TECHNICAL REPORT NUMBER 18

STATE OF THE ART OF WATER POLLUTION CONTROL IN SOUTHEASTERN WISCONSIN

volume two

SLUDGE MANAGEMENT

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Special acknowledgement is due Lyman F. Wible, P.E., SEWRPC Water Quality Program Coordinator, and Robert P. Biebel, P.E., SEWRPC Sanitary Engineer, for their contributions to this report.

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TECHNICAL REPORT
NUMBER 18

STATE OF THE ART OF WATER POLLUTION CONTROL IN SOUTHEASTERN WISCONSIN

Volume Two

SLUDGE MANAGEMENT

Prepared by Stanley Consultants, Inc.,
for the
Southeastern Wisconsin Regional Planning Commission
P. O. Box 769
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916 N. East Avenue
Waukesha, Wisconsin 53186

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August 1977

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SOUTHEASTERN WISCONSIN REGIONAL PLANNING COMMISSION

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August 26, 1977

STATEMENT OF EXECUTIVE DIRECTOR

Pursuant to the provisions of Section 208 of the Federal Water Pollution Control Act as amended, the Southeastern Wisconsin Regional Planning Commission on July 1, 1975, undertook an areawide water quality management planning program. The objectives of this program are: to determine current stream and lake water quality conditions within the Region; to compare these conditions against established water use objectives and supporting water quality standards; to explore alternative means of meeting those objectives and standards through the abatement, as necessary, of both point and diffuse sources of water pollution; and to recommend the most cost-effective means of meeting the established objectives and standards over time. The formulation of sound recommendations for the abatement of water pollution and the attainment of water use objectives requires, among other things, definitive knowledge of the state of the art of the technology of wastewater treatment and disposal. If the areawide water quality management plan is to be sound and practical, it must seek to apply properly, as necessary, the best available wastewater treatment technology and avoid the proposed application of outmoded, as well as of unsound, unreliable, or unsafe practices.

To assure that the areawide water quality management plan would be founded on a sound technical basis, the Commission retained a consulting engineering firm—Stanley Consultants, Inc.—to conduct a review of the state of the art of water quality management. The study was intended to provide definitive data on the applicability, effectiveness, reliability, and cost of the various techniques currently available for the treatment of sanitary and industrial wastewaters, urban storm water runoff, rural storm water runoff, and the residual solids—or sludges—resulting from the treatment of these wastewaters.

The findings of this review of the state of the art are presented in a four-volume report. This, the second volume, presents the state of the art of wastewater sludge management. The information contained in this volume is required in the areawide water quality management planning effort to assure that the ultimate disposal of the pollutants removed from wastewater is done in a sound manner; the information is particularly important to that effort for the following four reasons: First, there are serious potential hazards to the environment attendant to the improper disposal of wastewater sludges. Second, the cost of sludge handling and disposal may represent as much as one-half of the total cost of sewage treatment. Third, sludge management—inclusive of the processing, transportation, and disposal of these substances—can be energy intensive. Finally, there is an increasing public awareness and concern over the potential for recycling sludge to reclaim the energy, nutrients, organic matter, and moisture contained within it.

It is the hope of the Commission staff that, in addition to reflecting properly the current state of the art of wastewater sludge management, this volume will actually contribute to that state of the art by providing a concise presentation of the techniques involved; evaluating their application to water quality management within the Region; and presenting the technical information in a format which permits consideration of the costs of alternative means of achieving the applicable water use objectives for the lakes and streams of the Region.

Respectfully submitted,

Kurt W. Bauer
Executive Director

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November 30, 1976

Southeastern Wisconsin Regional
Planning Commission
916 N. East Avenue
Old Courthouse
Waukesha, Wisconsin 53186

Attention: Mr. Kurt W. Bauer, Executive Director

Gentlemen:

Re: State of the Art Studies
208 Water Quality Management
Planning Program

We are pleased to submit our final draft report entitled "Sludge Treatment and Disposal Alternatives and Cost Information." We trust that you will find it to be a useful tool in the development and analysis of sludge and residue disposal alternatives in your region.

This final draft report incorporates comments received on our October 8, 1976, preliminary draft submittal.

Should you have any questions during your use of this report, please feel free to call us.

Sincerely,

STANLEY CONSULTANTS, INC.

RG Fritchie

R. G. Fritchie, P.E.
Project Manager

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Chapter I

INTRODUCTION

GENERAL

This report describes the state of the art of sludge processing and disposal applicable to the Southeastern Wisconsin Region (see Map 1). The types of sludge considered include sludge from wastewater treatment facilities, water treatment facilities, and septage from the many septic systems and holding tanks used by residents in the Region. Most sludges consist of materials removed from water, both at water treatment plants, to produce potable water, and at wastewater treatment facilities, to produce an effluent suitable for discharge. Also included in the sludges are the chemicals and/or biological solids which are integral parts of the treatment processes.

The disposal of sludges constitutes a sizable problem for the Region. A majority of the sludge generated in the Region is from wastewater treatment facilities, and options for these facilities are emphasized herein. New environmental control regulations have made certain conventional practices for sludge disposal unacceptable. Increased awareness of the environmental consequences of improper sludge disposal has intensified the need for improved regional planning, engineering, and implementation of residue processing and disposal systems. Sludge management alternatives can vary from systems that provide environmentally acceptable ultimate sludge disposal to systems which recover and reuse the components of sludges for environmentally beneficial purposes. This report presents information that can be used in the development of alternative plans for the Region.

For the largest wastewater treatment facilities in the Region, specifically the South Shore and Jones Island wastewater treatment plants of the Milwaukee Metropolitan Sewerage District, it should be noted that the development of specific detailed facilities plans will be necessary to confirm and refine information contained herein. This would also be true for large regional sludge handling facilities, should such systems show potential application in subsequent investigations in the Region.

SCOPE

The specific scope of this investigation includes:

1. Evaluation of alternative treatment and disposal processes for sludges generated by wastewater treatment facilities; water treatment facilities; and privately owned septic tank systems.

2. For each process identified, development of:

   a. Cost curves relating construction and operating costs to suitable design parameters.

   b. Information on energy, chemical, and manpower requirements of the process.

   c. Information on reliability, economic life, and other noncost selection factors.

3. Identification of technical and regulatory parameters, including land suitability factors, for ultimate disposal of residual waste after treatment.

4. Development of sludge treatment schematics for potential application to the sludges generated in the Region.

5. Evaluation of alternative methods of transporting sludges from the point of sludge generation to the point of sludge processing and/or ultimate disposal or reuse.

STUDY AREA

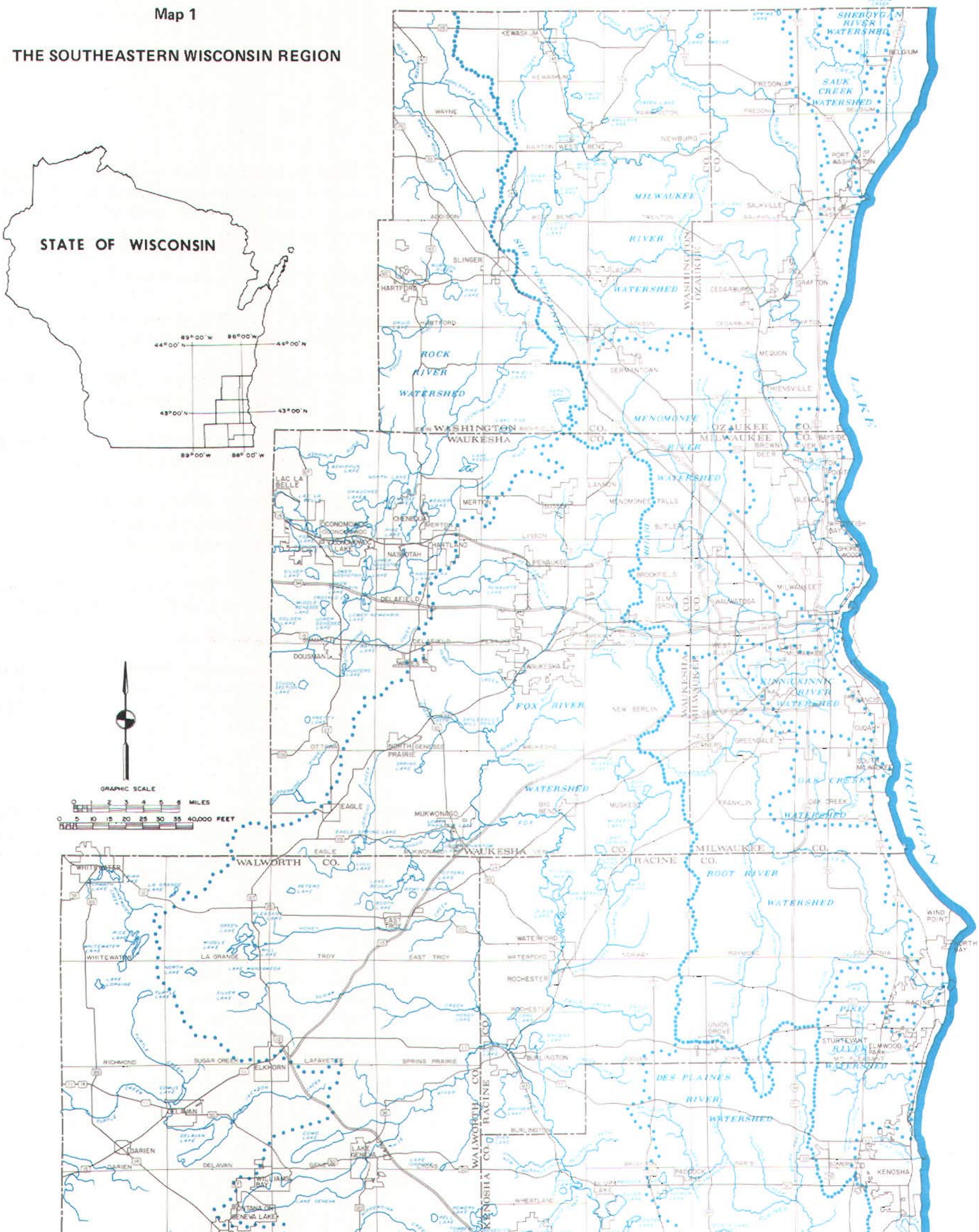
Treatment processes, schematics, and cost formation have been developed for application in the Southeastern Wisconsin Region including Kenosha, Milwaukee, Ozaukee, Racine, Walworth, Washington, and Waukesha Counties (see Map 1).

Appendices

Included as appendices in this report are Appendix A, containing full references used; Appendix B, showing cost curves for conventional processes; Appendix C, giving characteristics of wastewater treatment facility sludges; Appendix D, showing unit processes used in municipal wastewater treatment facilities in the Region, and Appendix E, a list of definitions of terms used in the report.

Map 1

THE SOUTHEASTERN WISCONSIN REGION



Source: SEWRPC.

Chapter II

QUANTITIES AND CHARACTERISTICS OF SLUDGES

INTRODUCTION

This chapter presents information on raw sludge quantities and characteristics that may result from various water or wastewater treatment processes. The quantities and characteristics of the raw sludges will be altered by the sludge processing and disposal practices discussed in subsequent chapters of this report.

WASTEWATER TREATMENT SLUDGES

Solids generated in wastewater treatment consist of materials removed during treatment, materials generated by the treatment process, and materials added to the liquid treatment system to obtain desired levels of treatment. In conventional liquid treatment schematics developed for the Region,[1] these materials consist of:

1. Screenings, grit, and skimmings removed in grit chambers and bar racks used in pretreatment.

2. Sludge and skimmings removed in primary clarifiers (primary sludges).

3. Biological solids (secondary sludges) generated in trickling filters, rotating biological contactors, or activated sludge systems used for removal of organics or nitrogen conversion. These sludges are removed by clarifiers, and may be removed in increased quantities by the addition of polymers and/or other chemicals.

4. Chemical solids generated by use of iron or aluminum salts for phosphorus precipitation, usually removed with other solids in primary or secondary clarifiers. As discussed in the above reference, lime precipitation may be required to meet future limits on phosphorus; the resultant lime sludge could be handled similarly to water softening lime sludge.

Processes detailed in the remaining chapters of this report for handling of these sludges, alone or in combinations, accomplish one or more of the following functions:

1. Reduce the volume of sludge to be disposed of by reducing the water content.

2. Destroy all or part of the organic or volatile portion of the sludge solids.

3. Dispose of the remaining solids and/or ash in an environmentally acceptable manner.

Typical solids contents and quantities of wastewater treatment sludges removed from primary or final clarifiers are presented in Table 1. In addition, pretreatment facilities (bar racks, grit chambers, coarse screens) usually remove from three to 10 cubic feet of debris (rags, grit, rocks) from each million gallons treated.

The chemical characteristics of sludges from treatment of domestic wastewater vary widely. Even daily variations are significant at a given facility. The range of values encountered requires individual assessment to accurately characterize each sludge. Comparative characteristics of raw sludge are not readily available, although numerous references list digested sludge characteristics. In addition, limited data on characteristics of sludges from wastewater treatment facilities in the Region are available at this time. Table 2 presents a range of values for chemical characteristics of digested, combined primary and secondary sludges. The values shown in Table 2 were developed by analyzing data presented in various references as well as available data from wastewater treatment plants in the Region. A more detailed analysis of sludge characteristics is presented in Appendix C.

Table 2 also presents a representative value for each characteristic. These representative values are not necessarily for any particular facility, but are simply indicators of expected characteristics within the range of values presented that are felt to be representative for the majority of existing wastewater treatment facilities in the Region. The wide range of values indicates the relative difficulty and inherent inaccuracy of predicting an average value.

The "typical" values represent expected characteristics from secondary treatment of a predominantly domestic wastewater with minor industrial contributions. From a chemical standpoint, there is little difference between treatment plant sludges (activated sludge, trickling filter, or bio-disc plants) produced when treating a given domestic wastewater. Adding aluminum or iron salts to the primary clarifiers or activated sludge aeration tank for chemical precipitation of phosphorus could increase phosphorus levels in the sludge to 4 to 5 percent. Also, alum addition could increase the aluminum concentration to 20,000 milligrams per dry kilogram (mg/dry kg), and iron salt addition could increase iron concentrations to 40,000 mg/dry kg. If major industrial dischargers or industries discharging high concentrations of heavy metals are present, the sludge would be expected to have higher heavy metal contents than those shown in Table 2. Especially with recent federal emphasis on this practice, pretreatment requirements for industrial dischargers can

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[1] *Stanley Consultants for the Southeastern Wisconsin Regional Planning Commission, Point Sources, July 1977.*

Table 1

WASTEWATER TREATMENT PLANT SLUDGE QUANTITIES

Type of Sludge	Dry Solids Content (percent)	Dry Solids Quantity (lb/mg of wastewater)
Primary Clarifier	2-6	790-1,250
Primary + Iron Salts	1-4.5	a
Primary + Aluminum Salts	0.4-2	a
Trickling Filter and Rotating Biological Contactors	3-7	475- 650
Activated Sludge	0.5-1.5	720-1,200
Combined Primary and Trickling Filter	3-6	b
Combined Primary and Activated Sludge	1-2.5	b

[a] *Quantity of sludge solids generated depends on wastewater characteristics and chemical dosage as well as on physical operating parameters.*

[b] *Quantity is sum of solids from primary and secondary systems.*

Source: U. S. Environmental Protection Agency, Stanley Consultants, and Metcalf and Eddy, Inc.

Table 2

CHEMICAL CHARACTERISTICS OF DIGESTED WASTEWATER TREATMENT PLANT SLUDGE

Major Constituents	Reported Range (percent of dry solids)	Typical (percent of dry solids)
Volatile Solids	30-75	40.00
Total Nitrogen	1.6- 6.0	3.50
Ammonia (as N)	0.02- 3.1	1.50
Phosphorus (as P)	0.4- 6.6	2.00
Potassium (as K)	0.06- 3.9	0.25
Calcium	0.2-18	4.00
Magnesium	0.05- 1.4	0.90
Sodium	0.1- 5.4	1.00
Heavy Metals	(mg/kg dry solids)	(mg/kg dry solids)
Aluminum	3,600-51,200	6,000
Iron	1,600-82,800	10,000
Zinc	500-28,400	2,000
Copper	100-17,000	700
Nickel	10- 8,000	100
Cadmium	4- 2,000	15
Lead	15-26,000	500
Chromium	60-32,000	900
Mercury	0.1-56	5

Source: Stanley Consultants.

be expected to reduce the heavy metals content of sludges to acceptable levels, although there may be many other sources of these metals in the wastewater (water supply, water distribution piping corrosion, household products). Raw sludges can be expected to have higher levels of volatile solids and nitrogen in different forms than digested sludges. Values in Table 2 should be adjusted accordingly.

Biologically, wastewater sludge contains an unpredictable mixture of bacteria, molds and yeasts, protozoa, crustaceans, viruses, and rotifers.[2] The mixture changes as the wastewater characteristics and the treatment plant opera-

[2] *P. A. Vesilind, Treatment and Disposal of Wastewater Sludges, 1974.*

tion change. Pathogenic organisms are concentrated in primary sludge, but are also present in secondary sludges. Table 3 presents reported bacteria levels for various wastewater treatment sludges at different stages of treatment. Recent data[3] indicate that most pathogens (viruses, bacteria, protozoa, and intestinal worms) are significantly reduced in sludge digestion operations.

SEPTAGE SLUDGES

Septage is the sludge periodically removed from septic tanks. Removal is recommended to be accomplished at approximately two- to three-year intervals. Reported characteristics of septage are presented in Table 4. Typical quantities of septage from a well-operating septic tank are from 0.02 to 0.08 pounds dry solids/capita/day.[4] Approximately 1 gallon of septage containing 0.2 to 0.8 pounds of dry solids is produced per 1,000 gallons of wastewater treated.[5] Characteristics of septage, like wastewater treatment sludges, can be expected to vary widely.

[3] *Wisconsin Department of Natural Resources, Guidelines for the Application of Wastewater Sludge to Agricultural Land in Wisconsin, Technical Bulletin No. 88, 1975.*

[4] *Metcalf and Eddy, Inc., Wastewater Engineering, 1972 and T. Viraraghavan "Septic Tank Efficiency," Journal of the Environmental Engineering Division, ASCE, April 1976.*

[5] *Engineering Science, Inc., for the U. S. Environmental Protection Agency, Sludge Processing, Transportation, and Disposal/Resource Recovery: A Planning Perspective, WPD 12-75-01, December 1975.*

WATER TREATMENT PLANT SLUDGES

Quantities and characteristics of sludges from water treatment, like those from wastewater treatment, are a function of the liquid treatment processes used and chemicals used in treatment.

Alum Coagulation Sludges

Alum coagulation sludges constitute the greatest quantity of water treatment plant sludges to be handled in the Region. These sludges are composed of aluminum

Table 4

CHARACTERISTICS OF SEPTAGE

Parameter	Typical Values
pH (units)	6.9
Total Solids (percent)	4
Volatile Solids (percent of total solids)	70
Oil and Grease (mg/l)	9,600
BOD (mg/l)	7,000
COD, total (mg/l)	60,000
COD, soluble (mg/l)	3,500
Nitrogen, total (mg/l)	650
Nitrogen, NH_3 (mg/l)	120
Phosphorus, total (mg/l)	210
Heavy Metals (mg/l)	
Iron	160
Manganese	5
Zinc	62
Cadmium	0.2
Nickel	1
Mercury	0.02

Source: Adapted from data from W. A. Feige et al and W. J. Jewell and R. Swan, eds., and local data.

Table 3

BACTERIA IN WASTEWATER TREATMENT PLANT SLUDGE

Sludge Type	Number (organisms/100 ml)		
	Fecal Coliforms ($\times 10^6$)	Salmonella	Pseudomonas
Raw Primary	11.40	460	46,000
Trickling Filter	11.50	93	110,000
Waste Activated Sludge	2.80	74	1,100
Anaerobic Digested Primary	0.39	29	34
Aerobic Digested Waste Activated Sludge	0.66	150	100,000
Anaerobic Digested Waste Activated Sludge	0.32	7.3	1,000

Source: Municipal Sludge Management and Disposal.

hydroxide and entrained particulate matter removed from the raw water during the coagulation, flocculation, and sedimentation process. The sludge is gelatinous in nature and not readily dewatered. Total solids percentage ranges from 0.1 to 2.0. Seventy-five to 90 percent of the total solids are turbidity-causing particles or other suspended materials, and 20 to 35 percent of the total solids are volatile.[6] Unless the raw water source contains an unusually large amount of organic matter, the sludge is relatively stable and is sometimes allowed to accumulate for several weeks or months before being discharged from the sedimentation basin. Quantity of sludge produced ranges from 100 to 600 pounds of dry solids per million gallons of water treated.

Chemical Precipitation Softening Sludges

Chemical precipitation softening sludges range from 2 to 30 percent solids. Eighty-five to 90 percent of the solids are calcium carbonate.[7] The remaining solids are primarily magnesium hydroxide. The sludge is non-gelatinous and dewaters readily. Approximately 2.75 pounds of dry sludge solids result from each pound of quicklime added to the water being treated.[8]

Filter Backwash Residues

Filter backwash waters contain small amounts of solids in comparison to coagulation and softening sludges. Backwash waters from filtration plants employing alum coagulation contain only about 0.01 to 0.04 percent solids, while backwash waters from plants removing iron and manganese usually contain about 0.14 percent solids.[9] Approximately one-third of the total solids is volatile. Total backwash flow usually amounts to 2 to 5 percent of the water filtered.[10]

Ion-Exchange Regeneration Brines

Spent brines from the regeneration of ion-exchange units used for water softening contain up to 35,000 milligrams per liter (mg/l) dissolved solids. Chloride concentrations range up to 22,000 mg/l.[11] There are almost no suspended solids in the brine. Brine water volume ranges from 3 to 10 percent of the total water softened.[12]

INDUSTRIAL SLUDGES

Industrial sludges are waste solids/liquid suspensions resulting from either industrial processing or wastewater treatment operations (including pretreatment prior to discharge to municipal sewers). Most of these residues can be roughly categorized as organic sludges, chemical sludges, or metal sludges. A detailed study of industrial sludge quantities and characteristics is not included in the scope of this investigation; however, a brief qualitative description is as follows:

1. Organic sludges: This category includes sludges from food processing industries and from paper and allied products industries. Sludge is often produced in large quantities, with high volatile contents and low levels of toxics.

2. Chemical sludges: This category includes residues from chemical, petrochemical, and allied products industries as well as oily sludges from metal fabricating industries. Sludge quantities are relatively small, but high oil concentrations of the sludges limit disposal possibilities.

3. Metal sludges: These sludges are generated by primary metals, metal fabricating, and metal treating (such as plating) industries. Sludges often are generated in large quantities and are high in metal salts and/or fines.

There are many treatment processes and handling and disposal options available for industrial sludges. Many of the unit operations involved are the same as for treatment of water, wastewater, and septage sludges considered in this report.

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[6] *Stanley Consultants for the Miami Conservancy District in Dayton, Ohio, Point Source Wastewater Controls, January 1976; American Water Works Association, Water Quality and Treatment, 1971; Stanley Consultants for the U. S. Air Force, AFM 85-13, Operation and Maintenance of Water Supply, Treatment, and Distribution Systems, review draft, April 9, 1976; American Water Works Association, Processing Water Treatment Plant Sludge, 1974; American Water Works Research Foundation, Disposal of Wastes From Water Treatment Plants, 1969; and A. E. Albrecht, "Disposal of Alum Sludges," Journal of the American Water Works Association, 64, January 1974.*

[7] *Stanley Consultants for the Miami Conservancy District in Dayton, Ohio, Point Source Wastewater Controls, January 1976; American Water Works Association, Water Quality and Treatment, 1971; Stanley Consultants for the U. S. Air Force, AFM 85-13, Operation and Maintenance of Water Supply, Treatment, and Distribution Systems, review draft, April 9, 1976; American Water Works Association, Processing Water Treatment Plant Sludge, 1974; American Water Works Research Foundation, Disposal of Wastes From Water Treatment Plants, 1969; and P. C. Singer, "Softener Sludge Disposal: What's Best?" Water and Wastes Engineering, 11, December 1974.*

[8] *Stanley Consultants, Operation and Maintenance of Water Supply, Treatment, and Distribution Systems, and C. W. Randall, et al, "Alum Recovery from Representative Water Treatment Plant Sludges," Journal of the American Water Works Association, 68, April 1976.*

[9] *Stanley Consultants, Point Source Wastewater Controls; American Water Works Association, Water Quality and Treatment; Stanley Consultants, Operation and Maintenance of Water Supply, Treatment, and Distribution Systems; American Water Works Association, Minimizing and Recycling Water Plant Sludge, 1973; and American Water Works Research Foundation, Disposal of Wastes From Water Treatment Plants.*

[10] *American Water Works Research Foundation, Disposal of Wastes From Water Treatment Plants.*

[11] *Ibid.*

[12] *American Water Works Association, Water Quality and Treatment.*

Chapter III

SLUDGE PROCESSING ALTERNATIVES

INTRODUCTION

Sludges generally must be processed to some degree in preparation for final disposal. Concentration and stabilization of sludge solids, pathogen destruction, volume reduction, and product recovery are typical operations performed. For any sludge disposal system, the disposal alternatives available determine which processing operations are required. Conversely, the processing operations which are feasible limit the disposal alternatives which can be used.

Residue processing alternatives which are technically feasible include the following unit operations:

1. Thickening
    a. Gravity
    b. Flotation
    c. Centrifuges and other mechanical thickeners
2. Stabilization
    a. Anaerobic digestion
    b. Aerobic digestion
    c. Chemical addition
    d. Heat treatment
    e. Composting
    f. Radiation
3. Conditioning
    a. Chemical addition
    b. Heat treatment
    c. Ash addition
    d. Elutriation
    e. Freezing
4. Dewatering
    a. Drying beds
    b. Drying lagoons
    c. Vacuum filters
    d. Pressure filters
    e. Centrifuges
    f. Other systems
5. Incineration
    a. Sludge—with or without heat recovery
    b. Refuse and sludge—with or without heat recovery
    c. Wet air oxidation
    d. Heat drying
    e. Pyrolysis
6. Product recovery
    a. Fertilizer or soil conditioner
    b. Animal feed supplements
    c. Fuels
    d. Coagulants and other conditioning chemicals
    e. Heavy metals and other trace elements
    f. Inert ash

These unit operations generally are arranged in combinations depending on the degree of treatment required. Each operation is not required for all processing combinations. These unit operations are performed, as necessary, in preparation for ultimate disposal. Ultimate disposal options are discussed in Chapter IV. A listing of the liquid treatment systems and sludge processing and ultimate disposal options currently used in municipal wastewater treatment facilities in the Region is provided in Appendix D.

A review of this information collected by the Commission indicates that sludge is handled, processed, utilized, and/or disposed of by the following unit operations:

Unit Process	Number of Wastewater Treatment Facilities in the Region Using the Unit Process
Processing	
Anaerobic Digestion	34
Aerobic Digestion	29
Vacuum Filters	3
Filter Presses	2
Centrifuges	1
Sand Drying Beds	30
Storage Lagoons	2
Heat Treatment Conditioning	1
Incineration	1
Ultimate Disposal	
Ash Disposal	1
Product Recovery (Milorganite)	1
Sanitary Landfill	7
Land Spreading	48
Contract Disposal	7

Thickening, sludge storage tanks, and chemical conditioning also are used in the Region for sludge processing. The remainder of this chapter discusses the technical capabilities for processing sludges through use of the various unit operations listed above and others appropriate for application in southeastern Wisconsin.

THICKENING

Thickening is generally one of the first steps in the sludge processing system following solids/liquid separation. The purpose of thickening is to remove free water from the sludge, thus reducing the volume and weight of liquid sludge to be handled in subsequent processes. Also, some dewatering processes require a minimum solids content of the input sludge. Figure 1 illustrates the amount of water removed from sludges with initially 1 percent and 5 percent solids, typical of primary and waste activated sludges, respectively. The water contained in the sludge is, of course, much more significant in the sludges with less than 15 to 20 percent solids. This water must be pumped, hauled, and otherwise handled by later operations. The relative amount of water per amount of solids increases significantly as initial solids quantity decreases. The optimum solids content from thickening operations is about 10 percent. Sludges containing solids concentrations much greater than 10 percent cannot be easily pumped. The main types of thickening operations are gravity, flotation, and mechanical devices (primarily centrifuges). Thickening processes are utilized successfully at several treatment plants in the Region.

Gravity Thickening

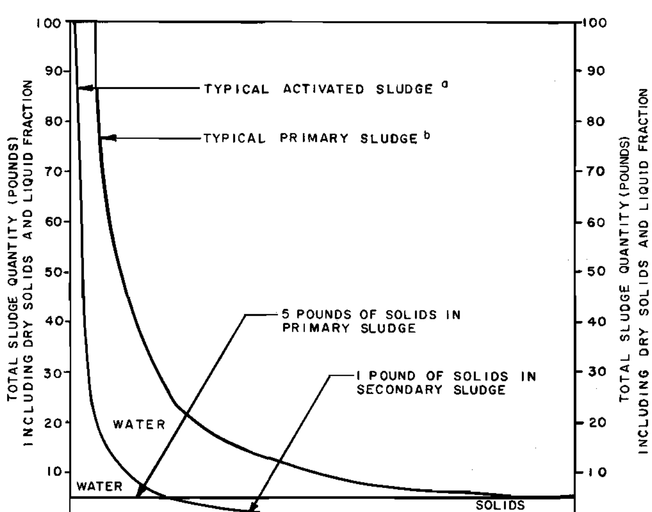
Gravity thickening is the most commonly used thickening technique and occurs to a certain extent in many water and wastewater treatment clarifiers. A gravity thickener is essentially a sedimentation basin designed to optimize sludge concentration, instead of liquid effluent clarity. The process is essentially a compression and compaction of sludge at the bottom of a basin by the weight of sludge and water above.

Sludge enters the thickener tank through baffles to reduce flow velocity and prevent short-circuiting. After solids/liquid separation occurs, the liquid leaves the tank over a weir, and the thickened solids are removed from the bottom of the tank through an outlet at the center. Tanks are typically circular and equipped with mechanical scrapers which move the sludge to an outlet while increasing sludge concentration by allowing upward flow of the released water.

Important factors affecting gravity thickener design include sludge characteristics, temperature, sludge blanket and liquid depths, detention time, and sludge blanket agitation. Thickener design often follows a design procedure based on settling test data to determine dry solids loading rates in terms of pounds per square foot of surface area per day (lb/sq ft/day). Increased solids detention time in the thickener results in higher sludge solids content up to the point that the sludge goes anaerobic and starts forming gas bubbles. Generally, 24 hours is the maximum detention time recommended. Typical performance of gravity thickeners is presented in Table 5.

Figure 1

TYPICAL RELATIONSHIP BETWEEN TOTAL SLUDGE QUALITY AND WATER CONTENT OF PRIMARY AND SECONDARY SLUDGES



a BASED ON 1 POUND OF DRY SOLIDS IN 100 POUNDS OF SECONDARY SLUDGE (1 PERCENT BY WEIGHT) TYPICAL OF WASTEWATER TREATMENT PLANT WASTE ACTIVATED SLUDGE

b BASED ON 5 POUNDS OF DRY SOLIDS IN 100 POUNDS OF PRIMARY SLUDGE (5 PERCENT BY WEIGHT) TYPICAL OF WASTEWATER TREATMENT PLANT PRIMARY SLUDGE

Source: Stanley Consultants.

Flotation Thickening

Flotation thickening is a well established process generally used to thicken waste activated sludge. The process consists of releasing small bubbles of air into the sludge mixture and allowing the bubbles to make contact with the sludge solids and float them to the surface for removal. Air is generally dissolved in recycled liquid effluent from the thickener, or a side stream such as primary or secondary effluent, at 40 to 80 pounds per square inch (psi) pressure. The pressurized recycle flow is then released into a flotation basin containing sludge at atmospheric pressure. At this lower pressure, the dissolved air comes out of solution, forming the air bubbles required for flotation.

Important design parameters include pressure, recycle flow ratio, feed solids concentration, detention time, air-to-solids ratio, type and characteristics of sludge, solids and hydraulic loading rates, and dosages of flocculating chemicals. Design of flotation thickeners is often based on bench- or pilot-scale studies to establish loading rates. Typical loading rates are 10 lb/sq ft/day for activated sludge or alum sludge and over 20 lb/sq ft/day for lime softening or wastewater treatment primary sludge. The use of coagulant aids such as polymers and/or alum can increase solids loading rates to the range of 40 to 50 lb/sq ft/day. Performance of flotation thickeners for biological sludges is comparable to, or slightly better than, that of gravity thickeners; especially for light flocculent sludges such as metal hydroxides or waste activated sludge.

Table 5

TYPICAL GRAVITY THICKENER PERFORMANCE

Type of Sludge	Solids Content Initial (percent)	Solids Content Thickened (percent)	Solids Loading Rate (pound/square feet/day)
Primary	2-6	8-12	20
Trickling Filter	3-6	7- 9	10
Activated Sludge	0.5-1.5	2.5- 4	5
Alum Coagulation Sludge	0.1-2	2- 5	5
Combined Primary and Trickling Filter	3-6	7-10	15
Combined Primary and Activated Sludge	1-2.5	5- 8	10

Source: Stanley Consultants.

Centrifuges and Other Mechanical Thickeners

Centrifuges of various types, moving screen concentrators, and rotating gravity thickeners[1] generally are capable of concentrating combined primary and biological sludges from an initial solids content in the range of 2 to 4 percent to a final content of 10 to 15 percent. These units are also capable of dewatering a thickened sludge of 8 to 10 percent solids to aout 15 to 20 percent solids. Further information about these processing systems is presented in the discussion of dewatering.

STABILIZATION

Stabilization of organic sludges is intended to make the sludge less odorous, less putrescible, and lower in pathogenic organisms. It is normally a necessary operation in any wastewater sludge treatment system, but not required for water plant sludges.

Sludge stabilization processes do not always have a well defined end point. A maximum concentration of pathogens can be measured, but to what extent the elimination of odorous, nuisance conditions must be carried is not universally accepted. Volatile solids content is generally used by regulatory agencies as a standard of sludge stability. This is based on the assumption that the volatile solids are also putrescible, odor-causing constituents. Other parameters that may be indicative of unstable sludge include high oxygen uptake rates and high BOD_5 of the solid fraction of the sludge. Stabilization processes include the following:

1. Anaerobic digestion

2. Aerobic digestion

3. Chemical addition

   a. Chlorine
   b. High pH
   c. Chemical solidification

4. Heat treatment

5. Composting

6. Radiation

Anaerobic Digestion

Anaerobic digestion is a process which biologically converts volatile organic solids to methane, carbon dioxide (CO_2), and water in a mixed, heated, oxygen-deficient digester. The gas formed during the process is typically 40 to 75 percent methane and can be burned to heat the digester and, in some cases, to provide energy for auxiliary treatment plant functions. A two-state system is often used in which digestion takes place in the first (heated, mixed) stage, and solids/liquid separation and storage take place in the second tank.

Historically, anaerobic digesters have had operational problems and frequent failures, primarily due to the process requirement for frequent monitoring and control. Current technology, better understanding of anaerobic processes, and operator training at treatment plants can minimize these problems. Toxic concentrations of heavy metals, surfactants, chlorinated hydrocarbons, or other materials can cause the failure of even a well operated digester by making it difficult to maintain biological activity. In certain situations, because of these factors, other stabilization methods (heat treatment, chemical) may be required in lieu of biological processes.

Anaerobic digester design is based on empirical loading parameters for detention time or volatile solids loading rate. Different loading parameters are used at specific temperatures because biological reaction rates, and the associated digestion process, are definite functions of

[1]*Stanley Consultants for Metropolitan Sewer Board for Twin Cities Area, Sludge Handling and Disposal, Phase 1—State-of-the-Art, Minneapolis and St. Paul, Minnesota, November 1972.*

temperature. Typical detention time for two-stage digestion is about 25 days, but design criteria should also consider the volatile solids loading on the digestor and other physical and chemical factors affecting digester operation such as degree of mixing and solids retention time, as well as peak period sludge loadings. Solids retention times (SRT) in the first digester must be greater than the regeneration time of the slowest growing gas-forming bacteria. Minimum SRT varies from 10 to 20 days depending on environmental factors such as temperature and pH.

The regulations of the Wisconsin Department of Natural Resources have established a maximum loading rate of 80 pounds of volatile solids per 1,000 cubic feet of volume per day in the active digestion units for completely mixed digestion units. Modifications to this loading rate may be considered provided calculations are submitted to justify the basis of design.

Volatile solids reductions in anaerobic digesters range from 40 to 60 percent. Conditions in the digester are not lethal to most pathogenic bacteria. However, the digester environment is such that most pathogens are not expected to reproduce themselves and, therefore, they die off naturally during the detention period.

Supernatant quality from the digesters is high in pollutants, as indicated in Table 6. This contributes a significant load when recycled through the wastewater treatment plant. Some plants could benefit from separate treatment of the recycle stream to reduce the impact on the treatment plant. Some may find it useful to return the supernatant during low loading periods at night or to otherwise equalize the impact on the treatment facility.

Digester gas containing methane is given off in the process of anaerobic digestion. The gas can be utilized as fuel for boilers and/or internal combustion engines to partially meet the treatment plant requirements for heating the digester contents, pumping sewage, operating boilers, building heating, and electricity generation.

Alum- or iron-phosphate sludges generally are not toxic to digester microorganisms, but the increase in nonvolatile solids and decrease in alkalinity have been reported to reduce digester performance slightly. Lime sludges in small quantities can assist in maintaining pH in the digester. Thickening of sludge to be anaerobically digested is usually advantageous, especially with dilute waste activated sludge. This minimizes the digester volume required, as well as the heating and mixing energy requirements.

Anaerobic digestion has been widely and successfully used in southeastern Wisconsin.

Aerobic Digestion

The aerobic digestion process biologically converts volatile organics to carbon dioxide and water in an aerated, aerobic reactor similar to an activated sludge aeration basin. The process is most commonly used to digest excess biological sludge from small activated sludge systems, using the same, or similar, aeration system as the activated sludge system. Design is based on recommended loading rates or bench/pilot studies. Detention times of 10 to 40 days and volatile solids loadings of 0.1 to 0.2 pound per cubic foot per day (lb/cu ft/day) are utilized. Low temperatures significantly decrease biological reaction rates, requiring longer detention times for adequate stabilization. In addition, the percent solids, sludge storage requirements, degree of volatile solids reduction and peak period sludge loading rates are factors affecting the size of facilities.

Table 6

ANAEROBIC DIGESTER SUPERNATANT CHARACTERISTICS

Parameter	Concentration (mg/l) in Digester Supernatant
Suspended Solids. . . .	500-15,000
BOD_5	500-10,000
COD	2,000-30,000
Ammonia.	400- 1,000
Phosphorus	100- 1,000

Source: Stanley Consultants.

Supernatant from aerobic digesters is significantly lower in oxygen-demanding constituents than that from anaerobic digesters, and is generally highly nitrified. Sludge stabilization is similar to that obtained by anaerobic digestion. Proprietary processes are available to use pure oxygen to increase the rate of biological reaction. The process is energy intensive when compared to anaerobic digestion, but has also been a reliable and popular process for sludge stabilization in the Region.

Chemical Stabilization

A commercially available process uses high dosages of chlorine (about 2,000 mg/l) at low pH to oxidize and stabilize sludge.[2] The sludge dewaters well and is free of pathogens; however, phosphates are redissolved and chlorinated byproducts (chloramines and chlorinated hydrocarbons) are formed.[3] At the present time, chlorine oxidation is not widely used and may be even more limited in the future.

Lime added to sludge to raise the pH to a range of 11 to 12 has been used as a stabilization process in a few instances. The pH must be maintained above 12 for a period of three hours in order to kill pathogens.[4]

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[2] *P. A. Vesilind, Treatment and Disposal of Wastewater Sludges, 1974.*

[3] *BIF Purifax Technical Bulletin, PFX 1. 21-2, 1972 and U. S. Environmental Protection Agency, Process Design Manual for Sludge Treatment and Disposal, October 1974.*

[4] *U. S. Environmental Protection Agency, "Municipal Sludge Management—Environmental Factors," Federal Register, 41 (108) June 3, 1976.*

Volatile solids are not permanently stabilized, and odors can occur if pH is allowed to decrease. Increased solids quantities, uncertain performance, and lack of regulatory agency approval have limited present usage.

Commercially available processes are being marketed to physically solidify the sludge in a rigid polymer capsule, typically of silicone materials. Although the processes are relatively new, preliminary results indicate that the sludge is permanently solidified to a dirt-like material which has good bearing strength and resists leaching.[5] Chemical stabilization is not a currently utilized process for the Region.

Heat Treatment

Heat treatment at temperatures of 300° to 500°F and pressures up to 200 to 400 psi for a period of 30 minutes has been shown to destroy pathogens (pasteurization) and break down the sludge biological cells and colloidal gels, releasing bound water as well as nutrients. The resultant sludge is relatively inert and easily thickened and dewatered. A variation of this process, wet air oxidation, generally requiring much higher pressures (1,000 to 1,750 psi), is a wet incineration process of burning the volatile solids to a gaseous state and is discussed as wet oxidation under the discussion below of incineration and similar processes.

Although an established process since 1900 and recently utilized at several installations, there are limiting factors on heat treatment usage: namely, economics, energy usage, difficulties in treating the recycled cooking liquor, and operational problems with the high temperature, high pressure, and equipment and odor problems. The cooking liquor from the process is extremely high in soluble pollutants, as shown below, and represents a significant portion of the loading (often 30 to 50 percent) to the wastewater treatment plant aerations system if recycled:[6]

Parameter	Concentration Range (mg/l) in Cooking Liquor
BOD_5	5,000-15,000
COD	10,000-30,000
Ammonia	500-700
Phosphorus	150-200

Separate side stream treatment units for the cooking liquor have been proposed involving long-term aeration and activated carbon adsorption due to the unknown characteristics of the organic compounds released in biological cell destruction that occurs in the process.[7] In addition to liquor treatment, it is often necessary to provide odor control for the process and subsequent sludge handling operations.[8] Heat treatment may be a viable option if (a) characteristics of the sludge make it unsuited to biological stabilization, and (b) the system is part of a heat treatment-dewatering-incineration (pyrolysis) scheme where total system economies may make the process attractive.

There are no heat treatment stabilization systems located in the Region; however, there are several relatively new units installed within the State of Wisconsin at treatment plants located in Green Bay, Marinette, and Oshkosh. Although the operating experience of these units has generally been limited, the operations have been reported as generally satisfactory.

Composting

Raw sludge composting is practiced in other countries but has not been widely used in the Region or elsewhere in the U.S. due to economics and public resistance to odors and other environmental problems. Systems often involve composting the sludge mixed with shredded or cubed municipal refuse, wood chips, or bark. In 1976, the Milwaukee Metropolitan Sewerage District conducted experiments with this technique at the South Shore sewage treatment plant. The findings were encouraging enough for additional experimental studies to be planned. Recently installed, full-scale operations have utilized a forced draft aeration system to control odors and increase the composting reaction rate at other sites in the United States.

Sludge composting systems have suffered bad publicity due to recent failures of systems composting municipal refuse. Sludge composting systems are currently operating at the Cities of Beltsville, Maryland; Bangor, Maine; and Carson, California. The City of Beltsville system is a 10 ton per day demonstration project of USDA and the Maryland Environmental Service. The City of Bangor operates a 10 ton per day system producing compost for use by the City street department. The City of Carson sells about 150 tons of composted sludge per day to a commercial processor who dries and bags the product for sale to retailers in Southern California. This is the only reported instance of selling compost.[9]

Composting is essentially a decomposition of organic matter by aerobic, thermophilic organisms to produce stable end products. The high temperature (120° to

[5] *Management and Disposal of Residues from the Treatment of Industrial Wastewaters, Proceedings of the National Conference on Management and Disposal of Residues from the Treatment of Industrial Wastewaters, Washington, D. C., February 3-5, 1975.*

[6] *U. S. Environmental Protection Agency, Process Design Manual for Sludge Treatment and Disposal.*

[7] *R. Culp, "Heat Treatment—Total Costs," presented at the Wastewater Treatment and Reuse Seminar, South Lake Tahoe, October 28, 1976.*

[8] *Ibid.*

[9] *W. Ettlich, "Composting as an Alternative," presented at the Wastewater Treatment and Reuse Seminar, South Lake Tahoe, October 28, 1976.*

140°F) results from the heat of decomposition and is sufficient to kill pathogens in the sludge. The conventional composting process consists of the following steps:[10]

1. Mixing with shredded refuse or other material to achieve 45 to 65 percent water content.

2. Digestion in periodically turned windrows for four to six weeks or in forced draft-aerated piles for about two weeks.

3. Curing for four to six weeks for windrows or two weeks for aerated piles.

4. Finishing operations such as grinding, screening, fertilizer fortifying, and/or pelletizing.

Radiation

Studies have shown that sludge may be disinfected by irradiation with gamma rays. The treated sludge is reported to have improved dewatering characteristics.[11] The process is still at a very experimental stage. High energy electron bombardment is a similar experimental stage. High energy electron bombardment is a similar experimental process. These processes have not found application in the Region in the past.

CONDITIONING

Conditioning often occurs, to a certain extent, during stabilization. However, additional conditioning may be required to increase dewatered sludge cake solids content and improve capture of fine solids. The following processes are technically capable of providing various degrees of conditioning.

1. Chemical addition

   a. Organic polyelectrolytes (polymers)
   b. Metal salts

2. Heat treatment

3. Ash addition

4. Elutriation

5. Freezing

Chemical Conditioning

Chemical coagulant aids are added to improve the dewaterability of sludges. The chemicals traditionally used are aluminum or iron salts, although organic polymers have recently become increasingly popular. Lime is sometimes added, particularly with iron salts, to adjust pH and supply alkalinity. Waste pickle liquor from steel mills has been used in some cases as a low-cost source of iron salts. The metal salts and organic polymers increase particle agglomeration, allowing the solids to be separated from the liquid phase by the various dewatering operations. Conditioning increases the solids content of the dewatered sludge cake and, more importantly, decreases the amount of solids escaping in the filtrate. Simple jar tests and full-scale plant trials are the most commonly used method of evaluating conditioning chemicals and determining optimum dosages. Chemical conditioning is successfully utilized within the Region.

Heat Treatment

Thermal conditioning of wastewater sludges provides a high degree of conditioning by breaking down the gelatinous structure of the biological sludge. Stabilization (pasteurization) also occurs in the process. Dewaterability in mechanical or air-drying systems is improved. Often, better performance can be obtained with sludge dewatering facilities following heat treatment without using chemicals. As noted under the previous action under stabilization processes, there are several heat treatment facilities in operation within the State.

Ash Addition

Ash from both sludge incineration and power generation has been used as a precoat or added to sludge as a conditioner for mechanical dewatering in several instances. This has resulted in significantly improved operation when dewatering dilute, flocculant sludges in pressure filters or vacuum filters. Typical ash to sludge dry solids ratios are 1:3 to 1:1.[12] Disadvantages of ash addition include increased quantities of dry solids to dispose of, a possibility of redissolving trace elements from the ash into the sludge suspension, and different physical and chemical characteristics (e.g., percent volatile solids, and heavy metal content) which limit ultimate disposal of the dewatered sludge cake. Ash addition is utilized at the Brookfield sewage treatment plant and several other locations throughout the county.

Elutriation

Elutriation is a well-established, although not widely used, water washing process which leaches from the sludge constituents such as excess alkalinity, which consume large amounts of conditioning chemicals.[13] Ferric chloride requirements reportedly can be reduced 50 percent.[14] The process is normally a multistage, counter-

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[10] *E. Epstein, et al, "A Forced Aeration System for Composting Wastewater Sludge," Journal of the Water Pollution Control Federation, 48, April 1976.*

[11] *Stanley Consultants, Sludge Handling and Disposal, Phase I—State-of-the-Art.*

[12] *Vesilind, Treatment and Disposal of Wastewater Sludges and Stanley Consultants, Sludge Handling and Disposal, Phase 1—State-of-the-Art.*

[13] *Vesilind, Treatment and Disposal of Wastewater Sludges and W. J. Weber, Jr., Physicochemical Processes for Water Quality Control, 1972.*

[14] *Vesilind, Treatment and Disposal of Wastewater Sludges and R. S. Burd, by Dow Chemical for Federal Water Pollution Control Administration, Department of the Interior, A Study of Sludge Handling and Disposal, WP-20-4, May 1968.*

current operation with a water to sludge ratio of 2:1 to 3:1.[15] The elutriation tanks are typically sized at about 10 pounds dry solids per square foot per day.[16] A major problem at many elutriation facilities is treatment of the leachate, which is high in nutrients and fine solids. Recapture and disposal of the fine solids is expensive and difficult requiring large polymer dosages. Elutriation has not found application within the Region.

Freezing

Freezing of sludge, particularly gelatinous biological or metal hydroxide sludges, significantly improves dewaterability of the sludges. The dehydration that takes place with freezing alters the physical characteristics of the solids so that they retain less water when thawed. There are presently no full-scale mechanical sludge freezing operations in the U. S. although, in the northern latitudes, natural freeze/thaw frequently occurs in sludge lagoons and sand drying beds. The Milwaukee Metropolitan Sewerage District evaluated mechanical sludge freezing on a laboratory scale and concluded that the system was not cost-effective.[17] The process has not found application in the Region.

DEWATERING

The objective of dewatering is to reduce the free water content as well as the total volume of sludges in preparation for ultimate disposal techniques. The various disposal alternatives have specific requirements for maximum allowable water content; in addition, sludge transportation costs and the capacity of the disposal facility influence the degree of dewatering required. Dewatering operations may involve the following:

1. Drying beds
2. Drying lagoons
3. Vacuum filters
4. Pressure filters
5. Centrifuges
6. Other systems

Drying Beds

In the past, sand/gravel drying beds have been the most widely used sludge dewatering method, particularly at small plants.[18]

[15] *Ibid.*

[16] *Vesilind, Treatment and Disposal of Wastewater Sludges.*

[17] *Sewerage Commission of the City of Milwaukee for U. S. Environmental Protection Agency, Evaluation of Conditioning and Dewatering Sewage Sludge by Freezing, January 1971.*

[18] *Stanley Consultants, Sludge Handling and Disposal, Phase 1—State-of-the-Art.*

Sludge drying beds are generally constructed with four to nine inches of sand placed over eight to 18 inches of graded gravel or stone with an underdrain system located in the gravel or stone layer. An alternate type of sludge drying bed has been constructed with paved bottoms and limited drainage systems for dewatering the sludges.

The beds require substantial amounts of land, based on typical loading rates of 10 to 25 pounds dry solids per squre foot per year. Dewatering results from both drainage and evaporation. Since evaporation is adversely affected by rainfall and cold temperatures, drying beds are covered in some regions, reducing the required surface area by 25 to 30 percent.[19] The climate of the Southeastern Wisconsin Region (about 30 annual inches of precipitation, 28 annual inches of evaporation) would suggest that covered drying beds may be applicable. Sludge stabilization is required to minimize odors, and chemical conditioning has been shown to improve dewatering; thickening is not necessarily required. Drying times range from about two weeks for easily dewatered sludge during good weather to six months for difficult cases. In recent years new drying beds have not been frequently constructed, due to low land availability and increasing labor costs for removal of the dried sludge. Drying beds have been widely and successfully utilized throughout the Region.

Drying Lagoons

Drying lagoons may be described as deep drying beds in which dewatering occurs primarily by evaporation. Drainage to groundwater is usually sealed off rather quickly by an accumulation of solids along the base of the lagoon. The typical lagoon is 1.5 to 3 feet deep (NR 110 limits storage lagoon depth to 3 feet) and sized at 2 to 2.5 pounds dry solids per cubic foot per year.[20] After drying periods of six to 18 months, the dewatered sludge is removed with an end loader or similar equipment. In actual practice the sludge sometimes is left in the lagoon, in effect using the lagoon for ultimate disposal as well as dewatering. Stabilization is required for odor control, while thickening and conditioning are useful for reducing the required lagoon volume and improving dewatering. Cold or wet weather adversely affects the rate and extent of sludge dewatering in a lagoon. Lagoons have been widely used, particularly at small plants, although increased concern about groundwater pollution from seepage, as well as odors and other problems, have limited the number of new installations using lagoons. The use of lagoons which function principally as a sludge storage facility is also practiced within the Region. Sludge drying and/or storage lagoons are utilized successfully on a limited basis within the Region.

Vacuum Filters

Mechanical dewatering by rotary vacuum filtration has been widely used for water and wastewater sludges for many years. The first large-scale installation was

[19] *U. S. Environmental Protection Agency, Process Design Manual for Sludge Treatment and Disposal.*

[20] *Ibid.*

in Milwaukee during 1917.[21] The typical system is based on a large cylindrical drum, covered with filter cloth (or similar medium), rotating approximately 30 percent submerged in a trough of sludge. A vacuum is drawn through the drum, pulling sludge up around the cylindrical sides of the drum, and drawing free water from the sludge as the drum rotates. A new type of design feeds sludge onto the top of the drum, attempting to increase dewatering efficiency. Stabilization is required to control odors; thickening for volume reduction and chemical conditioning using ferric chloride and lime are standard practice for wastewater sludges. Vacuum filtration is established technology which is widely used, although future landfill limitations on minimum sludge solids content may not always be economically achievable. In the Region, vacuum filters are used successfully at the Milwaukee Jones Island and Racine wastewater treatment plants, although the Kewaskum wastewater treatment plant discontinued use of vacuum filtration due to operating problems.

For alum sludges, a variation of conventional vacuum filtration is rotary precoat vacuum filtration, in which a two- to four-inch thick layer of diatomaceous earth (or similar material) is applied around the outside of the drum. The precoat material captures fine particles which would pass through conventional filter cloth and does not become rapidly clogged by gelatinous sludges. A knife blade scrapes off a thin layer of precoat as the drum revolves, continually exposing a fresh filtering surface. Increased weight of dry solids in the sludge cake, as well as significantly higher operating costs, are disadvantages of this system.

Pressure Filters

Also called "filter presses," pressure filters have been used for dewatering in the U.S. since 1898.[22] In the Region, pressure filters are used at the Kenosha and Brookfield wastewater treatment plants. Pressure filters are generally capable of producing a drier dewatered sludge cake than any other mechanical process. A dryer cake has increasingly been required prior to disposal of sludges in landfills, a trend which has caused the use of filter presses to increase where landfill disposal is the only ultimate disposal option available. The dryer cake is also of benefit in incineration, pyrolysis, or wet air oxidation processes. Pressure filtration is a batch operation in which sludge is pumped into a filter, made up of a series of parallel plates held together in a frame; the high pressure (250 psi in one system, 100 in another) pumping squeezes the free water from the sludge, through porous media lining the plates, and out of the filter. The pump is then shut off, and the plates are separated as the filter frame expands, allowing the dewatered sludge cake to fall out from between the plates. Modern systems are automated reducing operator time for system operation. Chemical conditioning is cost-effective in most instances. Some plants, including Brookfield, have found that ash addition or precoating is desirable to increase solids capture and prevent filter blinding, while the units at Kenosha are operated incorporating chemical conditioning of the sludge, utilizing lime and ferric chloride but no ash addition or precoating.

Centrifuges

Centrifuges have been used to some extent to thicken or dewater sludges since the first U.S. installation in Milwaukee during 1920 to thicken activated sludge; however, the process has had general acceptance only since the mid-1950's.[23] The basic operating principle of centrifuges is the application of an artificial gravitational force by means of high speed rotation. This causes the sludge solids to separate from the liquid phase. In addition, solids fractions with different settling characteristics (size, density) will be removed separately by the centrifuge, which may allow recovery of relatively pure materials. Dewatering performance and costs are comparable with those for vacuum filtration. High operating costs for maintenance and conditioning chemicals (polymers) may be reduced in the future as equipment design improves. The City of Burlington has recently started operating a centrifuge operation in which the aerobically digested sludge is conditioned with polymers prior to dewatering in the centrifuge.

Other Systems

Several dewatering systems which are relatively new to the U.S. are capable of dewatering sludges to concentrations greater than that attainable by thickening but less than that produced by vacuum filters, centrifuges, or pressure filters. These include the following systems:

1. Rotating gravity concentrators
2. Belt-filter press or multiroll presses
3. Squeegee or capillary suction devices
4. Moving screen concentrators

The rotating gravity concentrator, as presently marketed in the U.S., consists of two separate rotating drum frames with a continuous filter cloth around both. Sludge is dewatered by gravity in the first cell. As the sludge forms a cake, it moves to the second cell where rolling of the cake vibrates out more water. Reported advantages of the rotating gravity concentrator include low capital and operating costs, small space requirements, and relatively low maintenance. Lack of data relative to long-term operation and performance and the low degree of dewatering are disadvantages. Chemical conditioning and stabilization are required pretreatment.

Belt filter presses or multiroll presses are similar systems of two endless belts with rollers on the inside. The sludge passes through the press between the two horizontal belts

[21] *Stanley Consultants, Sludge Handling and Disposal, Phase 1—State-of-the-Art.*

[22] *Ibid.*

[23] *Ibid.*

allowing the rollers to press the free water from the sludge. The belt filter press design attempts to remove additional water by adjusting the placement of the rollers. The belt filter press is relatively new to the U.S., but is used at numerous installations in Europe.[24] The multiroll press[25] has been used in a few full-scale units in the U.S. both units require stabilization and conditioning pretreatment.

The squeegee or capillary dewatering system is a horizontal screen with a roller to press water from the sludge.[26] The unique feature of this system, however, is a thick second belt which makes contact with the underside of the screen. This second belt provides a capillary action which draws the water out of the sludge. Following capillary dewatering the screen passes under a roller which squeezes more water from the sludge. Chemical conditioning is required for acceptable solids capture. The only installations of this sytem are pilot scale.[27]

Moving screen concentrators consist of two independent, endless, horizontal belts of filter cloth. The sludge flows onto the first belt, whiere gravity dewatering (draining) takes place until the slowly moving belt dumps the sludge onto the second belt. The second belt passes through several rollers which squeeze additional water from the sludge. Conditioning chemicals (polymers) are required. The system has low capital and operating costs, similar to the other systems yielding a low degree of dewatering. There are few reported installations using moving screen units in the U. S.[28] There are no known installations of any of the above-noted dewatering devices within the Region.

Incineration and Similar Processes

Incineration typically consists of the following three steps in order to stabilize, further dewater, and reduce the final volume of sludge for disposal.

1. Heating the sludge to 212°F.

2. Vaporizing the water from the sludge.

3. Burning the combustible fraction of the remaining sludge.

The similar processes of heat drying, pyrolysis, and wet air oxidation include at least one of the above steps.

[24] *U. S. Environmental Protection Agency, Process Design Manual for Sludge Treatment and Disposal.*

[25] *Stanley Consultants, Sludge Handling and Disposal, Phase 1—State-of-the-Art.*

[26] *Ibid.*

[27] *U. S. Environmental Protection Agency, Process Design Manual for Sludge Treatment and Disposal.*

[28] *Ibid.*

Water treatment plant sludges generally are not incinerated because stabilization is not required and more cost-effective methods of dewatering/volume reduction are possible. Incineration only reduces volatile solids; therefore, water treatment sludges (high in lime or alum) will realize little volume reduction.

INCINERATION OF WASTEWATER TREATMENT PLANT SLUDGES

Wastewater treatment plant sludge solids usually have a heating value of about 7,500 British thermal units per pound (Btu/lb) on a dry basis. This is sufficient heating capacity to dry the sludge if the solids content is about 15 percent or greater; however, auxiliary fuel must be burned to initially start combustion. Auxiliary heat input and additional dewatering would also be required to raise the combustion temperature high enough (1,350° to 1,400°F) to eliminate odors. The minimum solids content to sustain combustion at recommended temperatures is 25 to 35 percent, depending on the sludge heating value and incinerator operation, although higher percent solids may be required if volatile solids content is low due to addition of large quantities of conditioning chemicals. Incineration is not a method of final disposal, however, because the incinerator ash must still be disposed of by a cost-effective, environmentally sound method.

Sludge incineration is practiced at hundreds of full-scale facilities; however, new technologies and improvements on existing technology are constantly evolving to increase process efficiency or meet air pollution controls. Air emissions from sludge incinerators must not violate ambient air quality standards for EPA New Source Performance Standards for Sludge Incinerators (40 CFR 60). There are several different types of sludge incinerators, the most popular being the multiple-hearth type. Other types are rotary drum, fluidized bed, and atomized suspension.

Generally, the only energy recovery for sludge incinerators is some degree of recycle of the hot flue gas to preheat combustion air or sludge. Waterwall incinerators or other types of heat recovery boilers have not been common because of the small amount of excess heat generated. The City of Brookfield wastewater treatment plant utilizes incineration for sludge solids reduction.

Incineration of Sludge with Refuse

Sludge can be incinerated along with refuse in furnaces essentially designed for burning municipal refuse. Often these incinerators are equipped with waste heat recovery boilers. The material handling of the sludge must be considered and should develop a sludge which is well mixed or blended with the refuse to make as homogeneous a fuel as possible.

Milwaukee has recently built a plant to prepare refuse for burning with coal in power plant boilers. To be incinerated in this type of system, wastewater sludge probably would have to be dewatered to about 60 percent solids to provide heating value equivalent to refuse and to prevent excessive slagging.[29] A possible application of the system would be to dry the sludge with excess heat from the flue gases at the power plant. The dried sludge then could be utilized as a fuel along with the refuse and coal. The cost of transporting the sludge to the refuse processing facility or the power plant must be evaluated along with the drying system costs.

Wet Air Oxidation
Also called wet incineration or wet oxidation, wet air oxidation is a system in which organics are oxidized in an aqueous, aerobic, high pressure reactor. Typical operating temperatures are 300^{o} to $700^{o}F$ at pressures of 1,000 to 1,750 psi. The oxidized dredge dewaters readily by gravity or mechanical operators. Several full-scale plants of this type are operating, including a batch type unit installed in the early 1960's at the South Milwaukee wastewater treatment plant. Most of these units are reported to be experiencing problems with equipment operation and maintenance and treatment of recycled liquor.[30]

Heat Drying
Rapid heat drying of sludge is practiced in several U.S. installations, including the Milwaukee Jones Island plant where waste activated sludge is dried to produce the low grade fertilizer, Milorganite. Unless the dried sludge is to be sold for fertilizer or otherwise utilized, heat drying generally is not cost-effective because less expensive dewatering techniques are adequate for most disposal alternatives. Utilization of waste heat from power generation and other heat recovery, energy saving steps can significantly reduce operating costs.

Pyrolysis
As used in this report, pyrolysis refers to a type of process which applies heat and pressure to organic matter in an oxygen deficient atmosphere to render the hydrocarbons into a solid, liquid, and/or gaseous fuel. There are several different commercial pyrolysis systems available for sludge or sludge/refuse processing. A major positive consideration for utilizing pyrolysis is to have a firm use for the fuel product generated, helping to make the system cost-effective. System technology, although new, is sufficiently developed that several major cities (Minneapolis/St. Paul, Minnesota; Kansas City, Missouri; and Oakland, California) have conducted detailed investigations of pyrolysis systems for refuse and sludge disposal. The process has not been tested on a full-scale basis to date, and all existing facilities have been EPA-funded demonstration projects.

PRODUCT RECOVERY

In many cases, sludge from wastewater or water treatment plants contain materials which can be sold on the open market or utilized by public agencies (such as highway or park departments) if recovered in the proper form. In light of the recent increase in public involvement in recycling, a resource recovery approach is a very acceptable alternative from a public relations standpoint. It is also encouraged in the Federal Water Pollution Control Act Amendments of 1972. Regional supply and demand are critical, since transportation costs often make shipment to other areas prohibitive. The product does not necessarily have to be sold for a profit in order to be cost-effective. The product recovery system net cost need only be less than that for other disposal alternatives. A problem with using sludges, particularly wastewater sludges, for incorporation into marketable products is that the highly variable characteristics of the sludge make the conversion to a product with consistent quality very difficult. For marketing success, the public must be assured that a sludge derived product is safe and aesthetically acceptable. Products recovered or derived from sludge include the following:

1. Fertilizer or soil conditioner
2. Animal feed supplements
3. Fuels
4. Coagulants and other conditioning chemicals
5. Heavy metals and other trace elements
6. Inert ash

Fertilizer or Soil Conditioner
Sludge contains several materials which are beneficial soil additives, including organic matter (humus), nitrogen, phosphorus, potassium, and other trace elements. Although the fertilizer content of typical wastewater sludge is low compared with chemically compounded fertilizers, the humus content is highly beneficial as a soil conditioner; and the organic nature of the fertilizer allows a slow release of nutrients which is often beneficial. The nitrogen available in an organic fertilizer is in the organic form whereas the nitrogen utilized in chemical fertilizers is in the inorganic form. Conversion of the organic nitrogen into soil organics is a slow release process while a faster release process is experienced with the use of the inorganic nitrogen utilized in chemical fertilizers.

Composting of sludge or sludge mixed with refuse or woodchips, which has been attempted with mixed success in the U.S., is a method of stabilizing the sludge and producing a soil conditioner. Composting has been previously discussed as a stabilization process. Most composting installations have failed, generally because of an inability to market the final product; some installations, however, are still operating.[31]

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[29] *B. I. Loran, "Burn That Sludge," Water and Wastes Engineering, 12, October 1975.*

[30] *U. S. Environmental Protection Agency, Process Design Manual for Sludge Treatment and Disposal.*

[31] *E. Epstein, et al, "A Forced Aeration System for Composting Wastewater Sludge," Journal of the Water Pollution Control Federation, 48, April 1976.*

Heat drying of sludge to produce an organic fertilizer such as Milorganite has been discussed. It is economically feasible for new systems only when the fertilizer has a reasonably established and firm market.

Marketing of dried sludge traditionally has been succesful, while compost and other soil conditioners often must be given away. This is generally because of the higher nutrient content of the dried sludge. Street and highway departments, private citizens, and gardeners are major users of soil conditioners and dried sludge.

Animal Feed Supplements

All reported work on utilizing sludge or sludge-derived materials for animal feed supplements has been on an experimental basis. Vitamin B_{12} extraction from sludge has been evaluated at both Milwaukee and Chicago and found to be technically feasible. A number of investigations have experimented with feeding dried sludge to animals as a low fraction of the normal feed ration with no adverse effects. Researchers have also grown yeast cells on carbohydrate-fortified sludges, the yeast was then extracted and used as a high protein feed for animals. In most cases, the process appeared to be technically feasible, but the marketing of the final product was uncertain.

Fuels

Sludge reduction by pyrolysis processes can yield a solid, liquid, and/or gaseous fuel as discussed previously. Generally the fuel is of relatively low quality, with low heating value and large amounts of impurities. However, the fuels can be utilized in specially designed systems if transportation costs are not prohibitive.

The methane gas derived from anaerobic digestion of sludges (representing six to seven million BTU per million gallons of wastewater treated) has been successfully used in treatment facilities for many years. The excess gas is typically scrubbed, compressed, and stored prior to burning in an internal combustion engine. This engine can be used for several purposes (run an electrical generator, air blower, water pump) in the treatment facility.[32]

Coagulants and Other Conditioning Chemicals Recovery

Lime sludges, from tertiary wastewater treatment phosphorus removal or lime water softening processes, can be thermally recalcined to recover calcium oxide (quicklime) which is then slaked with water to form calcium hydroxide (hydrated lime). Coagulants, such as aluminum or iron salts and magnesium carbonate, can be recovered from water treatment sludges by redissolving from the precipitated solids. Generally, chemical recovery processes are economically feasible only for larger operations, although local chemical availability and prices are also important.

Lime recovery by recalcination consists of mechanically dewatering the calcium carbonate sludge, followed by incineration in rotary kilns to drive off the carbon dioxide, yielding calcium oxide. The flue gas, 15 to 20 percent carbon dioxide, is often used to recarbonate the wastewater stream. Buildup of ash in the recycled lime can become a problem, particularly if the raw water is high in turbidity or soluble metals such as aluminum, magnesium, or iron which are precipitated at high pH. Centrifugation of the lime sludge allows the lighter solids (metal precipitates and turbidity) to be separated from the heavier calcium carbonate. The stream of lighter solids can then be treated to recover other materials such as magnesium, if desired. Recalcination is currently practiced regularly at a number of U.S. installations.

Magnesium hydroxide has been shown to be a coagulant favorably comparable to alum; therefore, it is sometimes desirable, when present, to recover it in lime sludge at high concentrations. One approach is centrifugation as described above. Another system redissolves the magnesium from the lime sludge as a soluble carbonate by bubbling CO_2 from the recalcining furnace through the sludge. This process is currently being practiced in Dayton, Ohio, along with recalcination, and at Melbourne, Florida.

Alum and iron sludges may be reclaimed by treatment with sulfuric acid. Thickened alum sludge reacts with sulfuric acid at a pH near 2.0 producing an aluminum sulfate solution. Suspended matter is separated from the solution by settling or vacuum filtration. Alum recovery ranges from 60 to 90 percent, depending on the method of solids separation used. Alum reclamation reduces the volume of sludge for ultimate disposal by up to 80 percent. Iron and manganese present in the alum sludge in precipitated form will be concentrated in the recycled coagulant and may accumulate to undesirable levels. Adsorbed, colored organic material may also be concentrated in the recycled alum. This type of process has been practiced at several plants in the U.S. for alum recovery, but iron salt recovery has not been attempted on a large scale.

Heavy Metals and Other Trace Elements

Heavy metals present in industrial sludge can be recovered by means of the process described above for alum. In addition, ion exchange and electro-deposition processes have been commercially developed to recover valuable metals.

Inert Ash

The ash from incineration of sludge could be used to form building blocks or for sanitary fill. In most cases, however, ash products have not been valuable enough to be marketed.[33]

SYSTEM RECYCLE STREAMS

In many cases the thickening, stabilization, heat treatment conditioning, dewatering, incineration, and similar processes result in recycle streams which contain organics and other pollutants and which represent potential treatment requirements. These recycle streams should be specifically considered in the detailed design of the wastewater treatment plant unit processes.

[32] *G. M. Wesner, "Utilization of Anaerobic Digester Gas," presented at the Wastewater Treatment and Reuse Seminar, South Lake Tahoe, October 28, 1976.*

[33] *Stanley Consultants, Sludge Handling and Disposal, Phase 1—State-of-the-Art.*

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Chapter IV

SLUDGE DISPOSAL ALTERNATIVES

INTRODUCTION

Sludges resulting from water and wastewater treatment must ultimately be returned to the environment. The available receiving environments are air, land, and water. Processing and disposal operations must be accomplished without degrading the air quality.

Ocean dumping, receiving water discharge, and disposal in Lake Michigan in the case of southeastern Wisconsin are not considered to be viable disposal alternatives. Current U.S. EPA policy is to eliminate existing ocean dumping operations from major eastern cities such as Philadelphia and New York within the next few years. In light of the limitations on phosphorus and other parameters for discharge to Lake Michigan, it is unlikely that regulatory agencies would approve sludge dumping there. Therefore, land is judged to be the only acceptable ultimate receiving environment for water and wastewater treatment plant sludges within the Region. Land application, placement in landfills, and lagoon disposal are the primary methods of disposal of sludge on land. All require that the sludge be stabilized or treated in some manner prior to disposal. Disposal of biologically unstable sludge is difficult due to potentially severe odor problems.

Land application of stabilized wastewater sludges (in liquid, dewatered, or dried forms) can be performed at moderate application rates to provide agricultural benefits in conjunction with sludge disposal, or at high application rates for the specific purpose of sludge disposal. Water treatment plant lime sludges may also be land spread for agricultural purposes. Land application of water treatment plant alum sludges or nonorganic industrial sludges will not provide significant agricultural benefits, and may require special consideration to avoid damage to soil and/or crops.

Placement of sludges in landfills is a method of ultimate disposal utilized for stabilized and dewatered or incinerated wastewater treatment plant sludges and dewatered water treatment plant sludges.

Lagoons are used for dewatering sludges from water and wastewater treatment plants. In some cases, due to negligence rather than design, the lagoons are never cleaned out, in effect becoming a means of ultimate disposal or at least long-term storage.

The major factors that determine the ultimate disposal method for a particular sludge are:

1. The types of sludge processing steps utilized.
2. Environmental suitability of specific sites for disposing of various types of sludges.
3. Availability of various types of sludge disposal sites.
4. Relative costs of alternative disposal methods. The aesthetic acceptability of alternative disposal methods.
5. Public acceptability of disposal methods.

This chapter discusses land application, landfill disposal, and lagoon disposal as methods for disposal of sludge on land and the considerations in selecting and properly applying a given method. The disposal options available for existing plants, which have varying degrees of processing, may differ somewhat from options for new or proposed plants.

LAND APPLICATION

Land application of wastewater sludges is practiced in numerous areas. Probably the largest operation is strip mine reclamation using anaerobically digested sludge from the Chicago Metropolitan Sewer District.[1] A 1975 survey of 58 wastewater treatment plants in Iowa revealed that 38 plants use land spreading for ultimate disposal.[2] Data for 61 wastewater treatment plants in the Region (see Appendix D) indicate that 58 plants are known to use land application for ultimate disposal.

Land application is used most predominantly at the smaller plants, processing less than 10 million gallons per day (mgd). The main reasons for this are that short haul disposal sites are available and that smaller plants are more likely to employ sludge treatment processes that make land application feasible.

It must be recognized during the planning effort that not every sludge is suitable for land application, nor is every land area suitable for sludge application. The planning effort must combine the technical efforts of agronomists, hydrologists, sanitary engineers, and soil scientists. In addition, public relations must be addressed early in the planning stage since adverse public opinion could conceivably stop the most cost-effective and environmentally sound land application project.

Preparation for Ultimate Disposal

Sludge must be stabilized prior to land application, in accordance with NR 110.27(5)(d) of the Wisconsin

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[1] *"Chicago Reclaiming Strip Mines with Sludge," Civil Engineering, June 1974.*

[2] *Stanley Consultants for Iowa Department of Environmental Quality, Wastewater Treatment Sludge Disposal, June 1975.*

Administrative Code. Stabilization renders the sludge more biologically inert and reduces its pathogen content. Recent U.S. EPA guidelines recognize anaerobic digestion, aerobic digestion, thermal treatment, chemical treatment, and incineration as acceptable stabilization methods.[3] For federal grant approval it is necessary to demonstrate that the degree of stabilization of any method will be equal to that reached by a properly operated anaerobic digester.

Evidence is lacking that land spreading of liquid digested sludge has caused disease to man or animals. The concern still exists, however, that pathogens may contribute to human and animal diseases. Therefore, in addition to the disinfection occurring in the sludge handling, conditioning, and stabilization steps, additional disinfection may need to be considered, for example, when people or animals come into contact with sludge.[4] When it is determined that additional pathogen reduction is required for certain types of disposal projects, the following disinfection methods are available:

1. Storing for long periods. One EPA publication recommends 60 days at 20°C (68°F) or 120 days at 4°C (39°F).[5] The Wisconsin Department of Natural Resources (WDNR) indicates that this method is generally the most cost-effective, environmentally sound option.[6]

2. Pasteurizing at 70°C (158°F) for 30 minutes. This treatment, usually obtained in heat treatment, has been shown to destroy pathogens found in sludge.[7]

3. Chemical treatment. A pH greater than 12 maintained for three hours or more has been shown to be effective in pathogen reduction.[8]

4. Thermal treatment. Incineration of sludge reduces the suitability of sludge for beneficial land application since organic matter is destroyed. Most thermal treatment systems (such as wet air oxidation) operate at temperatures and pressures exceeding those required for pasteurization.

5. Composting. Composting at 55°C (131°F) and curing in a stockpile for 30 days is an acceptable disinfection practice[9] and has been demonstrated effective in killing most pathogens.[10]

Most land application systems in the Region use anaerobically or aerobically digested sludge or heat dried, waste activated sludge such as Milorganite. Sludge, chemically treated with pH adjustment using high lime dosage, may be advantageous for application on acidic soils. The degree of stabilization required is dependent upon the method of application, the crop grown, and the use of the crop.

For land reclamation and application to farm crops, such as corn, stabilization should reduce volatile solids to a point at which odor problems do not occur. Sludge should not be applied to gardens or grazing lands for dairy or beef cattle unless the sludge has been pasteurized to destroy pathogenic organisms or unless suitable waiting periods are established for these land uses. Following sludge application, waiting periods of one year for gardens, two months for dairy cattle, and two weeks for other grazing livestock may be considered in lieu of pasteurization.[11]

Application Limitations

Land application rates are affected by a host of interrelated factors. WDNR Technical Bulletin No. 88 is the State of Wisconsin guideline for developing sludge land application systems. The Bulletin refers to U.S. Environmental Protection Agency (U.S. EPA) guidelines that were in draft form in 1975. The EPA issued the last proposed technical bulletin, Municipal Sludge Management: Environmental Factors, for public comment on June 3, 1976.[12]

Systems receiving funding from the EPA should consider the guidance of WDNR Technical Bulletin No. 88. The EPA technical bulletin may also apply. The addition of nutrients and heavy metals are two factors involved in limiting sludge application. These limitations are discussed

[3] *U. S. Environmental Protection Agency, "Municipal Sludge Management—Environmental Factors," Federal Register, 41 (108) June 3, 1976.*

[4] *P. A. Vesilind, Treatment and Disposal of Wastewater Sludges, 1974; Wisconsin Department of Natural Resources, Guidelines for the Application of Wastewater Sludge to Agricultural Land in Wisconsin, Technical Bulletin No. 88, 1975; and Municipal Sludge Management, Proceedings of the National Conference on Municipal Sludge Management, Pittsburgh, Pennsylvania, June 11-13, 1974.*

[5] *U. S. Environmental Protection Agency, "Municipal Sludge Management—Environmental Factors."*

[6] *Wisconsin Department of Natural Resources, Guidelines for the Application of Wastewater Sludge to Agricultural Land in Wisconsin.*

[7] *Municipal Sludge Management, National Conference on Municipal Sludge Management.*

[8] *J. B. Farrell, "Overview of Sludge Handling and Disposal," Proceedings of the National Conference on Municipal Sludge Management, Pittsburgh, Pennsylvania, June 11-13, 1974.*

[9] *U. S. Environmental Protection Agency, "Municipal Sludge Management—Environmental Factors."*

[10] *E. Epstein and G. B. Wilson, "Composting Raw Sludge," Proceedings of the 1975 National Conference on Municipal Sludge Management and Disposal, Anaheim, California, August 18-20, 1975.*

[11] *Wisconsin Department of Natural Resources, Guidelines for the Application of Wastewater Sludge to Agricultural Land in Wisconsin.*

[12] *U. S. Environmental Protection Agency, "Municipal Sludge Management—Environmental Factors."*

in detail in the WDNR and EPA bulletins cited above. The following discussion highlights major considerations. The emphasis in past investigations has been to determine the maximum application rate that can be applied without causing harm to the soil structure or to plants grown on the soil. Higher application rates (and therefore lower disposal costs) may be acceptable although these higher rates may require sacrificial crops or sacrificial land for sludge disposal. Overapplication can permanently impair the soil by causing a buildup of heavy metals limiting crop growth, or may impair the environment by overtaxing the soils' capabilities to remove pollutants before they reach the groundwater. In cases where higher applications rates are deemed to be acceptable, a suitable crop and resource monitoring program should also be considered.

Although sludge may contain potentially toxic materials, no definitive interpretation has been made of the effect of the recent Resource Conservation and Recovery Act of 1976 on classification of sludge as a hazardous waste requiring a permit for disposal under that statute (see Congressional Record, September 27, 1976).

Nutrient Limitations

The major essential plant nutrients contained in sludge consist of nitrogen (N), phosphorus (P), and potassium (K). Concentrations of these elements are variable depending on the origin of the wastewater, type of sludge processing, and other factors. Typical nutrient concentrations (dry basis) for liquid anaerobic sludge in Wisconsin are:[13]

N (total) - 3.4 to 9.5 percent.
P - 2.7 to 6.1 percent.
K - 1.2 to 1.9 percent.

The nitrogen content is lower in dewatered and dried sludge than in liquid sludge due to the loss of ammonium which is the liquid phase. Heat drying reduces the amount of nitrogen lost with the liquid, although some ammonia is lost by volatilization.

The nutrients that can be applied to a particular site are dependent on the soil type, nutrient requirements of the crop grown, method of sludge application, and other factors. Typical nutrient requirements per acre for corn are 150 to 185 pounds N, 25 to 35 pounds P, and 140 to 155 pounds K. Sorghum and certain grasses require 200 to 300 pounds N per acre. One ton of typical sludge containing 4, 2, and 1.2 percent N, P, and K, respectively, will provide 80 pounds N, 40 pounds P, and 24 pounds K.

Nitrates in excess of plant needs can be leached into groundwater supplies where toxic nitrate levels may occur. Because of the potential for nitrate toxicity and the relatively large amount of nitrate or ammonia in sludges, nitrogen becomes an important limiting factor in land disposal of wastewater treatment plant sludges.

The amount of N available for plant use depends upon the percentages of organic N and inorganic N, and the rate of mineralization of the organic N to inorganic N, which is the nitrogen form available for plant uptake. The typical sludge mentioned above, with a 50 percent organic N and a 15 percent mineralization rate, will provide 46 pounds of available N per ton during the year of application (assuming no loss through volatilization). Without immediate incorporation into the soil following sludge application, 50 percent or more of the inorganic N may be lost to volatilization. Dewatered and composted sludges have negligible amounts of inorganic N. Based on N requirements, the amount of sludge applied per acre could range from about 5 tons per acre per year of liquid sludge with immediate soil incorporation to 20 or 30 tons per acre per year of dewatered or composted sludge. In most cases, supplying sufficient N will result in an oversupply of P. Conversely, the K supplied will usually be less than required and supplemental K may be required. Bulletin No. 88, as a guideline, provides a detailed procedure for calculating allowable sludge application rates based on nutrient loadings.

Where sufficient land exists to utilize the amount of N available in liquid sludge, ammonia volatilization is undesirable. However, if higher application rates are desirable because of land limitations, sludge dewatering and exposure may be an effective way to reduce the inorganic N by removing nitrogen in the liquid and encouraging volatilization of ammonia.

The phosphorus content of sludge is essentially the same as that of organic fertilizers of similar composition. Since phosphorus is normally not leached from soils, it will remain available to crops for several years. Soils have been known to absorb 1,000 to 3,000 pounds per acre of phosphorus to a depth of three feet. However, if overloaded, soil will cease to remove phosphorus. In addition to overloading, phosphorus may be transported to surface waters by attachment to soil particles which are eroded. Phosphorus is another possible limiting factor to sludge loading of the soil, following nitrogen.[14]

Heavy Metals Limitations

Heavy metals and other trace elements (micronutrients) are needed in small quantities for good plant nutrition. Excessive quantities of, or inbalance in, the micronutrients may cause plant phytotoxicity, dangerous levels of certain elements in food crops, and groundwater contamination.

Soil chemistry, crops grown, and sludge characteristics are the primary factors that determine allowable heavy metals loadings to land. Heavy metals of importance that are normally found in sludge include cadmium, chromium, copper, lead, mercury, nickel, and zinc. Trace amounts of copper and zinc are essential to plants and animals. In addition, nickel is essential to animals.

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[13] *Wisconsin Department of Natural Resources, Guidelines for the Application of Wastewater Sludge to Agricultural Land in Wisconsin.*

[14] *"Recycling Sludge and Sewage Effluent by Land Disposal," Environmental Science and Technology, Vol. 6, October 1972.*

While each of the elements found above is toxic to plants, copper and nickel have the highest toxicity. Cadmium, lead, and mercury can be concentrated in animal tissue. Therefore, low concentrations in sludges can be magnified through the food chain and eventually cause adverse effects.

The transfer of essential nutrient elements from soils into plants and then into animal tissues is a complicated process. Plants vary in their susceptibility to toxic metals. Chard, spinach, beets, turnips, mustard, and tomatoes are very sensitive. Corn, small grains, and soybeans are moderately tolerant. Grasses (fescue, love, bermuda, orchard, rye) are generally highly tolerant of metals.[15]

To minimize the risk of excessive cadmium in the food chain, the ratio of cadmium to zinc (Cd/Zn) has been suggested to be limited to 1 percent. Under these conditions, injury to crops from excessive zinc would occur before the cadmium content would become a health hazard.[16]

Equations have been developed[17] which limit the amount of zinc, copper, and nickel that can be applied to the land over a period of time. The equations are of the form:

$$\text{Allowable rate} = C_1\ (\text{CEC})/(\text{Zn eq} - C_2)$$

where:
- C_1 = Constant. The reported values of C_1 range from 8,150 to 32,600; this limits the zinc equivalent addition to 2.5 to 10 percent of the unamended soil CEC, respectively.
- CEC = Cation exchange capacity of the soil.
- C_2 = Constant. The reported values of C_2 range from 0 to 300, which allows some CEC value for the added sludge.
- Zn eq = mg/l Zn + 2 (mg/l Cu) + 4 to 8 (mg/l Ni)

[15] *U. S. Department of Agriculture, Factors Involved in Land Application of Agricultural and Municipal Wastes, Agricultural Research Service, National Program Staff of Soil, Water, and Air Science, Beltsville, Maryland, July 1974.*

[16] *Ibid.*

[17] *C. G. Chumbly, Permissible Levels of Toxic Metals in Sewage Used on Agricultural Land, A.D.A.S. Advisory Paper No. 12, 1971, cited in Factors Involved in Land Application of Agricultural and Municipal Wastes, U. S. Department of Agriculture, Beltsville, Maryland, July 1974; R. L. Chaney, "Crop and Food Chain Effects of Toxic Elements in Sludge and Effluents," Proceedings of the Joint Conference on Recycling Municipal Sludges and Effluents on Land, Champaign, Illinois, July 9-13, 1973; and U. S. Department of Agriculture, Factors Involved in Land Application of Agricultural and Municipal Wastes.*

The equations are all based on the assumption that the soil pH will remain at or above 6.5 at all times.[18]

The soil pH and CEC have important relationships with potential heavy metal uptake in plants. CEC is a measure of the amount of exchangeable cations in the soil. An optimum soil pH for phosphorus and potassium uptake by plants is 6.5 to 7.0. Below a pH of 6.5, plant uptake of heavy metals increases and uptake of phosphorus and potassium decreases.

Zinc equivalent has been developed as an expression for potential plant susceptibility to phytotoxicity. The zinc equivalent expresses the toxicity of zinc, copper, and nickel to typical plants grown on sludge amended soil. The zinc equivalent accounts for copper being twice as toxic as zinc, and nickel being four to eight times as toxic as zinc. Initial drafts of the EPA technical bulletin used these various formulas based on CEC and zinc equivalent to determine the amount of sludge that can be applied over the life of a project. The June 1976 draft of the U.S. EPA technical bulletin dropped the use of the zinc equivalent approach resulting in no definitive national guides that limit sludge application on the basis of heavy metal content. Technical Bulletin No. 88 contains modifications of these formulas based on a total metal equivalent loading in pounds per acre, which is equal to 65 times the soil CEC. Metal equivalents (in pounds per ton of sludge) are calculated as follows:

$$\frac{(\text{mg/l Zn}) + (2 \times \text{mg/l Cu}) + (4 \times \text{mg/l Ni})}{500}$$

Bulletin No. 88 suggested limiting yearly cadmium additions to two pounds per acre with 20 pounds per acre as a lifetime maximum. Chaney recommends a zinc to cadmium ratio of 100 or larger before sludge is applied to the land.[19]

When sludge is applied to grass land, another relationship becomes important. That is the ratio of potassium to calcium and magnesium in the soil. When the ratio K/(Ca+Mg) is greater than 2.2, low magnesium levels in blood serum (grass tetany) affect grazing animals. Magnesium fertilizer or feed supplements can correct the imbalance.

Soil pH may be increased (or maintained) by periodic additions of lime. This practice may be necessary where acid soil conditions prevail. Lime sludges from water treatment plants could be used for this purpose.

Because of the apparent lack of firm scientific data needed to establish precise sludge application regulations based upon heavy metals loading, monitoring of the

[18] *U. S. Department of Agriculture, Factors Involved in Land Application of Agricultural and Municipal Wastes.*

[19] *R. L. Chaney, "Crop and Food Chain Effects of Toxic Elements in Sludge and Effluents."*

environment should be considered as a part of sludge land application programs with special consideration required for programs utilizing loadings exceeding typical guideline recommended application rates.

Other Limitations

In addition to the complex soil-crop interrelationships for nutrients and heavy metals previously presented, it is also necessary to consider potential pollution of surface water, groundwater, or air from sludge application. Walker has proposed that problems associated with land application of different sludge types be compared according to the criteria presented in Table 7.

Sludge Storage

Sludge storage requirements prior to application in the Region depend upon the type of stabilization, the use of the sludge (such as land reclamation or crop production), and the sludge form (liquid, dewatered, dried).

Since liquid sludge generally should not be applied in winter conditions, land application methods require storage capacity for as long as six months or more. Storage also is necessary through the growing season and to coincide with desirable farm plowing practices unless land is left idle for sludge application. Lagoons are commonly considered usable for long-term sludge storage.

Dewatered sludge should be stockpiled in a manner that prevents runoff to surface water. Covering is desirable to divert precipitation.

Odors can be a problem with sludge storage, even if the sludge has been stabilized. To minimize complaints, sludge should be stored in remote areas, preferably at the disposal site, whenever possible.

Sludge Transport

In the study area, transportation of liquid and dewatered sludge is predominately by truck. Pipeline, rail, and barge are other possible methods of transportation. Transport of dried sludge, such as Milorganite, is by the same method as commercial (solid) fertilizer. The economical feasibility of land application of digested wastewater treatment sludge as compared with systems using volume reduction processing steps is often determined by the economics of transport (see Chapter VI).

Sludge Application

Liquid sludge application methods depend on the type of sludge and the type of land on which the sludge is applied using the following methods:

1. Spray irrigation.

2. Ridge and furrow irrigation.

3. Tank or tank truck with a spreader device.

4. Tank or tank truck with a direct incorporation device.

Solid sludge usually is spread with a spreader device mounted on a truck or with a farm manure spreader. Where long hauls are necessary, it is possible to reslurry dewatered sludge after transport and apply as a liquid. WDNR Technical Bulletin No. 88 presents typical sludge application equipment. Sometimes nurse tanks are used; the tank truck delivering the sludge to an application site

Table 7

POTENTIAL ENVIRONMENTAL CONSTRAINTS FOR LAND APPLICATION

Sludge Treatment	Relative Level[a] of Problems Associated with Combined Primary and Secondary Sludge Treated by Different Processes				
	Odor	Pathogens	Initial Toxicity	Heavy Metals[b]	Nitrogen Pollution
Raw-Untreated	H	H	H	M	H
Raw-Limed[c]	M	L	H	L	H
Raw-Chlorine, pH 2-3	N	N	H	NR	H
Raw-Chlorine, pH 6-7	M	L	H	NR	H
Anaerobic Digested	M	M	H	H	M
Anaerobic-Limed	M	L	H	M	M
Composted	N	N	L	M	L
Heat Dried	L	N	M	NR	H

[a] *H = high, M = medium, L = low, N = negligible, NR = not reported.*

[b] *Rating for metal level applies to sludge from one treatment plant.*

[c] *Limed to pH 11.5 +.*

Source: J. M. Walker, Compost Science, March-April 1975.

transfers the sludge to application equipment. This procedure minimizes mud and debris being deposited on roads from the transport equipment.

Certain precautions which should be considered during sludge application are listed below:

1. Sludge should be applied during that portion of the growing cycle when the fertilizer value of the sludge is needed and thus the sludge is removed from the soil and incorporated as plant tissue.

2. Sludge should not be spread on sloping ground unless provision is made to incorporate it into the soil immediately to avoid runoff contamination. Good farming erosion/runoff control practices such as contour farming, terracing, and use of border strips should be encouraged.

3. Sludge should not be applied to frozen ground to avoid contaminating adjacent surface water by runoff. If dikes and other runoff collection/control structures are present, it may be permitted to apply limited sludge quantities.

4. Sludge should be incorporated into soil directly or soon after spreading. This procedure provides the following advantages:

    a. Less nitrogen loss by volatilization of ammonia.

    b. Minimized odor and public health (pathogen) risks.

    c. Minimized runoff from rainfall, particularly on sloping ground.

5. A minimum soil depth of four feet should exist to bedrock, groundwater, or impermeable strata.[20]

Environmental Hazards

The following environmental factors should be considered when planning and operating land application systems:

1. Several sludge constituents (such as organic matter, pathogens, heavy metals, and fertilizers) are potentially serious pollutants if they should enter ground or surface waters by means of runoff, seepage, or airborne drift.

2. Stabilization reduces but does not eliminate hazards to public health and nuisance odors.

3. Adequate soil thickness and peripheral buffer zones can reduce environmental hazards.

4. Sandy soils should be generally avoided because of their limited CEC and high porosity.

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[20] *Wisconsin Department of Natural Resources, Guidelines for the Application of Wastewater Sludge to Agricultural Land in Wisconsin.*

LANDFILL DISPOSAL

General

Landfill disposal of wastewater sludge is used at plants in the Region that do not use land spreading.

Landfill refers to disposal of sludges along with refuse in a publicly or privately owned, State-licensed, sanitary landfill. A sanitary landfill should incorporate careful engineering design to control environmental effects. The following factors should be evaluated during landfill design:

1. Careful consideration of geology, soils, hydrology, and related factors to provide sufficient protection of groundwater resources.

2. Control of the material accepted at the landfill.

3. Control of the actual dumping site within the landfill.

4. Compaction of filled material into cells of maximum density.

5. Daily cover of filled material and final cover of the completed landfill to minimize leaching, odors, and vector problems (rodents and flies).

6. Diversion of upland surface runoff around the landfill working areas.

7. Potential collection of leachate for treatment.

Sludge stabilization is not required for public health reasons but may be a necessary step to minimize odors during dewatering and transport to the landfill.

Problems sometimes occur in transporting sludge to the landfill during inclement weather. Therefore, some storage capacity at the generation point is required.

Landfills require that sludges be dewatered to minimize free-water content. This is because a wet sludge is difficult to work around the landfill site and has the potential of producing considerable amounts of leachate. Although limits are uniformly established, for landfills with relatively low refuse-to-sludge ratios or with potential leaching problems, anticipated limits may require a minimum of 35 percent dry solids and some sites may require as high as 50 percent.

Leachate

The high water content of poorly dewatered sludges may be released into the landfill reacting with constituents of refuse to generate leachate—a low volume, high strength liquid stream which can seriously contaminate groundwater. Leachate should not be generated in significant quantities from a properly designed and operated sanitary landfill. However, many existing landfills have leachate problems to the extent that collection and treatment are warranted. Collection and treatment costs are very site-specific but could increase landfilling costs significantly.

Leachate is collected by underdrains which flow by gravity or are pumped to holding treatment basins. Treatment may be a combination of biological (aerated lagoon), physical/chemical (coagulation and precipitation, activated carbon, chemical oxidation), and land spraying methods. Leachate is difficult to treat biologically due to the variable and high concentrations of organic matter and heavy metals; the organics may be toxic and/or resistant to biological organisms. Landfill leachate prevention is more cost-effective than leachate treatment.[21]

SLUDGE LAGOONS

Lagoons have been used for ultimate disposal with mixed success in the past, particularly at smaller plants which have sufficient land available, although they have not been used for ultimate disposal in the Region. The process consists of simply placing the sludge in pits where dewatering takes place primarily by evaporation, although some seepage may take place. The pits are allowed to fill up with sludge and are then covered with a layer of soil. The covered pits do not normally have adequate bearing strength for future use.

Seepage is an environmental problem because of potential groundwater contamination from nitrogen and heavy metals. Stabilization is required to minimize odors. Thickening is desirable to minimize liquid volume and extend the useful life of the lagoon.

SUMMARY

This section has briefly reviewed considerations for ultimate disposal of sludges. Additional guidance can be found in the WDNR Technical Bulletin No. 88 and the EPA Bulletin, Municipal Sludge Management—Environmental Factors. Options available for ultimate disposal for the majority of facilities in the Region are land application and landfill.

When sludge is applied to land, the agriculturally beneficial components of sludge can be utilized for crop growth, or sludge can be applied at some maximum rate to provide economical disposal. Both systems must consider potential pollution of the receiving environment and continued maintenance of the land resource.

Sludge disposal in landfills results in loss of potential agricultural benefits but may reduce potential receiving environment pollution. Such disposal may be mandatory where sludge characteristics preclude or severely limit application to land.

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[21] *M. Lawlor, "Dealing with Leachate at Solid Waste Disposal Sites" Public Works, 107, May 1976; R. J. Thornton and F. C. Blanc, "Leachate Treatment by Coagulation and Precipitation," Journal of the Environmental Engineering Division, ASCE, August 1973; and E. S. K. Chian and F. B. DeWalle, "Sanitary Landfill Leachates and Their Treatment," Journal of the Environmental Engineering Division, ASCE, April 1976.*

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Chapter V

REGIONAL SLUDGE PROCESSING AND DISPOSAL SCHEMATICS

INTRODUCTION

Before sludge processing and disposal alternatives can be developed, an evaluation is necessary to identify processing systems which are not feasible or generally applicable for the Region. Table 8 summarizes this evaluation.

Processing alternatives which are highly limited in applicability to the Region at this time include the following:

1. Freeze conditioning—limited due principally to high costs and undeveloped technology.

2. Elutriation (except in special cases)—limited due principally to the high strength recycle and lack of cost-effectiveness.

3. Composting—limited due principally to uncertain process performance, costs, and marketing of product, and high labor requirements. If land application of digested sludge for smaller facilities is limited for whatever reason, then composting may be a viable alternative.

4. Animal feed supplement production—limited due principally to undeveloped technology and marketing of product.

5. Radiation stabilization—limited due principally to undeveloped technology, uncertain costs, potential safety hazards.

At this time, application of the following alternatives is limited to the two large wastewater treatment plants at Milwaukee (Jones Island and South Shore) and possibly the three medium sized plants in the Region (Racine, Kenosha, and Waukesha) or to new regional facilities of comparable size:

1. Incineration (wastewater treatment sludges).

2. Heat drying for fertilizer production (wastewater treatment sludges).

3. Pyrolysis (wastewater treatment sludges).

4. Wet air oxidation (wastewater treatment sludges).

5. Alum recovery (water treatment sludges).

6. Lime recalcination (water treatment sludges).

The large and medium sized plants could expect to realize considerable economy of scale for these operations, resulting in lower costs per ton of sludge. In addition, the complexity of these operations requires more highly trained personnel than normally found at small facilities. Finally, land spreading and related operations may not be applicable to large plants due to high transportation costs, limited availability of land, and presence of heavy metals; thus making alternative operations more attractive.

The remaining alternatives considered are generally applicable for use within the Region. For purposes of systems level sludge management planning, the most proven and reliable unit processes have been combined into total sludge processing and disposal systems which are generally representative of the costs and performances required for sludge management in southeastern Wisconsin.

WASTEWATER TREATMENT PLANT SLUDGE SCHEMATICS

Two basically alternative wastewater sludge treatment and disposal systems most generally can be applied to plants in the Region. These are land disposal preceded by thickening, stabilization, and storage; and landfill preceded by stabilization, conditioning, and dewatering as shown on Figure 2. Lagooning as an ultimate disposal option, preceded by thickening and stabilization, may be applicable in a few instances for small communities but generally would not be recommended for usage throughout the Region. Storage lagoons to allow flexibility in timing of land application would be common for many facilities.

At the larger plants in the Region, incineration, pyrolysis, or product recovery as dried commercial fertilizers such as Milorganite may be practiced. Regional plants treating the combined sludges from several small plants may be able to utilize incineration, pyrolysis, or other systems cost-effectively.

Land Disposal System

Sludges from the treatment of domestic wastewaters can be disposed of by application to agricultural or forest land, adding to the soil beneficial organic matter and nutrients such as nitrogen, phosphorus, and various trace elements. Proper application is required to avoid potential soil contamination, crop damage, groundwater or surface water pollution, or other adverse effects. To minimize odors and potential health hazards, stabilization is required. Storage must be provided to hold the sludge until it can be applied to the soil. Generally, thickening will be a cost-effective preliminary treatment step, reducing the equipment size and operating costs for subsequent steps. Sludge application methods and loading rates should consider State Agricultural Extension Service recommendations for each sludge and disposal site. Traditionally, land disposal for small facilities has been

Table 8

FACTORS CONSIDERED IN DEVELOPMENT OF SLUDGE PROCESSING ALTERNATIVES

Process	Process Performance	State of Technology Development	Overall Costs[a]	Resource Consumption[a]	Major Factors Limiting Application in the Region	Overall Applicability for Use Within the Region
Gravity Thickening	Effective for heavy sludges	Good	Low	Low	--	Generally applicable
Flotation Thickening	Most effective for medium and light sludges	Good	Low	Moderate to low	--	Generally applicable
Mechanical Thickening	Variable	Fair	Moderate to high	Moderate	Requires close operator attention	Generally applicable
Anaerobic Digestion	Good	Good	Moderate	Low	Potential upsets, high strength recycle, potential safety hazards	Generally applicable
Aerobic Digestion	Good	Good	High	High	High energy use, cold reduces efficiency	Generally applicable
Thermal Stabilization/ Conditioning (Heat Treatment)	Good	Fair	High	High	High strength recycle, odors, potential safety hazards	Generally applicable
Chemical Stabilization/ Conditioning	Variable, but generally good	Good to fair	Variable	Moderate to high	--	Generally applicable
Freezing	Good	Poor	High	Uncertain	Undeveloped technology, high costs	Highly limited
Elutriation	Variable, but generally good	Fair	Variable	Moderate	High strength recycle	Highly limited
Radiation Stabilization	Uncertain	Poor	Uncertain	Low	Undeveloped technology, potential safety hazards	Highly limited
Drying Beds	Variable, but generally good	Good	Moderate	Low	High land requirements	Generally applicable
Drying Lagoons	Variable, but generally good	Good	Low	Low	Potential leachate problems	Generally applicable
Vacuum Filters	Achieves moderate dewatering	Good	Moderate	Moderate	--	Generally applicable
Centrifuges	Achieves moderate dewatering	Good to fair	Moderate	Moderate	--	Generally applicable
Pressure filters	High degree of dewatering	Good	Moderate	Moderate	--	Generally applicable
Other Dewatering Units	Achieves low dewatering	Fair	Moderate	Moderate	--	Generally applicable
Incineration	Good	Fair	High	Uncertain	High energy requirements, high costs	Limited to larger facilities
Heat Drying (Ion Fertilizer Production)	Good	Good	High	Moderate to high	High energy requirements	Limited to larger facilities
Pytolysis	Good	Fair	High	Uncertain	Undeveloped technology	Limited to larger facilities
Wet Air Oxidation	Good	Fair	High	High	Undeveloped technology, potential safety hazards	Limited to larger facilities
Composting	Highly variable	Poor to fair	Uncertain	Low	Uncertain performance, costs, and marketing	Limited to larger facilities
Animal Feed Production	Variable	Poor	Uncertain	Uncertain	Undeveloped technology, marketing uncertainties	Highly limited
Lime Recalcination	Good	Fair	High	Moderate	High energy use, potential safety hazards	Limited to larger facilities
Alum/Ferric Recovery	Uncertain	Poor	Uncertain	Low	Undeveloped technology	Limited to larger facilities
Landfill	Variable, but generally good	Good	Moderate	Moderate	High land requirements	Generally applicable
Land Spreading	Variable, but generally good	Good to fair	Moderate	Low	High land requirements	Generally applicable

[a] *See Table 9.*

[b] *See Tables 16, 17, 18, and 20.*

Source: Stanley Consultants.

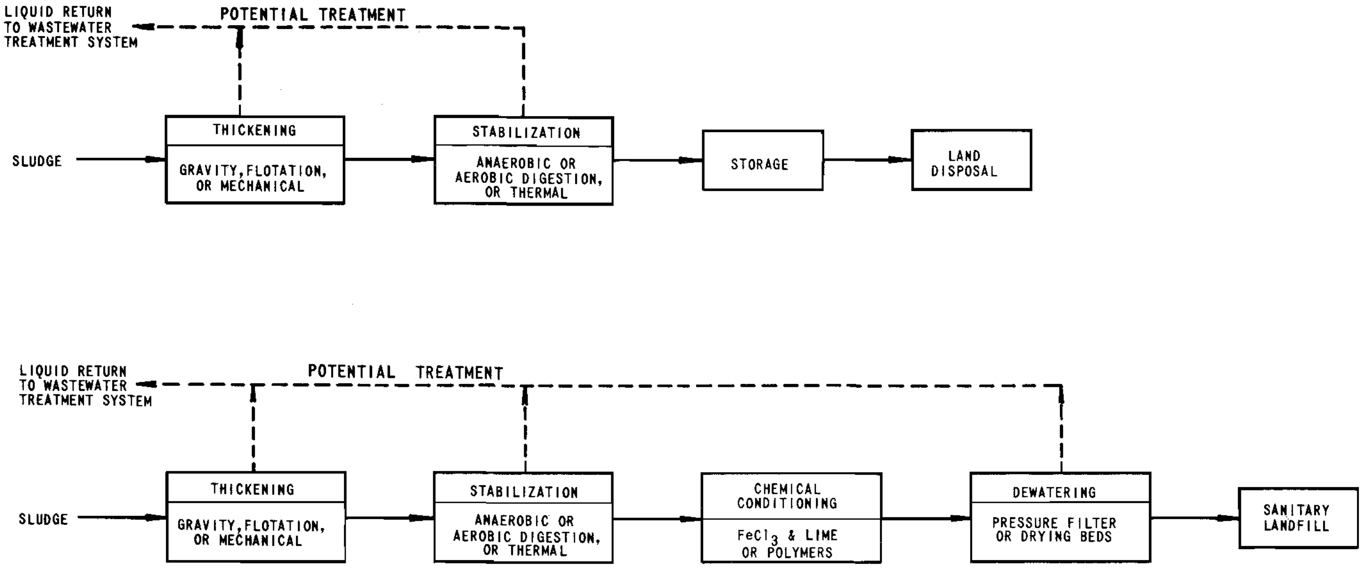
done on a relatively informal basis, with farmers or other sludge haulers withdrawing sludge on an irregular basis. A regional land disposal system for the combined sludges from several small plants might result in lower overall costs per ton.

Landfill Disposal System

Sanitary landfills are being used for the ultimate disposal of dewatered sludge by few plants in the Region on a regular basis. For these plants it should continue to be an acceptable alternative in the future.

Figure 2

WASTEWATER TREATMENT PLANT SLUDGE SCHEMATICS



Source: Stanely Consultants.

Anticipated future landfill requirements may specify a minimum of 25 to 50 percent dry solids in the sludge depending on the individual landfill. Mechanical dewatering in pressure filters is the only way to ensure that 35 to 50 percent solids content can be accomplished regularly; although vacuum filters, centrifuges, and sand drying beds generally are capable of dewatering sludge to approximately 25 to 35 percent. The degree of dewatering required will vary with each particular case.

Chemical conditioning using metal salts, lime, organic polymers, and ash addition are required to facilitate dewatering. Stabilization usually will be required prior to landfilling to avoid odor problems. Anaerobic or aerobic digestion generally would be applicable to most plants for partial stabilization and conditioning. Small activated sludge plants (particularly those using diffused air aeration) could use aerobic digestion. Heat treatment may be applicable to larger plants particularly where stabilization is by incineration, but the process is not expected to be widely used in the Region.

Thickening would generally be cost-effective in reducing the cost of subsequent processes (see Chapter VI). Heavy sludges, such as primary sludge, can be effectively thickened by gravity units, although air flotation is expected to be more effective for light, flocculant sludges such as waste activated.

Lime sludges from precipitation of phosphorus can be handled by similar processes used for lime softening sludges. For plants using more than about 20 tons per day of quicklime, recalcination may be economical.

WATER TREATMENT PLANT SLUDGE SCHEMATICS

Alum Coagulation Sludge

Alum sludges traditionally have been discharged to receiving bodies of water through storm sewers or to wastewater treatment facilities through sanitary sewers. In some cases, sludges have been dewatered in drying beds, drying lagoons, or by mechanical processes and the sludge cake landfilled. However, the hydrated, gelatinous nature of alum sludges makes dewatering difficult and expensive. In light of modern sewer use ordinances and environmental control regulations, the recommended handling and disposal alternatives are shown on Figure 3. Small plants are considered to be those with design flow less than about 5 mgd.

Discharge to a wastewater treatment plant by way of the sanitary sewer system is becoming increasingly popular as a disposal method for the water treatment plant; however, these solids then become a source of sludge solids for the wastewater treatment plant. To avoid causing hydraulic surges to the sewer system or treatment plant, sludge should be discharged continuously over a long period of time, not dumped as a batch. This may require the use of a holding tank for the sludge as it is removed from the clarifier. The practice should be terminated if sewer clogging due to buildup of sludge solids should occur. Normally, however, the alum sludge will tend to improve solids removal in the wastewater treatment plant primary clarifier.

Landfills generally will accept alum sludge only if it has been dewatered to the extent that it does not cause operating problems for the compaction equipment working the landfill and does not generate excessive quantities of leachate. This normally requires dewatering to at least 35 to 40 percent dry solids. Because alum sludges are difficult to dewater, mechanical dewatering equipment requires the attention of a skilled operator, as well as relatively conservative design. For these reasons, mechanical dewatering is not generally recommended for small plants; dewatering by large drying beds or lagoons is more applicable for the small plants. At larger plants, pressure or vacuum filters, normally utilizing a precoat, can be expected to provide adequate mechanical dewatering; as can centrifuges, although substantial polymer additions may be required. Flotation thickening is beneficial in most cases to improve dewatering.

Alum may be recovered at larger plants by the acid-leaching process described in Chapter III. Flotation thickening is required prior to acid treatment. The breakeven point for alum recovery reportedly occurs at the 20 mgd plant size, depending on local chemical prices and raw water quality.[1] However, for plants in the 10 to 20 mgd range, feasibility of alum recovery should be studied on an individual basis.

[1] *American Water Works Association, Processing Water Treatment Plant Sludge, 1974; and C. W. Randall, et al, "Alum Recovery from Representative Water Treatment Plant Sludges," Journal of the American Water Works Association, 68, April 1976.*

If sufficient land area is available, drying lagoons or sand drying beds are a potential dewatering method. Dewatering by gravity draining is not a problem because the leachate is high quality water unlike that from wastewater sludges. Natural freeze/thaw conditions improve the dewatering of the sludge. In a few cases, small plants may find it is economical to allow the lagoon to fill permanently and finally cover the sludge over instead of dredging it out for disposal in a sanitary landfill.

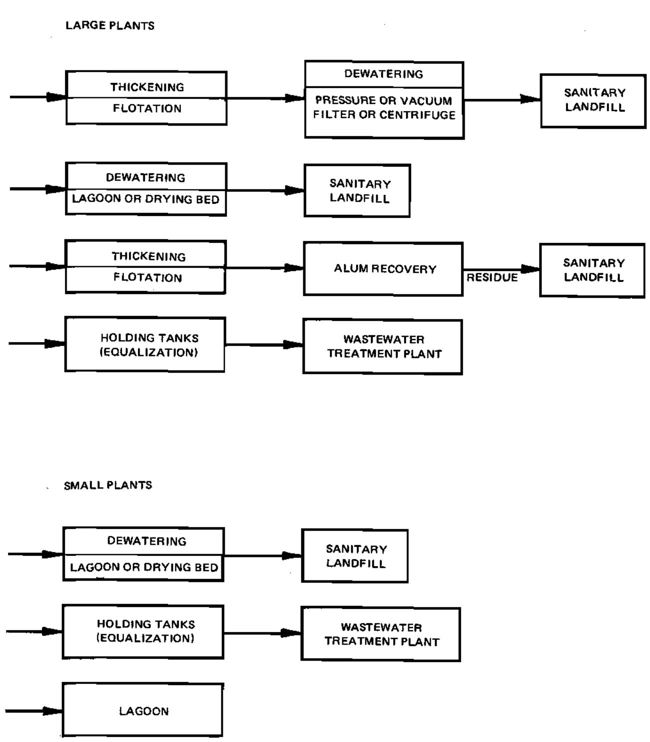
Lime Softening Sludge

Lime softening produces a sludge which is primarily calcium carbonate ($CaCO_3$), which is relatively inert, high pH, nongelatinous, and fairly easily dewatered. Recommended handling and disposal alternatives for lime sludge are presented on Figure 4. It should be noted that recalcination (lime recovery) is not included. This is because there are no lime softening plants in the Region large enough to utilize recalcination economically (the commonly accepted breakeven size is 20 tons per day of quicklime).

Most landfills will accept properly dewatered lime sludges. Lagoons and sand drying beds can readily dewater lime sludge to 50 percent solids, which is acceptable in most landfills. Mechanical dewatering using centrifuges,

Figure 3

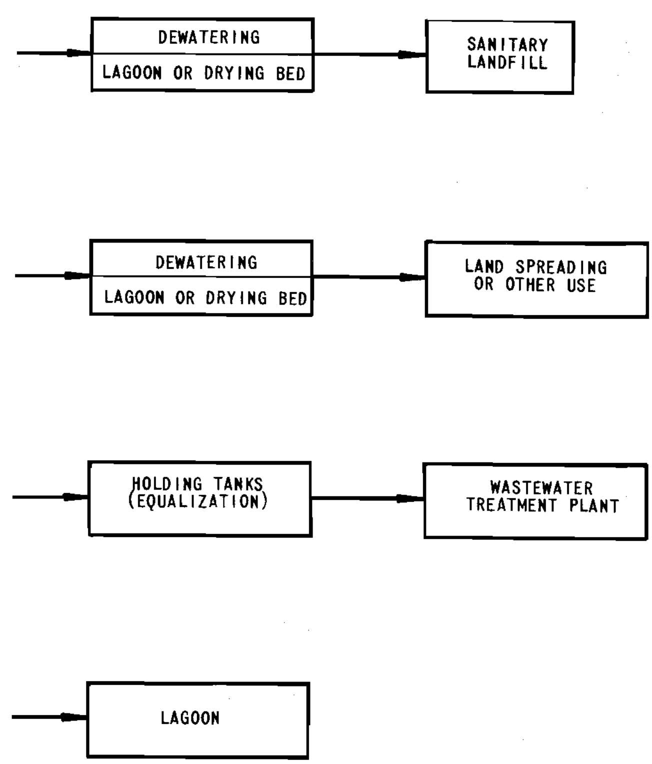
WATER TREATMENT ALUM SLUDGE SCHEMATICS



Source: Stanley Consultants.

Figure 4

WATER TREATMENT LIME SOFTENING SLUDGE SCHEMATICS



Source: Stanley Consultants.

vacuum filters, or other units can also dewater lime sludges to greater than 50 percent solids. For the size of softening plants in the study area, however, mechanical dewatering is not as cost-effective as drying lagoons or sand drying beds.

Lime sludges have acid-neutralizing abilities and may be spread on farmland to raise soil pH. The sludge must be stored until the soil is ready for liming; this is normally done in a drying/storage lagoon. Using wastewater treatment sludge for stabilization and/or conditioning chemicals or wastewater stream pH control are similar beneficial uses.

Plants with sufficient land area may dewater and dispose of lime sludge in permanent lagoons which are never dredged out but rather covered over when filled with dewatered sludge. Leachate from lime sludge lagoons has few pollution constituents and is not generally an environmental problem.

Discharge to the sanitary sewer system must be studied more carefully for lime sludge than for alum sludge because of the increased tendency of lime sludge solids to deposit in sewer lines causing clogging. Flow velocities should be maintained above 2.5 feet per second (fps) to avoid deposition. However, sludge discharges must not be so large as to cause hydraulic overload problems. Increased BOD, suspended solids, and phosphorus removals in the primary clarifier can result from lime sludge discharge to wastewater treatment plants. It has been reported that excessively high quantities of lime sludge fed to anaerobic digesters can cause biological failure of the digester. In most cases, however, minimal adverse effects are expected at the wastewater treatment plant.

Filter Backwash Water

Backwash water from coagulation/filtration systems is normally collected in a holding tank. From this tank, there are basically three options:

1. Mix the tank to suspend floc particles, and return the backwash water to the head of the water treatment plant thus recycling the flocculating chemicals.

2. Mix the tank and slowly discharge to a sanitary sewer.

3. Allow the flocculant materials to settle to the bottom of the tank. Draw off these solids to be handled along with the other alum sludge while the supernatant liquid is returned to the head of the plant.

Ion-Exchange Resin Regeneration Brines

Historically, brines have been discharged to surface waters, injected into groundwater, evaporated, or discharged to wastewater treatment plants by way of sanitary sewers. Discharge to the sanitary sewer at a low rate is often the recommended approach.

SEPTAGE TREATMENT OPTIONS

Historically, septage has been discharged to wastewater treatment plants, dumped into open ditches, and disposed of in various unknown ways depending on the procedures of the septic tank cleaner. Newly developed septage treatment systems involve chemical stabilization (as for wastewater treatment sludge) using chlorine or high pH. Both systems require extremely large amounts of chemicals, and the stabilized sludge must be disposed of by landfill. The most cost-effective systems are to discharge controlled amounts of septage into properly operating wastewater treatment plant sludge handling and disposal systems, or to construct and operate similar systems exclusively for septage from designated portions of the Region. Introducing the septage into the liquid processing system of wastewater treatment facilities should be minimized unless septage quantities are relatively small and proper supervision and control are available.

Controlled discharge of septage to agricultural lands has been practiced in the Region, but higher degrees of stabilization than can be obtained in the septic tank may be required in the future.

INDUSTRIAL SLUDGES

Organic sludges from food processing plants and pulp/paper mills can be disposed of by the same methods used for municipal wastewater treatment plant sludges. Chemical and metal sludges generally cannot be applied to the land because of high levels of toxics (such as phenolic hydrocarbons, oils, and heavy metals). Incineration and pyrolysis may be increasingly applicable to disposal of organic and chemical industrial sludges which have high heating values. The two existing landfills in the Region which are licensed to accept industrial sludges, the Reclamation, Inc., landfill near Racine County and the Laur II landfill near Germantown, are relatively large operations and likely could provide a high ratio of refuse to sludge. Generally at least 10 to 1 on a weight basis is desirable. Smaller landfills, or landfills with potential leaching problems, may not be licensed (or willing) to accept industrial sludges. The establishment of a strategically-located and specially designed and operated landfill to handle only sludges and other "hazardous and toxic" wastes should be investigated.

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Chapter VI

COST CONSIDERATIONS IN PROCESS SELECTION

INTRODUCTION

Sludge handling and disposal costs represent a large and continually growing share of total expenditures for water pollution abatement in the Region. The rural resident is faced with increasing costs for septage removal. Water utilities are faced with new restrictions on allowable disposal of solids generated in water treatment operations. In the wastewater field, the increasingly higher degrees of treatment required prior to discharge, coupled with more stringent criteria on allowable ultimate disposal options, have dramatically increased solids quantities as well as handling costs.

Concern about the increasing quantities of solids and costs for processing and disposal has generated extensive analysis of alternative disposal methods and has increased the processing options available in recent years. Regional processing and disposal sites, large-scale energy or material recovery systems, and changes in conventional design and application of available technology are being proposed throughout the nation to minimize the cost and environmental impact of sludge handling and disposal.

Conventional Facility Costs

Conventional solids handling systems for the wastewater treatment facilities used in the Region[1] include the following unit operations:

1. Gravity thickening.
2. Flotation thickening.
3. Anaerobic digestion.
4. Aerobic digestion.
5. Sludge drying beds.
6. Sludge lagoons.
7. Vacuum filters, centrifuges, and filter presses.

Trucks are used in the Region to transport solids to ultimate disposal sites. Ultimate disposal consists of landfills, lagoons, land application, and product marketing (Milorganite).

The cost of conventional solids handling and disposal is a function of the volume, solids content, sludge processing systems used, mode of transport, and distance of transport to ultimate disposal. Cost curves have been developed for the following unit operations based on a number of literature references:[2]

1. Gravity thickening.
2. Flotation thickening.
3. Anaerobic digestion.
4. Aerobic digestion.
5. Centrifuge dewatering.
6. Vacuum or pressure filter dewatering.
7. Sludge drying beds.
8. Sludge drying lagoons.
9. Multiple hearth incineration.
10. Truck hauling costs.
11. Land spreading of digested sludge.

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[1] *Stanley Consultants for the Southeastern Wisconsin Regional Planning Commission, Point Source Wastewater Treatment Alternatives and Cost Information, November 1976.*

[2] *U. S. Environmental Protection Agency, Process Design Manual for Sludge Treatment and Disposal, October 1974; Stanley Consultants for Metropolitan Sewer Board for Twin Cities Area, Sludge Handling and Disposal, Phase 1—State-of-the-Art, Minneapolis and St. Paul, Minnesota, November 1972; R. S. Burd, by Dow Chemical for Federal Water Pollution Control Administration, Department of the Interior, A Study of Sludge Handling and Disposal, WP-20-4, May 1968; Stanley Consultants for the Miami Conservancy District in Dayton, Ohio, Point Source Wastewater Controls, January 1976; Battelle-Pacific Northwest Laboratories for the Council on Environmental Quality, Evaluation of Municipal Sewage Treatment Alternatives, Contract EQC 316, February 1974; Engineering Science, Inc., for the U. S. Environmental Protection Agency, Sludge Processing, Transportation, and Disposal/Resource Recovery: A Planning Perspective, WPD 12-75-01, December 1975; Stanley Consultants for the Metropolitan Atlanta Water Resources Study Group, Wastewater Treatment Unit Process Design and Cost Estimating Data, January 1975; Bechtel, Inc., for U. S. Environmental Protection Agency, A Guide to the Selection of Cost-Effective Wastewater Treatment Systems, EPA-430/9-75-002, July 1975; and Black and Veatch Consulting Engineers for U. S. Environmental Protection Agency, Estimating Costs and Manpower Requirements for Conventional Wastewater Treatment Facilities, Project No. 17090 DAN, October 1971.*

Selecting a particular combination of these options is a function of the following factors:

1. The distance that the sludge must be hauled for ultimate disposal and the relative economies of hauling a dilute sludge versus installing systems to dewater sludge and reduce hauling costs.

2. The acceptability of the solids content at the point of ultimate disposal for a particular method of ultimate disposal. Land spreading of liquid sludge may be practical, but disposal of watery sludge in landfills has caused difficulties.

3. The onsite land available at a treatment facility to utilize drying beds or lagoons.

4. The characteristics of the sludges expected from liquid treatment processes at a facility and required characteristics for ultimate disposal.

Cost curves for conventional treatment processes are presented in Appendix B. The cost curves provide a guide to process performance and conventional design practice. Capital costs do not include land, engineering, legal, or contingency factors. Land costs will not be a significant factor in most of the unit operations; exceptions are sludge drying beds, sludge lagoons, and land spreading. Total construction project cost should be obtained by multiplying construction costs from the cost curves (Appendix B) by 1.27 to include engineering, legal, administration, and interest during construction. Curves are generally given in terms of cost versus tons per day of dry sludge. Quantities of solids to be expected from treatment facilities can be estimated using factors in Chapter II and the Stanley Consultants' report, Point Source Wastewater Treatment Alternatives and Cost Information.

The performance notations at the bottom of each curve guide development of costs for alternative process schematics as presented in Chapter V. Values from the cost curves are summarized in Table 9.

Table 9

COSTS FOR CONVENTIONAL SLUDGE HANDLING AND DISPOSAL UNIT PROCESSES

Process	Construction Cost (millions of dollars)				Operation and Maintenance Cost (dollars per ton dry solids)				Total Annual Costs[a] (dollars per ton dry solids)	
	0.1 Ton Per Day	1 Ton Per Day	10 Ton Per Day	100 Ton Per Day	0.1 Ton Per Day	1 Ton Per Day	10 Ton Per Day	100 Ton Per Day	1 Ton Per Day	100 Ton Per Day
Gravity Thickening										
5 pounds dry solids per square feet per day	0.062	0.12	0.27	0.95	50.0	13.0	5.7	3.2	49.77	6.11
10 pounds dry solids per square feet per day	0.047	0.085	0.20	0.70	30.0	8.5	3.7	2.0	34.55	4.15
20 pounds dry solids per square feet per day	0.035	0.063	0.15	0.48	20.0	5.8	2.4	1.2	25.11	2.67
Flotation Thickening										
10 pounds dry solids per square feet per day	0.05	0.09	0.25	0.90	100.0	23.0	6.0	2.5	50.58	5.26
20 pounds dry solids per square feet per day	0.04	0.07	0.20	0.70	70.0	16.0	4.0	1.8	37.45	3.95
Anaerobic Digestion										
3 percent dry solids in feed	0.060	0.22	1.10	14.0	75.0	18.0	7.8	4.8	85.36	47.67
4 percent dry solids in feed	0.055	0.18	0.90	9.7	52.0	14.0	6.7	4.2	69.11	33.90
5 percent dry solids in feed	0.046	0.16	0.72	7.2	39.0	9.5	4.2	3.7	48.99	25.45
Aerobic Digestion										
3 percent dry solids in feed (15 day detention)	0.056	0.18	0.8	5.0	290.0	88.0	33.0	19.0	143.16	34.32
Centrifuges, 3 to 5 percent dry solids										
with polymers	–	0.20	0.44	1.5	–	70.0	25.0	15.0	131.29	19.60
without polymers	–	0.20	0.44	1.5	–	17.0	8.7	6.8	78.29	11.40
Pressure Filtration	0.08	0.2	0.7	4.2	140.0	48.0	24.0	16.0	109.29	28.87
Vacuum Filtration	0.045	0.1	0.4	2.6	100.0	30.0	11.0	8.0	60.65	15.97
Sludge Drying Beds										
12 pounds per square feet per year	0.032	0.13	1.2	12.0	80.0	35.0	30.0	27.0	74.84	63.78
20 pounds per square feet per year	0.018	0.075	0.7	7.0	62.0	28.0	25.0	25.0	50.99	46.45
Sludge Drying Lagoons (low range capital costs)	0.01	0.038	0.15	0.59	35.0	16.0	8.0	6.0	27.65	7.81
Multiple Hearth Incineration										
25 percent dry solids	0.25	0.6	1.4	6.0	400.0	88.0	23.0	15.0	271.88	33.39
40 percent dry solids	0.20	0.5	1.7	5.0	210.0	50.0	15.0	9.0	203.24	24.32
Truck Hauling, assume 10-mile haul										
3 percent dry solids	–	–	–	–	35.0	35.0	35.0	35.0	35.0	–
5 percent dry solids	–	–	–	–	15.0	15.0	15.0	15.0	15.0	–
20 percent dry solids	–	–	–	–	5.0	5.0	5.0	5.0	5.0	5.0
40 percent dry solids	–	–	–	–	4.0	4.0	4.0	4.0	4.0	4.0
Land Spreading										
3 to 5 percent dry solids	–	–	–	–	58.0	25.0	14.0	10.0	25.0	10.0
20 to 40 percent dry solids	–	–	–	–	15.0	4.2	2.4	1.8	4.2	1.8

[a] *Total project cost (1.27 x construction cost) annualized for 20 years at 6 1/8 percent plus annual operation and maintenance costs.*

Source: Stanley Consultants and SEWRPC.

Sludge treatment costs can be expected to vary greatly. Factors involve not only what unit processes will be applied, but where those unit processes would be applied. Traditional practice has been to develop a sludge handling program for every treatment facility. This has resulted in underutilization of equipment at most plants of less than 1 mgd. A more regional approach where sludge is directed to aerated holding tanks at small facilities and transferred by tank trucks to larger facilities for ultimate processing should be explored in subsequent 208 planning efforts.

Nonconventional System Costs

Various combinations of the conventional facility unit operations presented previously are and will continue to be used by the majority of treatment facilities in the Region. Extended aeration package plants generally have incorporated aerobic digestion followed by land spreading. Biological sludges, and combined aluminum or iron salt and biological sludges, have usually been anaerobically digested and followed by drying beds and land disposal for small facilities (design flow less than 5 mgd). Larger facilities have incorporated thickening and mechanical dewatering. Detailed investigations have been carried out prior to selecting a specific process arrangement at a given facility.

Several nonconventional unit operations are applicable for large facilities where economies of scale and space limitations make the systems attractive. Large-scale sludge processing and disposal facilities can be constructed and operated to serve a single wastewater treatment facility (the usual case) or to treat the combined sludges from several independent treatment facilities (a possible trend in metropolitan areas if financing and management problems can be resolved).

Selection of an overall approach to solids handling for larger facilities requires detailed performance and cost evaluations of various alternatives. The results of some of the current trends from completed investigations are reviewed in this chapter, but costs are presented only to show the general magnitude of investment required and cannot be a substitute for detailed investigations of alternatives.

Expected advances and costs are presented for each of the major unit operations in sludge handling and disposal.

Thickening

Gravity, air flotation, and centrifugal thickening of wastewater treatment plant sludges have been discussed. Operating experience with activated sludge systems utilizing pure oxygen as the oxygen supply indicates that higher solids (1.5 to 3.0 percent) concentrations occur in waste activated sludge which may be thickened to 4 to 6 percent solids by the gravity thickening process (eliminating the need for the more expensive flotation thickening system). Other considerations are usually involved in selecting pure oxygen systems.

The major future advances in thickening technology will be to reduce effects on total plant performance by adding systems to remove fines from thickener return streams. Conventional practice is to return the centrate, filtrate, or thickener underflow directly to the head end of the plant. These fines can build up in the system and cause high solids carryover in plant effluents. Separate treatment of this recycle stream can reduce this problem but at increased system cost.

Conditioning and Stabilization

Conventional practice consists of using aerobic and anaerobic digestion to stabilize sludge and polymers or ferric chloride and lime to condition the sludge to aid in dewatering. The anaerobic digestion process is widely used in the Region. It has the advantage of solids reduction and methane gas generation which provides fuel for other treatment operations. Systems employing heated digesters, mixing, and dispersed solids feeding systems in a two-stage arrangement (one digester for storage and one for digestion) are typical of current design practice. Aerobic digesters are used where operational simplicity is advantageous. They usually have lower capital costs, but much higher operating costs than anaerobic digesters.

Thermal conditioning (heat treatment) offers a system of conditioning solids without the use of chemicals. The relative trade-off is between the costs of energy to supply the heat and pressure and the additional liquid treatment costs to handle the recycled cooking liquor, versus the cost of chemicals to achieve comparable water removal in dewatering processes. Operating results indicate that solids contents of vacuum filtered sludges following thermal conditioning are 35 to 45 percent, about double conventional vacuum filter performance with chemical conditioning.[3] The hydrolysis of sludges releases considerable soluble organic matter to the transport water which may require separate handling. The stabilized, high solids content sludges from dewatering systems following heat treatment have been applied to land without further processing. Typical costs for heat treatment, including aeration of returned supernatant are indicated in Table 10.

Chemical conditioning will continue to be used in many systems. Major advances can be expected in using high molecular weight polymers as substitutes for ferric chloride and lime and other methods to reduce chemical costs. Tests with various materials on a particular sludge are required to obtain optimum chemicals and dosages. Costs can be expected to range from $7 to $10 per dry ton processed for chemicals alone in chemical conditioning. Elutriation (washing of sludge with water to lower alkalinity) has been used to lower conventional chemical costs. This process is not needed for most polymers since they are not adversely affected by high alkalinity.

Freezing, like heat treatment, alters the physical and chemical integrity of sludges. Past investigations in

[3] *Stanley Consultants, Sludge Handling and Disposal, Phase 1—State-of-the-Art.*

Milwaukee[4] and elsewhere indicate that the high costs for freezing make it unattractive. Natural freezing during winter conditions has also been considered, but the process would not be as reliable as other methods.

In addition to these systems itemized above, high lime and chlorine oxidation have been used to stabilize sludges. Operating data and costs are limited for these options.

Dewatering

Dewatering is used where high solids contents are needed in subsequent processing operations or where hauling costs indicate savings in hauling a more concentrated sludge. High solids contents (40 to 50 percent) usually are advantageous for incineration and may become necessary for acceptance of sludge in sanitary landfills in the future. Intermediate solids levels (20 to 30 percent) are usually adequate for incineration processes, the economic trade-off being between energy costs for water evaporation in the incinerator versus the costs of producing a drier sludge for charging to the incinerator. Lower solids levels usually are adequate for reducing transport cost and for land application systems.

Conventional practice at small facilities in the Region includes use of sand drying beds, drying lagoons, or direct land application of digested sludge. Larger facilities, due to decreased land availability, usually incorporate mechanical dewatering prior to subsequent processing or disposal. Problems of performance at reasonable chemical costs have often been due to variations in quantities and characteristics of sludges input to the processes. Increasing use of sludge holding tanks to equalize loadings can be expected in future design. Typical costs for sludge holding tanks are given in Table 11.

Long-term storage for subsequent land application usually can be more economically done in earthen lagoons. Costs for unlined earthen lagoons are provided in Appendix B. Lining a lagoon in areas where there is seepage to groundwater may be a problem with the cost ranging from $0.30 to $2.00 per square foot of lagoon sides and bottom depending on lining material.

The technology and design of all available dewatering methods is constantly under development. This development may lead to lower costs for conventional facilities than presented herein and the application of lower cost-lower performance systems where subsequent processing or disposal steps do not require high solids concentrations.

Incineration and Product Recovery

Conventional practice in incineration and product recovery, where carried out, includes the multiple hearth incinerator and fertilizer production following dewatering and sludge drying (flash dryer, rotary kiln, multiple hearth). Efforts are continuing to make composting, animal feed production, and use of sludge in construction materials economically attractive. No major commercial systems have been successful due to lack of suitable markets for processed sludge or manufactured end products and the high cost of converting sludge to a marketable product, although several demonstration type facilities have been placed in operation as described in Chapter III.

Recent trends in incineration and product recovery that appear to be economically viable options include:

1. Joint incineration of sludge and refuse (or using refuse derived fuel and sludge as supplemental fuel in power plants).

2. Heat recovery boilers on incinerators using waterwall construction.

3. Joint pyrolysis of sludge and refuse.

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[4] *Sewerage Commission of the City of Milwaukee for U. S. Environmental Protection Agency, Evaluation of Conditioning and Dewatering Sewage Sludge by Freezing, January 1971.*

Table 10

HEAT TREATMENT COSTS

Dry Solids Loading (ton/day)	Construction Cost[a,b] (dollars)	Operating Costs[a,c] (dollars/ton)
1	400,000	50-80
10	850,000	15-30
100	5,500,000	10-20

[a] *ENRCCI = 2,445, August 1976.*

[b] *Cost includes decant tank, reactor, boiler, wet scrubber, and carbon adsorption of off gasses, and aeration of recycle stream prior to returning to treatment plant.*

[c] *Costs vary as a function of strength of cooking liquor and volume and extent of off-gas treatment. Higher cost should be used for regional analysis.*

Source: U. S. Environmental Protection Agency and R. Culp, presentation at Wastewater Treatment and Reuse Seminar, South Lake Tahoe, October 28, 1976.

Table 11

SLUDGE HOLDING TANK COSTS

Tank[a] Volume (1,000 cubic feet)	Capital Cost[b] (dollars)	Annual Operating Cost[b] (dollars)
1	24,000	2,500
10	70,000	7,000
100	270,000	22,000

[a] *Concrete tanks, usually sized to hold one day's sludge production.*

[b] *ENRCCI = 2,445, August 1976.*

Source: Stanley Consultants.

Joint incineration of sludge and refuse is advantageous because the heating value of shredded refuse usually is high enough so that auxiliary fuel, the major operating cost of conventional incinerator systems, is not required. Various ratios have been used depending on sludge type and water content, but it appears that greater than a 4:1 refuse/sludge ratio is required to avoid the need for some auxiliary fuel. Total system practicality often is more a function of transport and refuse preparation requirements than of incinerator costs as the different waste streams need to be brought together and mixed well for processing. Larger capacity units are required to process the increased quantities handled. The concept, although economically viable, has not been totally technically successful to date.[5] Using sludge in conjunction with refuse-derived fuel has been explored to a limited degree.

Reported costs for incineration systems are presented in Table 12. From 1.5 to 2 pounds of steam is produced per pound of sludge (dry weight basis). Production of from two to three pounds of steam per pound of refuse is common. It should be noted that incineration systems usually have not been considered if land for other disposal options is readily available.

Joint pyrolysis (destructive distillation using heat and pressure) of sludge/refuse mixtures is being examined in a number of areas. The proposed system at Minneapolis/St. Paul is the most extensively evaluated to date. Detailed estimated costs of sludge processing unit operations are reported in Table 13. A recent decision has been made not to implement construction of the proposed system.

Costs for nonconventional systems presented in this chapter will provide a guide to the general order of magnitude of costs to be expected. These general costs cannot be substituted, for detailed investigations at particular facilities or regional facilities in the regional planning effort.

Transportation

Conventional practice in the Region is to use trucks for transporting solids from the point of processing to the point of ultimate disposal. Other major commodity transport systems (rail, barge, and pipeline) have been examined as alternatives to truck-based systems. Comparative costs must be developed for a particular system. Table 14 lists the comparative costs from one study.[6]

Total system transport costs using combinations of these factors may serve in regional planning investigations prior to more detailed analyses of specific systems. The necessity of intermodal transport in most systems requires that docking and transfer facilities be included in system analyses.

[5] *Municipal Sludge Management and Disposal, Proceedings of the National Conference on Municipal Sludge Management and Disposal, Anaheim, California, August 18-20, 1975.*

[6] *U. S. Environmental Protection Agency, Decision-Makers' Guide in Solid Waste Management, EPA SW-500, 1976.*

Table 12

INCINERATION COSTS

Process	Capacity (ton/day)		
	10	100	1,000
Refuse Incineration[b]			
Capital Cost (millions of dollars)	1.8	6.0	22
Operating Cost (dollars per ton)	23.0	15.0	12
Refuse/Sludge Incineration[c]			
Capital Cost (millions of dollars)	2.2	7.2	24
Operating Cost (dollars per ton)	20.0	12.0	8
Refuse/Sludge Incineration with Heat Recovery			
Capital Cost (millions of dollars)	3.5	9.0	26
Operating Cost[d] (dollars per ton)	23.0	14.0	10

[a] *Costs based on ENRCCI = 2,445, August 1976.*

[b] *Based on 25 percent solids feed, approximately $8 per ton of Operation and Maintenance cost is for fuel.*

[c] *Based on 4:1 ratio of refuse to sludge and refuse shredding at $4 per ton.*

[d] *A potential income of $3 to $5 per ton for the sale of steam may be available and, if so, could be expected to reduce operating costs shown.*

Source: Stanley Consultants and Municipal Sludge Management, Proceedings of the National Conference on Municipal Sludge Management, Pittsburgh, Pennsylvania, June 11-13, 1974.

Table 13

SLUDGE PROCESSING UNIT COSTS

Process	Design Capacity (tons per day)	Capital Cost (million dollars)	Operation and Maintenance Cost (dollars per ton)
Flotation Sludge Thickeners			
(16 at 55-foot diameter)	240	18.4	4.82
Storage Tanks (8)	232	6.5	1.25
Heat Treatment[b]			
(8 at 10,500 gallons per hour) . . .	232	26.4	5.99
Dewatering by Vacuum Filters			
and Filter Presses.	186	9.6	7.84
Rotary Kiln Drying[c]	142	15.9	11.19
Heat Recovery[d]	240	13.8	4.62
Pyrolysis System[e]			
(per eight-hour day)	360	21.5	17.50

[a] *A total of 75 to 85 percent of the existing primary sludge will be processed in existing facilities consisting of storage tanks, gravity thickeners, vacuum filters, and incinerators. These facilities have a 240-ton per day capacity and cost $12.5 million to construct. Operation and maintenance costs reported for these facilities are as follows: storage, $0.30 per ton; vacuum filter dewatering, $11.93 per ton; and incineration $9.14 per ton. Using pyrolysis off-gases for auxiliary fuel was expected to lower incinerator cost to $6.00 per ton.*

[b] *The relatively low operation and maintenance is due to use of pyrolysis gases as energy source. Without this gas use, operation and maintenance would be $12.65 per ton.*

[c] *Without using sludge incinerator off-gases, operation and maintenance cost would be $21.02 per ton. The dryer product will be used as fertilizer in a manner similar to the Milwaukee system.*

[d] *A heat recovery system is to be added to the existing primary sludge incinerator system. Capacity and operation and maintenance costs are related to capacity of this system.*

[e] *The pyrolysis system will process 64 tons per day of sludge (dry weight) plus 260 tons per day of shredded refuse (wet basis). Design capacity is 360 tons of refuse/sludge/water per day. Operation and maintenance cost is given for this combination. On a dry weight basis, this cost would be about $24 per ton.*

Source: Metropolitan Waste Control Commission/Twin Cities Area, Final Report, Sludge/Refuse Pyrolysis System, St. Paul, Minnesota, June 1975.

Ultimate Disposal

Options available within the Region for ultimate disposal include landfills and surface land spreading. Costs for the systems can be expected to be quite variable depending upon land cost, site preparation costs, and the cost of applying the sludge. Concern over heavy metal toxicity and nitrate leaching has reduced allowable loading rates for surface spreading in recent years. In 1967 application rates of 100 to 200 tons per acre per year were thought reasonable.[7] The trend has been to reduce this significantly to 10 to 20 tons per acre per year based primarily on nitrogen loadings. Philadelphia[8] estimated a maximum

[7] *R. S. Burd by Dow Chemical for Federal Water Pollution Control Administration, Department of the Interior, A Study of Sludge Handling and Disposal, WP-20-4, May 1968.*

[8] *Municipal Sludge Management and Disposal, Proceedings of the National Conference on Municipal Sludge Management and Disposal.*

Table 14

TRANSPORTATION COSTS

	Cost[a] (dollars per dry ton per mile)
Transport (3 to 5 percent solids)	
Tank truck	3.00
Railroad.	0.25
Barge	0.20
Pipeline	1.55
Transport (20 to 40 percent solids)	
Dump truck.	0.65
Railroad.	0.25
Pipeline	Infeasible
Barge	0.03

[a] *Based on 1974 dollars.*

Source: U. S. Environmental Protection Agency.

application of two tons per acre per year using the draft U. S. EPA guidelines to determine heavy metal limitations for the area. As noted in Chapter IV, however, the portion of this draft guideline regarding heavy metals loading limitations has met with significant controversy, and the June 1976 draft of the U. S. Environmental Protection Agency technical bulletin covering land application of sludge dropped the zinc equivalent formula, resulting in no definitive national guidelines that limit sludge application based upon heavy metals loadings. As application rates are reduced, land costs can be expected to increase as a percentage of total cost and may make other processing alternatives more economical than land spreading.

In many respects, the available ultimate disposal options determine the need for other sludge processing unit operations and thus the total cost for sludge handling and disposal. If land spreading is an available option, then transport to the site can be accomplished using tank trucks. Tank trucks used for sludge spreading are available in 1,200-, 2,500-, and 5,500-gallon capacities. Some may be equipped with systems to inject sludge below the ground surface. The trucks cost from $14 to $20 per gallon of capacity and have an operating cost of $0.30 to $0.45 per mile (smaller trucks cost more per unit capacity, but are cheaper to operate). The sludge may be stored in lagoons at the disposal site prior to application. Table 15 has been developed from information presented in the Proceedings of the National Conference on Municipal Sludge Management and Disposal, Municipal Sludge Management and Disposal, at Anaheim, California, August 18-20, 1975 and may be indicative of costs for alternative application methods at the disposal site.

Table 15

COMPARATIVE COSTS OF APPLICATION METHODS

Application Method	Development Cost (dollars per acre)	Operating Cost (dollars per dry ton)
Center Pivot Irrigation . . .	150	2.60
Traveling Arm Irrigation . .	150	4.35
Solid Set Irrigation	360	2.10
Plow-In.	90	7.10
Surface Application.	100	6.70

Source: Municipal Sludge Management and Disposal, Proceedings of the National Conference on Municipal Sludge Management and Disposal, Anaheim, California, August 18-20, 1975.

Specific costs experienced at a number of facilities using a number of unit processes are summarized in Table 16. These costs can be used to guide costs for regional analysis purposes prior to detailed studies at a particular site for purposes of facility design.

Total Sludge Management Costs

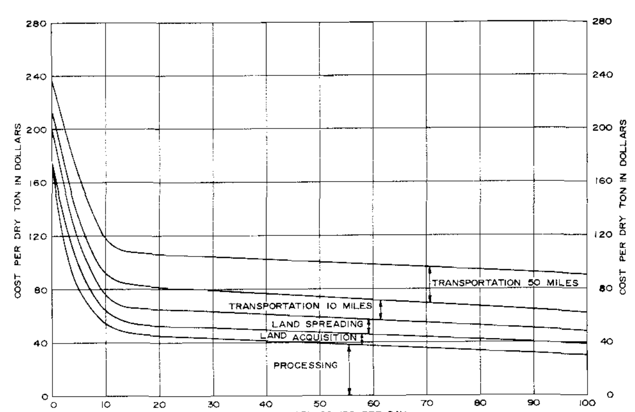
Figure 5 has been developed from the cost curves presented in Appendix B to generally depict the relative costs for the various phases of sludge management. The land acquisition cost was based upon a cost of $850 per acre, which is an average of the sale prices of land in the Region, excluding Milwaukee County, during 1975 as reported by the Wisconsin Department of Revenue. An average loading rate of eight tons of sludge per acre per year was assumed to determine the land acquisition cost.

SEPTAGE TREATMENT COSTS

The incremental cost of processing septage in municipal wastewater treatment facilities can be approximated using the cost curves (Appendix B) for unit processes. Separate treatment facilities for septage can also be estimated using the cost information provided herein.

Figure 5

PROCESSING, TRANSPORTATION, AND UTILIZATION COSTS



Source: Stanley Consultants and SEWRPC.

Table 16

WATER TREATMENT PLANT SLUDGE DISPOSAL: REPORTED OR PREDICTED COSTS

Process	Plant Location	Plant Size: Average Flow (mgd)	Plant Size: Design Flow (mgd)	Sludge Type	Cost (dollars per ton)	Cost (dollars per mg)	Date of Cost Analysis	Notes	Reference
Lagoons	--	--	--	Alum	40.0		1969	Predicted cost cited as maximum probable cost for lagooning alum sludge	American Water Works Research Foundation, Disposal of Wastes from Water Treatment Plants, 1969
	New Britain, Connecticut	9.0	20	Alum	39.00	3.30	1969		Ibid.
	Sommerville, New Jersey	90.0	170	Alum	2.00	0.09	1969		Ibid.
	Willingboro, New Jersey	3.0	10	Lime	33.50	4.90	1969		Ibid.
Sand Drying Beds	San Francisco, California (Sunol Valley Plant)	--	40	Alum	56.60	1.18	1969		Ibid.
	Lompoc, California	4.1	7	Lime	4.89	24.20	1969		Ibid.
Mechanical Dewatering and Disposal									
Filter Press	Oakland, California (Sobrante Filter Plant)	22.0	40	Alum	52.00	--	1974	Predicted cost (includes sludge conditioner and filter press precoat)	American Water Works Association, Processing Water Treatment Plant Sludge, 1974
	Hypothetical	--	100	Alum	--	6.90	1974	Predicted cost	Ibid.
	Sturgeon Point, Evans, New York	50.0	90	Alum	126.00	11.58	1975	Predicted cost	Ibid.
	England	--	--	Alum	20.20	--	1971		G. L. Culp and R. L. Culp, New Concepts in Water Purification, 1974
Scroll Centrifuge	Oakland, California (Sobrante Filter Plant)	22.0	40	Alum	56.00	--	1974	Predicted cost	American Water Works Association, Processing Water Treatment Plant Sludge
	Sturgeon Point, Evans, New York	50.0	90	Alum	132.00	12.10	1975	Predicted cost	Ibid.
	Hypothetical	--	10	Lime	11.40	11.40	1969	Predicted cost	American Water Works Research Foundation, Disposal of Wastes from Water Treatment Plants
	Austin, Texas	30.0	120	Lime	25.10	25.10	1969		Ibid.
Vacuum Filter	Johns-Manville Corporation	--	--	Alum	76.00	3.96	1969	Precoat filter	Ibid.
	Sturgeon Point, Evans, New York	50.0	90	Alum	175.00	16.06	1975	Precoat filter; predicted cost	American Water Works Association, Processing Water Treatment Plant Sludge
	Oakland, California (Sobrante Filter Plant)	22.0	40	Alum	62.00	--	1974	Precoat filter; predicted cost	Ibid.
	Hypothetical	--	10	Alum	122.00	25.40	1969	Precost filter; predicted cost	American Water Works Research Foundation, Disposal of Wastes from Water Treatment Plants
	Minot, North Dakota	3.5 to 10	--	Lime	7.29	21.80	1969		Ibid.
	Boca Raton, Florida	7.6	23	Lime	16.00	16.00	1969		Ibid.
	Hypothetical	--	10	Lime	12.35	12.35	1969	Predicted cost	Ibid.
Freeze-Thaw	Sturgeon Point, Evans, New York	50.0	90	Alum	161.0	14.78	1975	Predicted cost	American Water Works Association, Processing Water Treatment Plant Sludge
	England	--	--	Alum	55.50	--	1971		G. L. Culp and R. L. Culp, New Concepts in Water Purification
	Hypothetical	--	20	Alum	88.00	--	1976	Predicted cost exclusive of labor, cake disposal, and prethickening; cited as being economical alternative above 40 mgd plant size	Wilhelm and Silverblatt, "Freeze Treatment of Alum Sludge," Journal of the American Water Works Association, 68, June 1976
			40	Alum	60.00	--	1976		
			60	Alum	48.00	--	1976		
			80	Alum	44.00	--	1976		
Recycle or Recovery Process									
Lime Recalcination	Dayton, Ohio	60.0	110	Lime	0.79[a]	2.20[a]	1969		American Water Works Research Foundation, Disposal of Wastes from Water Treatment Plants, 1969
	Lansing, Michigan	23.0	40	Lime	2.00	2.60	1969	Does not produce enough lime to supply own needs	Ibid.
	Miami, Florida	81.0	120	Lime	5.08[a]	6.95[a]	1969	Approximately 22 percent of recalcined sludge is mined from lagoon from past accumulations	Ibid.
Alum Recovery	Hypothetical	–	100	Alum		2.30	1974	Predicted cost	American Water Works Association, Processing Water Treatment Plant Sludge
	Sturgeon Point, Evans, New York	50.0	90	Alum	165.00	15.13	1975	Predicted cost	Ibid.
	Hypothetical	–	--	Alum	--	–	1976	Predicted cost; cited as being economical alternative above 20 mgd plant size	C. W. Randall, et al, "Alum Recovery from Representative Water Treatment Plant Sludges," Journal of the American Water Works Association, 68, April 1976

[a]*Profit from resale of lime.*

Source: Stanley Consultants.

Chapter VII

NONCOST FACTORS IN PROCESS SELECTION

INTRODUCTION

In evaluating alternative residue handling and disposal systems, consideration must be given to a number of factors in addition to technical feasibility and direct costs. These considerations generally involve secondary and/or long-term effects of the alternative systems. Although they may not seem particularly important initially, these factors often make the difference between well designed, cost-effective facilities that work and those that do not.

RESOURCE CONSUMPTION

Energy Requirements

The energy requirements of sludge handling and disposal processes should be considered during process selection in order to minimize total life-cycle costs and resource/environmental effects. In many cases, decreased costs for smaller units are traded for higher operating costs (such as labor and power) due to longer periods of operation. Increased energy usage contributes to secondary environmental effects at the power plant and fuel source. The existing energy situation as well as the anticipated future energy shortage and sharply rising fuel costs have made process energy requirements increasingly important. Table 17 lists typical energy requirements for several sludge handling systems of various capacities.

Chemical and Other Material Use

The economic cost of chemical and other material usage is incorporated in the operation and maintenance costs presented on the cost curves. However, additional environmental costs are associated with the manufacturing and raw material mining of the material consumed. Selection of a process involves a long-term commitment to these secondary environmental effects. Table 18 lists typical chemical uses in sludge processing, and Table 19 presents approximate energy requirements to produce the chemicals.

LEGAL CONSTRAINTS

Existing waste treatment laws, as well as grant and bonding regulations, affect sludge handling and disposal decisions in various ways. An attempt is made here to summarize the major legal constraints involved. Until recently, handling and disposal of sludges and other residues has been largely neglected by regulations as well as by public works engineering practice. Legal precedent as a result of litigation is constantly changing and must be considered for each individual case.

Waste treatment regulations, such as Chapters NR 110 and NR 111 of the Wisconsin Administration Code, specify which unit operations may be applied as well as the basic design parameters to be used. Although the

Table 17

TYPICAL SLUDGE UNIT PROCESS ENERGY REQUIREMENTS

Unit Operation	Sludge Quantity (pounds dry solids per day)			
	200	2,000	20,000	200,000
Thickening				
Gravity (kwh per day)	10	15	30	50
Flotation (kwh per day)	50	360	4,000	27,000
Anaerobic Digestion				
Mixing (kwh per day)	50	150	500	4,000
Heating[a] (10^6 Btu per day)	0.1	1	10	100
Chemical Conditioning (kwh per day)	5	10	20	40
Mechanical Dewatering (kwh per day)	10	75	500	5,000
Sludge Incineration (10^6 Btu per day)	1	10	100	1,000
Sludge Hauling[b] (Btu per day per mile)	3,000	10,000	50,000	250,000

[a] *Methane gas generated by the digestion process normally can be burned to supply more than enough energy to heat the digester.*

[b] *Assuming dewatered sludge of 30 percent solids.*

Source: Adapted from reports of Stanley Consultants; Battelle-Pacific Northwest Laboratories for the Council on Environmental Quality; and W. F. Garber et al, "Energy-Wastewater Treatment and Solids Disposal."

Table 18

SLUDGE PROCESS CHEMICAL USE

Process	Chemical	Reported Dosage (pounds per ton dry solids)
Stabilization		
High pH	Lime	250-1,000
Chlorine oxidation	Cl_2	2,000 mg/l
Conditioning		
Gravity thickening	Polymer	3-6
Flotation thickening	Polymer	4-10
	Alum	1-20
Elutriation	Polymer	0.5-2
Vacuum Filtration	Polymer	1-35
	$FeCl_3$ + Lime	1-125 ($FeCl_3$) + 10-370 (Lime)
Pressure Filtration	Polymer	3-5
	Lime	10-15
	Fe_2O_3 + Lime	260 (Fe_2O_3) + 550 (Lime)
Centrifuge	Polymer	2-13
Capillary Dewatering Unit	Polymer	10
	$FeCl_3$	150
Drying Bed	Polymer	0.5-20

Source: U. S. Environmental Protection Agency; and R. Jacke, "Polymer Cuts Disposal Costs."

Table 19

INDIRECT ENERGY USE

Product	Energy Required for Production (10^6 Btu/ton)
Alum	2.5
Polymer	2.0
Chlorine	42
Lime	5.5

Source: D. G. Argo and G. M. Wesner, "AWT: Energy Need a Prime Concern."

regulations allow other unit operations to be used if sufficient engineering justification is submitted, the effect is to limit waste treatment to unit operations which have been well established over the years. While the intent of such rules is to minimize process failures due to unproven technology, the application of new and improved waste treatment technology is somewhat inhibited.

Present grant and bonding provisions have the effects of favoring capital-intensive alternatives and inhibiting development of private waste treatment utilities for municipal systems.[1]

[1] *Battelle-Pacific Northwest Laboratories for the Council on Environmental Quality, Evaluation of Municipal Sewage Treatment Alternatives, Contract EQC 316, February 1974.*

Section 144.03 of the Wisconsin Statutes requires all septic tanks to be registered by a permit from the county clerk. This allows quantification of septage sludge, but does not apply any control over disposal of the periodically removed solids.

Land disposal of sludges in Wisconsin requires submittal of a facilities plan according to Section 147.26(2)(6) of Chapter 147, State of Wisconsin Laws of 1973. DNR Bulletin No. 88 and associated documents from DNR provide detailed guidelines for preparation of such a plan in accordance with current technology.

LABOR REQUIREMENTS

The requirements for operation and maintenance manpower depend upon the degree of process automation and instrumentation. However, labor costs are a major concern in process selection. Table 20 lists typical manpower requirements for several sludge processing operations.

PUBLIC ATTITUDES

Public attitudes toward sludge disposal generally tend to be relatively negative although the recent "ecology" movement has improved public understanding to some extent. The problem remains, however, that few individuals care to have materials of sewage origin disposed of in their own neighborhood.

The most frequent public concerns involve odors, pathogenic bacteria and viruses, and unsightly conditions at sludge disposal sites. While most stabilization processes do not eliminate odors and pathogens, significant reductions in both are attainable. If required, complete pathogen destruction by heat treatment or other means can be employed. Proper training and strict supervision of operating personnel at sludge processing and disposal sites are essential to minimize aesthetic problems.

Public relations campaigns have been shown to be a critical factor in the successful sale (or free distribution) of sludge-derived products such as soil conditioners and fertilizers. Landfill and land spreading site selection and acquisition could also benefit significantly from an effective public relations effort.

As a result of poor sludge disposal practices in the past, public skepticism toward current disposal is well established. However, if proper steps are taken in conjunction with a public education program to control and minimize potential aesthetic and health problems, considerable improvements can be realized.

OTHER NONCOST FACTORS

Additional factors which do not directly involve costs must be considered when selecting sludge handling and disposal processes. Table 21 presents a summary of these for several processes.

Table 20

SLUDGE PROCESS ESTIMATED LABOR REQUIREMENTS

Process	Labor Requirements (manhours per year)			
	0.1 Ton per Day Dry Solids	1 Ton per Day Dry Solids	10 Ton per Day Dry Solids	100 Ton per Day Dry Solids
Gravity thickening	400	700	2,000	6,000
Flotation thickening	600	1,000	3,000	8,000
Anaerobic digestion	1,000	1,100	2,300	15,000
Aerobic digestion	1,000	1,800	5,300	24,000
Thermal stabilization/conditioning	2,200	2,500	5,900	40,000
Drying beds	500	3,300	26,000	200,000
Drying lagoons	400	700	1,000	5,200
Mechanical dewatering	1,000	2,000	6,000	50,000
Incineration	1,100	1,800	5,700	36,000
Lime recalcination	1,900	2,300	6,000	42,000

Source: Adapted from reports of Stanley Consultants and the Environmental Protection Agency.

Table 21

NONCOST FACTORS IN PROCESS SELECTION

Process	Land Requirements	Adverse Climatic Conditions	Ability to Handle Sludge Quantity Variations	Ability to Handle Sludge Quality Variations	Ability to Handle Industrial Pollutants	Process Reliability	Degree of Operation and Maintenance Required	Occupational[a] Hazards	Process Byproducts
Gravity Thickening	Low	–	Fair	Good	Good	Good	Low	–	Recycled liquid
Flotation Thickening	Low	–	Fair	Good	Good	Good	Moderate	Mechanical	Recycled liquid
Mechanical Thickening	Low	–	Poor	Fair	Good	Good	High	Mechanical	Recycled liquid
Anaerobic Digestion	Moderate	–	Fair	Poor	Poor	Fair	High	Explosions	Gas, recycled liquid
Aerobic Digestion	Moderate	Cold	Good	Fair	Fair	Fair	Moderate	Mechanical	Recycled liquid
Thermal Stabilization/ Conditioning	Low	–	Poor	Good	Good	Fair	High	Explosions	Recycled liquid
Chemical Stabilization/ Conditioning	Low	–	Fair	Fair	Good	Good	High	Chemicals	–
Freezing	Low	–	Poor	Good	Good	Fair	High	Mechanical	Recycled liquid
Elutriation	Low	–	Fair	Fair	Good	Good	Moderate	–	Recycled liquid
Drying Beds	High	Rainfall	Good	Good	Good	Fair	Low	–	Recycled liquid
Drying Lagoons	High	Rainfall	Good	Good	Good	Fair	Low	–	–
Vacuum Filters	Low	–	Poor	Fair	Good	Good	High	Mechanical	Recycled liquid
Centrifuges	Low	–	Poor	Fair	Good	Good	High	Mechanical	Recycled liquid
Pressure Filters	Low	–	Poor	Fair	Good	Good	High	Mechanical	Recycled liquid
Other Dewatering Units	Low	–	Poor	Fair	Good	Good	High	Mechanical	Recycled liquid
Incineration	Low	–	Poor	Good	Good	Good	High	Explosions	Aerosols, ash
Heat Drying	Low	–	Poor	Good	Good	Fair	High	Explosions	Odors, aerosols
Pyrolysis	Low	–	Poor	Good	Good	Good	High	Explosions	Aerosols, fuel, ash
Wet Air Oxidation	Low	–	Poor	Good	Good	Fair	High	Explosions	Recycled liquid
Composting	High	Cold, Rainfall	Good	Fair	Fair	Poor	High	–	Odors, compost
Animal Feed Production	Low	–	Poor	Poor	Poor	Fair	High	–	Residual sludge
Lime Recalcination	Low	–	Poor	Good	Fair	Good	High	Explosions	CO_2, aerosols
Alum/Ferric Recovery	Low	–	Poor	Good	Fair	Good	High	Chemicals	Residual solids
Landfill	High	Cold, Rainfall	Good	Good	Fair	Good	High	Mechanical	–
Land Spreading	High	Cold, Rainfall	Good	Fair	Poor	Good	High	Mechanical	–

[a] *Although these hazards exist, proper equipment design and operation should result in nonhazardous processes.*

Source: Stanley Consultants.

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APPENDICES

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Appendix A

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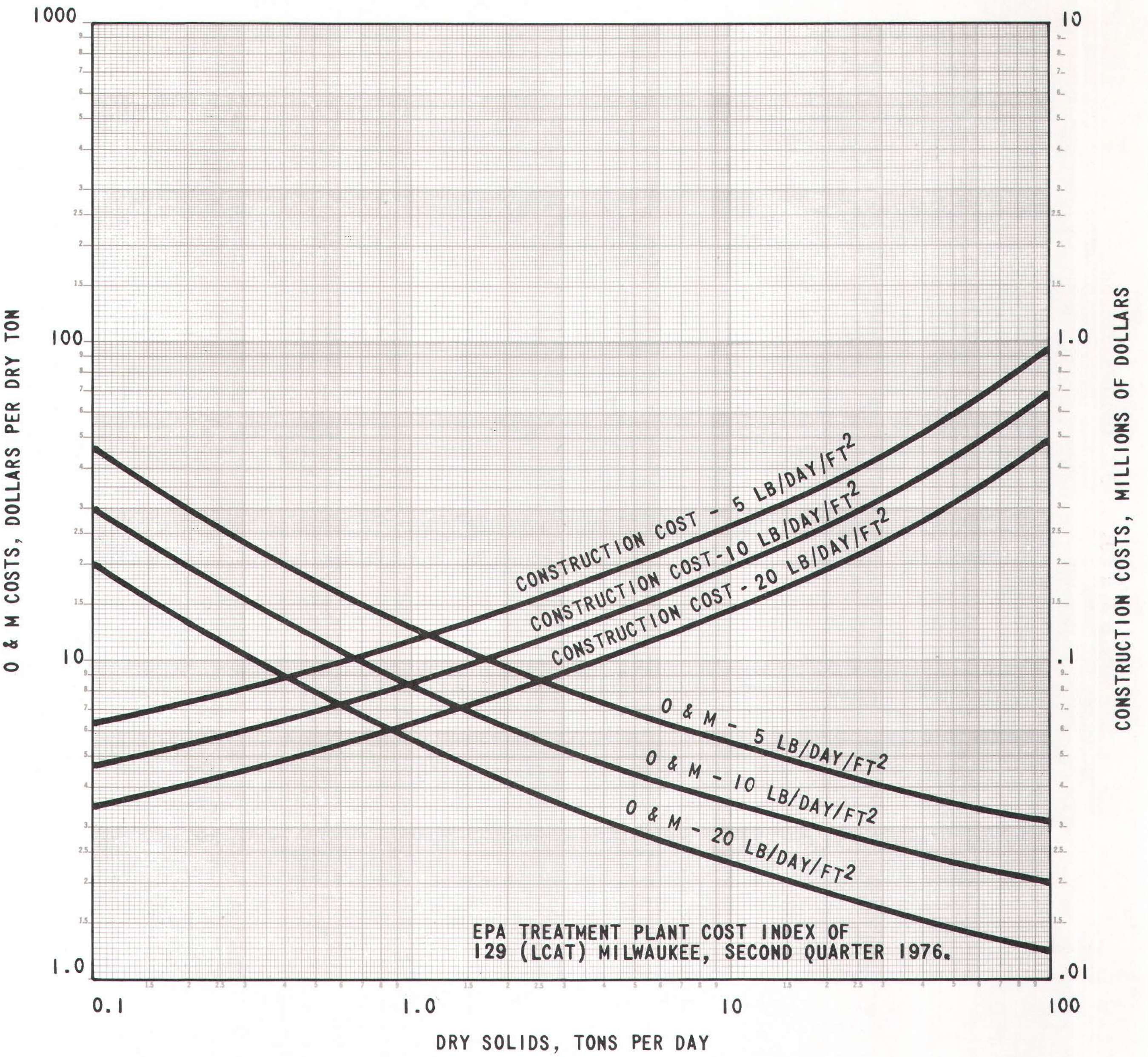
Appendix B

COST CURVES FOR CONVENTIONAL PROCESSES

Figure B-1

GRAVITY THICKENING



COSTS INCLUDE: THICKENER, CONTROLS, SLUDGE PUMPS.

COSTS BASED ON: LOADING RATE AS SHOWN, TANK DEPTH 10 FT.

NOTES:

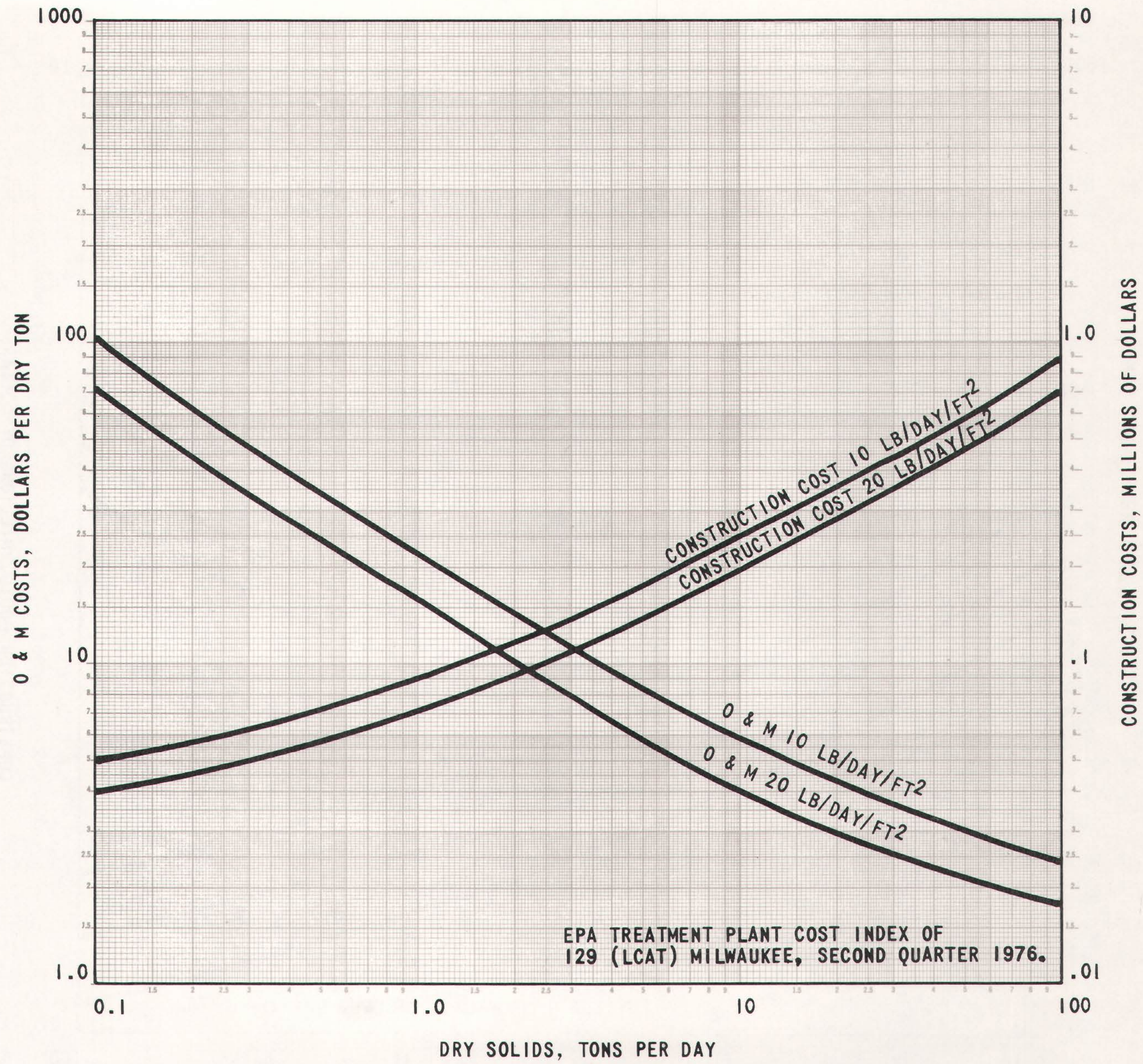
1. LOADING RATE OF 5 LB/DAY/FT^2 APPLICABLE TO WASTE ACTIVATED SLUDGE ± IRON OR ALUM. SALT ADDITION.
2. LOADING RATE OF 10 LB/DAY/FT^2 APPLICABLE TO PRIMARY SLUDGE PLUS IRON OR ALUM. SALT ADDITION, PRIMARY/WASTE ACTIVATED MIXED, OR TRICKLING FILTER SLUDGE ± IRON OR ALUM. SALT ADDITION.
3. LOADING RATE OF 20 LB/DAY/FT^2 APPLICABLE TO PRIMARY SLUDGE OR PRIMARY/TRICKLING FILTER SLUDGE MIXED.
4. EXPECTED PERFORMANCE:

LOADING RATE	INITIAL SOLIDS	UNDERFLOW SOLIDS
5 LB/DAY/FT^2	0.8-1.2%	2.5-3.5%
10 LB/DAY/FT^2	2-3%	4-6%
20 LB/DAY/FT^2	3-6%	7-10%

Source: Stanley Consultants.

Figure B-2

FLOTATION THICKENING



COSTS INCLUDE: THICKENER, CONTROLS, AIR SYSTEM, SLUDGE PUMPS.

COSTS BASED ON: LOADING RATES AS SHOWN, TANK DEPTH 10 FT.

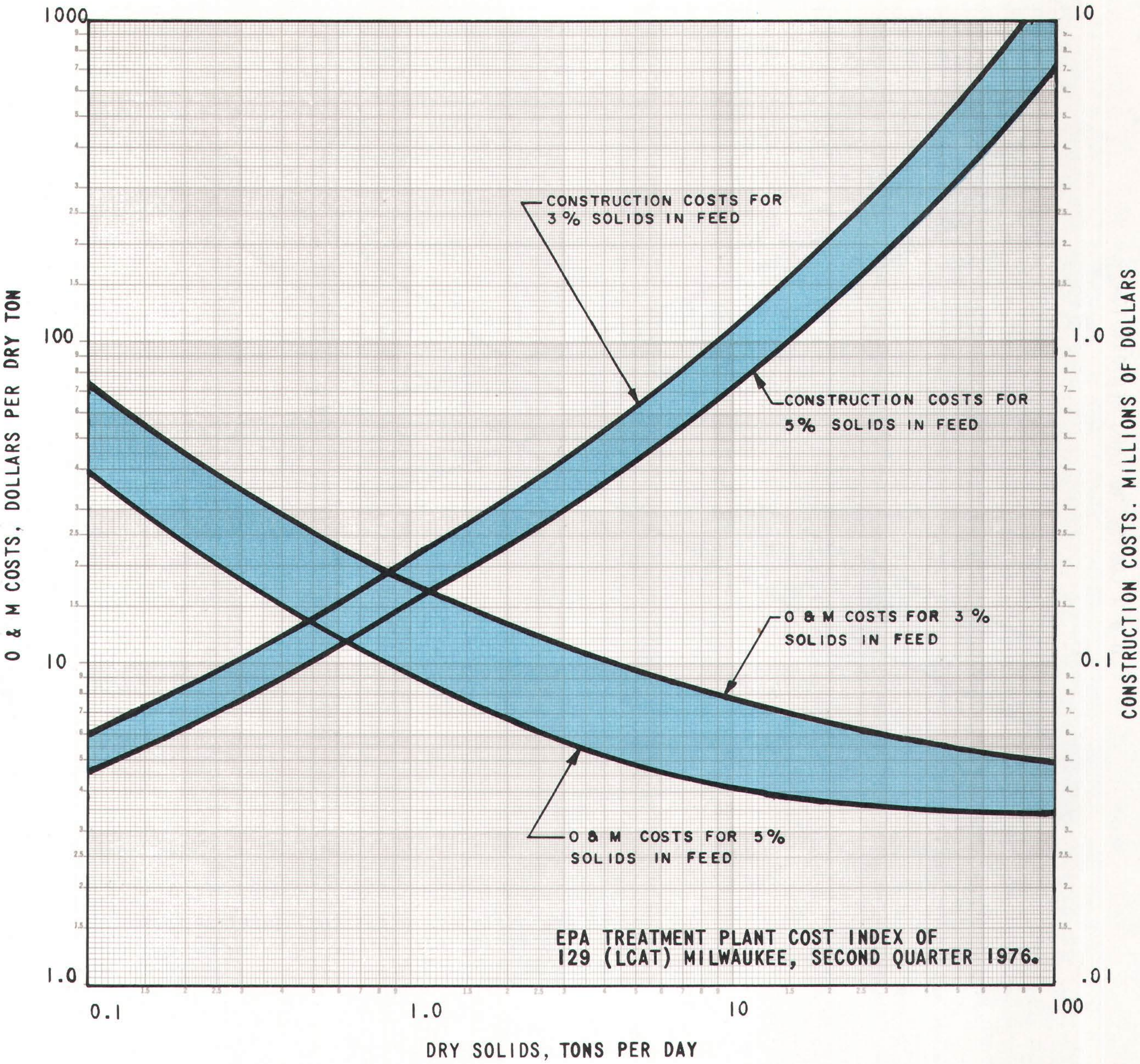
NOTES:
1. LOADING RATE OF 10 LB/DAY/FT^2 APPLICABLE TO WASTE ACTIVATED SLUDGE ± IRON OR ALUM. SALT ADDITION.
2. LOADING RATE OF 20 LB/DAY/FT^2 APPLICABLE TO PRIMARY/WASTE ACTIVATED MIXED OR PRIMARY PLUS IRON OR ALUM SALTS
3. EXPECTED PERFORMANCE:

LOADING RATE	INITIAL SOLIDS	THICKENED
10 LB/DAY/FT^2	0.8-1.2%	4-6%
20 LB/DAY/FT^2	2-3%	6-8%

Source: Stanley Consultants.

Figure B-3

TWO-STAGE ANAEROBIC DIGESTION



COSTS INCLUDE: SLUDGE HEATING, CIRCULATING, AND CONTROL EQUIPMENT TWO DIGESTION TANKS.

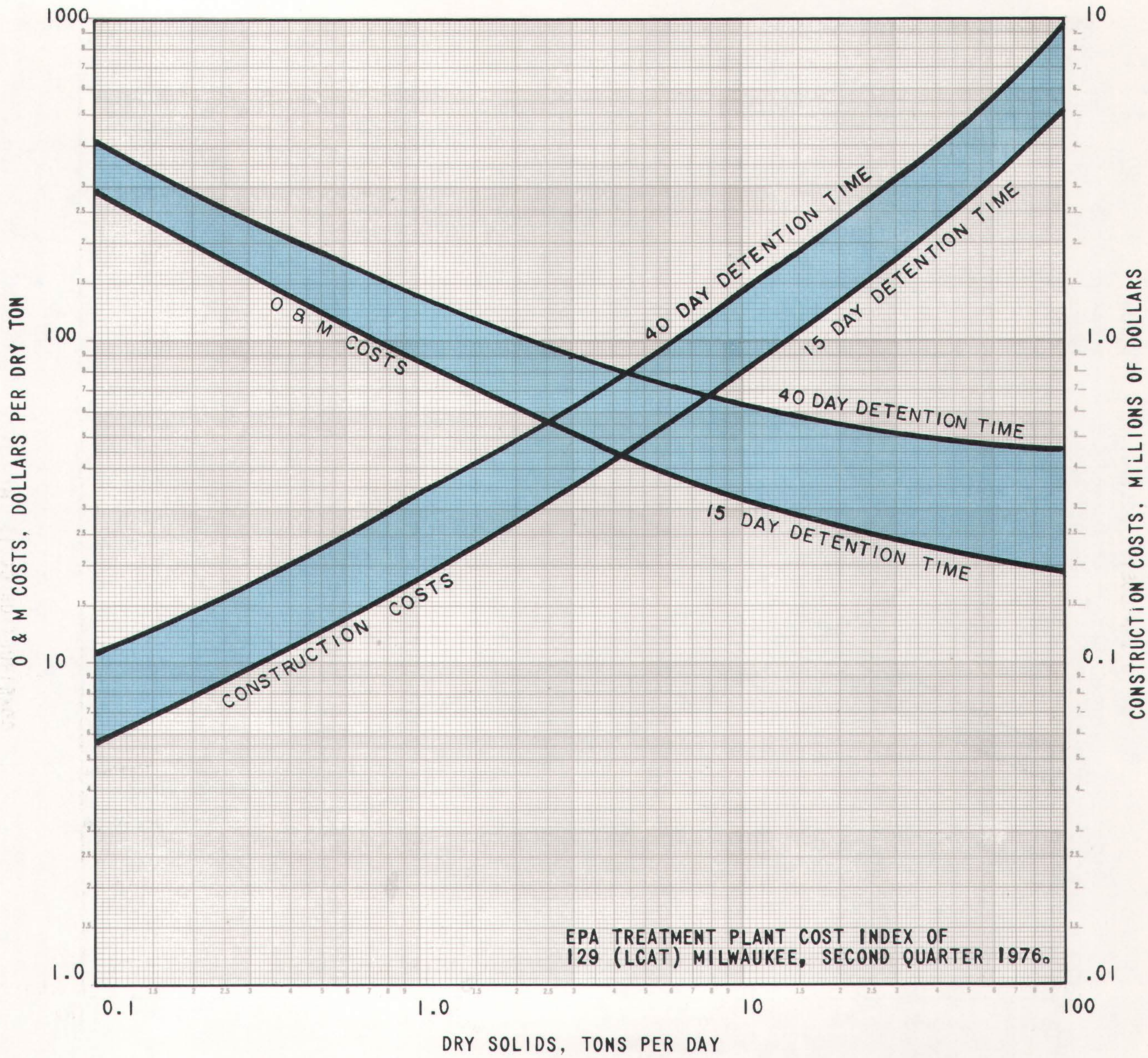
COSTS BASED ON:
1. 40 DAYS OF TOTAL DETENTION TIME IN THE TWO DIGESTER SYSTEM.
2. FEED SOLIDS AS SHOWN.

NOTES:
1. EXPECTED PERFORMANCE 40% DRY SOLIDS REDUCTION
2. 3 TO 5% SOLIDS EXPECTED IN INFLUENT TO DIGESTER
3. 3 TO 5% SOLIDS EXPECTED IN DIGESTER EFFLUENT

Source: Stanley Consultants.

Figure B-4

AEROBIC DIGESTION



COSTS BASED ON: 1. DETENTION TIME OF 15 TO 40 DAYS.
2. 3% INCOMING SOLIDS.
3. AIR SUPPLY OF 30 CFM PER 1000 CU. FT. OF TANK.

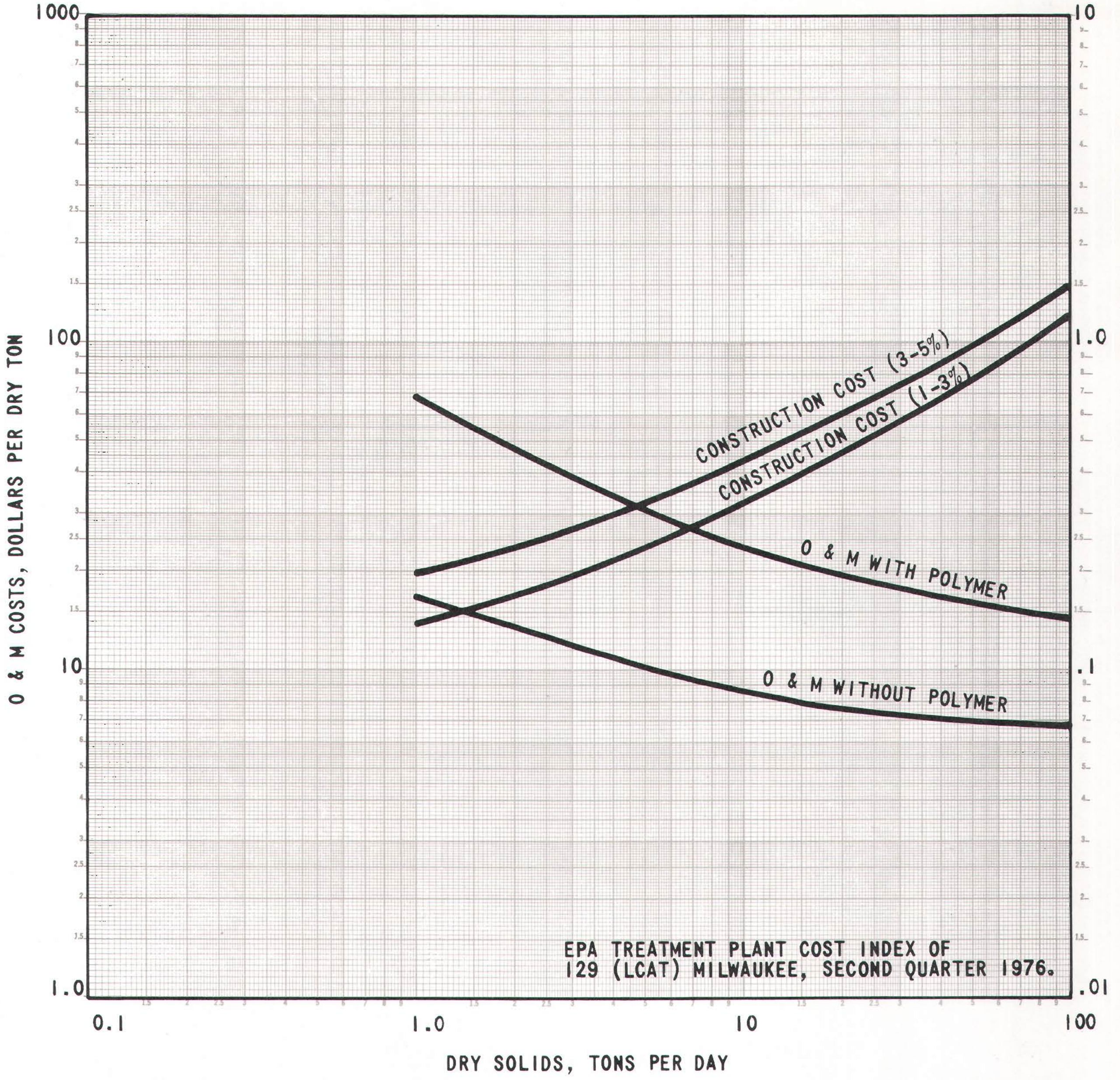
COSTS INCLUDE: TANKS AND DIFFUSED AIR SYSTEM.

NOTES: 1. EXPECTED PERFORMANCE 40% DRY SOLIDS REDUCTION.
2. 4 TO 5% SOLIDS EXPECTED FROM DIGESTER.

Source: Stanley Consultants.

Figure B-5

CENTRIFUGE DEWATERING



COSTS INCLUDE: CENTRIFUGES, CONTROLS, HOUSING.

COSTS BASED ON: LOADING AS SHOWN, POLYMER 10 LB/TON.

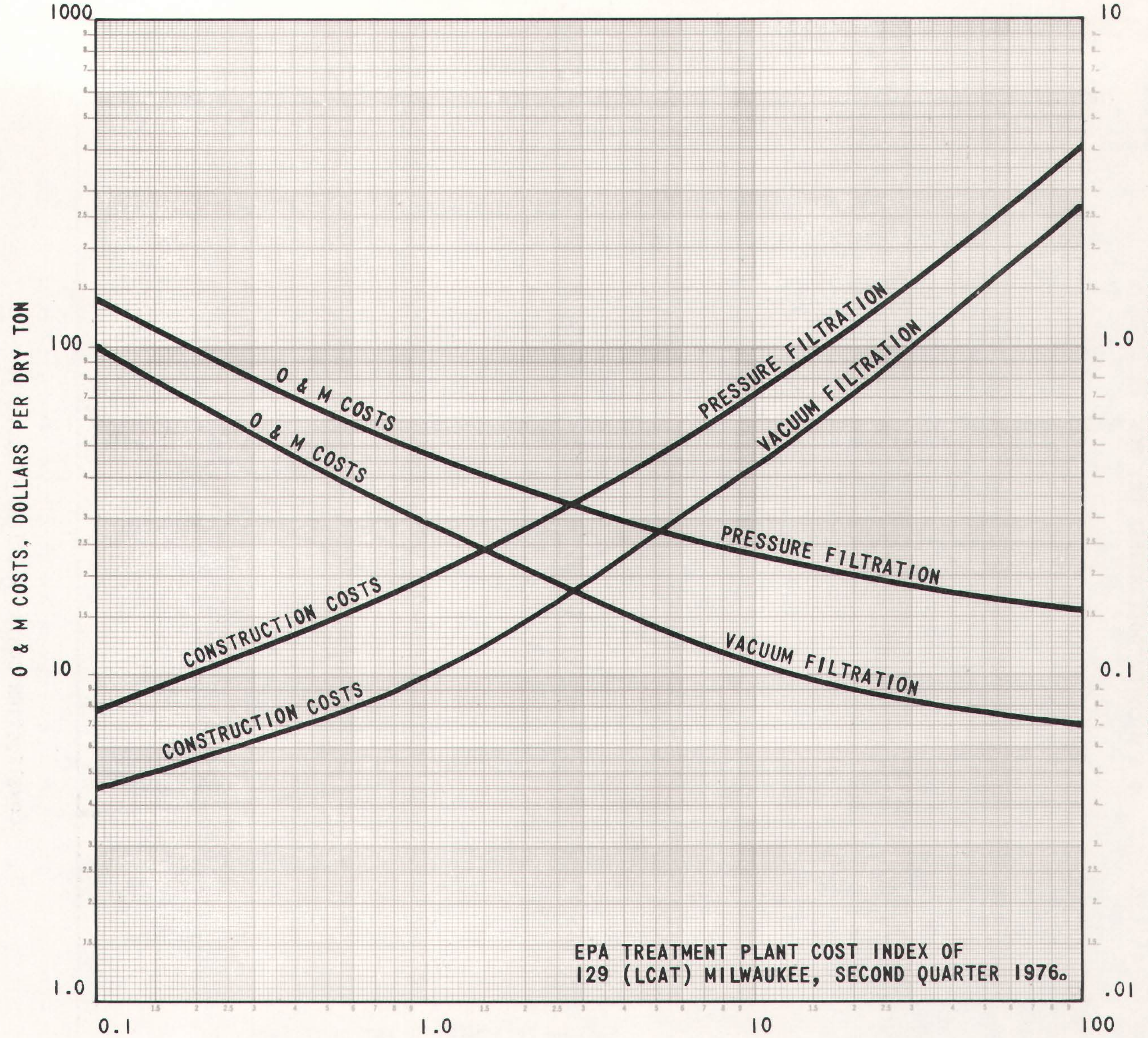
NOTES:
1. 3 $LB/FT^2/HR$ APPLICABLE TO WASTE ACTIVATED ± CHEMICALS AS THICKENER.
2. 5 $LB/FT^2/HR$ APPLICABLE TO PRIMARY SLUDGE ± BIOLOGICAL SLUDGE IN DEWATERING APPLICATIONS BEFORE OR AFTER DIGESTION.
3. EXPECTED PERFORMANCE:

SOLIDS IN	SOLID OUT	SOLIDS CAPTURE	CHEMICALS
1-3%	4-8%	80-90%	NO
1-3%	15-20%	85-95%	YES
3-5%	20-25%	50-70%	NO
3-5%	25-30%	90-95%	YES

Source: Stanley Consultants.

Figure B-6

VACUUM AND PRESSURE FILTER DEWATERING



COSTS INCLUDE: CHEMICAL CONDITIONING AND FILTER BUILDING.

COSTS BASED ON: VACUUM FILTER YIELD OF 5 LB. DRY SOLIDS PER SQ. FT. PER HOUR. PRESSURE FILTER CYCLE TIME OF 2 HOURS.

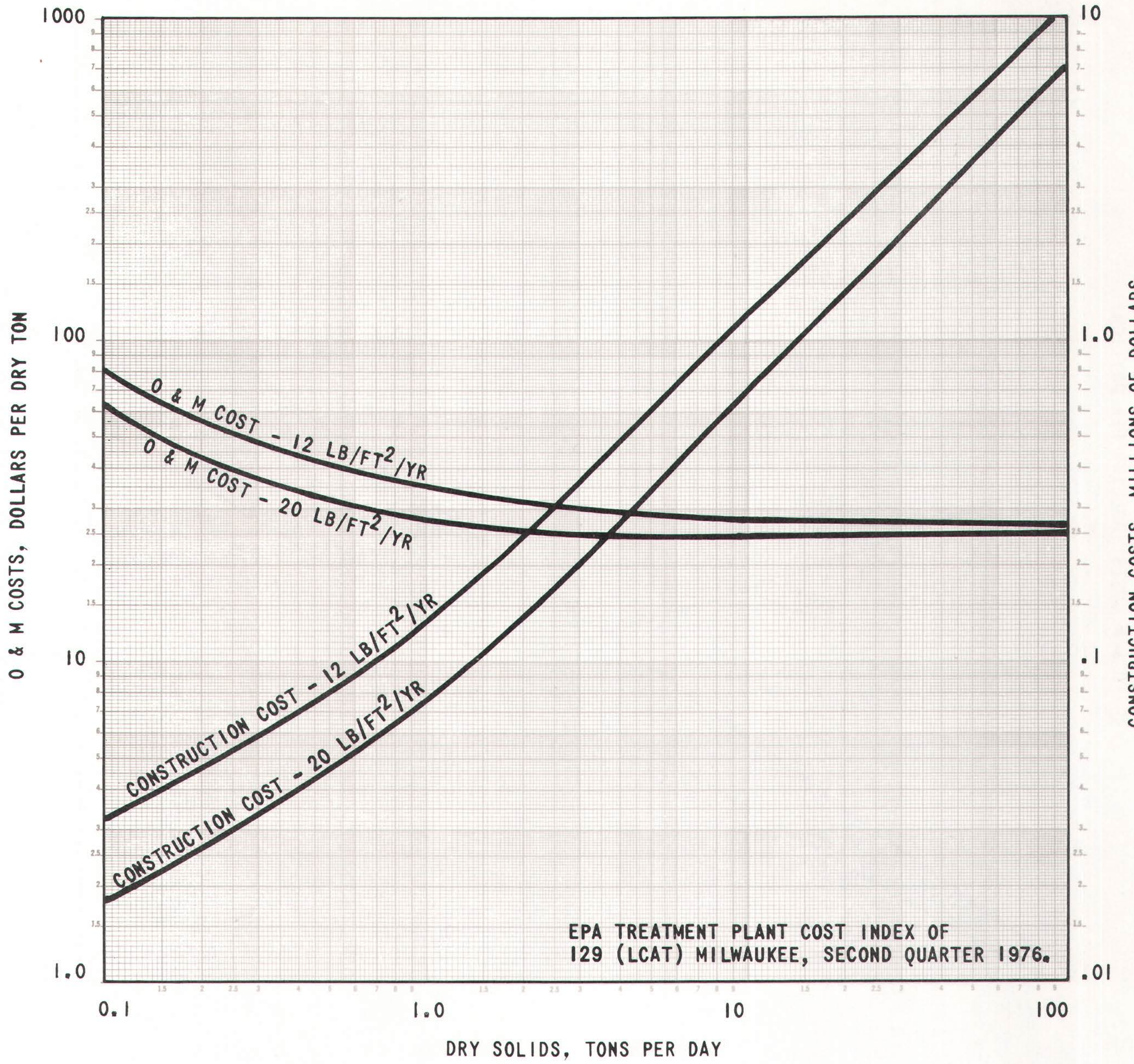
NOTES:

1. EXPECTED PERFORMANCE 20-25% SOLIDS CAKE WITH 90-95% SOLIDS CAPTURE WITH 2-4% FEED WITH VACUUM FILTER.
2. EXPECTED PERFORMANCE 35-45% SOLIDS CAKE WITH 95% SOLIDS CAPTURE WITH 2-4% FEED WITH PRESSURE FILTRATION.
3. CONDITIONING CONSISTS OF 3-5% FERRIC CHLORIDE AND 8-10% LIME, BUT ASH (FROM INCINERATION) CAN ALSO BE USED FOR PRESSURE FILTERS WHICH CAN LOWER O & M COSTS SHOWN.
4. COSTS DO NOT INCLUDE PROVISIONS FOR SLUDGE DISPOSAL.
5. THE PRINCIPLE REFERENCE FOR THE FILTER PRESS COSTS INCORPORATED AN OPPERATIONAL SCHEDULE AT DESIGN LOADING AS FOLLOWS:
   - 40 HRS. PER WEEK OPERATION — PLANT CAPACITY UP TO 2 MGD
   - 80 HRS. PER WEEK OPERATION — PLANT CAPACITY OF 2 MGD TO 5 MGD
   - 100 HRS. PER WEEK OPERATION — PLANT CAPACITY OF 5 MGD TO 20 MGD
   - 168 HRS. PER WEEK OPERATION — PLANT CAPACITY OF GREATER THAN 20 MGD
6. VACUUM FILTER CURVES ARE BASED UPON A BROADER REFERENCE LIST AND PRESENTS A CROSS SECTION OF DESIGN OPERATING SCHEDULES

Source: Stanley Consultants.

Figure B-7

SLUDGE DRYING BEDS



COSTS INCLUDE: SAND & GRAVEL, DISTRIBUTION PIPING, LAND, AND UNDERDRAINS.

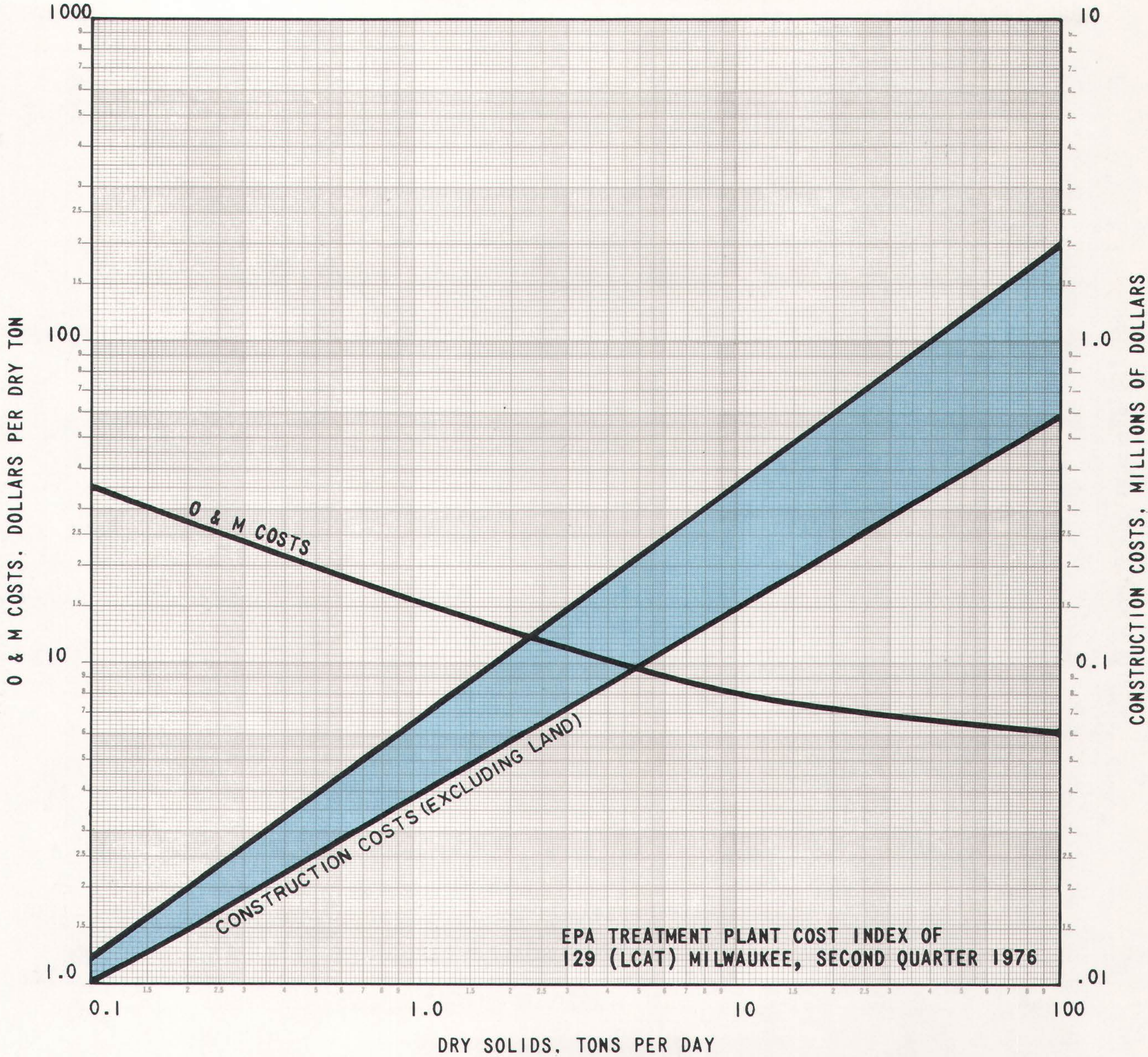
COSTS BASED ON: LOADINGS AS SHOWN, 3%-5% SOLIDS TO BEDS.

NOTES:
1. LOADING RATE OF 12 $LB/FT^2/YR$ APPLICABLE TO BIOLOGICAL PLUS ALUM. OR IRON SALT ADDITION.
2. LOADING RATE OF 20 $LB/FT^2/YR$ APPLICABLE TO BIOLOGICAL SLUDGES.
3. EXPECTED PERFORMANCE: DEWATERS TO 40% SOLIDS.

Source: Stanley Consultants.

Figure B-8

SLUDGE DRYING LAGOONS



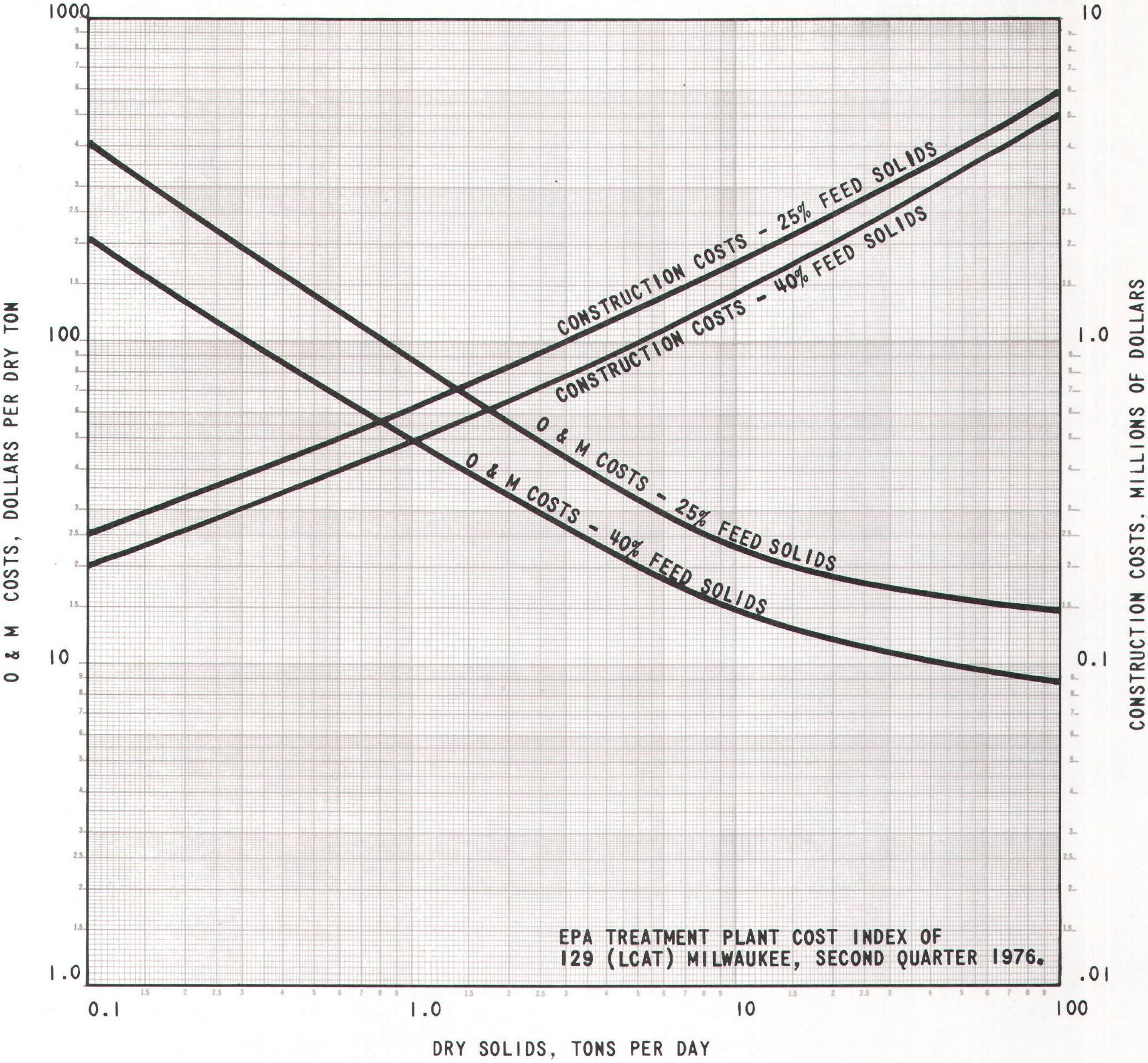
COSTS BASED ON:

1. SOLIDS LOADING OF 2.3 $LB/FT^3/YEAR$.
2. SOLIDS TO LAGOON 1 TON/MG.
3. A RANGE OF CAPITAL COSTS IS GIVEN TO COVER VARIATIONS IN CONSTRUCTION REQUIREMENTS

Source: Stanley Consultants.

Figure B-9

MULTIPLE HEARTH INCINERATION



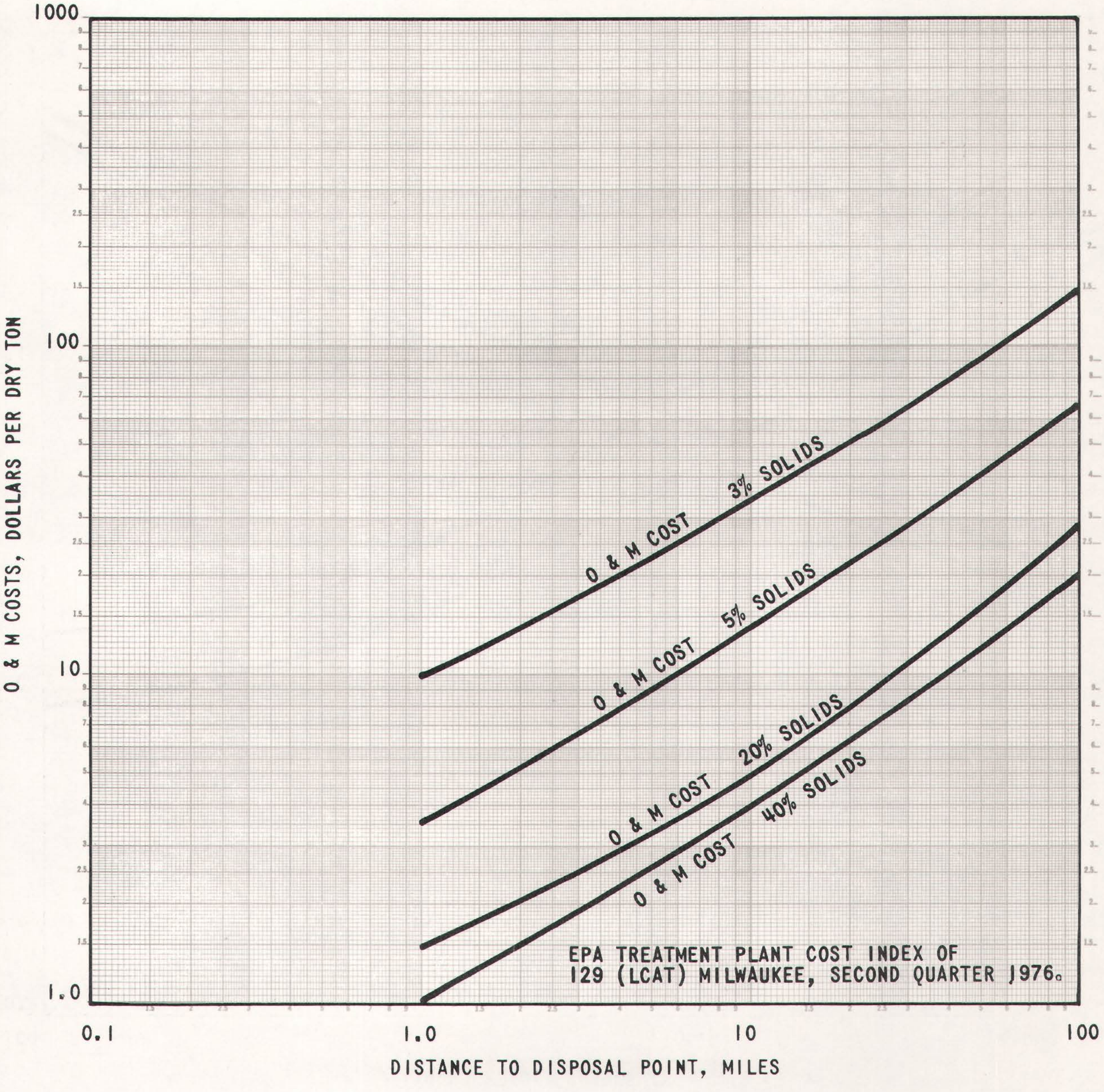
COSTS BASED ON: FEED SOLIDS AS SHOWN.

NOTE: EXPECTED PERFORMANCE 80% VOLUME AND 75% WEIGHT REDUCTION FOR INCOMING SLUDGE.

Source: Stanley Consultants.

Figure B-10

TRUCK HAULING COST



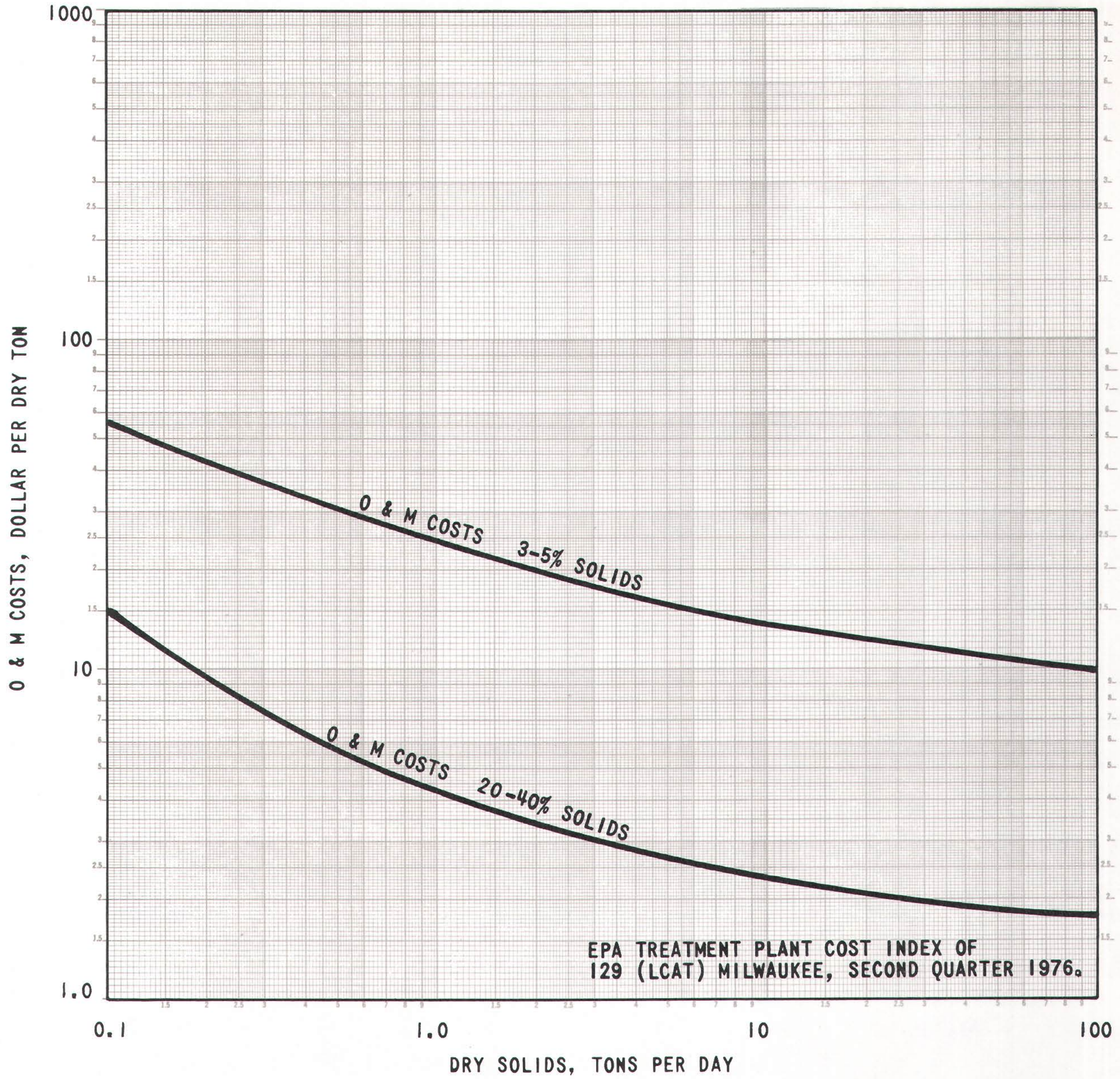
COST BASED ON: TANK TRUCK TRANSPORT FOR 3-5% SOLIDS
DUMP TRUCK TRANSPORT FOR 20-40% SOLIDS
SOLIDS CONTENT AS SHOWN

NOTES:
1. 3% SOLIDS EXPECTED FROM DIGESTED PRIMARY PLUS BIOLOGICAL SOLIDS ± IRON OR ALUM SALTS.
2. 5% SOLIDS EXPECTED FROM DIGESTED PRIMARY ± IRON OR ALUM SALTS.
3. 20% SOLIDS EXPECTED FROM CENTRIFUGE OR VACUUM FILTER DEWATERING.
4. 40% SOLIDS EXPECTED FROM SAND DRYING BEDS OR PRESSURE FILTER DEWATERING.

Source: Stanley Consultants.

Figure B-11

LAND SPREADING



NOTES:
1. 3-5% SOLIDS FROM DIGESTED SLUDGE.
2. 20-30% SOLIDS FROM DEWATERED DIGESTED SLUDGE.
3. COSTS EXCLUDE LAND COSTS WHICH MAY REQUIRE ANNUALLY FROM 10 TO 30 ACRES/TON PER DAY FOR ADEQUATE DISPOSAL.
4. COSTS HIGHLY VARIABLE.

Source: Stanley Consultants.

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Appendix C

CHARACTERISTICS OF WASTEWATER TREATMENT FACILITY SLUDGES

	16 Cities			35 Wisconsin Cities[a]										Other[b]	
	All Values			All Values				Milwaukee MSD						All Values	
	Range	Average	Milwaukee	Range	Average	Kenosha	Whitewater	Jones Island	South Shore	Racine	South Milwaukee	Waukesha	West Bend	Range	Average
Major Constituents (Percent Dry Solids)															
Volatile Solids	41-69	52	69	--	--	--	--	--	--	(35)	--	(40)	--	40-75	60
Total Nitrogen (as N)	1.6-5.8	2.9	5.8	2.4-3.1	--	(2.1)	--	--	(3.3)	(1.6)	--	(2.9)	--	1.8-6.0	3.1
Ammonia (as N)	--	--	--	0.02-0.26	--	(0.10)	--	--	--	(0.05)	--	--	--	0.15-3.1	1.4
Phosphorus (as P)	1.0-2.7	1.6	1.8	2.7-6.1	--	(1.9)	--	--	(2.7)	(5.9)	--	(4.0)	--	0.4-6.6	2.3
Potassium (as K)	0.3-3.9	1.2	0.8	1.2-1.9	--	(0.16)	--	--	(0.34)	(0.06)	--	(1.4)	--	0.08-2.0	0.41
Calcium	0.9-11.6	3.6	0.9	4.2-18.0	--	--	--	--	--	--	--	(6.3)	--	0.2-14	3.8
Magnesium	0.2-1.1	0.6	0.5	0.8-1.2	--	--	--	--	--	--	--	(1.2)	--	0.05-1.4	0.6
Sodium	0.1-1.5	0.4	0.2	0.6-2.2	--	--	--	--	--	--	--	(2.2)	--	0.1-5.4	1.0
Barium	0.03-0.11	0.06	0.04	0.05-0.13	--	--	--	--	--	--	--	(0.09)	--	0.02-0.09	0.05
Boron	0.002-0.016	0.006	0.003	0.02-0.08	--	--	--	--	--	--	--	--	--	0.001-0.10	0.005
Heavy Metals (mg/kg)															
Aluminum	8,100-51,200	18,300	8,100	3,600-12,000	--	--	--	--	--	--	--	(5,330)	--	5,900-44,000	17,300
Cadmium	7-444	104	444	5-400	64	110 (27)	7	185	15 (65)	170 (290)	7	18 (20)	400	4-2,000	76
Chromium	169-14,000	2,225	14,000	50-32,000	3,950	2,000 (750)	215	7,400	16,000 (2,665)	3,500 (1,140)	22,500	2,070 (1,600)	800	60-30,000	2,700
Copper	458-2,890	1,345	1,288	140-10,000	1,150	2,900 (2,550)	420	500	270 (500)	2,850 (890)	280	2,680 (1,880)	580	100-17,000	930
Iron	8,800-82,800	30,550	43,000	8,000-78,000	--	(39,600)	--	--	--	(1,600)	--	(27,400)	--	4,000-42,000	18,600
Lead	136-7,630	1,850	2,253	40-4,600	810	550 (405)	245	850	1,350 (1,190)	4,600 (2,780)	270	980 (680)	1,400	15-26,000	790
Mercury	3.6-18.0	8.6	3.4	0.6-31	6.8	0.6 (1.1)	--	--	2.6 (2.8)	8 (4)	1.5	11 (12)	8.5	0.1-56	8.1
Nickel	36-562	236	360	15-1,700	480	220 (630)	20	140	340 (510)	250 (250)	20	170 (240)	135	10-8,000	250
Titanium	1,080-4,580	2,330	1,580	--	--	--	--	--	--	--	--	--	--	--	--
Zinc	560-6,890	2,130	1,370	490-12,200	2,980	5,500 (2,970)	1,370	3,400	2,900 (1,080)	8,000 (4,530)	620	12,200 (12,100)	3,500	500-28,400	2,940

[a] *Values in parentheses are from data gathered in SEWRPC survey of treatment facilities and sludge handling practices in the Region and SEWRPC file data.*

[b] *Based on a review of values for the various parameters given in References from Metcalf and Eddy, Inc.; Stanley Consultants; T. J. Trout, J. L. Smith, and D. B. McWhorter; D. A. Holzworth et al; H. G. Brown et al; R. C. Stover et al; R. L. Chaney; R. B. Dean and J. E. Smith, Jr.; J. B. Farrell; H. Bernard; M. B. Kirkham and G. K. Dotsan; J. A. Edminsten; A. Montaque; E. F. Ballotti and T. E. Wilson; E. Epstein and G. B. Wilson; and J. V. Lagerwerff et al.*

Source: Stanley Consultants.

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Appendix D

UNIT PROCESSES USED IN MUNICIPAL WASTEWATER TREATMENT FACILITIES IN THE REGION

KENOSHA COUNTY

City of Kenosha
PC-C-AS-FC-D//AN-FP-LS-F

Village of Paddock Lake
PC-AS-FC-D//AN-LS

Village of Silver Lake
CS-C-FC-D//AD-LC-LS

Village of Twin Lakes
PC-TF-FC/AS-FC-D//AD-AN-DB-LF

Town of Bristol Utility District No. 1
AS-FC-D//AD-LC-LS

Town of Pleasant Prairie Sanitary District No. 73-1
AS-FC-C-SF-D//AD-Kenosha

Town of Pleasant Prairie Sewer Utility District "D"
CS-FC-D-P//AD-Kenosha

Town of Salem Sewer Utility District No. 1
AS-FC-D-P//AD-Kenosha

Town of Somers Sanitary District No. 2
EA-FC-D//S-Kenosha

Pleasant Park Utility Company, Inc.
AS-FC-SF-D//AD-Kenosha

MILWAUKEE COUNTY

Milwaukee Metropolitan Sewerage Commissions
Jones Island
PS-AS-C-FC-D//VF-Milorganite

South Shore Plant
PC-AS-C-FC-D//AN-LC-LF-LS

Village of Hales Corners Plant
PC-TF-C-FC-D//AN-DB-LS

City of South Milwaukee
PC-AS-C-FC-D//AN-Zimpro-DB-LC-LF-LS

Rawson Homes Sewer and Water Trust
AS-FC-D-LS

OZAUKEE COUNTY

City of Cedarburg
PC-TF/AS-C-FC-D//AN-DB-S-LS

City of Port Washington
PC-AS-C-FC-D//AN-AD-LS

OZAUKEE COUNTY (continued)

Village of Belgium
PC-AS-FC-D//AN-DB-LS

Village of Fredonia
PA-PC-AS-FC-D//AN-DB-LS

Village of Grafton
PC-AS-C-FC-D//AD-AN-LS

Village of Saukville
PC-TF-FC-D//AN-DB-LS

Village of Thiensville
PA-PC-AS-C-FC-D//AD-AN-DB-LS

RACINE COUNTY

City of Burlington
AS-C-FC-D//AD-C-LS

City of Racine
PC-AS-C-FC-D//AN-VF-LF-LS

Village of Sturtevant
PC-TF-C-FC-D//AN-DB-LC-LS-LF

Village of Union Grove
PC-AS-C-FC-D//AN-DB-S-LS

Caddy Vista Sanitary District
PC-TF-FC//AN-DB-LS

North Park Sanitary District
AS-FC-D//AN-DB-LS

Western Racine County Sewerage District
AS-FC-D//AD-DB-LS

WALWORTH COUNTY

City of Delavan
PC-TF-FC-D//AN-DB-LC-LS

City of Elkhorn
PC-TF-FC-C-D//AN-DB-LF-LS

City of Lake Geneva
PC-TF-C-FC-D//AD-LF

City of Whitewater
PC-TF-FC/PC-AS-FC-D//AN-DB-LS

Village of Darien
AS-FC-D-P//AD-LS

WALWORTH COUNTY (continued)

Village of East Troy
PC-TF-FC//AN-DB-LS

Village of Fontana
PC-TF-FC-P-D//AN-LS

Village of Genoa City
PC-TF-FC-D//AN-DB-LS

Village of Sharon
PC-TF-FC-D//AN-LC-LS

Village of Walworth
Imhoff-TF-FC-D-P//AN-DB-LC-LS

Village of Williams Bay
PC-AS-FC-P-D//AN-LS

WASHINGTON COUNTY

City of Hartford
AS-C-FC-P-M-D//AD-DB-LS

City of West Bend
PC-AS-C-FC-D//AN-LS

Village of Germantown
AS-C-FC-D-P//AD-LC-LF-LS

Village of Jackson
PC-TF-FC-D//AN-DB-LS

Village of Kewaskum
PA-PC-AS-C-FC-P-M-D//AD-VF-LS-LF

Village of Newburg
AS-FC-D//AD-LS

Village of Slinger
PA-PC-TF-PA-FC-D//AN-DB-LS

Allenton Sanitary District
PC-AS-FC-D//AN-DB-LS

WAUKESHA COUNTY

City of Brookfield (Fox)
PC-AS-C-FC-D-P//AD-FP-Incineration-LF

City of Muskego (Big Muskego Plant)
P-D//LS

City of Muskego (Northeast Plant)
CS-C-FC-P-D//AD-DB-LS

City of New Berlin Greenridge Plant (Abandoned 1975)
CS-FC-D-P//AD-LS—Brookfield

City of New Berlin Regal Manors Plant
CS-FC-D-P//AD-DB-LS—Brookfield

WAUKESHA COUNTY (continued)

City of Oconomowoc
PC-TF-FC-D//AN-DB-LS

City of Waukesha
PC-TF-FC-TF-C-FC-D//AN-S-LS

Village of Dousman
PC-AS-FC-D//AD-LS

Village of Hartland
PC-AS-FC-D//AN-DB-LS

Village of Menomonee Falls Pilgrim Road Plant
PA-PC-TF-C-FC-AS-C-FC//AD-AN-DB-LF-LS

Village of Menomonee Falls Lilly Road Plant
AS-FC-C-D//AD-DB-LF-LS

Village of Mukwonago
PC-TF-C-FC-D//AD-DB-LS

Village of Pewaukee
PC-TF/RBC/FC-D//AN-AD-LF-LS

Village of Sussex
PC-TF-FC-C-D//AD-DB-LS

KEY

Liquid—

PC	Primary Clarifier
FC	Final Clarifier
D	Disinfection
AS	Activated Sludge
CS	Contact Stabilization
EA	Extended Aeration
RPC	Rotating Biological Contactor
C	Chemical Addition (phosphorus control)
TF	Trickling Filter
PA	Pre-Aeration
P	Lagoon
M	Microstrainer

Sludge—

LS	Land Spread (application)
LF	Landfill
LC	Contract Disposal
AN	Anaerobic Digestion
AD	Aerobic Digestion
DB	Drying Beds
VF	Vacuum Filter
S	Storage Lagoons
FP	Filter Press
C	Centrifuge

Source: Stanley Consultants.

Appendix E

DEFINITION OF TERMS

The following list of definitions of terms related to sanitary sewerage systems includes and expands upon the definitions developed by the Technical Coordinating and Advisory Committee on Regional Sanitary Sewerage System Planning and published in SEWRPC Planning Report No. 16, A Regional Sanitary Sewerage System Plan for Southeastern Wisconsin, February 1974. The original list of definitions of terms set forth in Planning Report No. 16 was expanded to include terms utilized in SEWRPC Technical Report No. 18, State of the Art of Water Pollution Control for Southeastern Wisconsin, Volumes 1 and 2; and SEWRPC Planning Report No. 29, A Regional Sludge Management Plan for Southeastern Wisconsin. The additional definitions were derived from the following sources: Preliminary Draft of SEWRPC Planning Report No. 29—Chapter IV, Areawide Wastewater Sludge Management Planning Program, Camp Dresser and McKee, 1977; Glossary Water and Wastewater Control Engineering, APHA, ASCE, AWWA, NPCF, 1969; Process Design Manual for Carbon Adsorption, USEPA, 1973; Environmental Engineers Handbook—Volume 1—Water Pollution, 1974; Wastewater Engineering, Collection, Treatment, Disposal, 1972.

Activated Carbon Adsorption—The process which involves the accumulation or concentration of substances on an activated carbon surface. Adsorption of substances in wastewater onto activated carbon can occur as a result of two separate properties of the wastewater-activated carbon system: (1) the low solubility of a particular solute in the wastewater; and (2) a high affinity of a particular solute in the wastewater for the activated carbon.

Activated Sludge Process—A biological waste treatment process in which a mixture of sewage and activated sludge is agitated and aerated in a tank to oxidize the organic matter in the sewage. The activated sludge, which consists of a growth of zoogleal organisms, is subsequently separated from the treated sewage by sedimentation and wasted or returned to the process as needed.

Aeration, Extended—A modification of the activated sludge process which provides for aerobic sludge digestion within the aeration system.

Aeration, Step—A procedure for adding increments of settled sewage along the line of flow in the aeration tanks of an activated sludge sewage treatment plant.

Appurtenances—Appliances or auxiliary structures comprising an integral part of a sewerage system, such as manholes, manhole covers, ladders, frames, and screens to provide for ventilation, inspection, and maintenance of the sewerage system, as well as specialized structures for conveying sewage, such as depressed siphons and junctions.

Bypass—A flow relief device by which sanitary sewers entering a lift station, pumping station, or sewage treatment plant can discharge a portion or all of their flow, by gravity, directly into a receiving body of surface water to alleviate sewer surcharge; also a flow relief device by which intercepting or main sewers can discharge a portion or all of their flow, by gravity, into a receiving body of surface water to alleviate surcharging of intercepting or main sewers.

Centrate—The liquid extracted from a sludge in a centrifuge used either for thickening or dewatering. Its composition depends on the physical and/or chemical treatment of the sludge, the centrifugal force used in the unit, and the design of the centrifuge.

Centrifuge—A mechanical unit in which centrifugal force is used to separate solids from water.

Chlorination—The application of chlorine to sewage effluent generally for disinfection.

Clarifier—A unit of which the primary purpose is to secure clarification of waste water such as sedimentation tanks or basins.

Clarification—Any process or combination of processes the primary purpose of which is to reduce the concentration of suspended matter in a liquid.

Composting—A process using aerobic thermophilic organisms to stabilize dewatered sludge; usually placed in piles and mixed with material such as wood chips, leaves, and other organic matter to keep the pile aerobic. The piles can be artificially aerated.

Conditioning of Sludges—A process used to aid in releasing liquid from sludges. It consists of treating the sludges with various chemicals or subjecting them to physical conditioning such as heating or cooling, or processing them biologically.

Contact Stabilization Process—A modification of the activated sludge process in which raw sewage is aerated with a high concentration of activated sludge for a relatively short period of time to obtain CBOD removal by absorption, the solids being subsequently removed by sedimentation, and transferred to a stabilization tank where aeration is continued to further oxidize and condition the sludge before reintroduction to the raw sewage flow.

Crossover—A flow relief device by which sanitary sewers discharge a portion of their flow, by gravity, into storm sewers during periods of sanitary sewer surcharge or by which combined sewers discharge a portion of their flow, by gravity, into storm sewers to alleviate sanitary or combined sewer surcharge.

Design Capacity, Average Hydraulic—The average influent sewage flow at which a sewage treatment plant will operate at design pollutant removal efficiencies.

Design Capacity, Organic—The average biochemical oxygen demand of the influent sewage, expressed as pounds of $CBOD_5$ per day, which the sewage treatment plant is designed to treat.

Design Capacity, Peak Hydraulic—The maximum influent sewage flow for which the plant is designed to operate without flooding; pollutant removal is still performed under this flow condition but at a much lower efficiency than the design efficiency.

Dewatering—The removal of additional liquid so that thickened sludge attains properties of a solid—that is, it can be shoveled, conveyed on a sloping belt, and handled by typical solids handling methods. Such dewatered sludge is usually in the form of a "cake" such as that produced by a centrifuge, vacuum filter, or filter press.

Digestion, Aerobic—The decomposition of organic matter in the presence of elemental oxygen.

Digestion, Anaerobic—The decomposition of organic matter resulting in gasification, liquification, and mineralization through the action of microorganisms in the absence of elemental oxygen.

Fertilizer—A material of known nitrogen, phosphorus, and potash content which is applied to land for the purpose of increasing plant growth by increased availability of known chemicals. The chemical content is commonly expressed as a three-number sequence (such as 20-10-5) denoting relative weights of N, P_2O_5, and K_2O.

Filter Backwash Waters—The water resulting from backwashing for removal of solids retained by granular media filters which are used to physically remove suspended solids from wastewater treatment plant effluents.

Filter Press—A mechanical press for separation of water from sludge solids.

Filtrates—The liquid extracted from a sludge in vacuum filters, filter presses, belt filters, and other devices in which liquid is separated from solids by applying a differential force across a porous fabric, screen, or other medium.

Filtration—The process of passing a liquid through a filtering medium consisting of granular material, such as sand, magnetite, anthracite, garnet, activated carbon or diatomaceous earth, finely woven cloth, unglazed porcelain, or specially prepared paper, to remove suspended or colloidal matter.

Fixed-Growth Media Biological Treatment Processes—A general categorization of processes such as trickling filters and rotating biological contactors.

Flash Mixer—A device for quickly dispersing chemicals uniformly throughout a liquid.

Force Main—A pipeline joining the discharge of a pumping station with a point of gravity flow designed to transmit sewage under pressure flow throughout its length.

Grit Chamber—A detention chamber designed to reduce the velocity of the influent sewage to permit the removal of coarse minerals from organic solids by differential sedimentation.

Heat Treatment or Conditioning—The application of heat and pressure to sludge to make the sludge more amenable to dewatering.

Holding Tank—An onsite storage tank for short-term storage of sewage as part of a sewage disposal process whereby the wastes are periodically removed from the tank and transported by tank truck to a suitable treatment and discharge facility. The systems are generally only utilized where centralized sanitary sewerage service is unavailable and soils are not suitable for septic systems installation and use.

Incinerator—A mechanical device for controlled combustion. Special designs may be used to incinerate or to maximize energy recovery or volume reduction, or destruction of toxic or hazardous materials.

Infiltration—The water entering a sanitary sewerage system from the ground, through such means as, but not limited to, defective pipes, pipe joints, connections, or manhole walls. Infiltration does not include, and is distinguished from, inflow.

Inflow—The water discharged into a sanitary sewerage system from such sources as, but not limited to, roof leaders, cellar, yard, and area drains, foundation drains, cooling water discharges, drains from springs and swampy areas, manhole covers, cross-connections from storm sewers and combined sewers, catch basins. Inflow consists of storm water runoff, street wash waters, and other forms of surface drainage and does not include, and is distinguished from, infiltration.

Intercepting Structure—A structure designed to intercept all dry-weather sanitary sewage flow in a combined sewer and a proportionate amount of the mixed storm water and sanitary sewage flow during periods of rainfall or snowmelt and discharge such flows to an intercepting sewer.

Sludge Lagoon—A bermed or ponded area for the storage and partial dewatering of wastewater sludge.

Leachate—The liquid that is produced from landfills due to organic decomposition, dewatering of sludge, and rain water.

Loading, Average Hydraulic—The arithmetic average of the total metered daily flow at a sewage treatment plant for any selected year.

Loading, Peak Hydraulic—The greatest total daily sewage flow received by a treatment plant in any selected year.

Microstrainer—An extremely fine rotating screen for the removal of very small suspended solids in sewage.

Multimedia Filter—A treatment unit utilized to process wastewater by passing the liquid through a multiple of three media—usually combinations of sand, anthracite, activated carbon, weighted sperical resin beds, and garnet—for the removal of suspended or colloidal matter.

Neutralization—The reaction of acid or alkali with an opposite reagent until the concentrations of hydrogen and hydroxyl ions in the solution are approximately equal.

Nitrification—The conversion of nitrogenous matter—primarily ammonia—into nitrates by bacteria.

Package Plant—A relatively small, usually prefabricated, sewage treatment plant.

Polishing Lagoon—An unaerated lagoon designed and intended to upgrade or stabilize secondary, tertiary, or advanced wastewater treatment process effluent by natural oxidation of organic matter and settling.

Population Equivalent—The existing or design organic loading to a sewage treatment plant expressed in population and based on an average normal domestic sewage strength and flow.[1]

Precipitation—The phenomenon that occurs when a substance held in solution in a liquid passes out of solution into solid form.

Pretreatment—The conditioning of a waste at its source before discharge to remove or to neutralize substances injurious to sewers and treatment processes or to effect a partial reduction in load on the treatment process. The term generally applies to the conditioning of industrial wastes before discharge to municipal sewerage systems.

Private Sanitary Sewerage System—A waste water disposal system providing conveyance, treatment, and final disposal for wastes from users who have agreed-upon rights to the benefits of the facility which is owned and operated by an individual owner, either a private business or a public institution.

Public Sanitary Sewerage System—A wastewater disposal system providing conveyance, treatment, and final disposal for wastes from users who all have equal rights to the benefits of the utility which is owned and operated by a legally established governmental body.

Pyrolysis—A process for heating sludge so that the organic matter present decomposes into burnable gases, liquids similar to petroleum, and char. The process is carried on in the absence of air or with an air supply which is for combustion.

Reverse Osmosis—The process in which a solution is pressurized to a degree greater than the osmotic pressure of the solvent, causing it to pass through a membrane, carrying only reduced levels of the chemical constituents of the solution.

Sand Drying Beds—A layer of sand contained between low level concrete or wooden walls, underlaid by a system of drains. Sludge is placed or poured on the bed and partially dewatered by air drying and filtration of the liquid through the sand into the underdrains for return to the treatment plant.

Screening—The removal of floating and suspended solids in sewage by straining through racks or screens.

Sedimentation—The process of subsidence and deposition of the suspended matter in sewage by gravity, usually accomplished by reducing the velocity of the sewage below the point at which it can carry suspended matter. Primary sedimentation occurs in a complete sewage treatment process before biological or chemical treatment; secondary sedimentation occurs after such treatment.

Septic System (Mound Type)—A septic system which incorporates as a drain field, granular material placed on a mound above the existing grade and receiving pumped septic tank effluent for discharge to the inside of the mounded bed through tile levees. The granular material allows the liquid to be lifted to the surface by capillary action to evaporate or be used by vegetation atop the mound, or allows the liquid to infiltrate the underlying soil after undergoing some filtration within the mound.

Septic Tank—A settling tank in which organic solids are settled and decomposed by anaerobic bacterial action, with the settled sludge being an immediate contact with sewage flowing through the tank. The treated sewage is then discharged to the groundwater reservoir by underground tile lines.

Sewage—The spent water of a community consisting of a combination of liquid and water-carried wastes from residences, commercial buildings, industrial plants, and institutions, together with any groundwater, surface water, or storm water which may be unintentionally present.

Sewage Lagoon—A shallow body of water containing partially treated sewage in which aerobic stabilization occurs.

Sewage Treatment Plant—An arrangement of devices and structures for treating sewage in order to remove or alter its objectionable constituents and thus render it less offensive or dangerous.

Sewage Treatment Plant Efficiency—The ratio of the amount of pollutant removed by the sewage treatment plant to the amount of pollutant in the influent sewage expressed in percent.

Sewer—A pipe or conduit, generally closed but not normally flowing under pressure, for carrying sewage.

Sewer, Branch—A common sewer receiving sewage from two or more lateral sewers serving relatively small tributary drainage areas.

Sewer, Building—A private sewer conveying sewage from a single building to a common sewer; also called house connection.

Sewer, Combined—A common sewer intended to carry sanitary sewage, with component domestic, commercial, and industrial wastes, at all times, and which, during periods of rainfall or snowmelt, is intended to also carry storm water runoff from streets and other sources.

Sewer, Common—A sewer in which all abutters have equal rights; also called public sewer.

Sewer, Intercepting—A common sewer that receives dry-weather sanitary sewage flows from a combined sewer system and predetermined proportionate amounts of the mixed storm water and sanitary sewage flows during periods of rainfall or snowmelt and conducts these flows to a point of treatment or disposal.

Sewer, Lateral—A common sewer discharging into a branch or other common sewer and having no other common sewer tributary to it.

Sewer, Main—A common sewer which receives flows from many lateral and branch sewers serving relatively large tributary drainage areas for conveyance to a treatment plant; also called trunk sewer.

Sewer, Outfall—A sewer that receives flows from a collection system or from a treatment plant and conveys the untreated or treated waste flows to a point of discharge into a receiving body of surface water.

Sewer, Relief—A common sewer built to carry the flows in excess of the capacity of an existing sewer, thus relieving surcharging of the latter.

Sewer, Sanitary—A common sewer which carries sewage flows from residences, commercial buildings and institutions, certain types of liquid wastes from industrial plants, together with minor amounts of storm, surface, and ground waters that are not intentionally admitted.

Sewer, Storm—A common sewer which carries surface water and storm water runoff from open areas, rooftops, streets, and other sources, including street wash and other wash waters, but from which sanitary sewage or industrial wastes are specifically excluded.

Sewerage System—A system of piping, treatment facilities, and appurtenances, for collecting, conveying and treating wastewater.

Skimmings—The material that is skimmed from the surface of clarifier basins including liquid, such as oil, floating grease and other debris.

Sludge—An aqueous suspension of residual solids generated through the treatment of a municipal or industrial wastewater, and of such a nature and concentration as to require special consideration for disposal. Industrial residuals having economic value without significant processing are not included under this definition.

Soil Conditioner—A material which, when applied to land, increases the ability of the soil to absorb water and hold nutrients as well as improving soil tilth.

Stabilization Lagoon—A shallow pond for storage of wastewater before discharge. Such lagoons may serve only to detain and equalize wastewater composition before regulated discharge to a stream, but often they are used for biological oxidation.

Stabilization Pond—A type of oxidation pond in which biological oxidation of organic matter is affected by natural or artificially accelerated transfer of oxygen to the water from air.

Station, Lift—A relatively small sewage pumping installation designed to lift sewage from a gravity flow sewer to a higher elevation when the continuance of the gravity flow sewer would involve excessive depths of trench, or designed to lift sewage from areas too low to drain into available sewers. Lift stations normally discharge through relatively short force mains to gravity flow points located at or very near the lift station.

Station, Portable Pumping—A point of flow relief at which flows from surcharged sanitary sewers are discharged into storm sewers or directly into a receiving body of surface water through the use of portable pumping units.

Station, Pumping—A relative large sewage pumping installation designed not only to lift sewage to a higher elevation but also to convey it through force mains to gravity flow points located relatively long distances from the pumping station.

Station, Relief Pumping—A flow relief device by which flows from surcharged main sewers are discharged into storm sewers or directly into a receiving body of surface water through the use of permanent lift or pumping stations.

Supernatant—The liquid that is decanted from an anaerobic or aerobic digester and which generally contains a high concentration of suspended and dissolved organic matter plus inorganics such as ammonium compounds, phosphates, heavy metals, bicarbonates of calcium, and magnesium, as well as various types of pathogens.

Thickening—Processes for concentrating sludges up to a maximum of about 10 percent solids content.

Treatment, Advanced—This may be defined as additional physical and chemical treatment to provide removal of additional constituents, particularly phosphorus and nitrogen compounds, by such means as chemical coagulation, sedimentation, charcoal filtration, and aeration. Although advanced treatment is traditionally conceived of as following secondary treatment or as combined with tertiary treatment, it can be performed following primary treatment or as an integral part of secondary treatment. Advanced treatment may remove 90 percent or more of the raw influent phosphorus and may remove up to 90 percent of the raw influent nitrogen, or effect up to 95 percent reduction in the oxygen demand of ammonia in the sewage treatment plant influent by coverting the ammonia compounds to nitrate.

Treatment, Auxiliary—This may be defined as a treatment measure used in combination with all other treatment methods, and includes, for example, effluent aeration and disinfection by chlorination.

Treatment, Primary—This may be defined as physical treatment of raw sewage in which the coarser floating and settleable solids are removed by screening and sedimentation. Primary treatment normally provides 50 to 60 percent reduction of the influent suspended matter and 25 to 35 percent reduction of the influent carbonaceous biochemical oxygen-demanding organic matter ($CBOD_{ult}$). It removes little or no colloidal and dissolved matter.

Treatment, Secondary—This may be defined as biological treatment of the effluent from primary treatment, in which additional oxygen-demanding organic matter is removed by trickling filters or activated sludge tanks and additional sedimentation. Secondary treatment normally provides up to 90 percent removal of the raw influent suspended matter and 75 to 95 percent removal of the raw influent $CBOD_{ult}$. Secondary treatment facilities can be designed and operated to also remove 30 to 50 percent of the raw influent nitrogenous biochemical oxygen demand ($NBOD_{ult}$) and 30 to 40 percent of the raw influent phosphorus content of the influent sewage.

Treatment, Tertiary—This may be defined as physical and biological treatment of the effluent from secondary treatment, in which additional oxygen-demanding matter is removed by use of shallow detention ponds to provide additional biochemical treatment and settling of solids of filtration using sand or mechanical filters. Tertiary treatment normally provides up to 99 percent removal of the raw influent suspended matter and 95 to 97 percent of the raw influent $CBOD_{ult}$.

Trickling Filter Process—A biological waste treatment process in which sewage is applied in spray form from nozzles or other distribution devices over a filter consisting of an artificial bed of coarse material, such as broken stone, through which the sewage trickles to underdrains, giving opportunity for the formation of zoogleal slimes which clarify and oxidize the sewage.

Vacuum Filter—A filter consisting of a cylindrical metal drum covered with cloth or other media revolving on a horizontal axis with partial submergence in liquid sludge. A vacuum is maintained under the media to extract moisture from the sludge which adheres to the cloth or media and is scraped off continuously for disposal.

Wet Air Oxidation—A method of sludge disposal that involves oxidation under pressure, at high temperatures.

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[1] *In the regional sanitary sewerage system planning program the average sewage strength was assumed to be 200 mg/l of $CBOD_5$ and the average domestic sewage flow was assumed to be 125 gallons per capita per day. This concentration and daily per capita flow are equivalent to 0.21 pound of $CBOD_5$/capita/day. The population equivalent was computed for either the existing or design loading by dividing the daily $CBOD_5$ loading in pounds by 0.21 pound of $CBOD_5$/capita/day. The computation of equivalent population can also be based on suspended solids by dividing the daily suspended solids loading in pounds by 0.21 pound suspended solids/capita/day.*