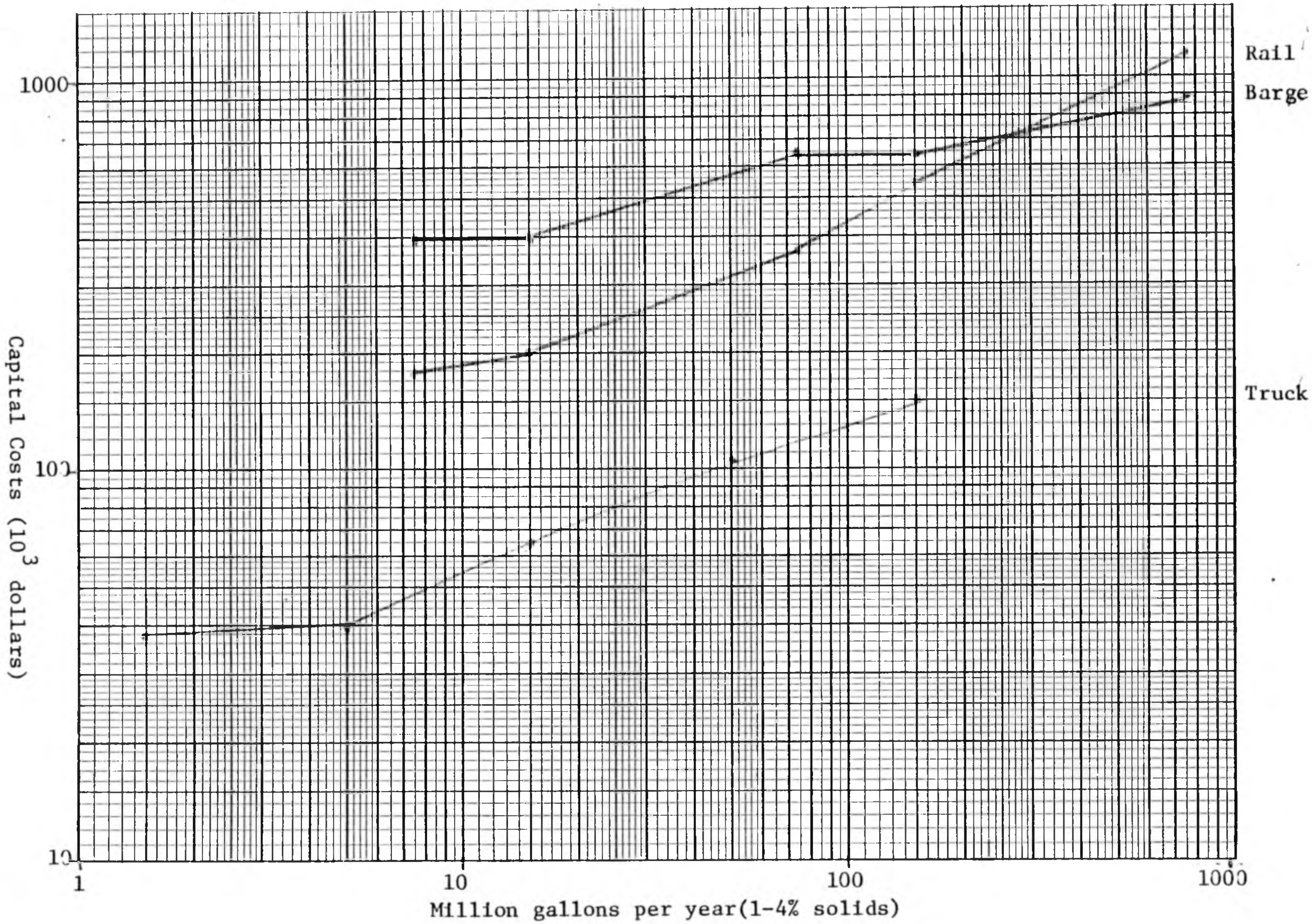


Fig. 7.13 CAPITAL COSTS OF RAIL, BARGE & TRUCK SLUDGE TRANSPORT SYSTEMS

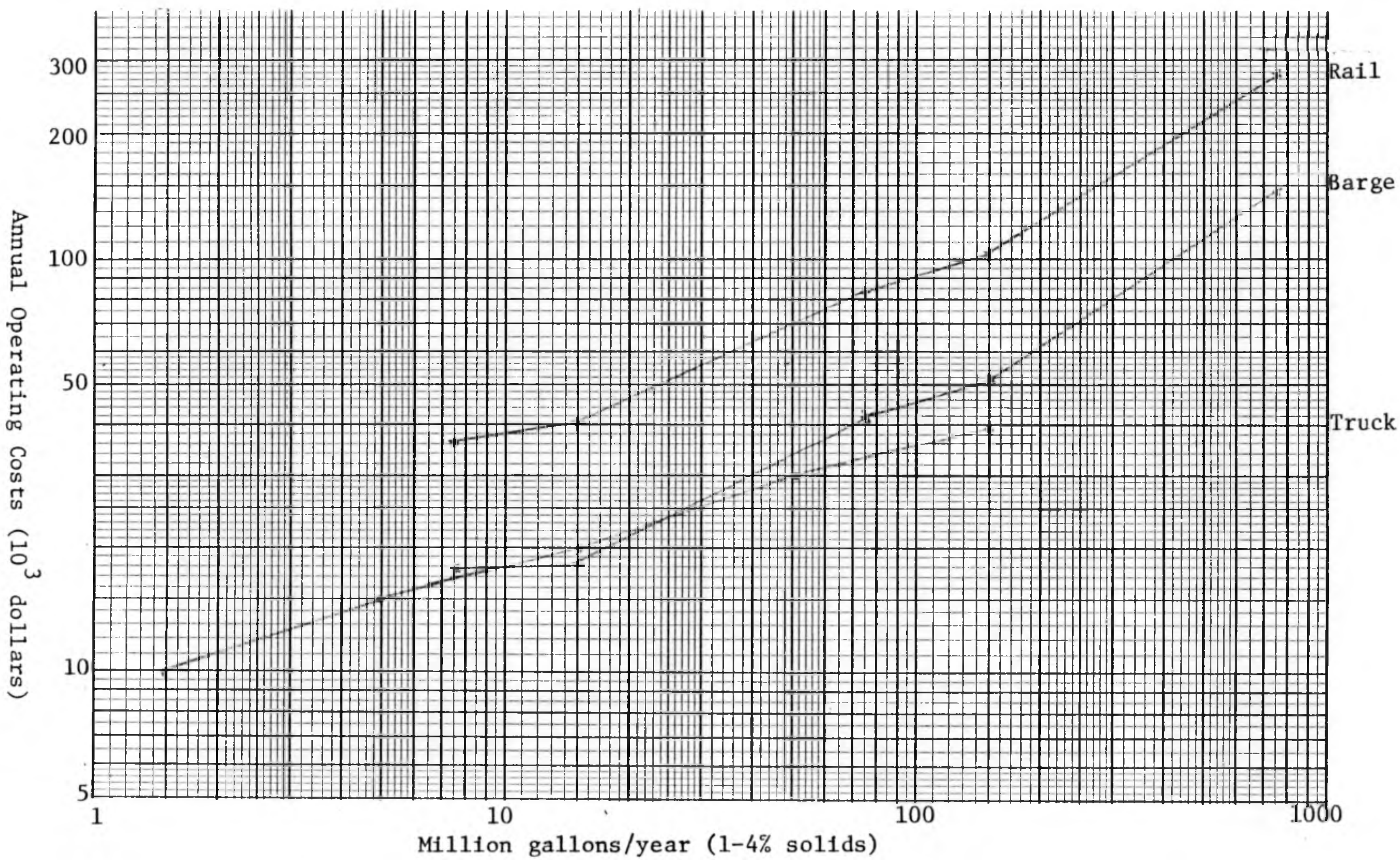
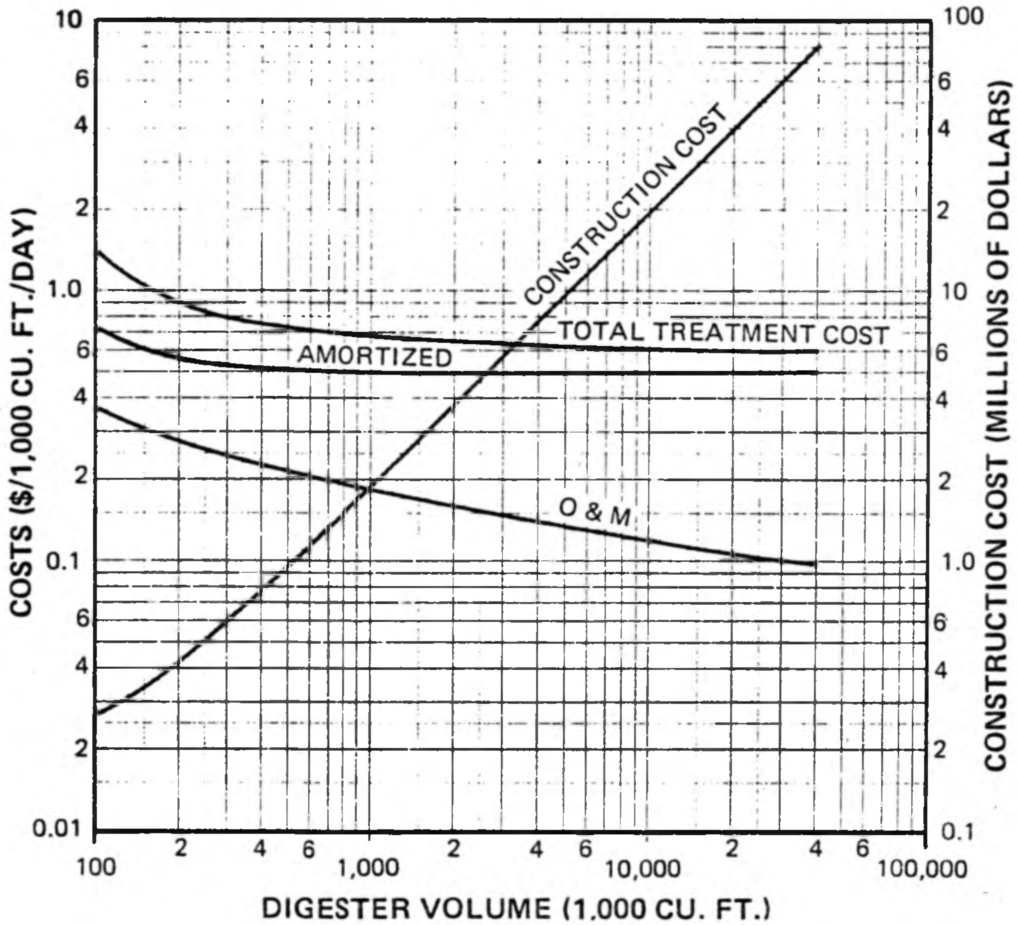


Fig. 7.14 OPERATING COSTS OF RAIL, BARGE & TRUCK SLUDGE TRANSPORT SYSTEMS

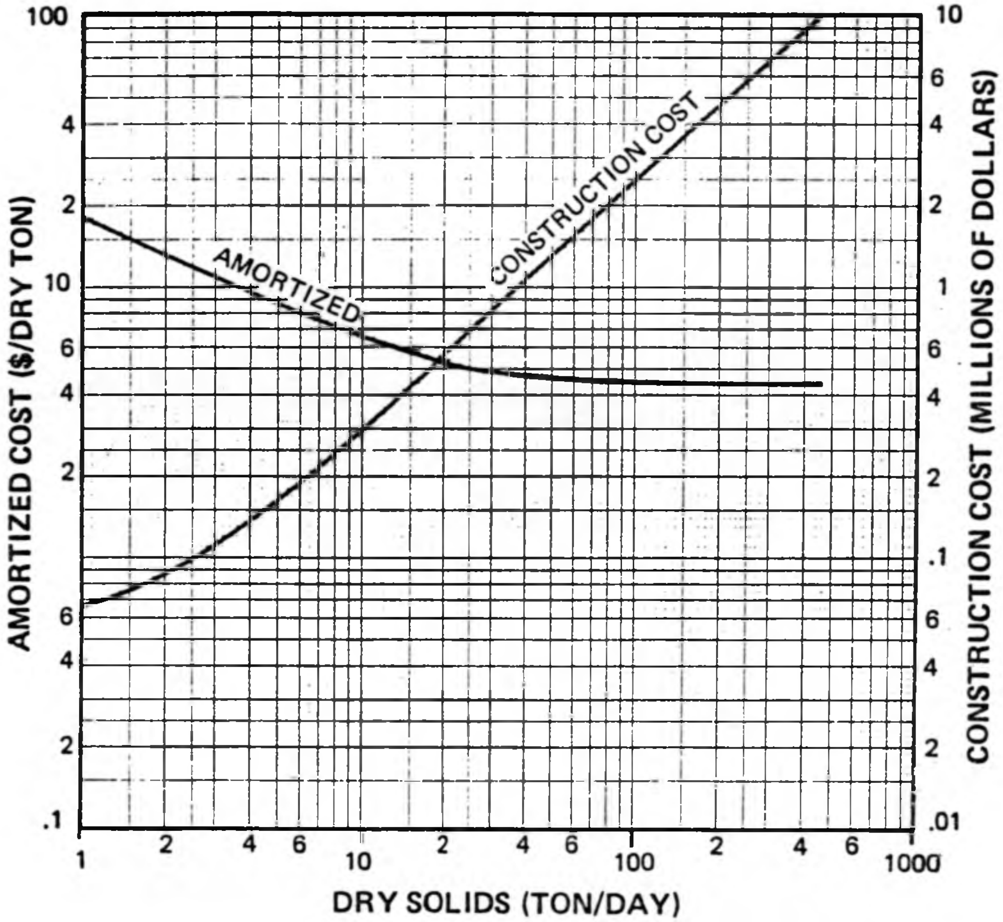


NOTES:

1. Minneapolis, Mar., 1972. ENR Construction Cost Index of 1827.
2. Amortization at 7% for 20 years.
3. Labor rate of $6.25 per hour.
4. Sludge heating, circulating and control equipment and control building included.
5. Source: EPA Cost and Manpower Report and Stanley Consultants.

Fig. 7.15 UNIT ANAEROBIC DIGESTION COSTS

Source: EPA,1974

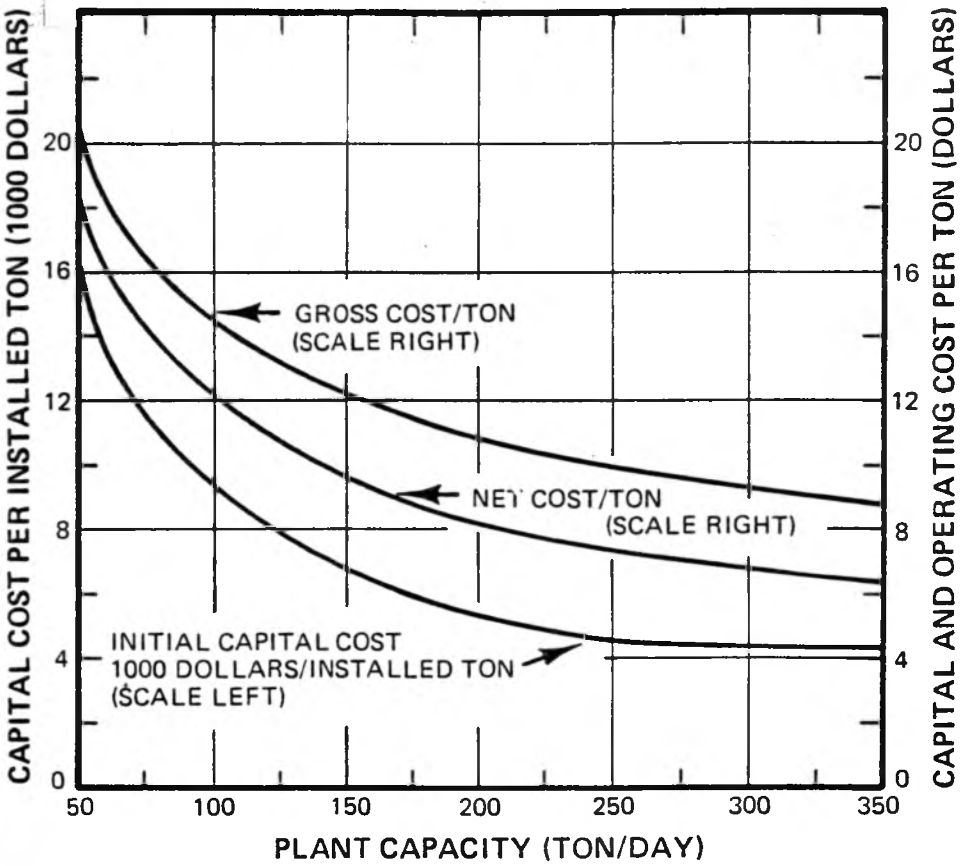


NOTES:

1. Minneapolis. Mar., 1972. ENR Construction Cost Index of 1827.
2. Amortization at 7% for 20 years.
3. Influent sludge of 38% primary and 62% waste activated sludge with a solids content of 3.5%.
4. 20 day volumetric displacement time.
5. Souce: EPA Cost and Manpower Report and Stanley Consultants.

Fig. 7.16 AEROBIC DIGESTION CAPITAL COST

Source: EPA,1974



NOTES:

1. Plant capacity is normally one or two shifts per day to achieve plant capacity.
2. Gross cost trend is the owning and operating facilities without any credits.
3. Net cost trend is for owning and operating facilities considering sales of compost and salvaged materials.
4. All costs consider compost digested sludge with refuse.
5. Source: Composting of Municipal Solid Wastes in the United States, US Environmental Protection Agency (1971).

Fig. 7.17 COMPOSTING COSTS

Source: EPA,1974

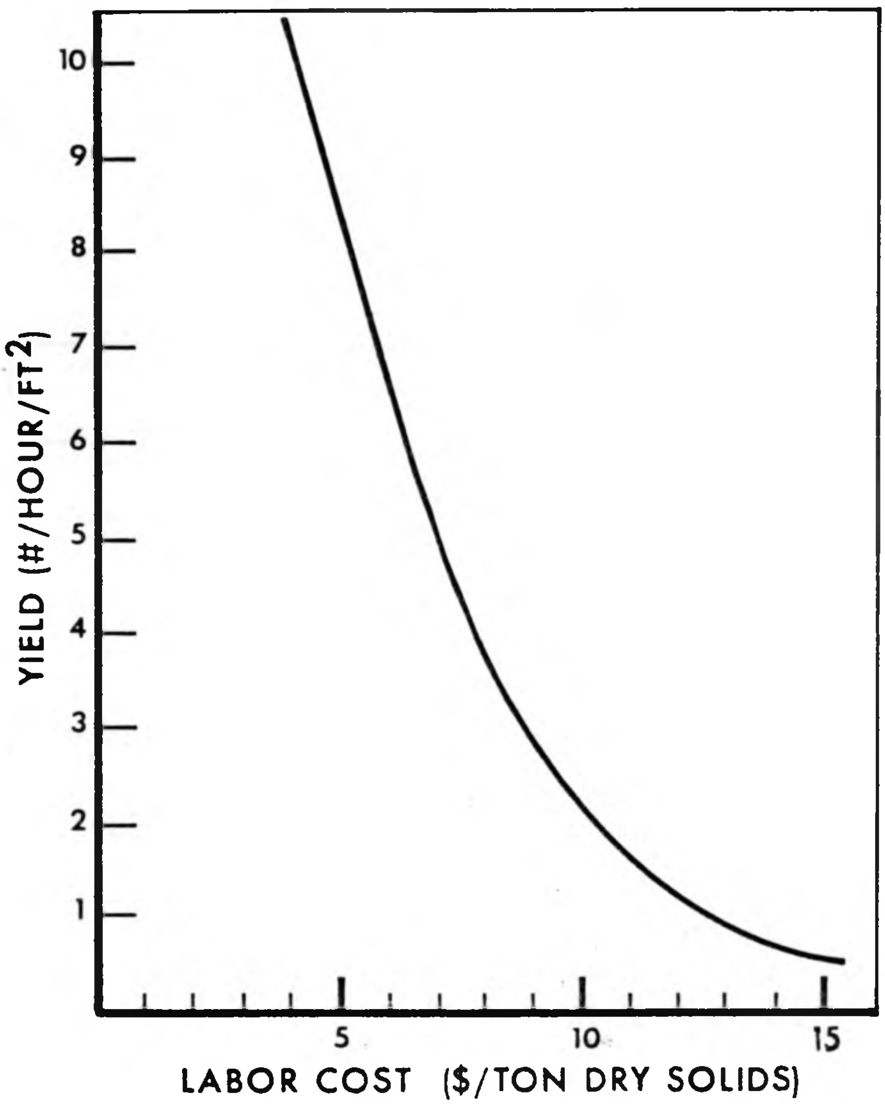
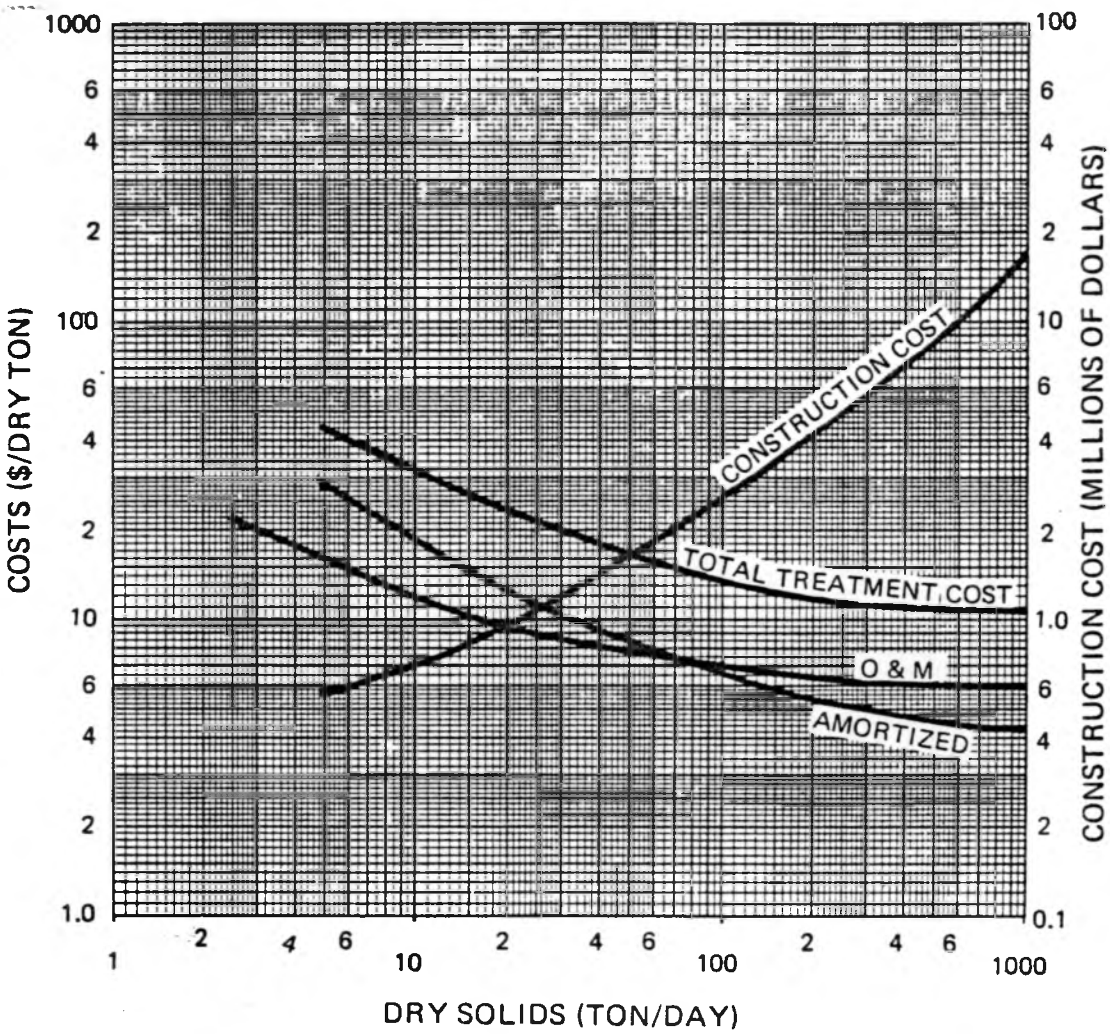


Fig. 7.18 VACUUM FILTRATION OPERATIONAL LABOR COSTS AS FUNCTION OF YIELD

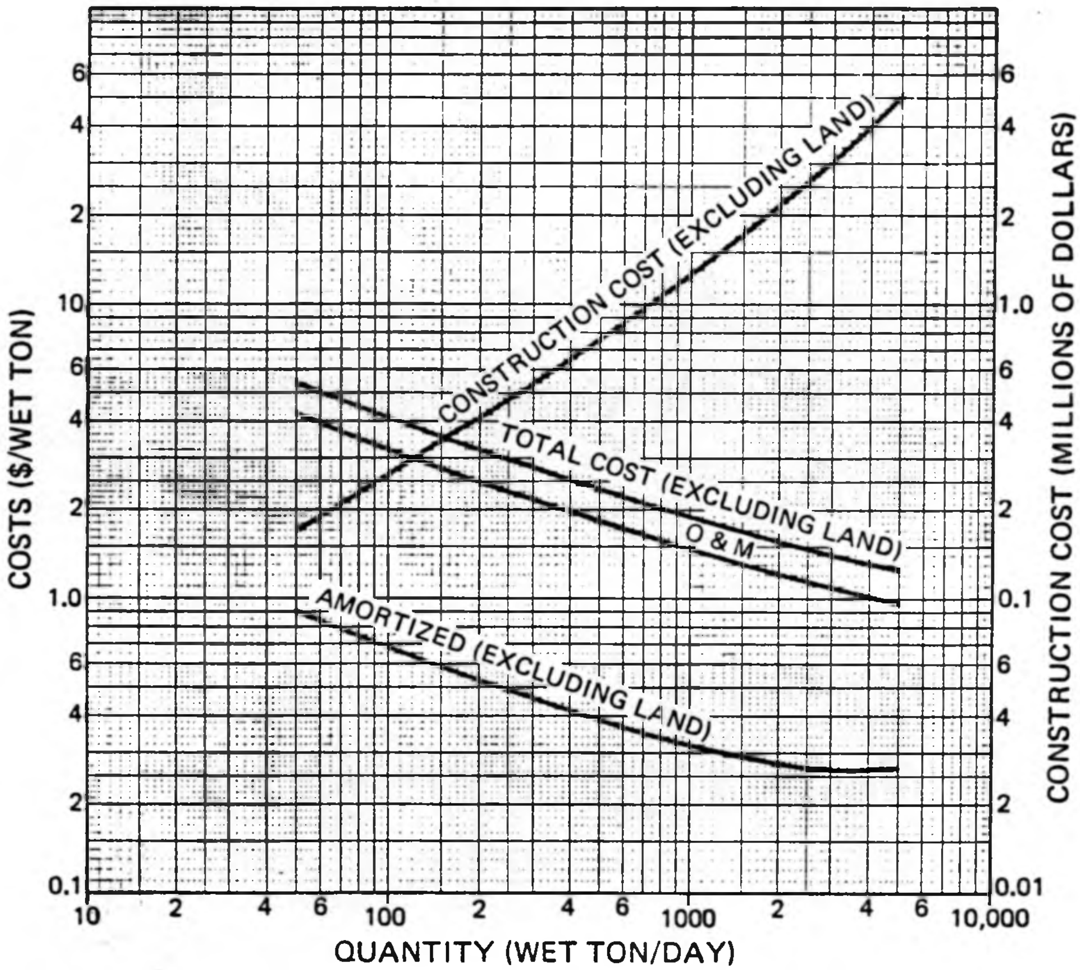
Source: EPA,1974



NOTES:
1. Minneapolis, Mar., 1972. ENR Construction Cost Index of 1827.
2. Amortization at 7% for 20 years.
3. Labor rate of $6.25 per hour.
4. Exhaust gas scrubber and enclosing structure included.
5. Costs do not include deodorization of gases: where required, add $4 to $10/dry ton.
6. Source: EPA Cost and Manpower Report and Stanley Consultants.

Fig. 7.19 MULTIPLE HEARTH INCINERATION COSTS

Source: EPA,1974



NOTES:

1. Minneapolis. Mar., 1972. ENR Construction Cost Index of 1827.
2. Amortization of 7% for 20 years.
3. Labor rate of $6.25 per hour.
4. Quantity assumes 6-day work week.
5. Wet sludge must be considered for cost per ton.
6. Source: U. S. P. H. S. and Stanley Consultants.

Fig. 7.20 CAPITAL AND O/M COSTS FOR SANITARY LANDFILLS

Source: EPA, 1974

Section 8

THE DECISION MAKING PROCESS

8. THE DECISION MAKING PROCESS

8.1 Selection of Alternative Sludge Management Schemes

Throughout the preceeding sections of this report, a variety of methods have been described for processing waste sludge. Once a basic understanding of each of the processes has been achieved, it is necessary to evaluate each of the alternatives in light of its technical, economical, social and environmental advantages and disadvantages. It must be clearly stressed that a selection of alternatives for any one community will not necessarily fit any other community. Two nearby communities may be of identical size, have identical treatment plants and operate under identical climatic conditions. If however, one of these communities was to have an industrial input that the other did not, then the final disposal method might be altered. Similarly, all factors may be identical except that one plant is in Northern Saskatchewan and one plant is in Southern Ontario. In this case, climatic conditions and land availability may eliminate the use of the same procedures in both communities.

A flowsheet of the possible combinations for sludge treatment and disposal is given in Figure 8.1. A community wishing to determine the optimum treatment plan should gather the following information, and then proceed through the selection process:

1. daily sludge production,
2. present treatment method,
3. sludge moisture content,
4. industrial inputs,
5. septic tank inputs,
6. sludge analysis
    a) volatile content
    b) calorific value
    c) chemicals (alum, ferric, lime)
    d) heavy metals,

7. farm land availability,
8. possible reclamation sites,
9. landfill volume available,
10. distances to 7,8,9 above,
11. public opinion
12. financial support, and
13. local, provincial and federal regulations.

As the different processes are considered, it will be necessary to undergo some degree of analytical work to aid in the support or rejection of certain alternatives. As an example, the filterability of a sludge may need to be tested to evaluate the selection of pressure or vacuum filters for the sludge dewatering process.

It must be kept in mind throughout the evaluation process that not all of the combinations shown in Figure 8.1 are reasonable alternatives. For this reason it is necessary to consider the ultimate reduction and disposal method before intermediate selections are made. As an example, the use of anaerobic digestion would not be logical if the final product was to be subjected to a combustion process such as incineration. The anaerobic digestion would reduce organics to methane gas, leaving inert matter for incineration. Auxiliary fuel requirements would thus be extreme. Similarly, it would be unwise to choose lime stabilization if wet oxidation was to be used for the combustion process, as it has been shown that lime fouls the wet oxidation reactors.

If the sludge management plan is being considered at the same time the wastewater treatment plant is being constructed, then the selection of alternatives may start with the incoming raw sewage. As the standards for effluent quality increase, through either legislation or the desire to preserve the natural environment, there is an increasing amount of impurities extracted from the water and thus a corresponding increase in the amount of sludge produced by the system.
waste, expressed as BOD_5, are the food for the micro-organisms in the treatment plant and the more food that is fed to the system, the more

sludge produced.

Recent large increases in sludge production are generally the result of the advent of chemical treatment to remove contaminents such as phosphorus. Production of alum, ferric or lime sludges not only changes the sludge production values but also changes the alternatives available for treatment. For example, as the amount of alum sludge increases the percent of the digestible volume of the sludge decreases. It would be unreasonable to anaerobically digest the sludge which contained mainly aluminum hydroxide and aluminum phosphate, with very little organic matter present. If tertiary chemical treatment is separate from the biological treatment process, then the sludges can be treated separately, but when the two are combined some limitations are bound to develop.

In most cases, a selection of the most feasible alternatives can be made on the basis of the 13 points of information previously gathered, Many of the pathways can be selected by merely omitting those processes which are clearly not viable alternatives. For example, landspreading would be highly unlikely for Metropolitan Toronto or any other major population centre, but it would not be unreasonable for prairie cities having vast areas of uninhabited land nearby. For the prairies ocean disposal would not even be an alternative, but it is a definite possibility for a city such as Vancouver.

When the alternative options have been selected, it is necessary to then undertake a cost benefit analysis of each plan in order to extract the final method. Using the cost information in this report, and data collected from the different equipment manufacturers, it is possible to evaluate each of the processes on a purely monetary basis. The difficult task is relating the other factors on a similar cost-benefit scale. Other factors here include water quality, (surface and ground water), air quality, (odour, dust), wildlife land management, noise pollution, (trucks), and aesthetics, (appearance). The system having the least monetary cost may be the most expensive environmentally and as such is not likely a viable alternative. A rating system is thus required in order to evaluate the non-monetary aspects.

Strategies for decision makers involved in selection of sludge management schemes have been discussed by Bell et al (1977), Burley et al (1977), Ehler et al (1976), Freeman (1975), Montague (1975), Myatt (1968), Neptune et al (1975, 1976), Schmidtke et al (1975), Simpson (1975) and the EPA (1976).

8.2 Choosing the Best Technical Option

As previously explained, the best option for sludge processing will vary depending on local sludge production, sludge characteristics, ultimate disposal, public opinion and local regional regulations. In this section, a basic outline for selection of the best sludge processing train will be outlined based on production, characteristics and ultimate disposal.

Starting with a thickened sludge, it is necessary to proceed through the decision loop as illustrated in Figure 8.2 If landfill or agricultural landspreading is to be considered, then stabilization is required. Dewatering of this stream will generally be used if landfilling is planned. Should volume reduction by wet or dry combustion be required, then dewatering or stabilization must be evaluated. Stabilization in this case will generally be heat treatment, which is conditioning more than stabilization. In the decision model, as illustrated in Figure 8.2, a square represents an operation and a diamond represents a decision.

8.2.1 Stabilization Assuming that a method has been selected that involves stabilization, then the type of stabilization to be employed must be selected. Points to consider while evaluating the different types of stabilization have been outlined in Section 2 of this report. A summary of the more important points are:

1. in Ontario, anaerobic digestion is a prerequisite of land disposal,
2. anaerobic digestion produces methane as a by-product for energy recovery,

3. anaerobic digestion is very sensitive to operating conditions,
4. aerobic digestion (or thermophilic anaerobic digestion) gives greater solids reduction than conventional anaerobic digestion,
5. thermophilic operation results in reduced retention times in reactors, therefore smaller sizes,
6. operation in the thermophilic zone normally requires auxiliary heat input,
7. high rate digestion implies mixing and separate phase separation which increases reaction rates but also increases capital, operation and maintenance costs,
8. two stage high rate anaerobic digestion is beneficial for primary or primary plus secondary sludges,
9. anaerobic contact digestion reduces the operation risks of anaerobic digestion,
10. aerobic digestion fits well with existing extended aeration treatment plants,
11. aerobic digestion is more competitive for waste activated sludge as primary sludge will exert a 50 percent increase in oxygen demand,
12. batch operated aerobic digesters are good for small extended aeration plants having only occasional sludge wastage,
13. daily fill and draw aerobic digestion produces a well thickened sludge,
14. continuous digesters require more equipment, thus more capital costs, but batch,or fill and draw,require more man hours, thus greater operational costs,

15. there are no set design standards for aerobic digesters,
16. mechanical surface aeration on aerobic digesters in cold climates causes excessive heat loss and ice build up,
17. digesters (aerobic or anaerobic) require heat conservation design,
18. aerobic digestion has higher power costs than anaerobic digestion,
19. on site equipment can often be easily converted to an aerobic digester,
20. supernatant from aerobic digesters is more easily treated than that from anaerobic digesters,
21. aerobically stabilized sludge thickens poorly,
22. compost is an excellent soil conditioner or fertilizer but it is not an economical process unless a market is available for the product,
23. putrefaction is stopped by lime stabilization but no organic destruction occurs as with digestion or composting,
24. lime stabilization is not permanent,
25. lime stabilization is a conditioning step for dewatering as much as a stabilization process,
26. lime stabilized sludge is excellent if sanitary landfilling is to be considered.
27. chlorine stabilized sludge is difficult to dewater on mechanical equipment and the filtrate is difficult to dispose of,
28. chlorine stabilized sludge dewaters easily on sand beds,
29. production of toxic chloramines can result from chlorine stabilization,

30. heat treatment dewaters sludge as well as providing stabilization, and
31. heat stabilization can handle toxic wastes not suitable for biological stabilization.

The alternative pathways in the decision model for stabilization is as depicted in Figure 8.3.

8.2.2 Dewatering After stabilization the sludge may go directly to land application or it may need to be further processed prior to landfilling or combustion. Volume reduction and dewatering is thus required in order to reduce transportation costs or decrease auxiliary fuel use in combustion. The major dewatering methods have been previously outlined in Section 3, and are shown in Figure 8.1. The major points to consider when evaluating dewatering methods are:

1. liquid sludge is transported by tankers and dry sludge or ash is transported by dump trucks,
2. vacuum filters are usually operated at large treatment plants only, due to high operating costs,
3. filterability increases with bulk content of the sludge, i.e. primary dewaters easier than secondary,
4. sludge yield off a filter varies directly with the feed solids concentration,
5. maximum solids off a vacuum filter is 30 percent,
6. conditioning prior to dewatering increases the sludge calorific value, but also the cost,
7. conditioning and stabilization occurs together if iron and lime coagulants are used,
8. polymers are much easier to use for conditioning and they increase the calorific value of the sludge directly,

9. only pressure filtration exceeds vacuum filtration in cake solids content,
10. filter presses are new in the North American sludge market and should be considered as a serious contender,
11. manual filter press operation is labour intensive but automation has now been developed,
12. pressure filters produce the most suitable sludge for incineration,
13. pressure filters can dewater even the most difficult to dewater sludges,
14. much less sludge conditioning is required with filter presses,
15. solids capture is the highest with pressure filters and thus the load to the treatment plant by the filtrate is minimized,
16. centrifugation results in a 20 - 25% cake with primary sludge and a 5 - 10% cake with waste activated sludge,
17. screening and degritting by hydroclones is often required prior to centrifugation,
18. batch centrifuges are usually selected for small community centrifuge operations,
19. centrifuges generally have lower capital and operating costs than dewatering by filtration,
20. centrifuges can handle a wide range of inputs and normally without chemical conditioning,
21. sand drying beds are used in small communities with small treatment systems and greater land availability,
22. climatic conditions can govern the use of drying beds if greenhouse structures are not used (i.e. cold or rain),

23. sand drying beds are labour intensive due to manual removal of sludge,
24. digestion is a prerequisite for sand drying beds due to odour control, oil and grease problems and release of bound water,
25. sand beds can be constructed to allow for mechanical cleaning,
26. sand beds are simple, inexpensive and require little maintenance,
27. drying lagoons are subjected to most of the sand bed remarks noted previously,
28. belt filters and squeeges are similar to other filtration methods, and
29. moving screen concentrations have low capital and operational costs required at small treatment plants.

The selection model incorporating the major decisions for sludge dewatering is shown in Figure 8.4. Before any method is selected however, careful laboratory or pilot plant testing should be carried out. In each case considerable testing may be required to determine conditioning requirements, solids yields, filtrate characteristics, etc. There are considerable variations with each particular type of mechanical equipment and thus laboratory examination of the characteristics will aid in the selection of the proper piece of equipment. Most equipment suppliers and consulting engineers have facilities available for such testing. Many required tests are outlined by Vesilind (1974).

8.2.3. Combustion Once dewatered, the sludge has only a limited number of pathways it can follow prior to ultimate disposal. If landfill or land reclamation is to be practical, some form of combustion may be practiced for volume reduction. If land application for fertilization and soil conditioning is to be practiced, combustion will not be utilized. Ocean disposal can be from barged ash or dewatered sludge, or submerged outfall injection of raw sludge.

If combustion is to be utilized as a volume reduction process prior to disposal then an evaluation of both wet and dry combustion processes must be made. The major points to consider when evaluating combustion as an alternative are:

1. land scarcity normally dictates combustion for reduction,
2. combustion aids in the destruction and reduction of wastes not suitable for landspreading or landfilling (i.e. heavy metals, PCBs),
3. centralization of combustion may be a practical alternative,
4. energy recovery can be expected ,
5. dewatering may be required,
6. incineration is commonly the cheapest method of sludge disposal where land is scarce,
7. anaerobically digested sludge is not suitable for incineration,
8. self-sustaining incineration requires 30 percent solids minimum,
9. residue ash of incineration varies from 15 to 45 percent of the original sludge weight and 10 percent of the original sludge volume,
10. incineration and pyrolysis of sludge works well in conjunction with municipal refuse disposal,
11. multiple hearth incinerators are simple, durable and capable of burning a wide variety of materials at various feed rates,
12. multiple hearth incinerators require considerable excess air,
13. odours and toxic organics can be destroyed in incinerators with correct exhaust gas temperatures,
14. fluidized bed incineraters are more adaptable to energy recovery processes,

15. fluidized bed incinerators are thermally efficient,
16. fluidized bed incinerators operate on minimum excess air,
17. fluidized bed incinerators are suitable for small communities in terms of costs, operation and quantity of sludge to be incinerated,
18. rotary kiln furnaces are simpler to design and operate but are not energy or environmentally suitable for most installations,
19. hard to dewater sludges can be combusted by wet oxidation without dewatering,
20. wet oxidation in small batch units is a viable alternative for small communities,
21. wet oxidized sludge has a poor fertilizer value,
22. wet oxidized sludge is sterile and suitable for landfill,
23. the process of wet oxidation eliminates the need for air pollution control systems due to natural scrubbing,
24. wet oxidation produces an effluent stream requiring further treatment (as would scrubbers on incinerators),
25. increased operating costs associated with mixing in the Barber-Coleman wet oxidation system must be balanced against costs of operating at higher temperatures and pressures with the Zimpro Process,
26. energy recovery can be coupled to wet oxidation,
27. pyrolysis is not as developed as incineration or wet oxidation,
28. pyrolysis produces a storeable fuel in the energy recovery process,
29. pyrolysis units create less air pollution than incinerators,
30. pyrolysis units require much less auxiliary fuel as there is no excess air to preheat, and

31. Saleable by-products such as acetic acid, methanol and solvents can be recovered.

The pathway for selection of an appropriate sludge combustion-reduction scheme is as shown in Figure 8.5. There are several routes which may be taken, the route primarily dependent on the quantity of sludge produced and the net calorific value. Factors such as auxiliary fuel supply and costs can become key issues in this decision process. Quantitites of waste oils, for example, may make one incineration process more viable than another.

8.2.4 Ultimate Disposal The route from the initial raw sludge has now extended through several different pathways, but each of these pathways must exit at one of the ultimate disposal methods. It is important to remember that combustion is merely a volume reduction, not an ultimate disposal method. Sludges going to ultimate disposal may be raw, digested, thickened, dewatered and combusted, or a combination of any of these processes. The final component will be a slurry, a cake or ash. Disposal of this residue is now mainly governed by regulations, land availability and public opinion. Consideration should be given to the disposal method that provides the most benefits (i.e. fertilizer or reclamation) while exhibiting the least environmental damage (air, water, soil). The major factors to consider when selecting the ultimate disposal method are:

1. land disposal provides a source of essential nutrients and organic matter for the soil,
2. fertilizers do not act as an organic soil conditioner as does sludge,
3. public acceptance is a key factor for recycling sludge to agricultural plants,

4. in sludge application, the aim is to apply the most sludge possible without creating pollution problems,
5. land application is limited by the "zinc equivalent", or the concentration of heavy metals in the sludge,
6. different soils can accept different amounts of heavy metals,
7. sludge application is also limited by nitrogen loading, which in excess leads to ground or surface water pollution,
8. sludge application rates apply not only to present applications but also to past applications,
9. the sludge application process itself must normally follow specific guidelines (i.e. Appendix 5.3),
10. climatic conditions may limit sludge application (i.e. runoff, snow cover),
11. storage facilities may be required at the disposal sites for times when application is not practical,
12. special equipment may be required for spreading the sludge (above or below ground),
13. ocean dumping of sludge in Canada is governed by the Ocean Dumping Control Act,
14. disposal of sludge to the ocean can cause extreme impairments to commercial activities, asthetics and marine biological life,
15. most countries utilizing ocean disposal are attempting to select better alternatives,
16. ocean disposal has been practiced with digested sludge and ash from inceration or wet oxidation,
17. digested sludge may be applied directly to landfills in conjunction with municipal sludge,
18. if sludge is to be landfilled, attention should be paid to the equipment used for compacting (i.e. compressibility changes from that of pure refuse),

19. sludge addition to landfills could obstruct future development of the area (i.e. unsuitable topography),
20. landfilling should not have detrimental effects on the water or land quality nor on the neighbouring public health,
21. landfill sites with sewage addition may require leachate collection systems, and
22. most of the pros and cons of sanitary landfilling are related to the pros and cons of landfilling municipal refuse.

The alternate pathways for selecting an acceptable final disposal option are outlined in Figure 8.6. When proceeding through this decision model it is essential to remember that each step taken must be in accordance with all local, provincial and federal regulations. In most cases an environmental assessment of the disposal area will be essential to receiving final approval.

At this point a few sludge management schemes should have been selected. In order to select the best alternative, it is now necessary to conduct a cost comparison, in terms of capital and operating costs, and environmental costs. For determining monetary costs, reference should be made to Section 7 of this report. Most equipment suppliers will give costs for individual pieces of equipment utilized in sludge management. Costs should include capital costs, interest, operating and maintenance costs,and revenues from the sale of by-products recovered (i.e. lime, methane, energy).

8.3. Choosing the Best Environmental Option

When undertaking this section of the selection process,consideration must be made of water pollution, air pollution, land pollution, and public health. Consideration should also be given to plant and animal life and the general aesthetics of the proposed scheme.

8.3.1 Water Pollution Problems When evaluating a selection of management schemes, the following factors should be evaluated to ensure minimal disturbance to all ground and surface waters:

1. pollution of surface waters can result from runoff from fields receiving sludge application.
2. pollutants may be leached from sludge deposits into groundwater supplies,
3. landfill leachate may require treatment before it can be discharged,
4. ocean disposal can create direct water pollution, and
5. water pollution from sludge disposal is not normally visible but is detected by well sampling around disposal sites.

Several schemes have been outlined to minimize water pollution problems. A few of these have been outlined in Section 5 of this report. In most cases if regulations for disposal are followed, the chances of pollution will be minimized.

8.3.2 Air Pollution Problems Most cases of air pollution can be directly traced to combustion processes as outlined in Section 4 of this report. Some pollution might also occur from anaerobic digesters. Technology is now available to limit atmospheric discharges and the purchase of such equipment should be accounted for in the total cost of the project. In some cases, such as wet oxidation, these costs will be minimal.

Air pollution might also be cited against land spreading or landfilling if odours, dust and debris are present. Odour is generally the result of inadequate digestion, a topic covered in Section 2. Dust and debris can be controlled with proper covering practices and water application. If water is to be applied to control dust, its effect on ground and surface water pollution must also be evaluated

8.3.3 Land Pollution Problems During an evaluation of environmental effects of sludge management schemes on land quality, particular attention should be paid to the following points:

1. ensure protection of land quality directly, i.e. nutrients, toxic metals, pathogens,
2. ensure that planning has accounted for the future use of the disposal area,
3. ensure access to site (truck, rail, pipeline) is not destroying localized areas,
4. ensure controlled access to all disposal sites, and
5. ensure all application of sludge to crops is done under a permit system where control is applied to application rates and ultimate use of crops grown in this area.

Much of the public disapproval is based upon land consumption and degradation and if all these points are covered and a suitable public education program has been employed, then opposition to a planned management scheme will be minimal.

8.3.4 Public Health If all aspects of water, air and land pollution have been studied, there should be little chance of danger to public health. Public health problems would be associated with the transmission of toxic substances and pathogens in the water, in the air or on crops grown in a sludge fertilized field.

Approval should be obtained from local public health authorities before any management program receives final approval.

8.4 Evaluating the Total Management Scheme

Wyatt et al (1975) have proposed an alternative evaluation matrix that will greatly assist in making the final decision on what sludge management scheme to accept. This matrix, as illustrated in Table 8.1, covers decisions to be made with reference to economics, environmental factors, feasibility and the general performance of the sludge management scheme. The matrix as outlined, may consist of more or fewer alternatives than shown.

The rating classifications to be used in conjunction with Table 8.1 are as shown in Tables 8.2 through 8.5. In each case, the rating will depend on local conditions, and thus a rating for a certain method will not be standard throughout Canada.

When the matrix has been completed, submission of the proposed sludge management scheme to the local, regional and/or provincial regulatory agencies may be made.

SECTION 8 - TABLES

Table 8.1

Alternatives Evaluation Matrix

PARAMETERS		ALTERNATIVE	ALTERNATIVE	ALTERNATIVE	ALTERNATIVE
Economics	Capital Cost				
	Amortization				
	O & M Cost				
	Reclamation Revenue				
	Present Worth				
		RATING	RATING	RATING	RATING
Environmental Factors	Water Quality				
	Air Quality				
	Land Quality				
	Flora & Fauna				
	Aesthetics				
	Community Impact				
	Resource Conservation				
Feasibility	Financial Feasibility				
	Public Acceptability				
	Land Use Compatability				
	Ease of Implementation				
Performance	System Effectiveness				
	Reliability				
	Adaptability				
	Calamity Resistance				
	Permanence				

Source: Wyatt et al, 1975

Table 8.2

Impact Ratings for the Planning of Ultimate Disposal of Residual Wastes

Rating	Water Quality	Air Quality	Land Quality	Aesthetics
+5	Significant improvement in all waters, fresh or marine	Improves basin-wide air quality, directly and indirectly	Notably increases soil productivity and use options	Greatly improves aesthetic qualities and provides for the future
+4		Substantially lowers local levels of most air pollutants	Temporarily increases soil productivity and use options	
+3	Significant localized improvement in water quality	Substantially lowers local levels of some air pollutants		Promotes aesthetic quality in localized areas
+2			Increases soil productivity or use options	
+1	Indirectly causes a slight improvement in water quality	Results in slight decrease in some air pollutants		Compatible with present aesthetic qualities
0	No changes in any water quality	No changes in air quality	No changes in land quality	No changes in present aesthetic quality
-1	Indirectly causes slight degradation	Produces slight increase in odours or dust		
-2			Decreases soil productivity or use options	Degradation of aeshtetic qualities in some local areas
-3	Water quality degraded in localized areas	Produces substantial increases in several air pollutants		
-4	Substantial degradation of fresh or marine waters	Significantly degrades local air quality	Ultimately limits soil productivity and use options	Some loss of areas with desirable aesthetic qualities
-5	Extreme degradation of potable water supplies	Degrades basin-wide air quality	Substantially limits soil productivity and use options	Totally incompatible with desired aesthetic standards

Source: Adapted from Wyatt et al, 1975

Table 8.3

Impact Ratings for the Planning of Ultimate Disposal of Residual Wastes

Rating	Public Health	Community Impact	Resource Conservation
+5	Substantially reduces threat to public health	Promotes or improves environment of community	Promotes beneficial use of sludge and reduces usage of natural resources
+4		Produces increase in community property values	
+3	Reduces potential of harm to public health		Substantially reduces usage of resources for sludge disposal
+2		Reduces nuisance effects of present situation in community	
+1			Consumes fewer primary resources with no increase in secondary resource production
0	No change in public health involvement	No change in social or physical elements of the community	Maintains present level of energy and materials resource usage
-1	Increases potential of harm to public health	Increases noise or odour levels in the community	
-2			Increases primary resource consumption and decreases secondary resource production
-3		Substantially increases traffic or lowers property values in community	
-4	Positively increases threat to public health	Involves displacement of residents from community	Consumes greater quantities of resources with no secondary production

Source: adapted from Wyatt et al, 1975

Table 8.4

Impact Ratings for the Planning of Ultimate Disposal of Residual Wastes

Rating	Financial Feasibility	Public Acceptability	Ease of Implementation	Land Use Compatability
+4	Readily falls within funding capabilities of responsible agency	Desired by overwhelming majority of the public	Readily implementable by existing agencies within current legislative limits	Compatible with existing land use plans
+3		Strongly supported by local groups		
+2		Supported by some local groups		Will require some plan & zoning changes
+1			Will require minor changes in legislative limits	
0	Marginally falls within funding capabilities of responsible agency	Public ambivalent toward this system		
-1		Opposed by some local groups	Will require minor re-organization of agencies	Will require substantial plan & zoning changes
-2			Will require major changes in legislative limits	
-3		Strongly opposed by local groups	Will require major re-organization of agencies	
-4	Financing unsupportable by grants & beyond local means	Opposed by over-whelming majority of the public	Exceeds legal limits beyond possibility of changing limits	Totally incompatible with land use plans

Source: Adapted from Wyatt et al, 1975

Table 8.5

Impact Ratings for the Planning of Ultimate Disposal of Residual Wastes

Rating	System Effectiveness	Reliability	Adaptability	Calamity Resistance	Permanence
+5	Will greatly exceed performance criteria	Will perform reliably 100 percent of the time	Will readily adapt to new processes or performance criteria	Fully functioning in event of earthquake, labour dispute, etc.	System will be adequate for 50-year life-span of major structure
+4		Simple system with little mechanical downtime			
+3				Will remain fully functional and require only minor repairs	
+2	Will exceed performance criteria in several parameters	Complex system with little mechanical downtime			
+1			Will adapt to some new performance criteria		
0	Will meet performance criteria		Will adapt to some new processes	Will maintain minimum function and require some repairs	System adequate for immediate planning horizon
-1		Simple system unproven in full-scale operation		Will cease functions for a very short period of time	
-2	Will fail to meet a few minor criteria	Has been demonstrated to have frequent mechanical problems			
-3				Will cease function for more than several days	
-4	Will fall substantially short of meeting criteria	Complex system unproven in full-scale operation	Will not adapt to new processes or performance criteria	In event of calamity, will cease function and require major repairs	Interim measure, usable for several years only

Source: adapted from Wyann et al, 1975

SECTION 8 - FIGURES

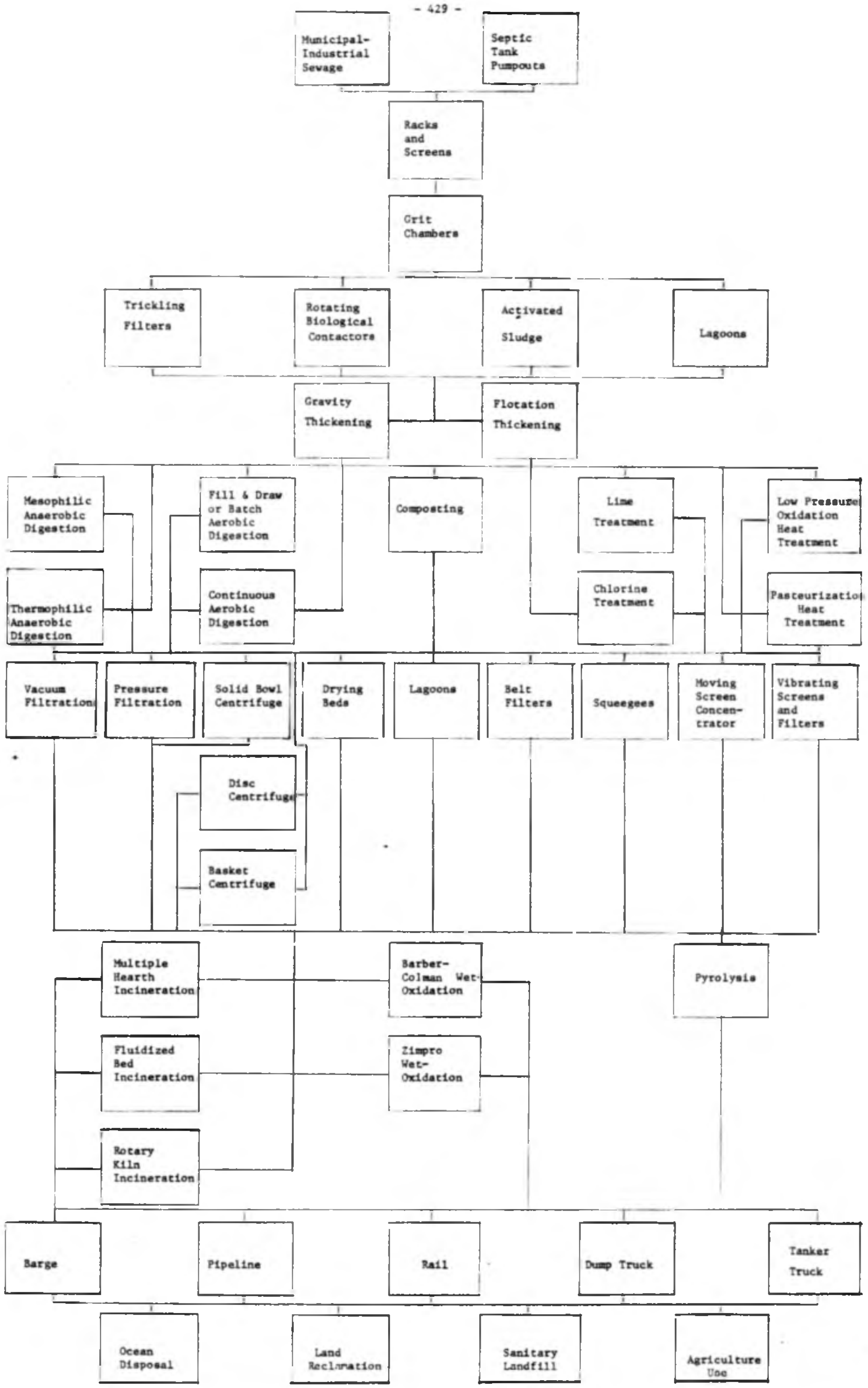


Figure 8.1: SLUDGE TREATMENT AND DISPOSAL ALTERNATIVES

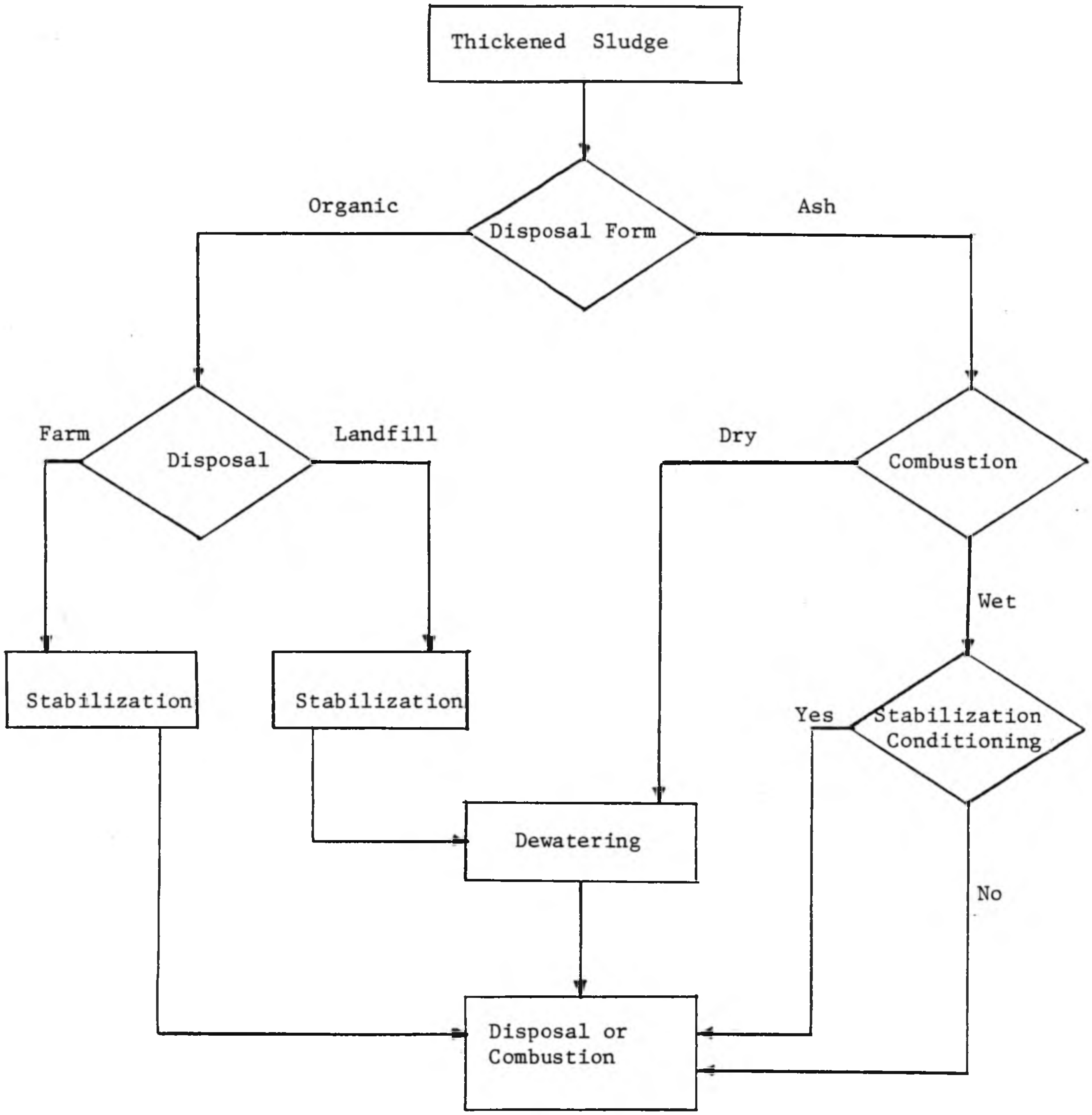


Figure 8.2 Disposal Pathways

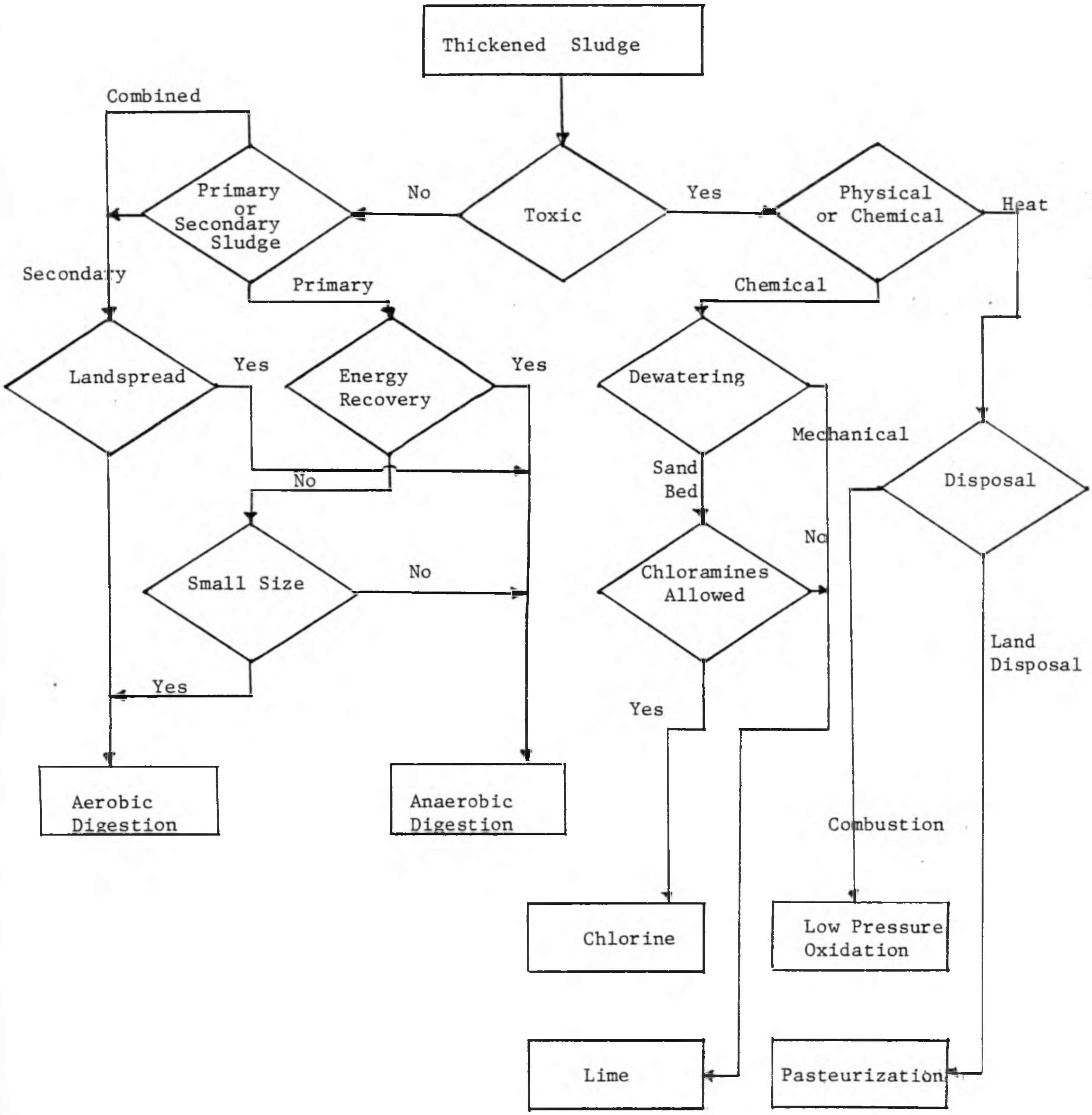


Figure 8.3 Stabilization Pathways

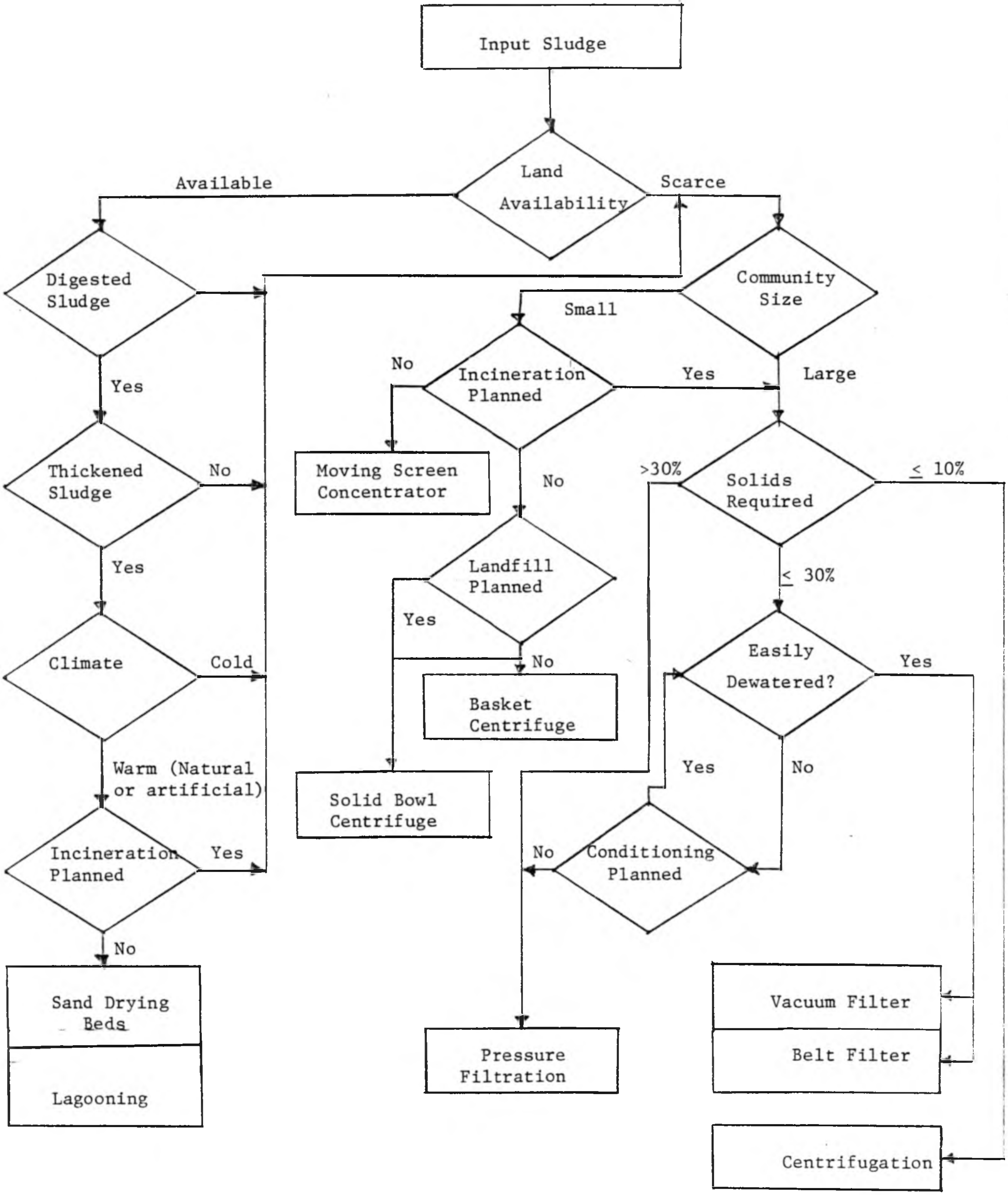


Figure 8.4 Dewatering Pathways

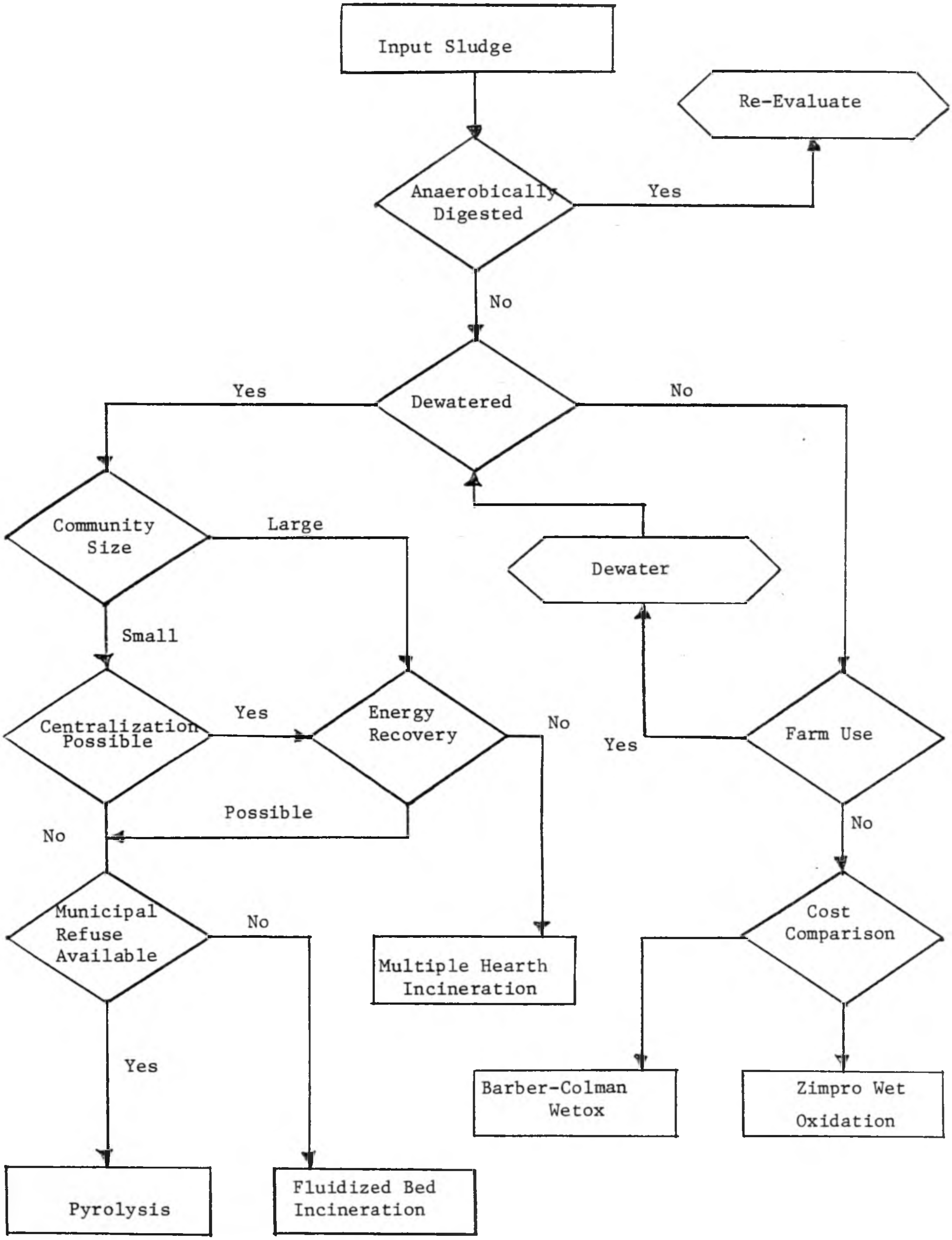


Figure 8.5 Combustion Pathways

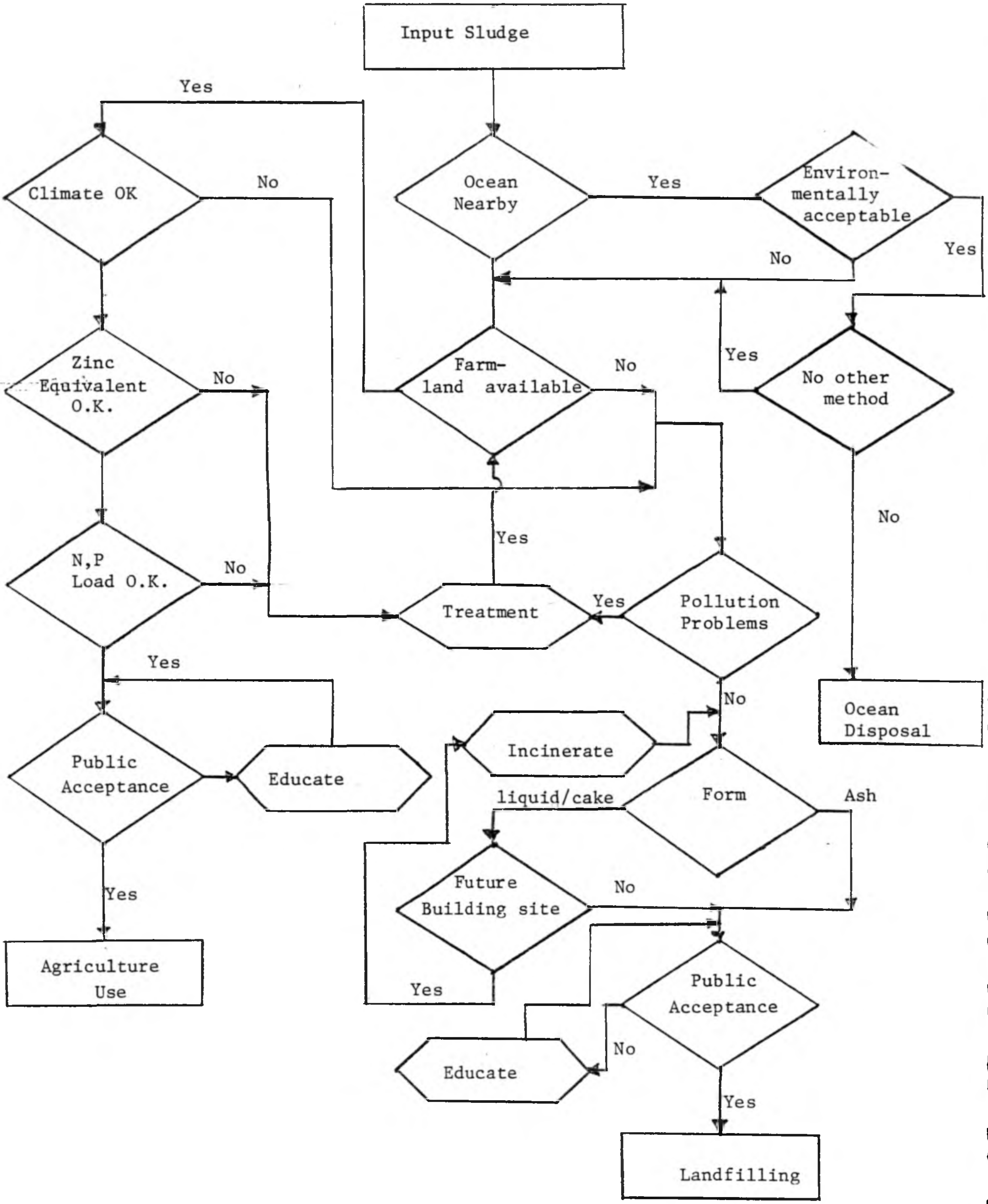


Figure 8.6 Ultimate Disposal Pathways

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