# WASTEWATER TREATMENT PLANT SLUDGE DISPOSAL

PART I

CURRENT MUNICIPAL WASTEWATER TREATMENT PLANT SLUDGE DISPOSAL PRACTICES IN IOWA

PART II

SLUDGE DISPOSAL--STATE-OF-THE-ART

PART III

RECOMMENDED SLUDGE DISPOSAL GUIDELINES

JUNE 1975

iowa department of environmental quality
Water Quality Management Division

STANLEY CONSULTANTS
INTERNATIONAL CONSULTANTS IN ENGINEERING, ARCHITECTURE, PLANNING, AND MANAGEMENT

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June 30, 1975

Iowa Department of Environmental
Quality
P. O. Box 3326
Des Moines, Iowa 50316

Attention Mr. Ubbo Agena

Gentlemen:

We are pleased to present our report entitled "Wastewater Treatment Plant Sludge Disposal." This report was prepared in accordance with your Contract Number 75-0800-09.

Without the cooperation and assistance of the many municipalities surveyed, portions of this presentation would not have been made possible.

Sincerely,

STANLEY CONSULTANTS, INC.

R. J. Gear

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# INTRODUCTION

## Background

Wastewater treatment plants are designed to remove pollutants from the wastewater. The suspended solids that are separated and removed from the main wastewater stream result in a solids phase (sludge) that requires separate treatment and disposal.

The sludge volume generally represents about 2 percent of the total wastewater volume. However, the equipment and operating and maintenance costs attributable to sludge handling may represent as much as 50 percent of the total wastewater treatment costs.

While there are many alternative methods available for handling and disposing of sludge, no single method is capable of solving all disposal problems (1)(2)(3). Local conditions and criteria vary, thus each disposal system has advantages. Sludge handling and disposal systems are designed to economically convert the removed solids to a form satisfactory for ultimate disposal.

Increasing demands for improving environmental quality and for energy conservation require that increased emphasis be given to sludge handling and disposal. More stringent wastewater effluent limitations result in increased quantities of sludge and, in addition, may also result in changes in sludge characteristics.

It has been suggested that the ultimate disposal of sludge should fulfill the following requirements (4):

1. Should not pollute air or water.
2. Should be economical.
3. Should conserve organic matter for beneficial purposes.
4. Should provide a permanent solution to sludge disposal.

## Sludge Processing Systems

Sludge handling and disposal systems consist of combinations of the following six unit operations (5):

1. Thickening
    a. No thickening
    b. Gravity
    c. Flotation
    d. Centrifuges
    e. Activated sludge modifications
2. Conditioning and stabilization
    a. No conditioning or stabilization
    b. Anaerobic digestion
    c. Aerobic digestion
    d. Thermal
    e. Chemical
    f. Freezing
3. Dewatering
    a. No dewatering
    b. Drying beds
    c. Drying lagoons
    d. Vacuum filters
    e. Filter presses
    f. Centrifuges
    g. Vibrating screens
4. Incineration
    a. No incineration
    b. Sludge - no heat recovery
    c. Sludge - with heat recovery
    d. Refuse and sludge - no heat recovery
    e. Refuse and sludge - with heat recovery
    f. Pyrolysis
    g. Heat drying
5. Product recovery
    a. No product recovery
    b. Refuse and sludge composting

c. Sludge composting

d. Fertilizer

e. Animal feed production

f. Construction materials

6. Ultimate disposal

a. Landfill

b. Lagoons

c. Surface application

d. Underground

e. Product marketing

Each unit process used is linked together by a critical element, transportation. Transportation mechanisms consist of the following:

1. Pipe
2. Rail
3. Truck
4. Barge

## Purpose of Study

The objective of this sludge handling and disposal study is twofold:

1. To provide an inventory of existing sludge handling and disposal systems and practices being utilized at selected Iowa municipal wastewater treatment plants.
2. To recommend guidelines for ultimate sludge disposal, based on current state-of-the-art.

## Report Format

The results of the twofold study outlined above are presented in the following parts:

1. PART I - CURRENT SLUDGE HANDLING AND DISPOSAL PRACTICES IN IOWA
2. PART II - SLUDGE DISPOSAL--STATE-OF-THE-ART

   This part primarily concentrates on sludge disposal by land application and landfill; however, a short section on sludge lagoons is included.

3. PART III - RECOMMENDED SLUDGE DISPOSAL GUIDELINES

Land application, landfill disposal, and lagoon disposal guidelines are recommended.

4. APPENDICES

Sludge disposal practices in other states and industrial restraints related to sludge handling and disposal are included.

A bibliographical listing of information abstracted from the literature follows each section.

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PART I

# CURRENT MUNICIPAL WASTEWATER TREATMENT PLANT SLUDGE DISPOSAL PRACTICES IN IOWA

PART I

# INTRODUCTION

## General

Surveys were conducted at selected Iowa municipalities to determine the sludge handling and disposal practices presently being utilized in the state. The surveys consisted of plant visits to interview operating personnel, review records and operating reports, inspect sludge handling equipment and disposal sites, collect sludge samples for laboratory analyses, and complete a detailed questionnaire. All data presented in this chapter are from the individual plant surveys.

## Description of Questionnaire

The questionnaire used for each wastewater treatment plant is outlined below:

1. Cost data
2. Wastewater treatment plant characteristics
    a. Location
    b. Hydraulic and waste loadings
    c. Treatment processes
3. Industrial contributors
4. Sludge handling
    a. Sludge, screenings and grit processes
    b. Sludge volume and characteristics (raw and stabilized)
    c. Chemicals used, if any
    d. Methane gas produced, if any
    e. Ultimate disposal methods
    f. Transportation methods
    g. Institutional arrangements
    h. Environmental effects
    i. Problem areas

## Wastewater Treatment Plants Surveyed

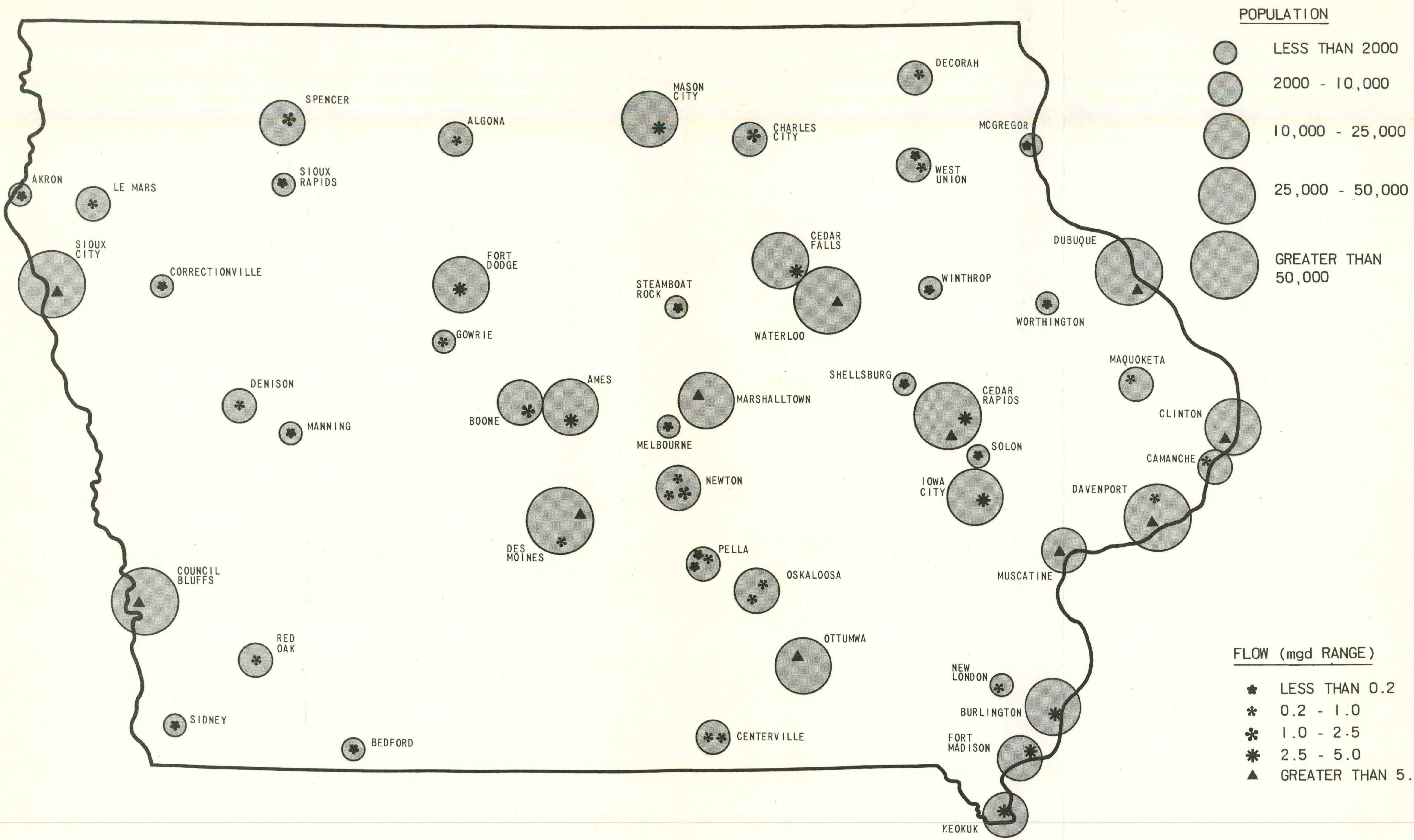
Fifty-nine wastewater treatment plants, operated by 49 separate municipalities, were interviewed between April 17, 1975, and May 14, 1975. The municipalities surveyed included all those with greater than 10,000 population which operate wastewater treatment plants and 26 smaller communities. Municipalities surveyed include the following:

1. Seven over 50,000 population.
2. Nine between 25,000 and 50,000 population.
3. Seven between 10,000 and 25,000 population.
4. Eleven between 2,000 and 10,000 population.
5. Fifteen less than 2,000 population.

Wastewater treatment plant sizes, classified according to actual average annual flow, include the following:

1. Twelve greater than or equal to 5.0 mgd.
2. Eight between 2.5 and 5.0 mgd.
3. Four between 1.0 and 2.5 mgd
4. Nineteen between 0.2 and 1.0 mgd.
5. Sixteen less than 0.2 mgd.

Locations of the treatment plants surveyed are shown on Figure I-1.




WASTEWATER TREATMENT PLANTS SURVEYED

FIGURE I-1

## SLUDGE HANDLING SYSTEMS

### General

Table I-1 lists the sludge handling and disposal systems used at the 59 wastewater treatment plants surveyed. Sludge digestion, conditioning, dewatering, incineration, and ultimate disposal methods are tabulated.

### Sludge Quantities

The amount of sludge handled at the various plants ranges from the equivalent of a few pounds per day to about 54 tons per day (dry weight). The amount of sludge actually disposed is dependent upon the type of stabilization (if any), the amount of solids returned to the wastewater stream, the actual solids load to the plant, the percent suspended solids removal in the plant, and other factors.

The amount of solids for disposal in the future will undoubtedly increase as a result of many of the plants removing more solids to meet upcoming effluent limitations. In addition, the characteristics of some sludges may change considerably.

TABLE I-1

SLUDGE HANDLING AND DISPOSAL SYSTEMS

| Municipal Wastewater Treatment Plant | Plant Average Annual Flow (mgd) | Digestion Type: No Digestion | Digestion Type: Aerobic | Digestion Type: Anaerobic: 1 Stage | Digestion Type: Anaerobic: 2 Stage | Digestion Type: Anaerobic: Additional Stage(s) | Digestion Type: Anaerobic: Imhoff | Digestion Type: Anaerobic: Unheated, Open Digester | Holding Tank(s) | Chemical Conditioning | Dewatering: No Dewatering | Dewatering: Vacuum Filter(s) | Dewatering: Filter Press(s) | Dewatering: Drying Bed(s) | Dewatering: Drying Lagoon(s) | Incineration: Fluidized Bed | Incineration: Multiple Hearth | Ultimate Disposal: Sludge Type: Digested | Ultimate Disposal: Sludge Type: Ash | Ultimate Disposal: Sludge Type: T.F. Humus | Ultimate Disposal: Sludge Type: Raw | Ultimate Disposal: Landfill | Ultimate Disposal: Lagoon | Ultimate Disposal: Surface Application: Private Land | Ultimate Disposal: Surface Application: Public Land | Ultimate Disposal: Surface Application: Private and Public Land |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Akron | 0.13 | | X | | | | | | | | X | | | | | | | X | | | | | | | X | |
| Algona | 0.59 | | | X | | | | | | | X | | | a | | | | X | | | | | | | | X |
| Ames | 4.9 | | | | X | | | | | | | | | b | | | | X | | | | | f | | | X |
| Bedford | 0.15 | | | X | | | | | | | | | | b | | | | X | | | | | | X | | |
| Boone | 1.6 | X | | | | | | | | X | | X | | c | | | | | | X | X | X | | | c | |
| Burlington | 4.5 | | | X | | | | | | | | a | | | d | | | X | | | | | | | | X |
| Camanche | 0.41 | | X | | | | | | | | | | | b | | | | X | | | | b | | X | | |
| Cedar Falls | 3.7 | | | | X | X | | | X | | | | | b | | | | | | | | | | X | | |
| Cedar Rapids - Main | 23.0 | | | X | | | | | | X | | | X | | | | X | e | X | | | X | e | | | |
| Cedar Rapids - Indian Creek | 4.3 | | | | X | | | | | | | | | b | | | | X | | | | | e | | | X |
| Centerville - West | 0.29 | | | | | | X | | | | | | | b | | | | X | | | | | | X | | |
| Centerville - East | 0.78 | | | X | | | | | | | | | | X | | | | X | | | | | | X | | |
| Charles City | 1.8 | | X | | | | | | X | | X | | | | | | | X | | | | | | | | X |
| Clinton | 7.0 | | | | X | | | | | | | | | b | | | | X | | | | | | X | | |
| Correctionville | 0.12 | | | | | | X | | | | | | | X | | | | X | | | | | | X | | |
| Council Bluffs | 5.4 | | | | X | | | | | X | | X | | | | | | X | | | | X | | | | |
| Davenport - Main | 17.5 | | | X | | | | | | | | | | | d | | | X | | | | | h | | | |
| Davenport - Ridgeview | 0.4 | | | X | | | | | | | | | | X | | | | X | | | | X | | | | |
| Decorah | 0.86 | | | X | | | | | | | | | | X | | | | X | | | | X | e | | | |
| Denison | 0.73 | | | X | | | | | | | | | | b | | | | X | | | | | | | | X |
| Des Moines - Main | 40.8 | | | X | | | | | | X | | X | | | | | | X | | | | X | X | | | |
| Des Moines - Highland Hills | 0.7 | | | | X | | | | | | | | | X | | | | X | | | | | | | X | |
| Dubuque | 10.4 | X | | | | | | | X | X | | X | | | d | X | | | X | | | X | | | | |
| Fort Dodge | 3.8 | | | | X | | | | | | | | | | d | | | X | | | | | | X | | |
| Fort Madison | 2.9 | X | | | | | | | X | X | | X | | | | | | | | | X | X | | | | |
| Gowrie | 0.20 | | | | | | | X | | | | | | b | | | | X | | | | | | X | | |
| Iowa City | 5.0 | | | | X | | | | | | | | | a | d | | | X | | | | | | | | X |
| Keokuk | 2.9 | | | X | | | | | | | | | | | d | | | X | | | | X | | | | |
| Le Mars | 0.82 | | | | X | | | | | | | | | b | | | | X | | | | | e | X | | |
| Manning | 0.15 | | | X | | | | | | | | | | b | | | | X | | | | b | | | X | |
| Maquoketa | 0.70 | | | X | | | | | | | | | | | | | | X | | | | | f | X | | |

TABLE I-1

SLUDGE HANDLING AND DISPOSAL SYSTEMS
(Continued)

| Municipal Wastewater Treatment Plant | Plant Average Annual Flow (mgd) | Digestion Type | | | | | | | Holding Tank(s) | Chemical Conditioning | Dewatering | | | | | Incineration | | Ultimate Disposal | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | Anaerobic | | | | | | | | | | | | | | Sludge Type | | | | | | Surface Application | | |
| | | No Digestion | Aerobic | 1 Stage | 2 Stage | Additional Stage(s) | Imhoff | Unheated, Open Digester | | | No Dewatering | Vacuum Filter(s) | Filter Press(s) | Drying Bed(s) | Drying Lagoon(s) | Fluidized Bed | Multiple Hearth | Digested | Ash | T.F. Humus | Raw | Landfill | Lagoon | Private Land | Public Land | Private and Public Land |
| Marshalltown | 6.5 | | | | X | | | | | | | | | | | | | X | | | | | X | | | b |
| Mason City | 4.1 | | | | X | | | | | | | | | b | | | | X | | | | | | X | | |
| McGregor | 0.09 | | | | | | X | | | | | | | X | | | | X | | | | X | | | | |
| Melbourne | 0.05 | | | | | | X | | | | X | | | a | | | | X | | | | | | X | | |
| Muscatine | 5.6 | X | | | | | | | X | X | | X | | | | | | | | | X | X | | | | |
| New London | 0.37 | | | | | | | X | | | | | | b | | | | X | | | | | | X | | |
| Newton - South | 2.1 | | | X | | | | | X | | | | | X | | | | X | | | | X | | | | |
| Newton - Northwest | 0.28 | | | | | | X | | | | | | | X | | | | X | | X | | X | | | | |
| Newton - Southwest | 0.24 | | | | | | X | | | | | | | X | | | | X | | X | | X | | | | |
| Oskaloosa - Southwest | 0.41 | X | | | | | | | X | X | | X | | | | | | | | | X | X | | e | | |
| Oskaloosa - Northeast | 0.50 | X | | | | | | | X | X | | X | | | | | | | | | X | X | | e | | |
| Ottumwa | 6.5 | | | | X | | | | | | | | | | d | | | X | | | | | | | X | |
| Pella - Northeast | 0.69 | | | X | | | | | | | | | | X | | | | X | | | | X | | | | |
| Pella - Northwest | 0.11 | | | | | | X | | | | | | | X | | | | X | | | | X | | | | |
| Pella - Southwest | 0.07 | | | | | | X | | | | | | | X | | | | X | | | | X | | | | |
| Red Oak | 0.87 | | | | X | | | | | | | | | b | | | | X | | | | | | | X | |
| Shellsburg | 0.04 | | | | | | X | | | | | | | b | | | | X | | | | | | X | | |
| Sidney | 0.05 | | | | | | X | | | | | | | b | | | | X | | | | | | X | | |
| Sioux City | 16.3 | | | | X | | | | | | | | | a | d | | | X | | | | | | | X | |
| Sioux Rapids | 0.03 | | | | | | X | | X | | X | | | a | | | | X | | | | | | X | | |
| Solon | 0.08 | | | | | | X | | | | X | | | a | | | | X | | | | | | X | | |
| Spencer | 1.9 | | | | X | | | | | | | | | b | | | | X | | | | b | | | | X |
| Steamboat Rock | 0.03 | | | | | | X | | | | | | | X | | | | X | | | | | | X | | |
| Waterloo | 15.1 | | | X | | | | | | X | | X | | | | | | X | | | | | | | g | |
| West Union - North | 0.18 | | | X | | | | | | | X | | | | | | | X | | | | | | X | | |
| West Union - South | 0.28 | | | | | | X | | X | | X | | | | | | | X | | | | | | X | | |
| Winthrop | 0.08 | | | | | | X | | | | X | | | a | | | | X | | | | | | X | | |
| Worthington | 0.03 | | X | | | | | | | | | | | | | | | X | | | | b | | X | | |

a - Not used
b - Alternate to liquid spreading
c - Trickling filter humus
d - Lagoon(s) cleaned out at least once in ten-year period
e - Backup
f - Supernatant
g - Stockpiling filter cake
h - Lagoons cleaned by private contractor, destination unknown

Sludge Digestion

Sludge digestion facilities are provided at 53 of the treatment plants, these include 4 aerobic and 49 anaerobic systems. Table 1-2 summarizes digestion type according to treatment plant size.

TABLE 1-2

SLUDGE DIGESTION CLASSIFICATION

| | Number of Treatment Plants | | | | | |
|---|---|---|---|---|---|---|
| | Treatment Plant Average Flow, mgd | | | | | |
| | <0.2 | 0.2-1.0 | 1.0-2.5 | 2.5-5.0 | ≥5.0 | Total |
| Aerobic Digestion | 2 | 1 | 1 | 0 | 0 | 4 |
| Anaerobic Digestion | | | | | | |
| Single-stage | 3 | 7 | 2 | 1 | 4 | 17 |
| Two-stage | 0 | 3 | 1 | 5 | 6 | 15 |
| Imhoff tank | 11 | 4 | 0 | 0 | 0 | 15 |
| Open tank | 0 | 2 | 0 | 0 | 0 | 2 |
| No Digestion | 0 | 2 | 2 | 0 | 2 | 6 |

Anaerobic sludge digestion data for 11 plants are listed in Table 1-3. Volatile solids reductions range from 45 to 63 percent. Gas production ranges from 5.6 to 12.2 cubic feet per pound of volatile solids added.

TABLE I-3

ANAEROBIC DIGESTION DATA

| Municipal Wastewater Treatment Plant | Raw Sludge | | | | Digested Sludge | | | Gas Production | |
|---|---|---|---|---|---|---|---|---|---|
| | gal/day | % SS | % VSS | lb/day | % SS | % VSS | lb/day | cf/day | cf/lb VSS* |
| Ames | 14,000 | 4.6 | 77 | 5,330 | 6.9 | 56 | 700 | 38,800 | 9.4 |
| (Supernatant) | | | | | 1.3 | 62 | 1,200(1) | | |
| Cedar Falls | 12,000 | 4.6 | 64 | 4,600 | 9.2 | 42 | 2,950(2) | 36,000 | 12.2 |
| Cedar Rapids - Main | 225,000 | 6.0 | 80 | 110,000 | - | - | - | 600,000 | 7.0 |
| Cedar Rapids - Indian Creek | 10,000 | 5.0 | 60 | 4,170 | 6.0 | 40 | 1,650 | 30,000 | 12.0 |
| Clinton | 18,000 | 5.0 | 43 | 7,500 | - | - | - | 22,500 | 7.0 |
| Council Bluffs | 16,700 | 4.0 | 70 | 5,570 | - | - | - | - | - |
| Fort Dodge | 39,500 | 5.0 | 73 | 16,460 | 7.0 | 50 | 4,750 | 67,600 | 5.6 |
| Keokuk | 41,000 | 9.3 | 85 | 31,700 | - | - | - | 158,500 | 5.9 |
| Marshalltown | 32,300 | 4.0 | 69 | 10,800 | 2.2 | 49 | 1,745 | 49,200 | 6.6 |
| (Supernatant) | | | | | 0.7 | 52 | 1,145 | | |
| Sioux City | 159,000 | 5.1 | 74 | 67,500 | 6.5 | 52 | - | 400,000 | 8.0 |
| Waterloo | 53,100 | 8.5 | 68 | 37,500 | 4.7 | 54 | - | - | - |

- Data not available.

(1) Supernatant withdrawn to lagoons.

(2) Little supernatant return to plant.

* Volatile Suspended Solids (VSS) added.

## Sludge Dewatering

Sludge dewatering facilities in use include vacuum filters, filter presses, drying beds, and drying lagoons.

Ten plants have vacuum filters; however, one plant discontinued use of its vacuum filter about 10 years ago. Available vacuum filter data are listed in Table I-4.

TABLE I-4

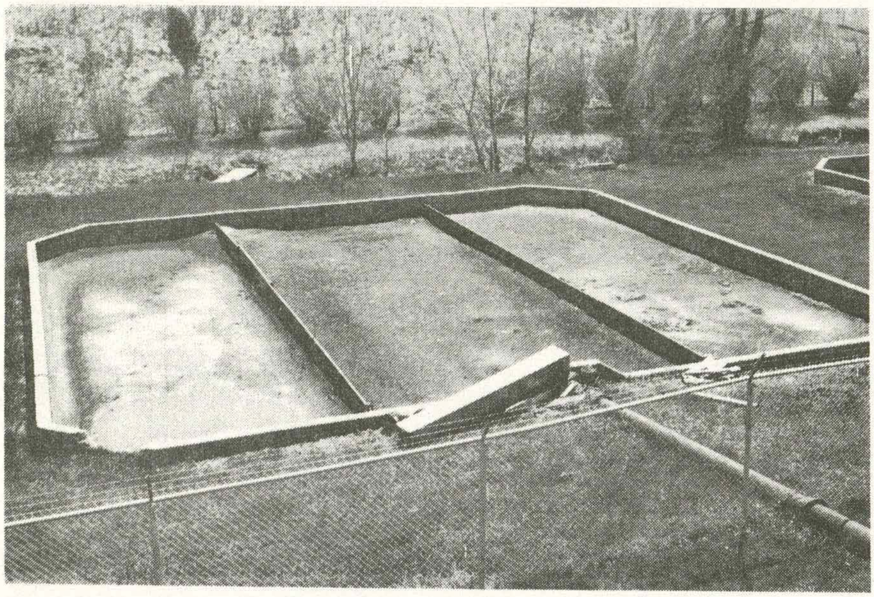
VACUUM FILTER DATA

| Wastewater Treatment Plant | Sludge Processed | Chemicals Added | Cake % Solids | PSF/hr | Cost $/Dry Ton | Final Disposition |
|---|---|---|---|---|---|---|
| Council Bluffs | Second Stage Anaerobic Digester | Polymer | [Only been operating short period of time - No data available] | | | City Landfill |
| Dubuque | Raw | Polymer | --- | 3.9 | 4.13(1) | Incinerated-Ash Lagoon-Landfill |
| Fort Madison | Raw | Lime & $FeCl_3$ | 31 | --- | 11.4(2) | City Landfill |
| Waterloo | First Stage Anaerobic Digester | | [Started operating filters Dec., 1974 - No data available] | | | Stockpiling Final Disposal Unknown |
| Des Moines | First Stage Anaerobic Digester | Polyelectrolyte | 25 | 4.8 | 3.45(1) | Metropolitan Landfill |
| Boone | Raw | Polymer | 16 | --- | 1.92(1) | County Landfill |
| Muscatine | Raw | Lime & $FeCl_3$ | 27 | --- | 9.0 | City Landfill |

--- Data not available.
(1) Chemical cost only.
(2) Includes labor to haul sludge to landfill.

Thirty-eight plants have drying beds. Of these, 7 plants no longer use the drying beds, and 17 plants employ the beds as backup to liquid sludge spreading. Three plants utilize drying beds for undigested trickling filter humus. At least one drying bed is drained to a storm sewer. Typical drying beds are shown on Figure I-2.

Drying lagoons are used at eight plants. Seven of these receive digested sludge and the other incinerator ash. For purposes of this report, a drying lagoon is considered to be any sludge lagoon presently receiving sludge and which has been previously cleaned out.



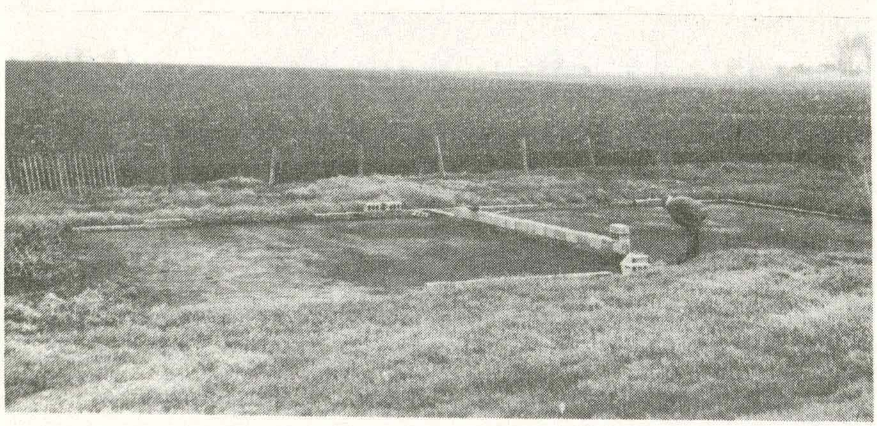


FIGURE 1-2 TYPICAL SLUDGE DRYING BEDS

Sludge Incineration

Incinerators are used at two treatment plants; both have flows greater than 10 mgd.

One plant contains a multiple hearth incinerator which receives dewatered digested sludge. The residue is a dry ash ready for ultimate disposal.

The other plant operates a fluidized bed incinerator which receives dewatered raw sludge and grease. The fly ash is wet-scrubbed and stored in an ash lagoon requiring periodic cleaning.

## ULTIMATE SLUDGE DISPOSAL METHODS

### Final Disposition

Ultimate disposal methods presently used at the 59 plants consist of the following:

1. Land application - includes spreading of liquid and dewatered sludge on agricultural land, park land, and gardens; and using dewatered sludge for filling low areas.
2. Landfill disposal.
3. Lagoon disposal - includes those sludge lagoons which have not been cleaned out and are still being used.

Treatment plants using land application for ultimate disposal are listed in Table I-5. Table I-6 lists the treatment plants using landfills and sludge lagoons for ultimate disposal. The primary disposal methods are summarized below:

| | |
|---|---|
| 1. Digested sludge disposal | |
| Land application | 38 plants |
| Landfill | 12 plants |
| Lagoon storage | 2 plants* |
| Lagoon storage (supernatant) | 2 plants |
| Stockpiling on-site | 1 plant |
| 2. Raw sludge disposal | |
| Landfill | 5 plants |
| 3. Trickling filter humus | |
| Land application | 1 plant |
| Landfill | 2 plants |
| 4. Incinerator ash | |
| Landfill | 2 plants |

* The majority of the sludge from one plant is landfilled.

TABLE I-5

ULTIMATE SLUDGE DISPOSAL METHODS--LAND APPLICATION

| Ultimate Disposal Method | Treatment Plan Flow Classification--Actual Average Annual Flow < 0.2 mgd | 0.2 to 1.0 mgd | 1.0 to 2.5 mgd | 2.5 to 5.0 mgd | ≥ 5.0 mgd | Total |
|---|---|---|---|---|---|---|
| LAND SPREADING (Digested Sludge) | | | | | | |
| Liquid spreading--no alternative system available | Akron(1)<br>West Union-North(2) | West Union-South(2) | Charles City(3) | | | 4 |
| Liquid spreading--drying beds no longer used | Melbourne(2)<br>Sioux Rapids(2)<br>Solon(2)<br>Winthrop(2) | Algona(3) | | | | 5 |
| Liquid spreading--drying beds with dried sludge to land alternative system | Bedford(2)<br>Shellsburg(2)<br>Sidney(2) | Centerville-West(2)<br>Denison(3)<br>Gowrie(2)<br>Le Mars(2)<br>Maquoketa(2)<br>New London(2)<br>Red Oak(1) | | Ames(3)<br>Cedar Falls(2)<br>Cedar Rapids-Indian Creek(3)<br>Mason City(2) | Clinton(2) | 15 |
| Liquid spreading--liquid to landfill alternative system | Worthington(2) | | | | | 1 |
| Liquid spreading--drying beds with dried sludge to landfill alternative system | Manning(1) | Camanche(2) | Spencer(3) | | | 3 |
| Liquid spreading--backup to lagooning | | | | | Marshalltown(3)* | 1* |
| Dried sludge from drying beds spread--no alternative system available | Correctionville(2)<br>Steamboat Rock(2) | Centerville-East(2)<br>Des Moines-Highland Hills(1) | | | | 4 |
| Lagooned sludge--cleaned out at from 1 to 10-year frequencies--land spreading or fill material | | | | Burlington(3)<br>Fort Dodge(2) | Davenport-Main(4)<br>Iowa City(3)<br>Ottumwa(1)<br>Sioux City(1) | 6 |
| LAND SPREADING (Trickling Filter Humus)<br>Dried sludge from drying beds spread | | | Boone(1)* | | | 1* |
| LAND SPREADING (Raw Sludge) | | | | | | |
| Liquid spreading--alternative to landfilling | | Oskaloosa-Southwest(2)*<br>Oskaloosa-Northeast(2)* | | | | 2* |
| SUBTOTAL | 13 | 12 & 2* | 2 & 1* | 6 | 5 & 1* | 38 & 4* |

(1) Public land (2) Private land (3) Public and private land (4) Unknown *Counted other places

TABLE I-6

ULTIMATE SLUDGE DISPOSAL METHODS--LANDFILL AND LAGOON DISPOSAL

| Ultimate Disposal Method | Treatment Plant Flow Classification--Actual Average Annual Flow < 0.2 mgd | 0.2 to 1.0 mgd | 1.0 to 2.5 mgd | 2.5 to 5.0 mgd | ≥ 5.0 mgd | Total |
|---|---|---|---|---|---|---|
| LANDFILL DISPOSAL | | | | | | |
| Vacuum filter cake--digested sludge | | | | | Council Bluffs<br>Des Moines-Main | 2 |
| Vacuum filter cake--raw sludge | | Oskaloosa-Southwest<br>Oskaloosa-Northeast | Boone | Fort Madison | Muscatine | 5 |
| Dried sludge from drying beds--digested sludge | McGregor<br>Pella-Northwest<br>Pella-Southwest | Davenport-Ridgeview<br>Decorah<br>Newton-Northwest<br>Newton-Southwest<br>Pella-Northeast | Newton-South | | | 9 |
| Dried sludge from drying beds--trickling filter humus | | Newton-Northwest*<br>Newton-Southwest* | | | | 2* |
| Dried sludge from lagoon--digested sludge | | | | Keokuk | | 1 |
| Incinerator ash--dry | | | | | Cedar Rapids - Main | 1 |
| Incinerator ash--from ash lagoon | | | | | Dubuque(1) | 1 |
| SUBTOTAL | 3 | | 2 | 2 | 5 | 19 & 2* |
| LAGOON DISPOSAL - Never Cleaned to Date | | | | | | |
| Digested sludge | | | | | Marshalltown<br>Des Moines - Main* | 1<br>1* |
| Digester supernatant | | Maquoketa* | | Ames* | | 2* |
| Backup system for emergency use | | Decorah*<br>Le Mars* | | | Cedar Rapids-Main*<br>Cedar Rapids-Indian Creek* | 4* |
| SUBTOTAL | | 3* | | 1* | 1 & 3* | 1 & 7* |
| NOT PREVIOUSLY CLASSIFIED | | | | | | |
| Stockpiled on-site--digested, vacuum filtered sludge | | | | | Waterloo | 1 |

(1) Previously used for on-site fill.

*Counted other places.

The land application methods consist of liquid spreading at 28 plants; spreading drying bed cake at 4 plants; spreading lagoon contents at 4 plants; using lagoon contents for fill material at 1 plant; and having private contractors dispose of lagoon contents, with no control over the sludge disposal location at 1 plant. Land application is used as an alternative to lagooning at 1 plant and landfilling raw sludge at 2 plants (both plants are in the same municipality). Dewatered undigested trickling filter humus is applied to the land at one plant.

Land application rates are not known for many of the plants. Rates were determined for some of the plants and vary from less than 1 ton per acre to as high as 140 tons per acre per year. Some plants rotate the application area and apply sludge to a given parcel of land only once; however, most plants utilize the same land each year.

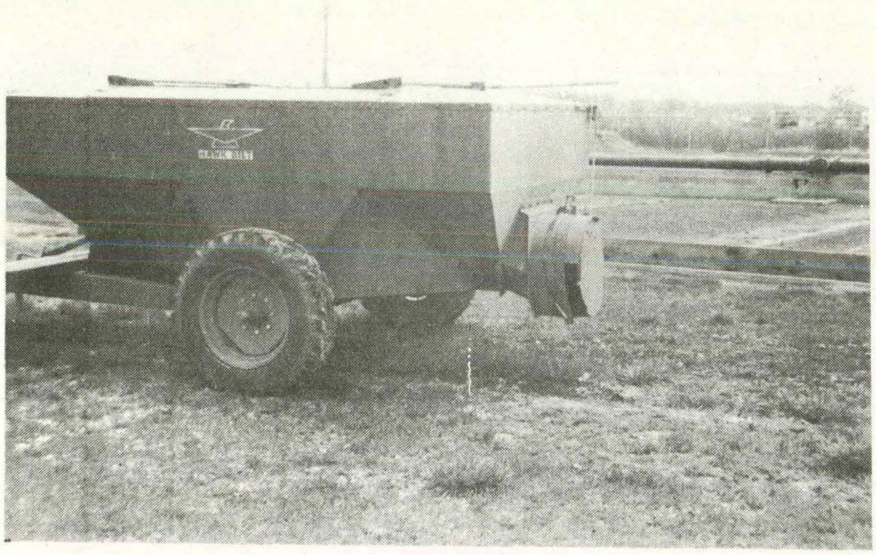
Crop production on land receiving municipal sludge is usually corn or beans; however, oats, grass, or trees are reportedly grown on some sludge application areas.

Landfill disposal of dewatered digested sludge is practiced at 12 plants. Landfilling dewatered raw sludge and dewatered trickling filter humus is practiced at 5 and 2 plants, respectively. Incinerator ash is landfilled at 2 plants. The dewatered fly ash from one incinerator has previously been used for on-site fill.

Sludge lagoons which have not been cleaned out during use receive digested sludge at 2 plants and digester supernatant at 2 plants. In addition, 3 plants use lagoons only during emergency situations.

Sludge Transportation Facilities

Liquid sludge is usually hauled in tanks either mounted on trucks or pulled behind trucks or tractors. The tank sizes vary up to 2,000 gallons. One plant uses a piping system to transport and surface spread liquid sludge. Typical liquid sludge transporting and spreading equipment is shown on Figure I-3. Round-trip transportation distance for hauling liquid sludge is usually less than 10 miles; however, one plant occasionally hauls about 25 miles, round trip.



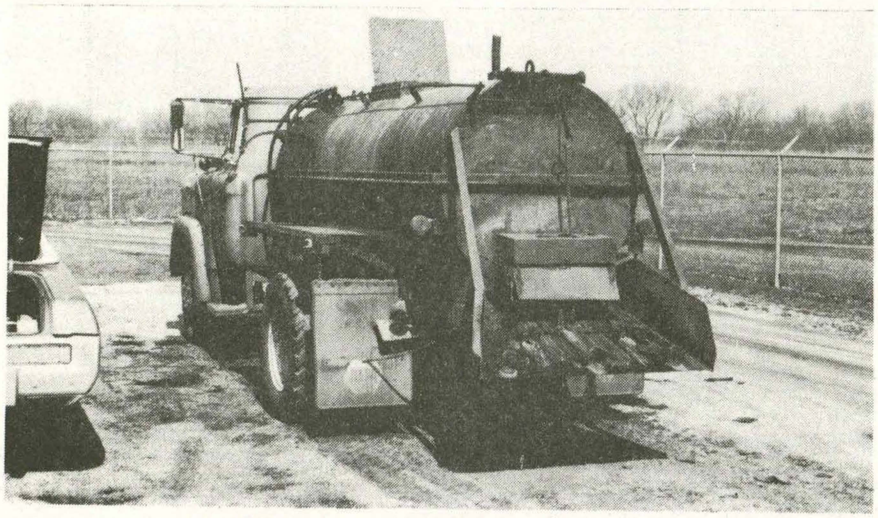


FIGURE 1-3 TYPICAL LIQUID SLUDGE HAULING AND SPREADING EQUIPMENT

Sludge dewatered on drying beds prior to land spreading is usually hauled in dump trucks or front-end loaders and stockpiled for use by local farmers. Local citizens haul from on-site stockpiles at some plants.

Dewatered sludge is hauled to landfills in open dump trucks. The maximum round-trip transportation distance is 27 miles.

Sludge from lagoons is usually stockpiled and later hauled in dump trucks for use on public land. At one plant, private contractors clean the lagoons and neither the sludge disposal method nor location are known.

Screenings and Grit Handling

Methods for disposing of screenings and grit are listed in Table I-7. Screenings from the wastewater stream are removed and disposal is as a solid residue at 40 (68 percent) of the treatment plants. Fourteen plants grind and return the screenings to the wastewater stream. The other five plants do not have bar screens. Forty (68 percent) of the treatment plants (not the same 40 that remove screenings) have grit removal facilities; however, only 31 percent of the plants with less than 0.2 mgd flow have grit removal facilities.

Landfills are used for screenings disposal from 19 plants and grit disposal from 18 plants. On-site disposal, which consists of on-site fill, on-site burial, or placing in lagoons, is used at 19 plants for screenings disposal and 21 plants for grit disposal. On-site disposal of screenings is practiced primarily at plants with less than 1.0 mgd flow.

TABLE 1-7

SCREENINGS AND GRIT DISPOSAL

| | Number of Treatment Plants | | | | | |
|---|---|---|---|---|---|---|
| | Treatment Plant Average Flow, mgd | | | | | |
| | <0.2 | 0.2-1.0 | 1.0-2.5 | 2.5-5.0 | ≥5.0 | Total |
| Screenings | | | | | | |
| Landfill | 3 | 4 | 1 | 3 | 8 | 19 |
| Open dump or burned | 0 | 1 | 1 | 0 | 0 | 2 |
| On-site disposal | 10 | 7 | 0 | 1 | 1 | 19 |
| Subtotal | 13 | 12 | 2 | 4 | 9 | 40 |
| % of total (by size) | 81% | 63% | 50% | 50% | 75% | 68% |
| Ground and returned | 2 | 5 | 1 | 3 | 3 | 14 |
| No screens | 1 | 2 | 1 | 1 | 0 | 5 |
| Subtotal | 3 | 7 | 2 | 4 | 3 | 19 |
| Grit | | | | | | |
| Landfill | 1 | 2 | 3 | 3 | 9 | 18 |
| Open dump | 0 | 0 | 1 | 0 | 0 | 1 |
| On-site disposal | 4 | 10 | 0 | 4 | 3 | 21 |
| Subtotal | 5 | 12 | 4 | 7 | 12 | 40 |
| % of total (by size) | 31% | 63% | 100% | 88% | 100% | 68% |
| No grit removal | 11 | 7 | 0 | 1 | 0 | 19 |

## COST DATA

Cost data for sludge handling and disposal is very limited at most plants surveyed. Costs for various sludge processes are available, or were estimated, for some plants and are summarized below:

1. Complete sludge handling and disposal. Operating and maintenance costs for a 5 mgd plant during 1973 was $27,700 or 12 percent of the total wastewater budget.
2. Sludge hauling and spreading costs.

| Plant Size (mgd) | Annual Cost ($) | |
|---|---|---|
| 3.7 | $3,360 | Manpower & truck O&M costs |
| 0.8 | 416 | Manpower |
| 0.4 | 600 | Manpower |
| 0.37 | 700 | Manpower & truck O&M costs |
| 0.12 | 250 | Manpower (drying bed cleaning and hauling) |
| 0.05 | 120 | Manpower |

Two of the plants reported manpower plus truck expenses for hauling and spreading at $2.00 and $2.30 per 1,000 gallons of liquid digested sludge.

3. Vacuum filtration costs. Table I-4 lists chemical costs for three plants and total vacuum filtration costs for two plants. Chemical costs ranged between $1.92 and $4.13 per dry ton filtered. Total vacuum filtering costs reported are $9.00 per dry ton and $11.40 per dry ton (including hauling labor).

4. Filter press costs. Costs (in 1972 dollars) for operating the filter presses at Cedar Rapids are summarized below (1):

| | $/Ton | | |
|---|---|---|---|
| | Percent solids in feed | | |
| | 4.5 | 5.5 | 6.5 |
| Operating | 5.83 | 4.69 | 3.83 |
| Capital | 12.05 | 9.71 | 7.91 |
| Total (including chemicals) | 26.83 | 21.69 | 18.20 |
| Total O&M | 14.78 | 11.98 | 10.29 |

5. Landfill gate charges. The following gate charges at landfills were reported:

| | |
|---|---|
| Boone | $6 per load (6-8 cubic yards) |
| Des Moines | $0.75 per cubic yard |
| Fort Madison | $0.60 per cubic yard |
| Muscatine | $5.00 per load (10-12 tons) |

These costs are equivalent to about $0.50 to $1.20 per wet ton and $1.85 to $7.38 per dry ton. The wide range of costs per dry ton is primarily a result of the range of solids in the dewatered sludge, 16 percent at Boone to 31 percent at Fort Madison (see Table I-4).

6. Digester cleaning costs. Two plants reported digester cleaning costs. One plant had two 60-foot diameter, 28-foot deep (592,000 gallons) digesters cleaned for $50,000 (1974-1975). The other plant had 75-foot diameter, 28-foot deep (925,000 gallons) digesters cleaned; one for $14,800 ~~in 1973 and the~~ other for $15,500 in 1974.

should get name of firm who cleaned for this price

## INSTITUTIONAL ARRANGEMENTS

### General

Ultimate sludge disposal methods involve people other than wastewater treatment plant operating personnel at most of the plants surveyed. However, municipalities have very little control over the sludge from many of the plants. Institutional arrangements for ultimate sludge disposal are separated into the following three classes for purposes of this report:

1. Land application
2. Landfill disposal
3. Lagoon disposal

### Land Application

Sludge is applied to both public and private land for agricultural purposes. Arrangements for disposing of the sludge are varied and consist of the following:

1. Liquid and dewatered sludge is hauled to and spread on public land with city equipment and personnel.
2. Liquid sludge is hauled to and spread on private land with city equipment and personnel.
3. Dewatered sludge is hauled to local farms with city equipment and spread by landowners.
4. Liquid sludge is hauled and spread by landowners. Some plants provide the hauling equipment while landowners provide the equipment at others.
5. Dewatered sludge from drying beds is stockpiled and individuals are allowed to haul for their private use. Most of the sludge hauled from stockpiles is used on garden plots.

When sludge is applied on private land, no contracts or formal agreements are employed. In most instances, the sludge must be applied at times suitable to the landowner; although some landowners set aside land for year-round application.

One community paid $240 in 1974 to have 4 acres available for year-round application. Another community receives $1.50 for each load of sludge the plant hauls to a local farm. These constitute the range of reported cost requirements.

Landfill Disposal

Dewatered sludge is hauled to landfills operated by city, county, and regional agencies. Hauling is done with municipal equipment and employees. Gate fees are charged at some of the larger landfills.

Lagoon Disposal

Of the 12 plants having sludge lagoons, 8 use them as dewatering lagoons. The other four plants have not cleaned their lagoons to date so it is not known if these lagoons will serve as ultimate disposal lagoons or will eventually be cleaned out.

Outside contractors are sometimes hired for cleaning the lagoons. One plant does not know what the contractor does with sludge after removal from plant property.

## SLUDGE HANDLING AND DISPOSAL PROBLEMS

The observations and discussions conducted during the treatment plant survey have revealed a number of operational and environmental problems exist from sludge handling and disposal operations in Iowa. Several of the major difficulties are summarized in the following discussions.

### Operational Problems

1. Digester overloads which result in decreased volatile solids reduction efficiency (improper stabilization) and additional load to the wastewater stream from supernatant returns.
2. Lack of liquid spreading back-up systems which results in digester overloads at plants having insufficient sludge storage capacity, particularly when weather (or other) conditions prevent sludge spreading.
3. Anaerobic digester difficulties, such as loss of gas production, due to industrial wastes or improper operation.
4. Irregular withdrawal of sludge from Imhoff tanks which results in excessive solids build-up and reduces the primary effluent quality.
5. Application of sludge at excessive depths on drying beds which causes long drying times and reduces the flexibility of operations.
6. Excessive grease in the plant influent from a new industry causes operating problems at one small facility. Grease is also difficult to handle and dispose of at some of the larger plants.
7. Hydrogen sulfide gas causes access problems to certain areas at one plant. Scrubbers are used at some plants to reduce hydrogen sulfide concentrations in the gas produced by anaerobic digestion.

## Environmental Problems

1. Raw sludge and trickling filter humus applied to agricultural land constitute potential environmental problems and health hazards.
2. Liquid sludge applied on the soil surface without incorporation into the soil present possible surface water pollution problems.
3. Sludge lagoons, drying beds, and stockpiled sludge areas which are subject to flooding cause pollution of surface waters.
4. Sludge applied to land without being tested for hazardous materials may cause plant toxicity or health hazards to animals or humans.
5. There is very little control over the practice of applying sludge to private land. In particular, stockpiled sludge from drying beds is used for gardens without sufficient monitoring or control.
6. Sludge lagoons in old gravel pits and areas with possible high groundwater tables pose a contamination hazard for groundwater supplies.
7. Drying beds drained to storm sewers instead of returning to treatment units present surface water pollution sources.
8. Landfill operations for sludge are not adequate at some facilities. Sludge is allowed to remain exposed for long periods of time without mixing with refuse or covering.
9. Grit and screenings are used for on-site fill without limiting access to the areas.

## Sludge Analyses

Sludge samples were collected from 5 treatment plants for analyses at the State Hygienic Laboratory and from 47 treatment plants for analyses at Iowa State University. The 47 samples sent to Iowa State are being analyzed for nutrients and certain trace elements. The results of the 5 sludge analyses conducted by the Hygienic Laboratory are listed in Table I-8.

All sludge samples collected were "grab" samples and, as such, the analyses should only be interpreted for indications of possible problem areas. As shown in Table I-8, concentrations of solids, nutrients, and heavy metals vary widely for the five sludges analyzed. Each of the five treatment plants use land spreading as their primary disposal method. Except for treatment plant 4, which spreads sludge on public land with grass production, each plant listed spreads sludge on private land with crop production. Interpretation of the data follows:

1. The relatively high concentrations of chromium from treatment plants 1 and 2, nickle from treatment plant 2, and zinc from treatment plant 4, indicate areas of possible concern from the crop toxicity standpoint.
2. The relatively high concentrations of arsenic from treatment plant 3 and barium from treatment plants 3 and 4 indicate areas of possible concern from toxicity to animals through the food chain.
3. The calculated cadmium to zinc (Cd/Zn) ratio is less than 1 percent which indicates that cadmium toxicity through the food chain should not be a problem (see PART II - SECTION 2). However, based on the recommended maximum concentrations listed in Table II-9, sludges from plants 1, 2, and 4 should not be applied to agricultural land.

TABLE I-8

SLUDGE DATA

| Treatment Plant I.D. Code | 1 | 2 | 3 | 4 | 5 |
|---|---|---|---|---|---|
| Plant Size (mgd range) | 0.2-1.0 | 0.2-1.0 | 1.0-2.5 | 0.2-1.0 | 1.0-2.5 |
| Primary Industrial Contribution | | | | | |
| Standard Industrial Classification | 3498 | 3634 | 2834 | 3692 | 2011 |
| Approximate Flow (% of Total) | 20 | 40 | 40 | 30 | 50 |
| Sludge Type | Aerobic (Waste Activated) | Anaerobic | Aerobic (Primary & Secondary) | Anaerobic | Anaerobic |
| Solids (%) | 1.75 | 10.60 | 6.46 | 4.22 | 4.76 |
| Volatile Solids (%) | 78.8 | 41.8 | 70.9 | 77.6 | 51.5 |
| pH (units) | 7.0 | 6.3 | 6.1 | 5.8 | 7.2 |
| Nitrogen (% as N) | 4.17 | 1.71 | 3.41 | 3.00 | 2.79 |
| Phosphorus (% as P) | 1.70 | 0.83 | 0.42 | 0.84 | 6.60 |
| Arsenic (mg/kg as As) | 15 | 14 | 530 | -- | -- |
| Barium (mg/kg as Ba) | 220 | 260 | 770 | 700 | 260 |
| Cadmium (mg/kg as Cd) | 5.4 | 13 | 8.1 | 9.4 | 4.1 |
| Chromium, Total (mg/kg as Cr) | 1,400 | 28,000 | 59 | 260 | 59 |
| Copper (mg/kg as Cu) | 480 | 1,200 | 400 | 510 | 200 |
| Lead (mg/kg as Pb) | 140 | 310 | 280 | 280 | 330 |
| Nickle (mg/kg as Ni) | <50 | 44,000 | 68 | 24 | 29 |
| Sodium (mg/kg as Na) | 54,000 | 13,000 | 22,000 | 17,000 | 10,000 |
| Zinc (mg/kg as Zn) | 2,600 | 1,400 | 1,900 | 18,000 | 900 |
| Cd/Zn Ratio (%) | 0.21 | 0.93 | 0.43 | 0.05 | 0.46 |
| Zinc Equivalent | 3,960 | 355,800 | 3,250 | 19,210 | 1,530 |

Notes: Grab samples collected April or May, 1975. All results except pH and solids reported on a dry weight basis.

Zinc Equivalent = mg/l Zn + 2 (mg/l Cu) + 8 (mg/l Ni).

4. The zinc equivalent [Zn eq = mg/l Zn + 2(mg/l Cu) + 8(mg/l Ni)] was inserted into an equation (see PART II - SECTION 2) for calculating the amount of sludge that can be applied to soil without causing plant toxicity. Allowable sludge application rates vary from approximately 800 to less than 3 tons per acre (for soil with cation exchange capacity of 30) over the application life for treatment plants 5 and 2, respectively. The data indicate that land application of sludges from treatment plants 2 and 4 is of concern from a plant toxicity standpoint.
5. The phosphorus concentration in the sludge from treatment plant 5 is 6.6 percent which indicates that phosphorus may limit the sludge application rate.

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# PART II
# SLUDGE DISPOSAL--STATE-OF-THE-ART

## SECTION 1 - PREPARATION FOR ULTIMATE DISPOSAL

### Conditioning and Stabilization

Sludge disposal on the land, in landfills, and in lagoons normally has one common requirement: the sludge must be stabilized or treated in some manner prior to disposal. Stabilization renders the sludge more biologically inert and reduces its pathogen content. Disposal of biologically unstable sludge (raw or insufficiently stabilized) is difficult due to severe odor problems.

Land Application - In addition to odor control, pathogen reduction is required and in some cases disinfection may be needed.

Landfill Disposal - Normally, stabilization should be provided to control odor and other environmental problems during transportation and disposal. In some instances, conditioning chemicals (such as ferric chloride and lime) used prior to dewatering, may provide sufficient short-term biological inactivity for odor control.

Lagoon Disposal - Raw and poorly digested sludge placement in lagoons is almost always accompanied by offensive odors. In addition, insects are normally more numerous and may constitute a public health hazard.

### Stabilization Methods

The INTRODUCTION lists five methods for conditioning and stabilization:

1. Anaerobic digestion
2. Aerobic digestion
3. Thermal treatment
4. Chemical treatment
5. Freezing

In addition, incineration produces a highly stabilized ash. Recently proposed EPA guidelines recognize the first four methods and incineration as acceptable stabilization methods (1). For Federal grant approval of methods 2, 3, and 4, it will be required to show that the degree of stabilization will be equal to that reached in a properly operated anaerobic digester. The practical degree of digestion is dependent upon the volatile solids in the raw sludge (2).

## Sludge Dewatering

Sludge dewatering methods are enumerated in the INTRODUCTION. The degree of dewatering necessary for the various disposal methods will be presented in each individual section.

## Bacteriological Considerations

When considering ultimate sludge disposal, pathogenic organisms are of concern in relation to the following:

1. Land Application: Disease transmission to man or animals. In addition to pathogenic bacteria, biologically stabilized sludge carries parasitic worms and eggs (3). Evidence is lacking that land spreading of liquid digested or otherwise stabilized sludge has caused disease to man or animals. The concern still exists, however, that pathogens may contribute to human and animal diseases. Therefore, disinfection may be needed where people or animals come into contact with sludge (4)(5)(6). Pathogenic organisms have been shown to be viable in soil for periods varying from a few hours to as long as several months. The survival time is dependent on a host of factors; including, type of organism, soil type, moisture, pH, temperature, and the presence of toxins (6).
2. Landfills: Bacterial pollution of surface and groundwater. Proper landfill design and operation will mitigate this hazard. Salmonella tests on raw sludges from three wastewater treatment plants in the Netherlands showed that dewatering sludge with from 4 to 9 percent solids to 25 to 30 percent solids causes a considerable reduction in aerobic bacteria, particularly in enteric bacteria, including Salmonella. The reduction was

found to be on the order of from 2 to 4 decimals for the content of enteric bacteria (7). Each of the three plants conditioned the sludge with lime and either ferric chloride or ferrous sulfate.

3. Lagoons: Bacterial pollution of surface water and disease transmission by vectors. Proper design will mitigate the groundwater hazard. Lagooning only stabilized sludge will, in addition to resulting in a reduced insect population, result in greatly reduced populations of pathogenic organisms reaching the lagoons.

## Disinfection Methods

When it is determined that additional pathogen reduction is required for certain types of disposal projects, the following disinfection methods are available (6):

1. Storing for long periods. EPA recommends 60 days at 20° C (68° F) or 120 days at 4° C (41° F) (1).
2. Pasteurizing at 70° C (158° F) for 30 minutes. It has been shown that pasteurization at 70° C (158° F) for 30 minutes destroys pathogens found in sludge (4).
3. Treating with chemicals. Methods include lime (or other chemicals) treatment to raise the pH for extended periods of time or chlorine addition.

   Lime treatment. EPA recommends a pH greater than 12 for 3 hours (1). At a pH of 11.5 and 0.5 hour of contact time, the pathogens in raw sludges have been reduced below detectable levels (8). Studies with primary sludges and trickling filter humus from the Richland, Washington, municipal wastewater treatment plant showed that an initial pH of 12.4 would maintain a pH greater than 11.0 for 24 hours and reduce pathogenic organisms by more than 99 percent (9).

Chlorine treatment. Concern over the ultimate and yet undetermined fate of the residual chlorine compounds makes this method less attractive (5).

4. Thermal treatment. Sludge incineration is not a suitable method for pretreating sludge for land disposal because of the loss of organic material. However, incinerators and other heat treatment processes are suitable for disinfection of sludge. Several thermal processes can be used for stabilization instead of digestion. Most of the systems operate at temperatures and pressures exceeding those required for pasteurization.

5. Composting. One additional method of disinfection acceptable to EPA is composting at 55° C (131° F) and curing in a stockpile for 30 days (1). A composting project conducted by the United States Department of Agriculture and Maryland Environmental Service showed that proper composting produces temperatures in the 55° to 65° C (131° to 149° F) range and effectively kills most pathogens (10).

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## SECTION 2 - LAND APPLICATION

### General

Application of wastewater sludges to the land is one of the oldest disposal methods. Land application systems are used with varying degrees of success and acceptance throughout the world. Vesilind reports that in the United States, land application of municipal sludges has not been widely practiced, due partially to the availability of inexpensive and convenient organic fertilizers (1). This statement is probably applicable for large treatment plants handling large sludge volumes; however, many small treatment plants in Iowa and other states utilize land application systems (see PART I and APPENDIX B).

Sludge systems have the primary goal of suitable ultimate disposal of sludge. Land application systems, unlike landfills, lagoons, and incineration, provide the benefit of utilizing the nutrients and humus in the sludge which would otherwise be wasted.

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.

### Application Methodology

Land application of sludge will usually be for agricultural utilization or land reclamation. The sludge forms and application methods will depend partially upon the type of land being used for sludge disposal.

Sludge Form - Liquid sludge, dewatered sludge, compost, and organic fertilizer are the forms in which sludge can be applied to land. Sludge must be considered a low-grade fertilizer because only limited amounts of nitrogen, phosphorus, and potassium are present. Common nutrient values are 2 percent N, 1.5 percent $P_2O_5$, and 0.5 percent $K_2O$ for digested sludge and 6 percent N, 2.5 percent $P_2O_5$, and 0.8 percent $K_2O$ for waste activated sludge. Commercial fertilizers normally contain 10 to 30 percent nitrogen and 5 to 20 percent phosphorus. However, when the soil conditioning properties of sludge are added to the fertilizer value, the economic value increases slightly (2). A discussion of each form follows:

1. Liquid sludge. Liquid stabilized sludge is used for both agricultural and land reclamation purposes. Liquid sludge can be applied directly from a stabilization process or from holding structures. Anaerobically digested sludge is the most common type of sludge spread in liquid form. From a fertilizer standpoint, liquid biologically-stabilized sludge has the advantage of containing more nutrients than an equivalent dry amount of the same sludge after dewatering. Almost half of the nitrogen and potassium in digested sludge is in the liquid phase (3). Land spreading of liquid sludge eliminates costly processing steps. However, the cost savings can easily be offset by transportation of the greater sludge volume unless land is available within reasonable distance.
2. Dewatered Sludge. Dewatered sludge is used for both agricultural purposes and land reclamation. Stabilized sludge that has been dewatered on drying beds or by mechanical means can be applied directly to the land or stockpiled for later use. In addition to losing nutrients with the liquid phase during dewatering, considerable nitrogen is lost through volatization from sludge on drying beds.
3. Compost. Sludge compost and sludge-garbage compost can be applied for either agricultural utilization or land reclamation. As pointed out in SECTION I, proper composting practices result in sludge disinfection. The nutrient value of compost is substandard to commercial fertilizer, similar to liquid and dewatered

sludge. However, compost is generally a better soil conditioner than either liquid or dewatered sludge. In addition, compost should reduce water pollution from subsurface water runoff because of its high moisture holding capacity (1). Many attempts to produce and market compost have met with failure in the United States. Most failures have resulted from erroneous evaluations which have usually been a combination of low estimates on construction and operating costs and high estimates on sales proceeds (3). Recent experience with composting sludge from the Blue Plains Wastewater Treatment Plant in Washington, D.C., indicates that composting sludge and wood chips will reduce sludge disposal costs while producing a material that is aesthetically pleasing, easily handled, and odor free (4).

4. Organic Fertilizer. Commercial fertilizer prepared from heat-dried sludge is sold for agricultural and residential utilization. Marketing the product remains a key problem. Milwaukee (Milorganite), Chicago, and Houston (Hou-actinite) are three major cities which have had limited success in producing a fertilizer-soil conditioner from waste sludge (5). Winston-Salem, North Carolina, which markets heat-dried, pelletized sludge under the trade name "Gro-gonite" is investigating nutrient enrichment and marketing under the trade name "Organiform" (6). The Kellogg Supply Co., located in Carson, California, obtains digested sewage sludge from the Los Angeles area. The sludge is composted and Kellogg has developed a complete line of fertilizers and soil conditioners which they sell to retail nurseries, landscape contractors, and other markets. The composted sludge is sold under the trade name "Nitrohumus" (7)(8). Kellogg has been in operation for almost 50 years.

Transportation and Application Methods - As listed in the INTRODUCTION, sludge transportation methods include pipe, rail, truck, and barge.

Liquid sludge can be transported by any of these methods. Dewatered sludge, however, is usually not transported by pipe. The following methods are available for applying sludge:

1. Spreading in thin layers from tank trucks with attached distribution mechanisms. The use of a tank truck is ideal for many communities because liquid sludge can be hauled economically for several miles, thus allowing flexibility in the location of the final disposal site. The tank truck has the advantage over the pipeline system of allowing sludge to be disposed in several different areas during any given year. Tank trucks are available with high flotation tires which permit sludge application on farm fields when they are damp and soft. The flotation tires avoid rutting the fields or densely compacting the soil (9). A similar system, which works quite well for many smaller communities where application land is available relatively close to the treatment plant, consists of the use of a farm tractor and liquid hauling trailer. This system has many of the same advantages as the tank truck and has a lower cost where relatively short-haul distances (approximately 2.5 miles or less) are involved.

2. Spray application from irrigation-type equipment. Probably the most notable sludge disposal technique where spray irrigation is used is the "Chicago Prairie Plan." Sludge is transported 180 miles down the Illinois River by barge and then pumped through a 10.8-mile pipeline to holding basins in Fulton County. After a holding period, the liquid sludge is sprayed onto reclaimed strip-mine areas through a large "rain gun" (10)(11)(12)(13)(14). Spray application of sludge has also been used at other locations on a smaller scale. However, at some installations other methods of application have replaced spray application due to aesthetic reasons.

3. <u>Sludge application in crop furrows</u>. This method of application is similar to ridge and furrow irrigation and is particularly successful in farmland that has been cultivated in a ridge and furrow method. The land must be relatively flat for this type of application to facilitate equal distribution of the sludge.

4. <u>Incorporation of sludge directly into the soil</u>. The Chicago Metropolitan Sanitary District presently disposes of a portion of its sludge by this method. Sludge is transported by unit train from Chicago to farmland near Champaign, Illinois. After a retention period in storage lagoons, sludge is pumped through a manifold system on a farm plow and incorporated directly into the soil. Research is being carried on at Rutgers University in New Jersey on land application of sewage sludge. Sludge has been applied in both liquid and dewatered forms and incorporated directly into the ground with farm plows (17)(18). At Denver, Colorado, liquid sludge is applied to the soil by spreader truck and then incorporated into the soil with a plow. Tracked vehicles must be used due to traction problems the sludge causes with rubber wheeled tractors (19).

5. <u>Trench incorporation of sewage sludge</u>. This method of application consists of digging open trenches, filling them with dewatered sludge, and then covering them over. This was studied by the USDA Agricultural Research Service at Beltsville, Maryland, where sludge was buried in trenches 2 feet wide by 4 feet deep, and then covered with one foot of soil (15)(16). Trenches were dug with a trenching machine and then filled with sludge with a front-end loader. Walker concluded that trenching seems to be a suitable procedure for high rate disposal and application of sewage sludge to land. However, trenching would not be appropriate in prime agricultural land because of subsoil being brought to the surface and the amount of trace elements applied (16).

6. Other methods. When drying beds are emptied, the dried sludge can be loaded directly onto manure spreaders and spread on agricultural land. An alternative is to load dewatered sludge onto dump trucks and haul it to a stockpile area where it can be later spread with farm equipment. This second method is particularly attractive where sludge lagoons are emptied periodically. In the past, dewatered sludge has sometimes been used for fill material and for land reclamation projects. In these cases, the sludge was normally hauled with dump trucks and spread with bulldozers or other similar equipment.

Soil Suitability

General - Addition of municipal sludges to soils can result in highly variable reactions, which are dependent on the chemical and physical structure of the unamended soil, land slope, climate, chemical and physical nature of the sludge, and other factors. The soil acts like a biological filter (20). The primary functions of the soil microbial component of the biological filter are as follows:

1. Metabolize biodegradable organic materials to carbon dioxide and water by decomposition. The rate of this process often determines the loading rate and capacity of the soil for waste renovation. As a part of this microbial reaction, soil humic materials accumulate which are significant in modifying the physical and chemical soil properties.
2. Degrade or detoxify potentially toxic or unwanted organic compounds; e.g., ABS, pesticides, NTA, phenols, etc.
3. Modify the adsorption and mobility of cations and anions within the soil profile; including phosphorus and heavy metals.
4. Modify the adsorption of nutrient elements and heavy metals by plants associated with the soil filter. The mechanisms involved are oxidation-reduction, mineralization-immobilization, chelation, and solubilization.

5. Produce the nitrogen transformations necessary for the proper functioning of soil in waste renovation; e.g., immobilization-mineralization, nitrification and denitrification.

6. Eliminate pathogenic organisms.

Properly applied sludge is capable of improving surface conditions, enhancing aggregation which helps soil structure, and improving water retention (15). Sludges applied to sandy soils provide organic material, increase aggregation of particles, and increase water retention. The increase in organic material also enhances biological activity which improves the mineral composition of the soil. In contrast, sludge applied as a soil conditioner to clay soils will decrease water holding capacity by improving soil structure. This will allow better water movement within the soil as well as increase the soil oxygen supply. Again, biological activity is increased by the improved soil atmosphere (21).

Soil Chemistry - Soil chemistry is a complex interrelated system. Factors altered by sludge amendment that influence plant (crop) production as well as food chain characteristics include pH, nutrient uptake, organic matter, and heavy metals.

Soil pH is a critical factor in nutrient and heavy metal uptake by plants. The specific mechanisms through which pH influences nutrient and heavy metal activity are complex. Generally, neutral soils (pH 6.5 to 7.0) are the most desirable for crop production. Sludge, which is generally a good buffer, will improve soil pH. In Ottawa, Illinois, a silica sand pit (pH 11) had negligible vegetation and heavy wind erosion problems. Sludge applications buffered the soil along with adding needed organic matter, inducing growth of a dense stand of rye grass, orchard grass, brome grass and weeds (13). The process of lowering the pH is primarily a product of nitrification of ammonia in the wastes (22).

At the other end of the spectrum, coal strip-mined land in the Shawnee National Forest in southern Illinois (pH 2.3 with acidic concentrations of 24,000 mg/l) was reclaimed with sludge, resulting in a minimal 60 percent reduction in acidity. Plant cover reached almost 100 percent (23).

Soil pH also affects the rate of biological decomposition of organic matter. While different types of soil microorganisms have different pH optima for maximum growth, the optimum pH range for rapid decomposition of wastes and residues is 6.5 to 8.5. Bacteria and actinomycetes have pH optima near neutrality and do not compete effectively for nutrients under acidic conditions (22). It is under the optimum decomposition rate that nitrogen, which aids in accelerating decomposition, is most rapidly released from organic to inorganic forms (22).

Generally, then, the optimum pH for good use of soil in sludge disposal is 6.5 to 7.0. Sludges will buffer marginal land to a more desirable level. However, for maximum breakdown and incorporation of sludge by soil, the initial soil pH should be near neutral.

Cation exchange capacity (CEC) of soil is defined as the amount of exchangeable cations expressed as milliequivalents per 100 grams (me/100 g) of clay determined at pH 7. CEC is a measure of potential fertility; related to the clay, organic content, and pH of the soil and is dependent on the structure and composition of the clays. Typical CEC values for clays are listed in Table II-1. Montmorillonite clays are the most abundant clays in Iowa, followed in abundance by illite clays.

TABLE II-1

COMPOSITION, CEC AND ENVIRONMENT OF SOME CLAY MINERALS

| Clay | pH | Environment | Formation | CEC (me/100 g) |
|---|---|---|---|---|
| Illite $K_n(Al_4Fe_4Mg_{10})(Si_8nAl)O_{20}(OH)_4$ | -- | Temperate soils, podzols and g/b podzolics, shales, tundra soils | Slight leaching (=hydromica) | 10-40 |
| Chlorite $(Mg,Fe)_5Al(AlSi_3)O_{10}(OH)_8$ | 7 | Developed aridisols | Stable in alkaline conditions | 10-40 |
| Montmorillonite $Al_4Si_8O_{20}(OH)_4 \cdot nH_2O$ | 7 | Neutral conditions, chestnut and prairie soils, moist gleys and margalitic soils | Unstable under leaching | 60-150 |
| Kaolinite $Al_4Si_4O_{10}(OH)_8$ | 4 | Acid tropical soils R/y podzolics | Leaching and oxidation | 3-15 |

Source: Reference (24)

The clay micelle particle is the site of cation exchange as shown in the following equation:

$$Ca^{++} + 2(Na^{+}\ominus) \rightleftarrows 2Na^{++} + (\ominus Ca^{++}\ominus)$$

The process of liming is a good example of the application of CEC to agricultural practices. Liming of soils is represented on Figure II-1.

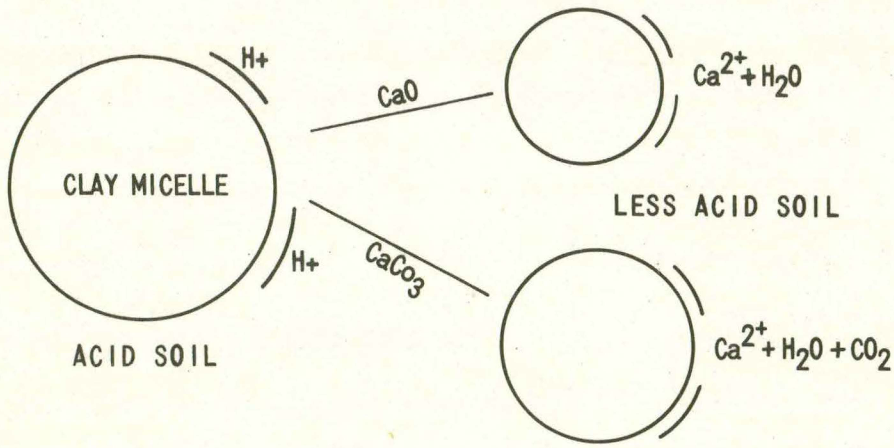


FIGURE II-1 LIME INDUCED CATION EXCHANGE

The final result is a rise in pH and an increase in the supply of exchangeable calcium ions (cations) (25). The interrelationship of pH and CEC is pointed out in the following discussion of the effect of liming on selected elements:

1. pH. Iron is dissolved in acidic soil solutions and is available to the plant. Iron is more tightly held to the clay micelle in neutral or alkaline soils. Thus, increases in pH by liming acidic soils decrease available iron, creating the potential of iron deficiency in plants.

   Under acidic soil conditions, phosphorus precipitates as iron and aluminum phosphates which are unavailable for plant nutrition. Under alkaline conditions, phosphorus is tied up as insoluble $Ca_3(PO_4)_2$. Neutral soil pH is necessary for best phosphorus nutrition. Liming of acidic soils releases available phosphorus.

Zinc and copper also are not available to the plant at high pH. For example, a problem of zinc toxicity in England was cured by liming of soils which made zinc unavailable to the plants and food chain (25).

2. Cation Exchange Capacity. CEC for selected elements is directly related to the percent clay fraction (number of clay micelles) in the soil and the pH (available ions). Table II-2 summarizes pH ranges for the exchange potential of selected elements.

TABLE II-2

pH-EXCHANGE POTENTIAL FOR SELECTED ELEMENTS

| | Available at pH |
|---|---|
| Calcium (Ca) | High (Alkaline) |
| Iron (Fe) | Low (Acid) |
| Phosphorus (P) | Neutral (6 to 7) |
| Potassium (K) | Variable |

Source: Reference (26)

Sludge amendment can increase CEC within sandy soils by improving soil texture. In clay soils sludge addition frees cations from extremely tight bonding to the clay micelles, making the cations available for plant uptake. A pH of 6.5 to 7.0 is the range in which the CEC for phosphorus and potassium is optimum for plant nutrition.

There are little data available on desirable minimal levels of CEC. In general, the higher the CEC in conjunction with good soil tilth and other factors, the better the soil fertility. Sludge applications will decrease the CEC of montmorillonite clays in Iowa, but will supply valuable nutrients for uptake in plant materials.

Nutrients - The most commonly needed elements for plant nutrition are nitrogen, phosphorus, and potassium. Typical concentrations of these elements found in sludge are listed in Table II-3.

TABLE II-3

TYPICAL NUTRIENT COMPOSITION OF SLUDGE

| Source | % (Dry Weight Basis) Total N | P | K |
|---|---|---|---|
| (22) | 2 | 1 | 0.2 |
| (27) | 1.8 | 5.30 | 0.11 |
| (27) | 1.6 | 3.20 | 0.06 |
| (28) | 2.25 | 0.82 | 0.12 |

Source: References (22)(27)(28)

The availability of nitrogen (N) to plants from sludges will vary widely and is related to the amount and chemical forms of the N present, the amount of sludge, and land application procedures. A generalized nitrogen cycle is shown on Figure II-2.

Activated sludge is higher in organic nitrogen than digested sludge. Liquid digested sludge is higher in soluble ammonium ($NH_4$-N) (often 50 percent of total N) than dewatered digested sludge (often 15 to 20 percent of total N) because much of the soluble $NH_4$-N stays in the liquid phase during the dewatering process. Soluble $NH_4$-N can be volatized from liquid sludge by aeration after lime treatment to high pH (22).

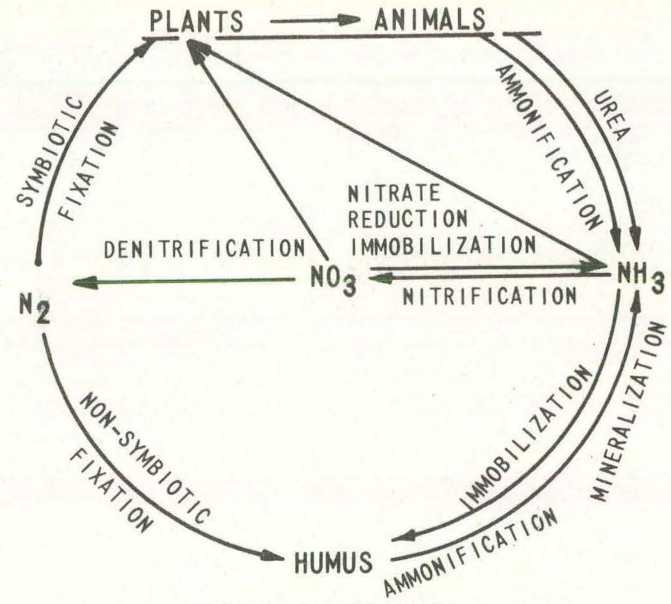


FIGURE II-2 THE NITROGEN CYCLE

SOURCE: REFERENCE (24)

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 sludge. Some of the nitrogen applied in sludge will be volatized and some will be removed as products of denitrification. About 35 to 50 percent of the organic nitrogen will be mineralized or converted to a plant-available form during the first year (27)(29)(30). This percentage depends upon soil condition, moisture condition, method of application, and other factors. Less nitrogen will be lost by volatilization if the sludge is incorporated into the soil during or immediately following application.

Unlike nitrogen, sewage sludge contains considerable amounts of phosphorus (P) in inorganic forms immediately available to plants. Thus, the phosphorus in sludge has the same value as the phosphorus in organic fertilizers of similar composition. Since phosphorus is normally not leached from soils, it will remain available to crops for several years (30). Soils have been known to adsorb 1,000 to 3,000 pounds per acre (lb/acre) of phosphorus to a depth of 3 feet. However, if overloaded, soil will cease to remove phosphorus. In addition to overloading, phosphorus may find its way into surface waters by attachment to soil particles which are eroded. Phosphorus in excessive amounts in surface water is a key eutrophic nutrient which could be a potential hazard from sludge application. Phosphorus is the second limiting factor to sludge loadings of the soil, following nitrogen (23).

Potassium (K) content of sludges is generally quite low (22). The soluble K usually remains with the water during treatment and liquid sludge contains higher K levels than dewatered sludge. Potassium is generally not a limiting factor to sludge application rates.

Trace Elements - Trace element concentrations of various sludges are presented in Table II-4. Of the elements listed, zinc (Zn), copper (Cu), nickel (Ni), and cadmium (Cd), are of greatest concern. Zinc, copper, and nickel concentrations in Table II-4 are sufficient to cause plant toxicity under proper soil and plant conditions. The general symptom of metal toxicity in plants (at pH 5.5) is chlorosis due to iron deficiency. Zinc, copper, and nickel all inhibit root growth and adsorption of other macronutrients.

The Agriculture Research Service, U.S. Department of Agriculture, described factors controlling phytotoxicity of added metals as follows (22):

1. Toxic metals added. Specific plants differ in their relative sensitivity to excess zinc, copper, and nickel. As a general statement of their relative injury to plants, copper is twice as toxic as zinc, and nickel is eight times as toxic as zinc. The zinc (equivalent) expression of toxicity given below is a reasonable approximation of the combined toxicity:

$$\text{Zn (Equivalent)} = \text{mg/l Zn} + 2(\text{mg/l Cu}) + 8(\text{mg/l Ni}):$$

TABLE II-4

TRACE ELEMENT CONCENTRATIONS OF VARIOUS SLUDGES

| Element | Percent (dry weight basis) Range | Percent (dry weight basis) Mean |
|---|---|---|
| Calcium | 6.0 - 0.096 | 2.81 |
| Magnesium | .77 - 0.001 | 0.33 |
| Zinc | 1.40 - 0.002 | 0.32 |
| Chromium | 1.36 - 0.001 | 0.22 |
| Lead | 0.39 - 0.002 | 0.095 |
| Cadmium | 0.036 - <0.001 | 0.006 |
| Silver | 1.3 - 0.65 | 1.01 |
| Sodium | 2.35 - 0.009 | 1.05 |
| Aluminum | 0.72 - 0.36 | 0.48 |
| Iron | 0.83 - 0.21 | 0.55 |
| Copper | 0.15 - 0.002 | 0.048 |
| Manganese | 0.081 - 0.002 | 0.037 |
| Nickel | 0.029 - 0.001 | 0.0069 |
| Boron | 0.004 - 0.002 | 0.0037 |

Source: References (21)(22)(27)(28)(29)

2. pH of the amended soil. The toxic metals are much more available at pH values less than 6.5. A soil metal content safe at pH 7 can easily become lethal at pH 5.5. The change in pH caused by sludge amendment should be carefully monitored.

3. Organic matter content of the amended soil. Organic matter forms insoluble chelates with the toxic metals and makes them less available to injure plants. This binding is especially important for copper and nickel. It appears that the chelation role is more important than the simple cation exchange role of the organic matter. At lower pH values, the organic matter

reduces metal availability relative to the same soil without the organic matter. At higher pH values, organic matter addition appears to increase zinc availability (at high zinc levels). Crop rotation, green manuring, or other practices which maintain high organic matter should help reduce metal toxicity.

4. Phosphate content of the amended soil. Phosphate decreases the stunting of plant growth caused by excessive levels of zinc, copper, and nickel; phosphorus strongly counteracts metal toxicity. Phosphate also increases iron deficiency chlorosis caused by excess copper. Sewage sludges contain about 1 to 5 percent phosphorus and may be higher in sludges from plants using advanced phosphorus removal processes.

5. Cation exchange capacity. The CEC of the soil is important in binding toxic metals. This includes both the CEC of the organic matter (which strongly binds copper and nickel by chelation), and that of the clay colloids. Thus CEC judgments may need to be based on the soil with a typical minimum organic matter content for soil type and climatic zone, presuming decomposition of the organic matter added in the waste. Although clay differences in CEC per unit weight are dramatic, and there is some indication that clays with higher CEC per unit weight of clay may be more effective in holding toxic metals, there appears to be no basis at this time to recommend that a soil with montmorillonite clay is better for disposal of metal-laden wastes than a soil with illitie clays if both have the same CEC.

6. Reversion to lower availability. In time, the metals added with sludge react with the soil to become inactivated and therefore less toxic to plants. This process has been labeled "reversion," but is poorly understood. The rate of reversion is lower at higher metal levels and occurs most rapidly in calcareous soils. Soil pH, and possibly phosphate and organic matter can be related to the rate of toxic metal reversion. On a poorly

managed site, the combination of rapid organic matter destruction and low pH (which slows metal reversion) may actually lead to an increase in toxic metal availability and injury. At pH 5.5 to 6.0, reversion of excessive levels of zinc could be a relatively slow process.

Physical Limitations - A tentative guide for evaluating soil limitations for waste disposal systems is given in Tables II-5 and II-6. Table II-5 can be used when sludge is applied to the land in a liquid form while Table II-6 can be used for dewatered sludge application.

Permeability, infiltration rate, soil drainage class, runoff, flooding hazard, and available water holding capacity are "physical" items considered in rating soils for sludge application. Another important item for the land application of sewage sludge is climate. However, climate is not included in the tables because it has little influence on site selection within small geographhic areas.

The degree of soil limitations for the various items listed in Tables II-5 and II-6 has been classified as either slight, moderate, or severe. A slight limitation indicates the soil can be developed for the desired use with only minor precautions. When moderate limitations are indicated, the soil can still be used for intended purposes, in most cases, but precautions will be necessary. Areas with severe limitation will require extreme precautions and management to overcome the limitations.

Very rapid or slow permeability is undesirable. If the permeability is too slow, hydraulic loading rates for liquid sludge are necessarily low. If the soil is very rapidly permeable, the liquid may move through the root zone too quickly for the water and plant nutrients to be taken up by the plants. Infiltration rate of water into the soil controls the rate at which liquid waste can be applied without causing runoff. A potential for rapid runoff is undesirable because organic waste may be carried directly into surface water; rapid runoff will also increase the hazard of soil erosion. Runoff is also influenced by slope, permeability of subsurface layers, and temperature (frozen soil).

## TABLE II-5

## SOIL LIMITATIONS FOR ACCEPTING NONTOXIC BIODEGRADABLE LIQUID WASTE(1)

| Item Affecting Use(2) | Degree of Soil Limitation | | |
|---|---|---|---|
| | Slight | Moderate | Severe |
| Permeability of the most restricting layer between 60 inches and surface horizon | Moderately rapid and moderate 0.6-6.0 in/hr | Rapid and moderately slow 6-20 and 0.2-0.6 in/hr | Very rapid, slow, and very slow >20 and <0.2 in/hr |
| Infiltration Rate | Very rapid, rapid, moderately rapid, and moderate >0.6 in/hr | Moderately slow 0.2-0.6 in/hr | Slow and very slow <0.2 in/hr |
| Soil Drainage Class | Well drained and moderately well drained | Somewhat excessively drained and somewhat poorly drained | Excessively drained, poorly drained, and very poorly drained |
| Runoff | None, very slow, and slow | Medium | Rapid and very rapid |
| Flooding | None | Soil flooded only during nongrowing season | Soil flooded during growing season |
| Available Water Capacity from 0.to 60 inches or a limiting layer (3) — Temporary Installation | >7.8 inches | 3-7.8 inches | <3 inches |
| Available Water Capacity from 0.to 60 inches or a limiting layer (3) — Permanent Installation | >3 inches | | <3 inches |

(1) Modified from a draft guide dated April 27, 1973, for use in the Soil Conservation Service, USDA. Liquid wastes are those that can be moved by pumps and applied through sprinkler systems.

(2) For definitions see Soil Survey Manual, U. S. Department of Agriculture Handbook 18-1951.

(3) Available water capacity, as used here, it the difference between the amount of soil water at field capacity and the amount at wilting point.

Source: Reference (22)

Poorly drained soil may be difficult to manage if the waste is to be transported by trucks or if the land is to be farmed, because the soil may not be accessable to vehicles during much of the year.

A large water holding capacity is important for sludge applications so that the soil can accept precipitation after sludge application. Minimum available water holding capacity requirements in

Table II-5 and II-6 have been introduced primarily as a measure of a desirable minimum soil volume that is necessary to complete reactions within the root zone.

TABLE II-6

SOIL LIMITATIONS FOR ACCEPTING NONTOXIC BIODEGRADABLE SOLIDS AND SLUDGES(1)

| Item Affecting Use(2) | Degree of Soil Limitations | | |
|---|---|---|---|
| | Slight | Moderate | Severe |
| Permeability of the most restricting layer above 60 in. | Moderately rapid and moderate 0.6-6.0 in/hr | Rapid and moderately slow 6-20 and 0.2-0.6 in/hr | Very rapid, slow, >20 and <0.2 in/hr |
| Soil Drainage Class | Well drained and moderately well drained | Somewhat excessively drained and somewhat poorly drained | Excessively drained, poorly drained, and very poorly drained |
| Runoff | None, very slow, and slow | Medium | Rapid and very rapid |
| Flooding | None | None | Soil flooded during some part of the year |
| Available water capacity from 0 to 60 inches or to a limiting layer(3) | >7.8 inches | 3-7.8 inches | <3 inches |

(1) Modified from a draft guide dated April 27, 1973, for use in the Soil Conservation Service, USDA. Solid wastes are those that cannot be moved by pumps.

(2) For definitions see Soil Survey Manual, U. S. Dept. of Agriculture Handbook 18- 1951.

(3) Available water capacity, as used here, is the difference between the amount of soil water at field capacity and the amount at wilting point.

Source: Reference (22)

The Iowa Water Quality Commission has adopted a recommended policy on the land disposal of animal wastes (30). This policy document deals with application rates, disposal on frozen or snow covered land, disposal on land subject to flooding, disposal on land areas near watercourses, incorporation of wastes into soil, and odor control from land disposal operations. Most of the policies contained in the document are applicable to the application of sewage sludges as well as animal wastes. The document is based upon suggested guidelines developed by the Agricultural Advisory Committee (31).

Effects on Plants

Nutrients - Typical crop uptake of nitrogen, phosphorus, and potassium per unit of harvested crop is summarized in Table II-7. Typical sludge application rates, contain 1.5 to 2 times the nitrogen levels needed for crop production (27)(30). These rates are based on the losses of nitrogen by denitrification and volatilization; initial organic and inorganic nitrogen content of sludge; N, P, and K requirements of the crop to be grown; and soil tests for available N, P, and K (27).

TABLE II-7

NUTRIENT REMOVAL VALUES PER HARVESTED UNIT

| Crop | Harvested Unit | Pounds per Harvested Unit | | |
|---|---|---|---|---|
| | | N | P | K |
| Corn grain | Bushel | 0.9 | 0.15 | 0.20 |
| Corn silage | Ton* | 6.67 | 1.16 | 5.40 |
| Soybeans | Bushel | 3.2 | 0.36 | 1.16 |
| Oats | Bushel | 0.65 | 0.11 | 0.16 |
| Wheat | Bushel | 1.25 | 0.25 | 0.20 |
| Barley | Bushel | 1.10 | 0.18 | 0.30 |
| Rye | Bushel | 1.09 | 0.22 | 0.31 |
| Flaxseed | Bushel | 2.3 | 0.29 | 0.28 |
| Popcorn | Pound | 0.0161 | 0.00268 | 0.00357 |
| Sorghum | Bushel | 0.81 | 0.192 | 0.207 |
| Alfalfa | Ton* | 53.3 | 5.83 | 37.5 |
| Legume mix | Ton* | 32.0 | 4.4 | 32.3 |
| Small grain hay | Ton* | 23.0 | 4.7 | 24.0 |
| Red clover | Ton* | 40.0 | 4.4 | 33.2 |
| Timothy | Ton* | 24.0 | 4.4 | 31.5 |
| Other hay | Ton* | 24.0 | 4.4 | 31.5 |

*Wet basis

Source: Reference (22)

Most soils have a large phosphorus fixing capacity. In one study a total application of 620 pounds of phosphorus per acre over an eight-year period resulted in no change of phosphorus concentrations below the second foot of soil depth (28). Generally, phosphorus is in forms available for plant utilization.

Potassium is generally lacking in sludge. If sludge is to be used as a fertilizer, it will have to be upgraded or supplemented to supply deficient potassium.

Fertilizer Requirements - As mentioned earlier, the rate of sludge application is primarily limited by the potential nitrate loadings. Because the land application of sludge is a process to remove nitrogen, crops assisting in that removal will benefit the sludge disposal program. Allowable rates of application depend on soil type, moisture, crop rotation, and other management techniques. Proposed U.S. EPA guidelines suggest that the information needed to determine sludge application rates on cropland includes the following (34):

1. Total and inorganic nitrogen content of sludge.
2. Nitrogen, phosphorus and potassium requirements of the crop grown.
3. Soil test for available phosphorus and potassium.

The sludge application rate should be such that the total amount of plant-available nitrogen is no greater than twice the nitrogen requirement of the crop grown.

The three major crops in Iowa are corn, soybeans, and oats. Of importance in pasture and hay fields is alfalfa. Typical fertilizer applications, though subject to variations, are given below (33).

1. Corn. Four corn cropping situations can be summarized:
   a. Continuous corn cropping -- 125 to 200 pounds of nitrogen per acre per year. Corn utilizes large amounts of nitrogen. It could be beneficial to make two applications.
   b. Corn following soybeans -- 100 to 150 pounds of nitrogen per acre per year.

c. Corn following a good legume sod or 10 tons of manure per acre -- 75 to 125 pounds of nitrogen per acre per year.

d. Corn following both a good legume sod and animal manure -- No nitrogen fertilizer needed.

Phosphorus broadcast applications range from 60 to 180 pounds $P_2O_5$ (26 to 65 pounds as P) per acre. Potassium applications range from 75 to 98 pounds $K_2O$ (63 to 82 pounds as K) per acre.

Because corn is a good nitrogen utilizer, it can be an excellent crop for sludge disposal on land.

2. Soybeans. Where phosphorus and potassium test low in the unamended soil, additions of these nutrients can be beneficial to soybeans. Up to 60 pounds per acre of $P_2O_5$ (26 pounds as P) can be added. Generally, because soybeans are nitrogen fixers, no nitrogen fertilization is required. Because of the need to remove nitrogen from sludge-amended soil, soybeans are not ideally suited for continuous cropping on sludge-amended soil.

3. Oats. Oats have a relatively high phosphorus requirement, low potassium needs, and benefit from some additional nitrogen. Broadcast fertilizing at rates of 26 to 65 pounds per acre phosphorus (as P); 75 to 83 pounds per acre potassium (as K); and 40 to 60 pounds per acre nitrogen (as N) are common. If legume crops are planted with oats, the nitrogen requirement diminishes. Oats, then, have the potential to remove some nitrogen, but not at levels equivalent to corn. Therefore, sludge loading potentials for oat planting is minimal.

4. Alfalfa. Alfalfa is an excellent forage crop which generally benefits from phosphorus and potassium fertilization at loadings of 17 to 26 pounds per acre phosphorus (as P) and 42 to 67 pounds per acre potassium (as K). Alfalfa is a nitrogen fixer, so does

not necessarily require nitrogen fertilization; however, alfalfa will normally utilize nitrogen from the soil.

Coordination of sludge applications with crop needs is more difficult with grain or soybeans than with pasture or hayfields. The design of a land application system needs to bring about a balance between sludge application, sludge storage facilities, and the fertilizer needs of crops.

Trace Elements - Heavy metals and other trace elements are needed in small quantities for good plant nutrition. Many Iowa soils are deficient in essential concentrations of heavy metals and sludge application can supply deficient micronutrients. However, heavy metals tend to be tightly held in the upper soil horizons having limited movement with percolating water and thus, tend to stay at the point of application unless transported by erosion or plant growth (21). These elements will accumulate over a number of sludge applications and may eventually reach maximum allowable levels. Excesses of some heavy metals (Ni, Cu, Pb, Zn, etc.) and imbalances [Cd/Zn and K/(Ca + Mg)]; discussions are included in later sections can occur, which may inhibit the use of the soil for agricultural uses. Careful monitoring of these micronutrients and proper disposal site selection should minimize their impacts.

Plants vary in their susceptability to toxic metals. Chard, spinach, beets, turnips, kale, mustard, and tomatoes are very sensitive. Corn, small grains, and soybeans (dominate Iowa crops) are moderately tolerant. Grasses (fescue, love, bermuda, orchard, rye, etc.) are generally highly tolerant of metals (22).

Table II-8 shows the concentrations of heavy metals found in corn grown on sludge-amended soils. The table is for corn grown with a 260-pound nitrogen application rate (15 to 20 dry tons sludge per acre). The data show that, on a short-term basis, application of sludge containing certain heavy metals in excess of recommended concentrations did not result in toxic levels in the corn. Also, the corn grain concentrated lower levels of cadmium, copper, and nickel than the whole corn plant (29).

TABLE II-8

FIELD CORN TRACE ELEMENTS SUMMARY(1)

| Element | Element Concentrations Whole Plant (mg/l) | Grain (mg/l) | Percent Removal in Grain(3) | Normal Element Toxicity Levels in Plants(3) (mg/l) |
|---|---|---|---|---|
| Cd | .05 | .02 | 4 | -- |
| Cu | 3.94 | .82 | 6 | 30 |
| Ni | 4.53 | 1.89 | 71 | 25 |
| Zn | 24.6 | 23.6 | 22 | 500 |
| Cd/Zn (Ratio) | .002 | .0008 | -- | .01(4) |

(1) Values are based on 260 lb available N application rate, 6-inch depth of soil and hydrochloric acid extraction.

(2) Percent removal of trace elements added in sludge.

(3) Reference (35)

(4) Cd/Zn ratio in sludge considered safe for land application.

Source: Reference (29)

The transfer of essential nutrient elements from soils into plants and then into animal tissues is a complicated process. Each of the essential nutrients may follow its own unique pathway, and its movement may be regulated by specific mechanisms as it moves along the food chain (36). The following discussion regards the biological impact of some of the more important elements.

1. Arsenic. Different chemical forms of arsenic vary in their toxicity. The accumulation of arsenic in the soil may sharply decrease growth of crops. Crops grown on arsenic contaminated soils contain relatively little arsenic in their foliage or seeds. Arsenic pollution of soils therefore reduces the productivity

of fields, but is not a hazard to the human or animal that eats plants grown on these fields (36).

2. Cadmium. The cadmium content of grain, fruit, and edible roots is lower than the cadmium content of the vegetative parts of the same plants. Where the level of cadmium in soil is high and the level of available zinc is very low, food and feed crops may concentrate cadmium to a level that could be injurious to people or animals that eat these crops. Specific concentrations of cadmium that will injure people and animals are not known with any degree of certainty, however (36).

3. Chromium. Chromium is not essential to plant growth, and high concentrations can be toxic to plants. Most agriculture crops, especially their seeds, contain only low levels of chromium. It appears that chromium is not available to plants in the form normally found in sludges.

4. Copper. In plants, copper is about twice as toxic as zinc, but it is readily eliminated by animals. Copper is absorbed primarily by roots but to some extent by leaves.

5. Lead. When lead is incorporated into soil, nearly all the lead is converted to forms that are not available to plants. Any lead that is taken up by plants tends to stay in the root system instead of moving to the top of the plant. Only on very heavily polluted soils will significant amounts of lead move from the soil through the roots to the tops of plants.

6. Magnesium. Grass tetany is a condition in grazing animals caused by low magnesium levels in the blood serum. It is not a true deficiency, but a result of a variety of interrelated factors. It was found that when the soil ratio K/(Ca + Mg) was above 2.2, grass tetany began to affect grazing animals. It is known that zinc, copper, manganese, and boron all stimulate the plant uptake of potassium, thus raising the K/(Ca + Mg) ratio. The magnesium imbalance can be corrected with magnesium fertilizer or by adding magnesium oxide feed supplements (37).

7. Mercury. Inorganic mercury is not highly toxic, and plants grown on soils containing it have very low concentrations of this element. Under certain conditions, inorganic mercury may be converted to the highly toxic methyl mercury. Mercury will enter plants through the roots or leaves with no apparent toxic effect. However, in animals mercury is not only toxic in relatively low concentrations but is also a cumulative toxin.
8. Nickle. Nickle is toxic to plants in relatively small amounts. It is about four times as toxic as copper and eight times as toxic as zinc. Nickle is not a food chain problem for animals.
9. Zinc. Zinc is an essential micronutrient for plants and animals. Zinc, in large quantities, is toxic to plants and it is used as a standard for plant toxicity.

## Sludge Loadings Based on Metal Toxicity

Chaney has recommended that sludge with concentrations of heavy metals in excess of those listed in Table II-9 not be applied to agricultural land. The recommendation is based on the following needs (22):

1. The need to limit metal additions to permit continued general agricultural use of sludge-amended soil.
2. The need to obtain sufficient agricultural benefit from sludge to justify the risk from the metals contained in the sludge.

Any sludge not exceeding the recommended concentrations is considered a domestic sludge.

TABLE II-9

MAXIMUM TRACE ELEMENT CONTENT
OF "DOMESTIC" SEWAGE SLUDGES

| Element | Maximum Concentration for Land Application of Sludge |
|---|---|
| Zinc (mg/kg) | 2,000 |
| Copper (mg/kg) | 1,000 |
| Nickle (mg/kg) | 200 |
| Cd (mg/kg) | 15 |
| Cd/Zn (%) | 1 |
| Lead (mg/kg) | 1,000 |
| Mercury (mg/kg) | 10 |
| Chromium, Total (mg/kg) | 1,000 |

Source: Reference (22)

To minimize the risk of excessive cadmium in the food chain, the ratio of cadmium to zinc (Cd/Zn) should be limited to one percent. As such, injury to crops from excessive zinc would occur before the cadmium content of the crop would become a health hazard (22).

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

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

Where:

$C_1$ and $C_2$ are constants

CEC = Cation exchange capacity of the soil

Zn eq = mg/l Zn + 2(mg/l Cu) + 8(mg/l Ni)

These equations are all based on the assumption that the pH of the sludge-amended soil will be maintained at or above 6.5 at all times (22). The equation for zinc equivalent (Zn eq) is based on the premise that, on the basis of plant toxicity, copper is twice as toxic as zinc and nickle is 4 times as toxic as copper (8 times as toxic as zinc).

Chumbley recommended that no greater than 500 pounds zinc equivalent of toxic metals be added per acre in any 30-year period (38). Leeper's data showed that toxic metals could be added up to 5 percent of the CEC before phytotoxicity occurred (35). Chaney states that toxic metal additions to agricultural soils should not exceed zinc equivalent levels equal to 5 percent of the CEC of the unamended soil (22).

The values of $C_1$ and $C_2$ have been determined to calculate the allowable rate in dry tons per acre. The allowable rate is the maximum amount of sludge that may be applied per acre whether the amount is applied annually or on a one time basis. The reported values for $C_1$ range from 8,150 to 32,600 which limit the zinc equivalent addition to 2.5 to 10 percent of the unamended soil CEC, respectively. Reported values for $C_2$ are either zero or 300, which allows some CEC value for the added sludge (22)(34)(39).

Management Considerations

Environmental Considerations - Land application of sludge involves critical integration of groundwater, surface water, air, soil, and crop systems. Environmental considerations for each system follow:

1. Groundwater pollution. Proposed U.S. EPA guidelines recommend that the permanent groundwaters (groundwater which is not removed by an underdrain system or other mechanical means) in the zone of saturation (where the water is not held in the ground by capillary tension) be protected from pollution (34).
2. Surface water pollution. Surface water pollution can best be eliminated by operating the application area as a closed system, that is, collecting runoff from the application area and reapplying at a later date (40). In many cases, this will not be feasible and surface water pollution can be controlled with proper site selection and by practicing sound soil conservation

to prevent soil movement with runoff. Regulating application periods and immediate soil incorporation of sludge which has been spread will help reduce pollutants in runoff water.

3. Air pollution. Odor problems, which can be a serious factor, can usually be controlled by good housekeeping and sound management (4). Bright, cool, sunny days with winds blowing away from inhabited areas are best for land disposal. Where odors are a problem, soil incorporation immediately after spreading helps control the release of odorous gases (30). Blowing dust can also be controlled by proper soil conservation practices and sludge handling procedures.

4. Soil and crop systems. The complex soil-crop interrelationships previously presented must be considered in relation to the specific sludge characteristics for each sludge application system.

Walker proposed that problems associated with land application of different sludge types be compared according to the criteria presented in Table II-10 (4).

Monitoring - When considering monitoring requirements, the first objective is to minimize the need for monitoring by controlling runoff (42). Blakeslee states that the questions of groundwater system contamination, metallic or other toxic residue build-up in soil systems, and food chain transfer of such materials to animals or man must be answered. Adequate monitoring to assure that unnecessary risks are avoided will prevent repeating past "mistakes" associated with other waste disposal problems (43).

TABLE II-10

ENVIRONMENTAL CONSTRAINTS FOR LAND APPLICATION

| Sludge Treatment | Relative Level(1) of Problems Associated With Combined Primary and Secondary Sludge Treated by Different Processes | | | | |
|---|---|---|---|---|---|
| | Odor | Pathogens | Initial Toxicity | Heavy Metals(3) | Nitrogen Pollution |
| Raw-untreated | H | H | H | M | H |
| Raw limed(2) | M | L | H | L | H |
| Raw chlorine, pH 2-3 | N | N | H | ? | H |
| Raw chlroine, pH 6-7 | M | L | H | ? | H |
| Anaer. digestion | M | M | H | H | M |
| Anaer. + lime | M | L | H | M | M |
| Composted | N | N | L | M | L |
| Heat-dried | L | N | M | ? | H |

(1) H = High, M = Medium, L = Low, N = Negligible

(2) Limed to pH 11.5+

(3) Rating for metal level related to sludge treatment applies only to sludge from same treatment plant

Source: Reference (40)

Monitoring requirements for land application systems are dependent on the following:

1. Rate of sludge application
2. Characteristics of the sludge
   a. Degree of stabilization
   b. Degree of pathogen reduction
   c. Heavy metals present
   d. Persistent organics present
3. Characteristics of the application site
   a. Land slope
   b. Physical features of the soil
   c. Proximity to water resources

4. Land use
   a. Agricultural utilization
   b. Reclamation of marginal land
5. Crop production
   a. Crops edible raw (root or other)
   b. Crops requiring cooking
   c. Grain crops
   d. Feed crops
   e. Trees
   f. Nonfeed grasses (park land, etc.)
6. Groundwater availability and uses
7. Local climate

In Maryland, soil and sludge tests are required for all land application projects; however, essentially no on-site monitoring is required for low rate farmland application or for marginal land use. The state of Maryland has adopted the land application guidelines listed in Table II-11 (4).

The U.S. EPA draft guidelines require the following of Federal grant applicants (34):

> The grant applicant must develop and implement a monitoring plan to provide for adequate monitoring of each land application site where the application rate will exceed 5 dry tons per acre per year for liquid digested sludge, or 50 dry tons per acre over a three-year period for dried or dewatered sludge. Use of bagged-sludge fertilizer products for the retail market will not require site monitoring.
>
> The site monitoring plan must be specifically designed for applicable local conditions, and is to include consideration of heavy metals, persistent organics, pathogens, and nitrates in groundwater, surface water, sludge, and soils.
>
> The size of the project and nature of the lands to which sludge is being applied is important. For new projects it will be necessary to estimate the sludge characteristics and crop response. Monitoring should be more frequent, at least initially, until successful performance is assured.

Products in the human food chain grown on sludge-amended soil should be monitored for heavy metals, persistent organics, and pathogens. At this time it appears that Salmonella and Ascaris ova would be the pathogens of choice for a monitoring program.

TABLE II-11

SLUDGE APPLICATION GUIDELINES FOR MARYLAND

1. Fertilizer application - general farming - digested sludge only
   - (a) nitrogen and metal limitation
   - (b) no monitoring at site
   - (c) lime to pH 6.5 for most crops
   - (d) soil and sludge test - University of Maryland (UM) and Maryland State Department of Agriculture (MSDA)

2. Reclamation - marginal land - digested sludge only
   - (a) one-shot application - 50 dry tons per acre
   - (b) little if any monitoring at site
   - (c) pH 6.5 or above
   - (d) soil and sludge test - UM and MSDA
   - (e) site inspection - Health Department and Soil Conservation Service (SCS)

3. Disposal application - surface - digested sludge only
   - (a) repeated application
   - (b) extensive monitoring
   - (c) pH 7.0 or above
   - (d) soil and sludge test - UM and MSDA
   - (e) site inspection - Health Department and SCS
   - (f) drainage
   - (g) public hearing

4. Trench application - all sludges - limed before dewatering
   - (a) one-shot application - up to 500 dry tons per acre
   - (b) extensive monitoring
   - (c) pH 7.0 or above
   - (d) soil and sludge test - UM and MSDA
   - (e) site inspection - Health Department and SCS
   - (f) drainage
   - (g) public hearing

Source: Reference (40)

Specific groundwater monitoring criteria recommended by the U.S. EPA, which includes the following, should be used (44):

1. Chemical pollutants such as heavy metals, dissolved salts, and nitrates.
2. Organic pollutants such as pesticides and residual organics.
3. Pathogenic organisms.

Specific criteria are listed in the U.S. EPA Manual for Evaluating Public Drinking Water Supplies (45). When the specific criteria are exceeded naturally in the groundwater, the natural concentrations should not be increased as a result of sludge application (44).

## Institutional Considerations

Land application of sludge for agricultural utilization or land reclamation many times involves one element of society normally not encountered during day-to-day operation of other sludge disposal methods, that is, the private sector. As explained in PART I, many communities in Iowa utilizing land application for ultimate sludge disposal rely on private land and/or individuals. This is particularly true for plants with less than 5 mgd flow. Although little statistical documentation exists, this is apparently the case in many states.

Of the 38 plants (listed in PART I) utilizing land application, 33 of the plants provide sludge for private use. None of the communities operating these 33 plants has a formal agreement with the private individuals involved. In all cases with existing land application systems, there is little or no control over restricting access to application areas. At those plants where private individuals haul dried sludge, there are no programs for instructing the users on handling precautions and suitable garden crops nor is the sludge sampled for pathogenic organisms.

Current arrangements for land application pose the following unanswered questions:

1. Is the treatment plant operating authority liable for misuse of sludge utilized by individuals? Misuse could result from any of the following:
   a. Using inadequately stabilized sludge in gardens.
   b. Applying excessive amounts of sludge resulting in high nitrate content in plants; or ground- or surface water pollution.
   c. Applying sludge with excessive concentrations of certain heavy metals.
   d. Contact with sludge by excessive numbers of people.
2. Where does sludge go if it is no longer accepted by the past user? Without binding agreements, treatment plants do not have guaranteed disposal sites unless the land is publicly owned. While smaller plants will usually be able to find other private land to apply the sludge, solids overloading will occur in the plant unless there are sufficient sludge storage facilities.

In some instances, larger plants may purchase the land necessary for land application. In this case, critical institutional problems will be:

1. Public opinion. Acquiring the necessary public acceptance to allow purchase of the necessary land. The Metropolitan Sanitary District of Greater Chicago prefers to buy rather than lease land. The "Prairie Plan" has shown that people are sometimes reluctant to receive waste from others on their land or in their area. The Three Rivers Water Shed Study in Ohio has shown that the general public is more inclined to accept their own waste than waste of other people (46).
2. System operation. Many communities have neither the desire nor the necessary expertise to engage in the field of agriculture. The decision must be made whether the community will perform their own agricultural service or if private contractors will be used.

Cost Data

Land application is frequently a low cost final disposal method for all sludge constituents. Since it is desirable and beneficial to spread sludge in a liquid state, the costly dewatering process can be eliminated. The capital cost associated with land spreading has traditionally been minimal. With controlled spreading operations, collection and treatment of leachate should not be required. The operating costs include transportation which is influenced by the haul distance. As the sludge quantity increases, the haul cost becomes critical. Generally, land spreading has been economical for small communities where haul costs are not as sensitive due to the low sludge quantities.

Public ownership or long-term lease of land used for spreading is desirable. However, many smaller communities haul sludge to farming areas without any formal written agreements. In most cases there is no revenue from or charges to the local landowner and the sludge disposal cost consists only of transportation expenditures. Where a spray irrigation type system is used, capital expenditures are needed for access roads, distribution systems, fencing, and other miscellaneous items. Burd reported operating costs ranging from $4.00 to $30.00 per ton of dry solids with an average of approximately $10.00 per ton (5). Others reported costs on large scale systems range from approximately $10.00 per ton at San Diego, California to approximately $60.00 per ton at Chicago, Illinois (3). The wide range in reported costs is due to the different modes of transportation, the solids content, and the different haul distances.

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# SECTION 3 - LANDFILL DISPOSAL

## General

Historically, landfilling has been an acceptable method for ultimate disposal of all types of solid waste. Stabilized sludge can be satisfactorily disposed in a sanitary landfill, either alone or in a mixture with municipal solid waste, when the landfill is properly engineered and operated. Careful site selection and daily cover can eliminate many of the past problems associated with the disposal of material in open dumps. In addition to providing an acceptable ultimate disposal technique, the sanitary landfill affords satisfactory environmental protection and can be a means for land reclamation.

The U.S. EPA has proposed guidelines dealing with acceptable methods for the utilization or disposal of sludges (1). A section of this document deals with sludge disposal methods in sanitary landfills.

## Sludge Quantities

Typical quantities of dewatered sludge will range from 0.6 to 1.3 pounds per capita per day (wet weight) depending upon the type of treatment provided and the moisture content of the dewatered sludge. In communities with significant industrial contribution, additional sludges will be produced by the industrial waste stream. Also, sludges from industrial pretreatment facilities and industrial wastewater treatment facilities may be hauled to a landfill for disposal. In addition to the waste sludge, screenings and grit removed at the sewage treatment facility may be deposited in a landfill.

## Preliminary Processing Requirements

Relatively little data are available on sludge handling in a landfill. In the past, operational problems have developed in the disposal of sludge. In a liquid state, the material may be difficult to mix with the refuse. Without careful application techniques, it tends to flow ahead of the refuse, creating problems in compacting and covering operations. Thus, most operations require that the sludge be dewatered prior to landfilling. Large settlements can occur when sludge is not properly mixed with the refuse, necessitating continual site maintenance.

Preliminary sludge processing recommendations before disposal in a sanitary landfill, as specified in the proposed U.S. EPA regulations, include stabilization and dewatering (1). Sludge stabilization prior to landfilling is difficult to justify in all cases. It does have the advantages of reducing odor problems, preventing nuisances, reducing the total sludge volume, reducing hazards to those working in the area, and usually produces a sludge which can be more easily dewatered. However, several existing plants dispose of raw dewatered sludge in sanitary landfills with no apparent harmful side effects. Although sludge stabilization is desirable for the reasons previously stated, it may be difficult to justify on an economic and environmental basis for all treatment facilities.

Stabilized sludge can be satisfactorily dewatered by using drying beds, drying lagoons, vacuum filters, or some other mechanical means. The moisture content of the dewatered sludge will vary depending upon local conditions and the type of dewatering process used. However, the previously mentioned dewatering processes should produce a sludge satisfactory for disposal in a landfill. Dewatered sludge should have a solids content of at least 15 percent to be mechanically handled and hauled to a landfill without specialized equipment (2).

A three-year demonstration project to investigate the economic and environmental effects of disposing of liquid sewage sludge into a sanitary landfill was conducted at Oceanside, California, with the final report being published in 1974 (3). The report concluded that through the use of proper sludge spreading techniques, solid waste has sufficient absorbing capacity to retain moisture from the sewage sludge. Additional benefits claimed in the report include increased landfill compaction, greater density, and reduced blowing of litter and dust. The report also concluded that sanitary landfills should not be used for disposal of septic tank pumping, raw liquid sludge, or other hazardous wastes unless special operator, equipment, and environmental protection measures are instituted.

Community Size Applications

Sludge disposal in a sanitary landfill can be satisfactorily used for a community of any size. However, sludge processing may vary considerably with plant size. Small treatment facilities will typically use sludge drying beds, periodically hauling the dewatered sludge to the landfill for final disposal. Larger communities may utilize vacuum filters for sludge dewatering with the sludge cake hauled to the landfill several days per week. Where sludge drying lagoons are utilized, the dried sludge will only be hauled to the landfill when the lagoons are cleaned out.

Design Considerations

The design of a landfill used for a sludge disposal should follow the same good practices required for a solid waste landfill. The U.S. EPA has published a set of recommended guidelines dealing with land disposal of solid waste (4). In addition, Iowa has rules and regulations for the design and operation of land disposal sites. In general, the recommended practices are:

1. The base of the landfill should have a sufficient depth of relatively impervious soil to prevent pollution of the groundwater.
2. The landfill should not be constructed in the flood plain of a lake, river, or stream.
3. The landfill should not be in hydrologic contact with a municipal or private water supply, either surface or underground.

4. Surface drainage should be directed away from the landfill area.
5. The landfill should be covered with 6 inches of relatively impervious soil each day and 2 feet of final cover. Grading should encourage drainage of surface water away from the landfill.

Dewatered sludge can be landfilled in a separate location or mixed with municipal solid waste. However, it is usually advisable to mix the dewatered sludge with refuse to minimize settlement and to reduce total land area needs (5). Volume requirements for dewatered sludge mixed with refuse are small, because sludge tends to sift into the voids of the refuse during compaction. If sufficient quantities of refuse are not available for mixing or if the sludge is handled in a liquid state, special handling of the sludge will be required.

Industrial Waste Constraints

APPENDIX A discusses industrial sources and disposal of hazardous substances. Sludges containing high concentrations of heavy metals, cyanides, coliform bacteria, or other hazardous substances can generally be disposed in a similar manner as sludges not containing these substances. However, a separate burial location and a more comprehensive monitoring program may be required to evaluate any immediate and potential long-term pollution effects.

Two landfill operational problems common in Iowa are associated with the packing industry. Large volumes of paunch manure are commonly hauled from beef packing plants. A smaller volume of paunch manure and occasionally large volumes of grease are hauled from municipal wastewater treatment plants. Both materials are difficult to handle at a landfill site; and where large quantities are expected, special handling provisions may be necessary. The special handling may include:

1. Disposal in a separate part of a landfill using soil for immediate mixing.
2. Disposal in a part of a landfill set aside for building material disposal using the building material for mixing or covering.

## Disposal of Incinerator Ash

Where incineration is used as a means of sludge reduction, an ash residue which consists of powdery inorganic matter is produced. As a result, blowing dust may be a problem at the final disposal site. The incinerator ash can be satisfactorily disposed of in a sanitary landfill. However, in many places incinerator ash is used as a fill material, and a study has been conducted to determine engineering properties of sludge ash (6). There are several composition variables which reflect the ash origin and the type of wastewater treatment or sludge handling procedures that produce the ash. Incinerator ash generally has a pH greater than 10.5 and may be corrosive to metals.

## Environmental Considerations

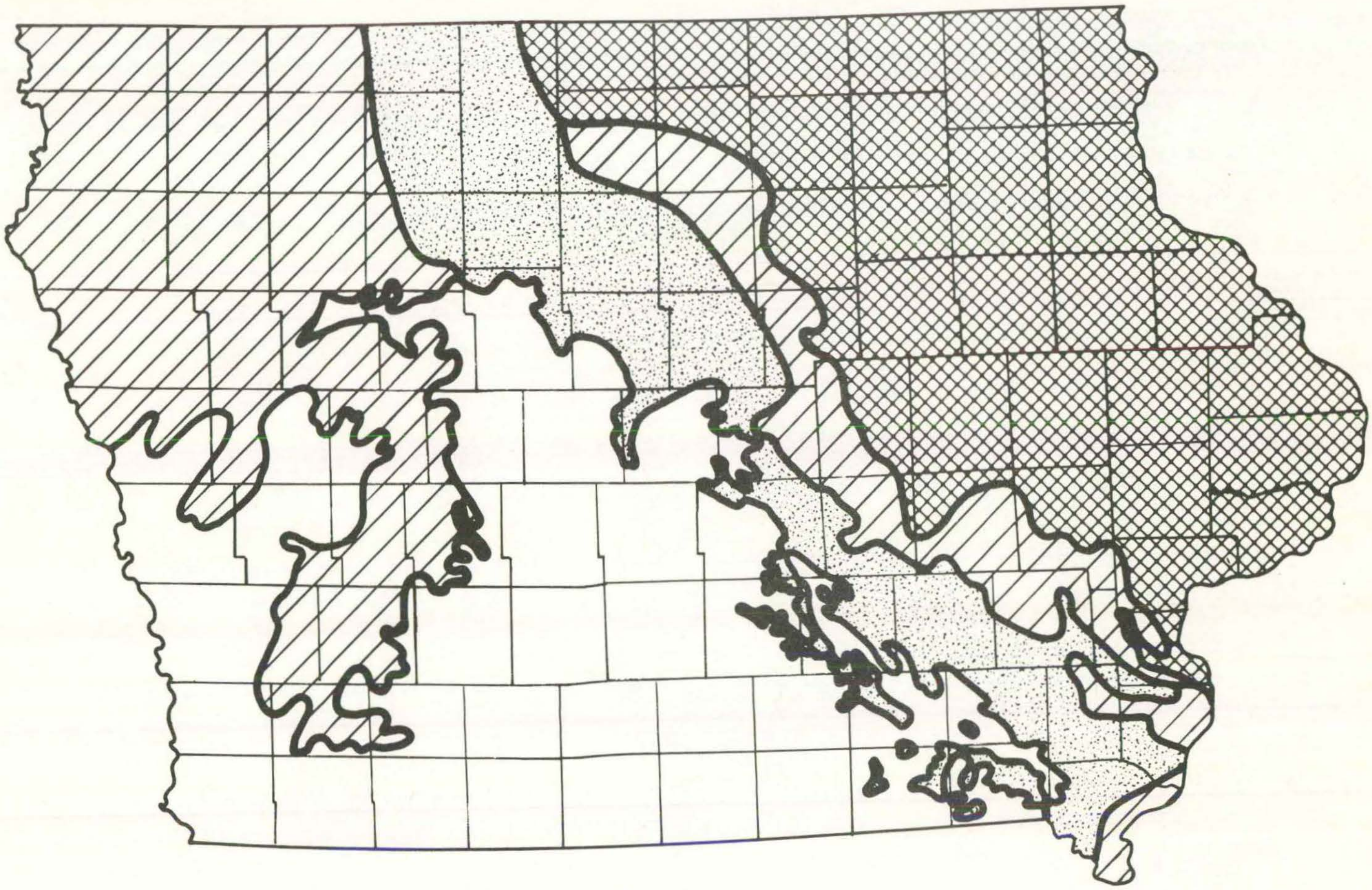
The major disadvantage of a landfill is the possibility of pollution of ground- and surface waters from leachate. Sludge, with its high water content compared to refuse, is a prime source of leachate. However, most dewatering steps remove free moisture leaving bound water remaining with the sludge. This moisture is not readily released. Also, with proper site selection, design, and operation, the effects of leachate can be minimized.

The Iowa Geological Survey has published a public information circular which deals with hydrogeologic considerations for solid waste disposal (7). They have divided the state of Iowa into four areas based upon the degree of hazard for bedrock aquifer contamination with respect to landfill site location. These areas are shown on Figure II-3 and are classified as follows:

A. Zone A is a high-hazard zone underlain by uppermost subcropping rock units that are regional aquifers. Caverns and solution zones in the bedrock are common.

B. Zone B is classified as a moderate-hazard zone and is underlain by rock units having a variety of lithologies and local bedrock aquifers exist.

C. Zone C is a low-hazard zone usually underlain by rock units having a shale lithology.



HIGH HAZARD ZONE

MODERATE HAZARD ZONE

LOW HAZARD ZONE

NO HAZARD ZONE

ZONES OF HAZARD FOR LANDFILL
SITE LOCATION

FIGURE II-3

SOURCE: REFERENCE (7)

D. Zone D is classified as a no-hazard zone and is underlain by fine grain-sized bedrock units.

The Iowa Geological Survey should be contacted for more detailed information during site selection and landfill design.

Another environmental consideration consists of the production of methane gas in a sanitary landfill. Generally, organic material having a higher moisture and volatile content will yield more gas (8). It is anticipated that methane gas production will be higher in a landfill disposing of sewage sludge than it will be in a landfill handling only refuse. At one experimental site in California, liquid wastes are being discarded in a landfill to help augment the somewhat sparse rainfall. This increases the decomposition rate and methane gas production (8).

Monitoring

Monitoring requirements at a sanitary landfill disposing of sewage sludge will generally be the same as those for a landfill disposing of solid waste. The degree of monitoring may be much more critical for landfills located in high hazard zones than for landfills located in zones with little or no hazard of aquifer contamination. The monitoring program at the landfill should be designed for applicable local conditions and should include monitoring of groundwater observation wells and any surface runoff for heavy metals, persistent organics, pathogens, nitrates, and additional parameters as determined by the sludge characteristics (9).

An article by Walker indicates that recent studies suggest that observation well monitoring systems may not be the most effective means to trace chemical pollutant flow paths or to determine groundwater chemical concentration at any time or depth (10). Instead, these studies show that chemical analysis of core samples from the underlying soils permits a positive definition of any chemical constituent within the profile. This method measures the chemicals whether they are present in precipitated form, held by retention of soil particles, or dissolved in groundwater.

Institutional Arrangements

Landfills used for sewage sludge disposal in Iowa will normally be owned and operated by a municipality, county, or other regional authority. Where a sanitary landfill accepting sludge is not operated by the wastewater treatment authority, a written contract or binding agreement should be obtained between the wastewater treatment authority and the operating authority of the landfill.

Costs

Landfills have traditionally operated at a low unit cost, partially as a result of nominal operating constraints imposed by regulatory agencies. Although increased emphasis on environmental factors will affect costs, landfills will continue to be an economical means of ultimate disposal.

It is anticipated that where landfill disposal of sludge is used, most communities in Iowa will haul sludge to municipal or regional facilities rather than constructing separate sludge disposal landfills. Where municipal or regional landfill facilities are used, the cost will usually consist of gate fees at the landfill. These gate fees will vary depending upon the cost of constructing and operating the landfill and the volume of waste handled. Existing landfill charges experienced by communities in Iowa, as reported in PART I of this report, range from $0.50 to $1.18 per wet ton. Another report published by Burd cites various investigators reporting operating costs of $0.95 to $3.80 per ton (11). The quantities of solids handled per year represented by the cost figures by Burd are not known.

To evaluate the true cost of a landfill versus a land spreading ultimate disposal technique, dewatering and hauling costs must be considered. Dewatering costs will depend upon the method used and the volume of sludge handled. Hauling costs are dependent upon the volume of sludge hauled and the distance to the landfill. Hauling costs are estimated to be approximately $2 per wet ton for a landfill located about 10 miles from the sewage treatment plant. This cost includes cost of purchasing and maintaining trucks and labor to haul the dewatered sludge. In order for landfilling of dewatered sludge to be more economical than land spreading of liquid sludge, the cost of dewatering and landfill fees would have to offset the higher cost of hauling the larger volumes of liquid sludge.

Liquid sludge will typically occupy 5 to 10 times more volume than dewatered sludge.

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## SECTION 4 - SLUDGE LAGOONS

### General

Lagooning sludge has been a popular method of sludge disposal. Excavated and natural depressions have been used as sludge lagoons. Sludge lagoons are used for either permanent disposal sites or for short- or long-term storage and dewatering lagoons. The primary distinction is permanent lagoons require "capping" when their storage volume is depleted.

Sludge lagoons are presently being used to a lesser degree in Iowa than previously. This decrease in usage has been the result of lagoons being "phased out" for the following reasons:

1. Lagoons being located in flood plains and being flooded periodically.
2. Abandoned gravel pits or other permeable depressions being used for lagoons resulting in a high probability of groundwater contamination.
3. Urban areas moving closer to, or surrounding, lagoons; particularly when raw sludge has been lagooned.

Changing requirements for other methods of sludge disposal may bring about increased use of lagoons for long-term storage and dewatering.

### Preliminary Processing Requirements

Sludge should be stabilized prior to being lagooned. Stabilization by digestion, chemical treatment, or thermal treatment (including incineration) serves the following functions:

1. Renders the sludge more biologically inert which significantly reduces odor problems.
2. Reduces the pathogen content in the sludge. This reduces the possibility of bacterial contamination of groundwater sources and disease transmission by insects.

Various techniques have been reported by researchers to reduce the water content and fully utilize lagoon capacity (1)(2).

## Design Considerations

Sludge lagoon design should be according to good engineering practice and applicable state and federal regulations. In addition to specific lagoon design criteria, the following items should be considered (3).

1. A location sufficiently removed from highways and dwellings, with actual separation distance dictated by the character of sludge.
2. Sludge discharge preferably below the liquid surface in the lagoon.
3. No pollution of groundwater supplies.
4. Draining off the sludge liquor to provide additional lagoon storage space. This liquor may be discharged back to the raw sewage influent to the treatment plant. Previously, dilution of the sludge liquor in a receiving stream was permitted; this practice is increasingly in conflict with tightened water quality criteria.
5. Lagoons, deeper than 5 feet, fenced as a safety measure. Shallower depths are often preferrable to facilitate drying.

## Community Size Application

Sludge lagoons are satisfactory for a community of any size provided conditions are suitable to adhere to the recommended design criteria. Land requirements may limit the practicability of lagoons for large treatment plants.

## Operation

Properly stabilized sludge is usually discharged to a lagoon at regular intervals based on solids accumulation in digesters (4). At least two cells should be used to allow alternate filling and settling to accelerate drying.

Land reclamation by lagooning has not been extensively researched. Sludge with 95 percent moisture has been dewatered to about 55 to 60 percent moisture in a 2- to 3-year period (5).

### Environmental Considerations

As previously discussed in this chapter, environmental considerations include the following:

1. Groundwater pollution. This is a critical item in Iowa. Areas of different groundwater zones in Iowa were previously shown on Figure II-3.
2. Odor control. Proper stabilization and area remoteness should limit odor problems.
3. Disease transmission. Proper stabilization will reduce the insect population and the pathogen content in the sludge.
4. Surface water pollution. Lagoons should not be constructed in areas subject to flooding. All liquid discharges should be routed to the wastewater treatment facility unless the discharge meets applicable effluent limitations.

### Costs

Based on dry solids, capital costs reported by investigators vary from \$1.50 to \$5.40 per ton dry solids (2)(5)(6). Land cost is the major variable. Increased concern over groundwater pollution may make many areas unsuitable for lagoons unless the basins are lined with impermeable material. The sealing costs will increase lagoon costs significantly.

Costs associated with operation and maintenance are normally minimal for ultimate disposal lagoons.

### Monitoring

In areas with identified high groundwater tables (see Figure II-3), monitoring should be required. Monitoring requirements should be the same as for landfills.

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# PART III
# RECOMMENDED SLUDGE DISPOSAL GUIDELINES

## SECTION 1 - INTRODUCTION

Recommended guidelines for land application of sludge are presented in SECTION 2, landfill disposal in SECTION 3, and lagoon disposal in SECTION 4. These recommended guidelines are based on current state-of-the-art information presented in PART 11. Guidelines which may be enacted by the Iowa Department of Environmental Quality should not be extremely rigid; provisions for exception should be allowed when it is shown that adequate sludge disposal is provided and the environment is protected. Periodic review and updating should follow as additional information concerning sludge stabilization, land application, and landfill disposal becomes available. In particular, the maximum sludge application limits proposed for agricultural land are based on the current state-of-the-art which does not contain adequate information on long-term effects of continuous sludge application on agricultural land.

The selected sludge disposal method must be environmentally and economically acceptable. Many variables are involved in selecting the best sludge disposal scheme. A sludge disposal method suitable for one set of conditions may be totally unacceptable under other conditions. Factors to be considered for ultimate sludge disposal include:

1. Existing sludge handling and disposal facilities
2. Proposed sludge treatment and handling methods
3. Sludge quantity
   a. Community size
   b. Industrial contribution
4. Composition of sludge
   a. Sludge type
      (1) Primary sludge
      (2) Waste biological sludge
      (3) Chemical sludge
   b. Possible hazardous materials in sludge
      (1) Heavy metals
      (2) Persistent organics

5. Pathogen population in treated sludge
6. Land area available for ultimate disposal
    a. Landfill
    b. Land application area
7. Distance to sludge disposal site
8. Institutional arrangements
9. Monitoring requirements

## SECTION 2 - LAND APPLICATION GUIDELINES

### Introduction

Land application of sludge is a method of ultimate sludge disposal that, unlike landfills and lagoons, allows the nutrients and humus in the sludge to be used for beneficial purposes. This use must be controlled, however, since not all sludge is suitable for land application nor is all land suitable for sludge application. In addition, certain plants are more desirable than others for growing on sludge-amended soil. Restrictions on the amount of sludge that can be applied to the land must be set to ensure that sludge application projects do not produce adverse environmental impact or cause disease or toxin accumulation in man or animals.

The recommended guidelines for sludge application apply to liquid sludge, dewatered sludge, and sludge compost. Sludge dried for sale as a commercial fertilizer should be applied according to recommended fertilizer application rates.

### Preliminary Processing Requirements

Sludge stabilization should be provided prior to land application to minimize odors, lower pathogen content, and render the sludge more biologically inert. The following are acceptable sludge stabilization methods prior to land application:

1. Anaerobic Digestion
2. Aerobic Digestion
3. Chemical Treatment (lime treatment, etc.)
4. Heat Treatment or Thermal Conditioning
5. Thermal Drying

Certain types of land application projects may require pathogen reduction beyond that normally obtained with digestion. The following are acceptable disinfection methods:

1. Storage for long periods
2. Pasteurization
3. Chemical Treatment
4. Composting and curing

Sludge Application Limitations

Heavy Metals - Sludge containing heavy metal concentrations exceeding those listed below should not be applied to agricultural land or to reclaim marginal land for agricultural use unless special management and monitoring programs are implemented.

| Parameter | Criteria |
|---|---|
| Zinc | 2,000 mg/kg dry weight |
| Copper | 1,000 mg/kg dry weight |
| Nickel | 200 mg/kg dry weight |
| Cadmium | 15 mg/kg dry weight |
| Cadmium/Zinc (ratio) | Less than .01 |
| Lead | 1,000 mg/kg dry weight |
| Mercury | 10 mg/kg dry weight |
| Chromium | 1,000 mg/kg dry weight |
| Arsenic | Limit not determined |

The sludge zinc equivalent [Zn eq = (mg/l Zn) + 2(mg/l Cu) + 8 (mg/l Ni)]-soil cation exchange capacity (CEC) relationship should be used to determine the maximum amount of sludge that can be applied during the sludge application project without exceeding 10 percent of the cation exchange capacity of the soil. The equation for calculating the application rate follows:

$$\begin{array}{c}\text{Allowable rate}\\\text{(tons per acre)}\end{array} = \frac{32{,}600 \times \text{CEC}}{\text{Zn eq} - 300}$$

The zinc equivalent for a sludge with the metals concentration listed above is 5,600 and the total allowable sludge application rate is 6.15 tons per acre per unit of CEC. For soil with a CEC of 33 me/100 g, an annual application rate of 10 tons per acre can be used for a 20-year period.

The zinc equivalent-cation exchange capacity relationship usually will not be the limiting factor for applying sludge to typical farmland in Iowa.

Nutrients - The application rate of sludge on agricultural land should be based on the nutrient requirements of the crop being produced. The three nutrients of concern are nitrogen, phosphorus, and potassium.

1. Nitrogen. Normally nitrogen can be applied in excess of the amount required, as indicated by annual soil tests, because about 50 percent of the nitrogen is not available as a plant nutrient in the year of application. Some of the nitrogen is lost through volatilization and leaching. Some of the organic nitrogen will convert to inorganic forms and be available after the year of application. The allowable application rate is determined by the nitrogen content of the sludge and the crop requirement after accounting for the available nitrogen in the soil.

   In most circumstances, nitrogen will control the sludge application rate, at least on a short-term basis.

2. Phosphorus. Since phosphorus is not easily leached from the soil, phosphorus applications can be somewhat in excess of the phosphorus requirement when proper precautions are taken to limit soil erosion. Care should be taken to prevent accumulation of phosphorus in concentrations detrimental to plants.

   When a sludge contains a relatively high concentration of phosphorus and a low concentration of nitrogen, phosphorus will probably be the factor limiting application rates. However, in most cases, phosphorus will not limit the application rate for municipal sludges.

3. Potassium. Potassium concentration in sludge is normally low and sludge application may not supply sufficient amounts for balanced plant nutrition. Potassium will rarely limit sludge application rates.

Crop Selection

As stated in the Introduction, certain plants are more desirable than others for growth on sludge-amended soil. Factors to be considered include the following:

1. Heavy metals. Most heavy metals accumulate in the leafy part of plants; therefore, it is undesirable to grow certain crops for human or animal consumption on sludge-amended soil. Grain crops are preferrable from a heavy metals standpoint.
2. Pathogenic organisms. Pathogenic organisms have been known to survive in soil for long periods of time. Crops to be eaten raw should not be grown on sludge-amended soil unless extensive monitoring is conducted.
3. Nutrients. When maximum sludge application rates are to be used, crops which require high levels of nitrogen and phosphorus should be grown. Crops removed from the fields are preferrable to grain crops from a nutrient removal standpoint.

Controlling Surface Runoff

The following recommendations are made to control surface runoff and minimize the possible contamination of water resources by land application of sludge:

1. Wastes applied on tilled land with slopes greater than 10 percent and on flood plains subject to flooding more frequently than once every ten years should be incorporated into the soil by immediate disking, plowing, or other similar methods.
2. Waste disposal on frozen or snow-covered land should be avoided, if possible. If wastes are spread on frozen or snow-covered land, such disposal should be limited to land areas on which:
   a. Land slopes are 4 percent or less or
   b. Adequate erosion control practices and/or diversions exist. Adequate erosion control includes terraces, mulch tilage, cover crops, or contour farming.
3. No wastes should be applied on land subject to flooding more than once every ten years during usual peak flow periods (April, May, and June). No wastes should be spread on these areas during frozen or snow-covered conditions.

4. No wastes should be spread closer than 200 feet to any of the following unless the wastes are incorporated into soil:
   a. Watercourse - stream, waterway, etc.
   b. Surface intake of tile line or other buried conduit.
   c. Sinkhole.
   d. Shoreline of a lake or pond.
   e. Any well with an open surface inlet.

Institutional Considerations

Institutional requirements will vary considerably depending upon the amount of sludge handled, type of transportation facilities used, size of sludge storage facilities, and availability of backup sludge disposal facilities. Ownership of the land used for final disposal or formal written agreements with the landowners should be required under the following circumstances:

1. System with no backup sludge disposal method and minimal amount of sludge storage capacity.
2. Systems where large capital expenditures are required for the transportation and distribution system for specific disposal sites (pipeline and spray irrigation system).
3. Areas where there is reason to believe that landowners may be reluctant to accept sludge application.

Under the following conditions, no written agreements should be required with landowners of potential sludge disposal areas:

1. Treatment systems which have backup sludge disposal methods (that is, dewatering and landfilling, or other).
2. Small treatment facilities (less than 1 mgd) with large sludge storage capacity (greater than 120 days).

Sludge Use By Citizens

The following precautions are recommended where dried sludge is hauled by private individuals for their own use on yards and gardens:

1. Sludge should be stabilized and dewatered.
2. Dewatered sludge should be stored for an extended period of time to reduce pathogenic organisms.
3. Sludge should be analyzed for heavy metals and pathogenic organisms. Where heavy metals concentrations exceed the levels listed earlier in this section, the sludge should not be made available for use by citizens.

Monitoring Requirements

Monitoring requirements are recommended as follows to protect water resources and food supplies for both animal and human consumption.

1. Sludge. The sludge analyses will help determine the type of monitoring required during a sludge application project. The following sludge characteristics should be quantified for the sludge form (liquid, dewatered, dried, etc.) to be applied to the land:
   a. Nutrients (nitrogen, phosphorus, potassium).
   b. pH
   c. Trace elements.
      (1) Cadmium, copper, nickle, and zinc in all cases.
      (2) Chromium, lead, mercury, arsenic, or others if industries contributing these wastes are discharging to the collection system.
   d. Pathogenic organisms, before root crops or other crops that are edible raw are grown; this is especially important when individual gardeners use sludge.
   e. Pesticide and residual organics if industries contributing these wastes are discharging to the collection system.

2. Groundwater. Permanent groundwater resources hydrologically connected to the sludge application area should be monitored prior to sludge application and during the application project in the following instances:

a. A "shallow," groundwater source is used for animal or human water supply.

b. Sludge application rates exceed recommended rates based on nutrient or heavy metals loadings.

c. Application of sludge containing excessive amounts of pesticides or residual organics.

d. Application of sludge not meeting recommended stabilization criteria.

When groundwater monitoring is required, key constituents found in the sludge and the parameters listed in the U.S. EPA Manual for Evaluating Public Drinking Water Supplies should be analyzed.

3. Soils. The amount of soil testing required will depend on the results of the sludge analyses, soil classification data available for the site, and the sludge application rate proposed. Items that may require monitoring are:

a. Cation exchange capacity (CEC)

b. pH

c. Trace elements

d. Nutrients (nitrogen, phosphorus, and potassium)

e. Pathogenic organisms

f. Pesticides and residual organics

The soil CEC and sludge trace elements, or the sludge nutrient concentration (primarily nitrogen) will determine the sludge application rate. Proper crop management should include routine soil testing to determine soil nutrient supplies.

4. Crops. The amount of crop monitoring required will depend on the results of the sludge analyses, type crop grown, use of the crop, and proposed sludge application rate. Crop analyses should be performed on the part of the crop used. Items that may require monitoring are:

   a. Nitrate nitrogen (animal feed)
   b. Magnesium, calcium, and potassium (grass tetany for animals)
   c. Trace elements
   d. Pesticides and residual organics.

## SECTION 3 - LANDFILL DISPOSAL GUIDELINES

### Introduction

These recommended system planning and operation guidelines were developed, assuming that no toxic concentrations of heavy metals or other materials were present in the sludge. APPENDIX A contains additional information on the disposal of hazardous waste.

### Preliminary Processing Requirements

Preliminary processing requirements for landfill disposal will normally consist of sludge stabilization and sludge dewatering. In certain cases, chemically conditioned dewatered sludge or liquid stabilized sludge may be landfilled providing adequate provisions are made at the landfill to handle the material, protect the health of the employees, and provide additional monitoring.

The following are acceptable sludge stabilization methods prior to landfill disposal:

1. Anaerobic digestion
2. Aerobic digestion
3. Chemical treatment (lime treatment, etc.)
4. Heat treatment or thermal conditioning
5. Incineration
6. Other thermal processes (such as pyrolysis, thermal drying, etc.)

The following are acceptable sludge dewatering methods prior to landfill disposal:

1. Drying beds
2. Drying lagoons
3. Vacuum filtration
4. Other mechanical means (centrifuge, filter press, etc.)

## Operational Considerations

The operation of a landfill used for sludge disposal should follow the same good practices required for a solid waste landfill. The following operational practices are recommended:

1. The sludge can be landfilled separately or mixed with solid waste in the landfill; however, mixing is preferable.
2. When incinerator ash is deposited in a landfill, special provisions may be required to contain the ash dust.
3. Sludges mixed with refuse should be spread uniformly in layers not over 2 feet thick and compacted.
4. The compacted waste should be covered with a minimum of 6 inches of suitable compacted earth cover at the end of each working day.
5. Erosion of sludges should be prevented and erosion of the fill cover kept to a minimum.
6. When each portion of the landfill is completed, a uniform cover layer of earth, compacted to a minimum of 2 feet should be placed over it and suitable grass or other cover planted to prevent erosion. The top of the fill should be mounded to prevent water penetration.
7. Drains should be used to divert ground- or surface water around the fill and to prevent flow over or through it.
8. Cover should not cake or crack in hot, dry weather since this will permit rain penetration. Cover should be kept mounded as the fill settles to reduce the possibility of standing water seepage.

## Institutional Considerations

A written contract or binding agreement should be obtained between the wastewater treatment authority and the operating authority of the landfill, unless the landfill is operated by the same entity.

Monitoring Requirements

The sludge to be landfilled should be periodically analyzed for nitrates, pathogens, heavy metals, and other parameters depending upon sludge origin.

Landfill monitoring should be designed for applicable local conditions and should include periodic monitoring of groundwater observation wells and surface runoff for heavy metals, persistent organics, pathogens, nitrates, and additional parameters as determined by the sludge characteristics.

## SECTION 4 - LAGOON DISPOSAL GUIDELINES

### Introduction

Sludge lagoons can be used for either permanent disposal or for short- or long-term storage and dewatering. These guidelines apply to all sludge lagoons regardless of intended use.

### Preliminary Processing Requirements

Preliminary processing requirements for lagoon disposal of sludge consist of sludge stabilization. The following are acceptable sludge stabilization methods prior to lagoon disposal:

1. Anaerobic digestion
2. Aerobic digestion
3. Chemical treatment (lime treatment, etc.)
4. Heat treatment or thermal conditioning
5. Incineration
6. Other thermal processes (such as pyrolysis, thermal drying, etc.)

### Design and Operational Considerations

The lagoon should be designed and operated to minimize potential odor and groundwater contamination problems. Where the lagoon is used for ultimate disposal, the location should not conflict with possible future land uses of the area. Following are recommended design and operational practices:

1. The lagoon should be sufficiently removed from highways and dwellings to minimize odor complaints.
2. The lagoon should be constructed in an impervious soil layer or else sealed to prevent groundwater contamination.
3. The lagoon should be protected from flooding.
4. The lagoon should be designed so that sludge liquor can be returned to the treatment plant, thereby increasing storage capacity.

5. Public access to the lagoons should be restricted.
6. Sludge should be discharged to the lagoons below the liquid surface level.
7. A minimum of two cells should be provided to allow alternate filling and settling to accelerate dewatering, if dewatering is an objective. This is not as critical if the lagoons are for storage prior to land application.

Institutional Considerations

Sludge disposal lagoons should be owned and operated by the wastewater treatment authority as an integral part of the wastewater treatment plant.

Monitoring Requirements

Monitoring requirements should be based on applicable local conditions. Where lagoons are adequately sealed and not in contact with groundwater supplies, groundwater monitoring should not be required. Where lagoons are located in areas with a potential for groundwater contamination, groundwater observation wells should be monitored for heavy metals, persistent organics, pathogens, nitrates, and additional parameters as determined by the sludge characteristics.

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I hereby certify that this report was prepared by me or under my direct personal supervision and that I am a duly Registered Professional Engineer under the laws of the State of Iowa.

Robert L. Thoem, PE

June 30, 1975 Reg. No. 5802

## APPENDIX A

## INDUSTRIAL CONSTRAINTS

### Background

The state of Iowa was originally settled and developed primarily as an agricultural state. Over the years, the trend has been toward greater industrialization with numerous agriculturally oriented industries located in Iowa. At the time of the 1970 census, approximately 13 percent of the people employed in the state were engaged in agricultural production. Approximately 30 percent were employed by industry with the remainder being employed by wholesale, business, professional, and other services.

At the present time, many diversified industries are located in the state of Iowa. Table A-1 lists the types of industries located in the state by the respective standard industrial classification. A majority of industries does not cause problems at municipal wastewater treatment facilities due to the small amounts and compatibility of their waste flow. However, some industries do cause wastewater treatment problems due to the nature and quantity of wastes discharged. The problems can be associated with either wastewater treatment and discharge criteria or with sludge handling and disposal, or both. Table A-2 presents a list of critical industrial groups as defined by the Corps of Engineers.

### Affects on Sludge Processing

Critical industrial groups can have several affects on sludge processing operations at municipal wastewater treatment plants. In many cases, increased quantities of sludge will be produced due to the increased flow and strength of the wastewater from industrial sources. The sludge may also have different characteristics than sludge produced in a wastewater treatment plant treating only domestic flow. In these situations, treatment facilities must be designed to handle the larger volumes and different types of sludges produced. In some cases, industrial contributors will cause large fluctuations in flow and organic

TABLE A-1

INDUSTRIAL GROUPS IN IOWA

**20 FOOD AND KINDRED PRODUCTS**

| | | |
|---|---|---|
| 201 | 204 | 207 |
| 202 | 205 | 208 |
| 203 | 206 | 209 |

**22 TEXTILE MILL PRODUCTS**

| | | |
|---|---|---|
| 221 | 224 | 227 |
| 222 | 225 | 228 |
| 223 | 226 | 229 |

**23 APPAREL AND OTHER FINISHED PRODUCTS MADE FROM FABRICS AND SIMILAR MATERIALS**

| | | |
|---|---|---|
| 231 | 234 | 237 |
| 232 | 235 | 238 |
| 233 | 236 | 239 |

**24 LUMBER AND WOOD PRODUCTS, EXCEPT FURNITURE**

| | | |
|---|---|---|
| 241 | 243 | 245 |
| 242 | 244 | 249 |

**25 FURNITURE AND FIXTURES**

| | | |
|---|---|---|
| 251 | 253 | 259 |
| 252 | 254 | |

**26 PAPER AND ALLIED PRODUCTS**

| | | |
|---|---|---|
| 261 | 263 | 265 |
| 262 | 264 | 266 |

**27 PRINTING, PUBLISHING AND ALLIED INDUSTRIES**

| | | |
|---|---|---|
| 271 | 274 | 277 |
| 272 | 275 | 278 |
| 273 | 276 | 279 |

**28 CHEMICALS AND ALLIED PRODUCTS**

| | | |
|---|---|---|
| 281 | 284 | 287 |
| 282 | 285 | 289 |
| 283 | 286 | |

**29 PETROLEUM REFINING AND RELATED INDUSTRIES**

| | | |
|---|---|---|
| 291 | 295 | 299 |

**30 RUBBER AND MISCELLANEOUS PLASTICS PRODUCTS**

| | | |
|---|---|---|
| 301 | 303 | 306 |
| 302 | 304 | 307 |

**31 LEATHER AND LEATHER PRODUCTS**

| | | |
|---|---|---|
| 311 | 315 | 317 |
| 313 | 316 | 319 |
| 314 | | |

**32 STONE, CLAY, GLASS, AND CONCRETE PRODUCTS**

| | | |
|---|---|---|
| 321 | 324 | 327 |
| 322 | 325 | 328 |
| 323 | 326 | 329 |

**33 PRIMARY METAL INDUSTRIES**

| | | |
|---|---|---|
| 331 | 334 | 336 |
| 332 | 335 | 339 |
| 333 | | |

**34 FABRICATED METAL PRODUCTS, EXCEPT MACHINERY AND TRANSPORTATION EQUIPMENT**

| | | |
|---|---|---|
| 341 | 344 | 347 |
| 342 | 345 | 348 |
| 343 | 346 | 349 |

**35 MACHINERY, EXCEPT ELECTRICAL**

| | | |
|---|---|---|
| 351 | 354 | 357 |
| 352 | 355 | 358 |
| 353 | 356 | 359 |

**36 ELECTRICAL AND ELECTRONIC MACHINERY, EQUIPMENT, AND SUPPLIES**

| | | |
|---|---|---|
| 361 | 364 | 367 |
| 362 | 365 | 369 |
| 363 | 366 | |

**37 TRANSPORTATION EQUIPMENT**

| | | |
|---|---|---|
| 371 | 374 | 376 |
| 372 | 375 | 379 |
| 373 | | |

**38 MEASURING, ANALYZING, AND CONTROLLING INSTRUMENTS; PHOTOGRAPHIC, MEDICAL AND OPTICAL GOODS; WATCHES AND CLOCKS**

| | | |
|---|---|---|
| 381 | 384 | 386 |
| 382 | 385 | 387 |
| 383 | | |

**39 MISCELLANEOUS MANUFACTURING INDUSTRIES**

| | | |
|---|---|---|
| 391 | 394 | 396 |
| 393 | 395 | 399 |

Source: Reference (1)

TABLE A-2

CRITICAL INDUSTRIAL GROUPS

| SIC No. | | SIC No. | |
|---|---|---|---|
| 098 | Fish Hatcheries, Farms, and Preserves | 285 | Paints, Varnishes, Lacquers, Enamels, and Allied Products |
| 10-14 | Division B - Mining | 2871 | Fertilizers |
| 201 | Meat Products | 2879 | Agricultural Pesticides, and Other Agricultural Chemicals, Not Elsewhere Classified |
| 202 | Dairy Products | 2891 | Adhesives and Gelatin |
| 203 | Canned Preserved Fruits, Vegetables (except Seafoods, SIC 2031 and 2036) | 2892 | Explosives |
| 2031, 2036 | Canned and Cured Fish and Seafoods; Fresh or Frozen Packaged Fish and Seafoods | 29 | Petroleum Refining and Related Industries |
| 204 | Grain Mill Products | 3011, 3069 | Tires and Inner Tubes; Fabricated Rubber Products, Not Elsewhere Classified |
| 206 | Sugar and Confectionary Products | 3079 | Miscellaneous Plastics Products |
| 207 | Fats and Oils | 311 | Leather Tanning and Finishing |
| 208 | Beverages | 32 | Stone, Clay, Glass, and Concrete Products |
| 209 | Miscellaneous Food Preparations and Kindred Products | 331 | Blast Furnaces, Steel Works, and Rolling and Finishing Mills |
| 22 | Textile Mill Products | 332 | Iron and Steel Foundries |
| 23 | Apparel and Other Finished Products Made From Fabrics and Similar Materials | 333, 334 | Primary Smelting and Refining of Nonferrous Metals; Secondary Smelting and Refining of Nonferrous Metals |
| 242 | Sawmills and Planing Mills | 336 | Nonferrous Foundries |
| 2432 | Veneer and Plywood | 347 | Coating, Engraving, and Allied Services |
| 2491 | Wood Preserving | 35 | Machinery, Except Electrical |
| 26 | Paper and Allied Products | 36 | Electrical Machinery, Equipment, and Supplies |
| 281 | Industrial Inorganic and Organic Chemicals (except SIC 2818) | 37 | Transportation Equipment (except Ship Building and Repairing, SIC 3731) |
| 2818 | Industrial Organic Chemicals | 3731 | Ship Building and Repairing |
| 282 | Plastics Materials and Synthetic Resins, Synthetic Rubber, Synthetic and Other Man-Made Fibers, Except Glass | 491 | Electric Companies and Systems |
| 283 | Drugs | 493 | Combination Companies and Systems |
| 284 | Soap, Detergents, and Cleaning Preparations, Perfumes, Cosmetics, and Other Toilet Preparations | | |

Source: Corps of Engineers Discharge Permit Application Form 4345.

loading at municipal wastewater treatment facilities. Large fluctuations which cause a treatment process upset and loss of treatment efficiency should not be allowed. Fluctuations which do not cause reduced treatment efficiency can be allowed providing the treatment facility is designed to properly treat the flow. The above-mentioned types of problems are often caused by food processing and related industries such as meat packing and grain processing industries. In addition to design considerations mentioned above, large quantities of grease are often produced by meat processing plants which require special design considerations.

Another restraint on sludge handling processes is inhibition of biological treatment due to toxic materials in the wastewater. Toxic material which can inhibit digestion processes include several heavy metals, cyanides, chloroform, some chlorinated organic compounds, and several others. Table A-3 presents a list of concentrations of materials which inhibit biological treatment processes. The listed concentrations may not always cause biological inhibition; however, without extensive pilot plant studies, this list can be used as a guide when evaluating possible problems.

Another industry-related problem is the production of hazardous wastes which must be treated and disposed. Hazardous waste as defined by EPA (3) "means any waste or combination of wastes which pose a substantial present or potential hazard to human health or living organisms because such wastes are nonbiodegradable or persistent in nature or because they can be biologically magnified, or because they can be lethal, or because they may otherwise cause or tend to cause detrimental cumulative effects." Hazardous wastes include toxic and flammable chemicals, explosives, biological and radioactive materials, and take many physical forms. While hazardous wastes make up only a small portion of the total solid waste picture, their potential as well as actual environmental impact can be severe. Hazardous wastes generally cannot or should not be handled or disposed of as normal waste due to their potential for creating adverse

TABLE A-3

CONCENTRATIONS OF MATERIALS WHICH INHIBIT BIOLOGICAL TREATMENT PROCESSES

| Pollutant | Concentration(1), mg/l Aerobic Processes | Anaerobic Digestion |
|---|---|---|
| Copper | 1.0 | 1.0 |
| Zinc | 5.0 | 5.0 |
| Chromium (Hexavalent) | 2.0 | 5.0 |
| Chromium (Trivalent) | 2.0 | 2000(2) |
| Total Chromium | 5.0 | 5.0 |
| Nickel | 1.0 | 2.0 |
| Lead | 0.1 | * |
| Boron | 1.0 | * |
| Cadmium | * | 0.02(2) |
| Silver | 0.03 | * |
| Vanadium | 10 | * |
| Sulfides (S) | * | 100(2) |
| Sulfates ($SO_4$) | * | 500 |
| Ammonia | * | 1500(2) |
| Sodium (Na) | * | 3500 |
| Potassium (K) | * | 2500 |
| Calcium (Ca) | * | 2500 |
| Magnesium (Mg) | * | 1000 |
| Acrylonitrite | * | 5.0(2) |
| Benzene | * | 50(2) |
| Carbon Tetrachloride | * | 10(2) |
| Chloroform | 18.0 | 0.1(2) |
| Methylene Chloride | * | 1.0 |
| Peintachlorophenol | * | 0.4 |
| 1,1,1-Trichloroethane | * | 1.0(2) |
| Trichlorofluoromethane | * | 0.7 |
| Trichlorotrifluoroethane | * | 5.0(2) |
| Cyanide (HCN) | * | 1.0 |
| Total Oil (Petroleum Origin)(3) | 50 | 50 |

* Insufficient data.

(1) Concentrations refer to those present in raw wastewater unless otherwise indicated.

(2) Concentrations apply to the digester influent only. Lower values may be required for protection of other treatment process units.

(3) Petroleum-based oil concentration measured according to the API Method 733-58 for determining volatile and non-volatile oil materials. The inhibitory level does not apply to oil of direct animal or vegetable origin.

Source: Adapted from Reference (2)

health or environmental impact. Table A-4 lists a few hazardous substances and their typical industrial sources. This is a sample list, and there are other industries which produce hazardous wastes. Also, many specific industries included in the broad categories listed in Table A-4 do not discharge hazardous wastes.

Technology is generally available to treat most hazardous waste streams by physical, chemical, thermal, or biological methods and for final residue disposal (5). Because of the nature of the materials handled, closer process control practices should be exercised. In situations where industries discharge large concentrations of hazardous materials, industrial pretreatment will normally be required. In some instances, municipal wastewater treatment facilities may be specially designed to treat hazardous materials.

Ultimate Sludge Disposal

In Iowa, ultimate sludge disposal normally consists of either land spreading or burial in a landfill. Sources of sludge containing hazardous materials include industrial pretreatment facilities, industrial wastewater treatment facilities, and in some instances municipal wastewater treatment facilities. Where excessive heavy metals or other hazardous materials are present in the sludge, surface spreading should either be restricted or else prohibited. Where land application can be used, the application rates should be reduced to account for the higher levels of hazardous materials in the sludge.

Most sludges containing hazardous materials should be disposed of in a landfill. The remainder of this paragraph is based upon a paper dealing with guidelines for landfill of hazardous industrial sludges presented by Curry at the 28th Industrial Waste Conference at Purdue University in 1973 (6). Detailed knowledge of hazardous industrial sludges to be landfilled is required. Since different sludges encountered become soluble under different and sometimes conflicting conditions, no one universal disposal procedure can be used. Since many sludges can be readily dissolved, it

TABLE A-4

HAZARDOUS SUBSTANCES WITHIN INDUSTRIAL WASTE STREAMS

| Industry | As | Cd | Chlorinated Hydrocarbons(1) | Cr | Cu | Cyanides | Pb | Hg | Miscellaneous Organics(2) | Se | Zn |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Mining and Metallurgy | X | X | | X | X | X | X | X | | X | X |
| Paint and Dye | | X | | X | X | X | X | X | X | X | |
| Pesticide | X | | X | | | X | X | X | X | | X |
| Electrical and Electronic | | | X | | X | X | X | X | | X | |
| Printing and Duplicating | X | | | X | X | | X | | X | X | |
| Electroplating and Metal Finishing | | X | | X | X | X | | | | | X |
| Chemical Manufacturing | | | X | X | X | | | X | X | | |
| Explosives | X | | | | X | | X | X | X | | |
| Rubber and Plastics | | | X | | | X | | X | X | | X |
| Battery | | X | | | | | X | X | | | X |
| Pharmaceutical | X | | | | | | | X | X | | |
| Textile | | | | X | X | | | | X | | |
| Petroleum and Coal | X | | X | | | | X | | | | |
| Pulp and Paper | | | | | | | | X | X | | |
| Leather | | | | X | | | | | X | | |

(1) Including polychlorinated biphenyls.

(2) For example, acrolein, chloropicrin, dimethyl sulfate, dinitrobenzene, dinitrophenol, nitroaniline, and pentachlorophenol.

Source: Reference (4)

is necessary to determine the conditions for each sludge that will maintain minimum solubility. These conditions must consider potential reactions with other sludges which produce conditions that may generate toxic concentrations of pollutants in the water in contact with them. When a landfill accepts several different sludges with different toxic metals, it may be necessary to set up separate areas for disposal of the specific sludges.

In addition to the special requirements necessitated by the sludges, standard requirements for operation of any landfill to prevent water penetration should be observed. In some cases lined landfills may be necessary. Even with maximum precautions over the operations, it is necessary to keep a close check on the leachate. If the leachate contains toxic concentrations of metals or some other hazardous material, it will be necessary to provide treatment.

Landfilling is not suitable for certain extremely toxic wastes which create hazardous fumes or dust and require greater isolation during the unloading and disposal operation (7).

It is evident that hazardous wastes require special processing and handling compared to other residuals. There appears to be a need for the state of Iowa to take steps to ensure proper management of these waste materials (both solid waste and sludge). A possible arrangement might be provision of several regional "clearinghouse" type processing and disposal centers for hazardous solid waste and sludge located strategically in the state. Hazardous materials which are not acceptable at other landfills could be hauled to a regional facility for preliminary treatment and ultimate disposal. Processing of solid waste and sludge at the landfill would be designed for the type of wastes expected in the region and could include such items as neutralization, special containerization, chemical fixation, dewatering, and incineration. The landfill could be lined with all leachate collected and treated. Management of such facilities could either be by the state, regional agencies, or private enterprise. For the latter two, the state should have close regulating authority and control. Charges for the operations could be through use of gate fees with each industry paying its appropriate share.

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## APPENDIX B
## OTHER STATE PRACTICES

This appendix summarizes existing sludge disposal practices in other Midwestern States. All information contained in this section was obtained from telephone conversations with personnel of the regulatory agency in the appropriate states.

### State of Illinois

General - Illinois does not have a formal set of sludge disposal regulations at the present time. The state has recently developed an extensive report on agricultural use of municipal sludge and is in the process of condensing this into a workable set of guidelines. These guidelines should be available by mid-1975.

Land Spreading - Land application of digested sludge with immediate incorporation into the soil to reduce ammonia loss is widely used in the state. No application of undigested sludge on top of the soil is allowed in Illinois. When new state guidelines are issued, each individual crop will have a formula relating nutrient uptake to sludge application rates.

Landfiling - Illinois has a formula to determine the maximum allowable liquid content of municipal sludge for disposal in a landfill. Liquid sludge can be disposed of in a landfill; however, a special permit is required.

### State of Indiana

General - Indiana has no formal published regulations. The state does not encourage the use of sludge lagoons due to runoff, misuse, and mismanagement. The disposal of undigested sludge is prohibited. Several larger cities in the state use incineration and dispose of the ash in landfills.

Land Spreading - An application rate of below five tons (dry weight) per acre per year is required for land application systems. This value was based on allowable nitrogen loadings and is considered to be conservative. In a majority of the communities, the liquid sludge is hauled and applied to the land by city-owned and operated vehicles.

Landfilling - The state considers any sludge containing less than 30 percent solids to be a hazardous material for landfill disposal.

State of Ohio

General - At the present time, Ohio has no formal guidelines on municipal sludge disposal. The Ohio State University Extension Service is currently developing a booklet to serve as a guideline for municipal sludge disposal on agricultural land. This booklet should be complete by mid-1975. Incineration is used in several of the larger cities with the residue ash disposed of in a sanitary landfill.

Land Spreading - A large majority of the municipalities in Ohio use land application as their ultimate sludge disposal technique. Ohio recommends that municipal sludge be treated to control odors, bacteria, and pathogens. The state recommends that farmers not accept municipal sludge unless a city or private contractor monitors for heavy metals, pathogens, and controls odors. The state also recommends that application rates be adjusted so that heavy metal concentrations do not exceed limits recommended by the U.S. Department of Agriculture. Ohio does not have a definite position on winter land spreading of municipal sludge, and deals with each municipality on a case-by-case basis. At least one city applies sludge to the land on a year-round basis with no apparent problems.

Landfilling - Ohio does not approve of landfilling as a municipal sludge disposal technique due to possible leaching problems. In one case, vacuum filtered sludge was mixed with earth and incorporated into the daily landfill cover.

State of Michigan

General - Michigan is presently in the process of developing a formal set of guidelines on municipal sludge disposal. Presently, sludge disposal by individual municipalities is dealt with on a case-by-case basis with federal guidelines being used as a guide. Sludge incineration with the resultant ash being hauled to a landfill is used at several of the larger treatment facilities in the state.

Land Spreading - Land spreading in Michigan has been hindered due to poor local social acceptance, public health concerns, and possible toxic materials in the waste. A few communities apply raw sludge to the land at the present time. Many smaller treatment facilities place the sludge on drying beds and allow the general public to remove the dried sludge for personal use.

Landfilling - Dewatered sludge cake is disposed in sanitary landfills. A few years ago a liquid content greater than 50 percent was considered a health hazard for landfill operators. At the present time, disposal of sludge in a sanitary landfill is based upon field judgment.

State of Wisconsin

General - Wisconsin does not have a formal set of guidelines dealing with sludge disposal. In general, sludge must be disposed of in a manner that will not create health, nuisance, or stream pollution problems. The University of Wisconsin is working on guidelines to address agriculture land disposal. These guidelines are due to be completed by mid-1975. It is anticipated that the state will begin regulating the land spreading of sludge on agricultural land by 1976. The state does not presently control landfill disposal of sludge. Incineration is used in a few of the larger cities with the ash being hauled to a landfill for disposal.

Land Spreading - Most of the municipal sludge in the state of Wisconsin is presently spread on the land.

Landfilling - Some sludge is deposited in sanitary landfills.

State of Minnesota

General - The state of Minnesota is presently in the process of developing sludge disposal guidelines. Both land spreading and landfilling are used at the present time with a few large plants using incineration.

Land Spreading - A large number of small municipalities haul sludge to farmland where it is incorporated into the soil as a soil conditioner. Proposed guidelines will limit agricultural application of sludge based upon nitrogen requirements and heavy metal levels. Site selection will be based on factors such as depth to water table and slope characteristics.

Landfilling - Some small communities haul sludge to landfills without any state control.

State of North Dakota

General - North Dakota has no rules or regulations concerning municipal sludge disposal. The majority of the municipalities use waste stabilization ponds, and therefore, have no sludge for disposal. Incineration is not used by any municipality in the state.

Land Spreading - At least one city in the state uses anaerobic digestion with the digested sludge placed on sand beds. Farmers pick up the dried sludge for application on cropland.

Landfilling - At the previously mentioned plant, sludge which is not used by the farmers is hauled to a landfill. No regulations cover landfill disposal of the municipal sludge.

State of South Dakota

General - South Dakota has no formal rules or regulations on municipal sludge disposal. A majority of the plants in the state are waste stabilization lagoons and, therefore, produce no waste sludge. South Dakota has had few sludge disposal problems due to the small volumes produced by the other municipalities.

Land Spreading - At some municipalities, sludge is dried on sand drying beds which is them picked up by local gardeners and farmers. One city has been incorporating dried sludge into the final cover on an abandoned landfill.

Landfilling - No sludge was reported to be buried in landfills in the state.

State of Nebraska

General - At the present time, Nebraska has no rules or regulations governing sludge disposal. However, the state is in the process of developing general guidelines. At the present time, each individual community can dispose of sludge by any method it chooses. A few of the larger treatment facilities employ incineration with landfills receiving the ash residue.

Land Spreading - A majority of the treatment facilities in Nebraska apply their sludge to the land. Many of these communities apply raw sludge with only lime treatment.

Landfilling - Landfill disposal of municipal sludge is used at some plants based upon agreements between the municipality and the local operating authority of the landfill.

State of Kansas

General - Kansas is presently in the process of developing sludge disposal guidelines. Existing sludge disposal practices are similar to other states with sludge being applied to the land and deposited in landfills.