

**Handbook of
Land Treatment Systems for
Industrial and Municipal
Wastes**

by

Sherwood C. Reed

Ronald W. Crites

Handbook of Land Treatment Systems for Industrial and Municipal Wastes

by

Sherwood C. Reed

U.S. Army Corps of Engineers
Cold Regions Research and Engineering Laboratory
Hanover, New Hampshire

Ronald W. Crites

George S. Nolte and Associates
Sacramento, California



NOYES PUBLICATIONS
Park Ridge, New Jersey, USA

Copyright © 1984 by Sherwood C. Reed and Ronald W. Crites

No part of this book may be reproduced in any form
without permission in writing from the Publisher.

Library of Congress Catalog Card Number: 84-6025

ISBN 0-8155-0991-X

Printed in the United States

Published in the United States of America by

Noyes Publications

Mill Road, Park Ridge, New Jersey 07656

10 9 8 7 6 5 4 3 2 1

Library of Congress Cataloging in Publication Data

Reed, Sherwood C.

Handbook of land treatment systems for industrial and
municipal wastes.

Bibliography: p.

Includes index.

1. Land treatment of wastewater--Handbooks, manuals,
etc. 2. Factory and trade waste--Handbooks, manuals,
etc. I. Crites, Ronald W. II. Title.

TD760.R45 1984 628.3'6 84-6025

ISBN 0-8155-0991-X

Table of Contents

1. INTRODUCTION TO LAND APPLICATION AS A TREATMENT CONCEPT	1
Purpose of the Book	1
Historical Background	1
Land Application in North America	2
Current Status	3
References	5
2. BASIC TECHNOLOGY AND DESIGN APPROACH	6
Concepts	6
Site Characteristics	6
Design Features	7
Performance	7
Slow Rate Process	8
Rapid Infiltration Process	10
Overland Flow Process	13
Limiting Design Parameter	15
References	17
3. WASTEWATER PARAMETERS AND SYSTEM INTERACTIONS	19
BOD	19
Organic Loading	21
Suspended Solids	22
Municipal Systems	23
Industrial Systems	23
Pathogenic Organisms	24
Parasites	25
Crop Contamination	25
Runoff Contamination	26

Groundwater Contamination	27
Aerosols	29
Example 3-1: Aerosols	34
Oils and Grease	35
Example 3-2: Oil Degradation Rate	37
Metals	38
Metal Limits	39
Example 3-3: Cadmium Loadings	40
Soil and Crop Removals	40
Nitrogen	42
Soil Responses	42
Nitrates	44
Design Factors	45
Organic Nitrogen	46
Example 3-4: Nitrogen Cycling in Greenbelts	47
Example 3-5: Nitrogen Cycling in Grazed Pastures	48
Phosphorus	49
Removal Mechanisms	50
Rapid Infiltration	51
Example 3-6: Phosphorus Removal	52
Overland Flow	53
Example 3-7: Phosphorus Adsorption	54
Inorganic Trace Elements and Salts	54
Boron	55
Selenium	56
Arsenic	56
Sodium	57
Example 3-8: Calculate SAR	58
Example 3-9: Leaching Requirement	60
Sulfur	60
Potassium	61
Trace Organics	62
Non Volatile Organics	64
Chlorinated Hydrocarbons	64
References	65
4. HYDRAULICS OF SOIL SYSTEMS	70
Soil Properties	70
Soil Physical Properties	71
Soil Chemical Properties	72
Water Movement in Soil	73
Infiltration Rate	73
Intake	74
Permeability	74
Transmissivity	75
Specific Yield	75
Water-Holding Capacity	75
Saturated Hydraulic Conductivity	78

Example 4-1: Subsurface Flow	80
Unsaturated Hydraulic Conductivity	81
Percolation Capacity	82
Design Percolation Rate	82
Example 4-2: Determining Design Percolation Rate.	82
Calculation of Vertical Permeability	84
Example 4-3: Geometric Mean Calculation of Permeability.	84
Profile Drainage	85
Groundwater Mounding	85
Prediction of Mounding	86
Example 4-4: Mound Height Analyses	87
Underdrain Spacing	90
Example 4-5: Underdrain Spacing	92
References	93
5. VEGETATION AS A TREATMENT COMPONENT	95
Vegetation in Land Treatment	95
Evapotranspiration	95
Evaporation	96
Calculating Evapotranspiration.	97
Example 5-1: Crop ET Calculation.	99
Potential Evapotranspiration	101
Prediction of ET	102
Agronomic Crop Selection	104
Slow Rate Systems	104
Example 5-2: Nitrogen Uptake	109
Overland Flow Systems	110
Rapid Infiltration Systems	111
Forest Crop Selection.	112
Nitrogen Uptake	113
Phosphorus and Trace Metals.	116
Crop Management and Water Quality	116
Overland Flow Crop Management.	118
Forest Crop Management	119
References	122
6. SITE IDENTIFICATION AND SELECTION	125
Preliminary Land Requirements	126
Wastewater Characteristics	126
Preliminary Loading Rates	127
Storage Needs.	128
Site Area Estimate.	128
Site Identification	130
Use of Map Overlays	131
Site Suitability Factors.	131
Climatic Factors	138
Water Rights and Potential Conflicts.	140
Site Selection	141

Site Screening Procedure	141
Example 6-1: Site Suitability Rating	141
References	146
7. FIELD INVESTIGATION PROCEDURES	148
Soil Properties	150
Physical Characteristics	150
Chemical Properties	153
Test Pits and Borings	154
Groundwater Conditions	155
Groundwater Depth and Hydrostatic Head	160
Groundwater Flow	161
Example 7-1: Groundwater Movement	163
Subsurface Permeability	164
Auger Hole Test	165
Example 7-2: Auger Hole Test	167
Mixing of Wastewater Percolate with Groundwater	168
Infiltration Rate	169
Basin Tests	171
Cylinder Infiltrimeters	174
Air Entry Permeameters (AEP)	176
Agronomic Factors	180
pH	181
Plant Available Phosphorus and Potassium	182
Salinity and Sodium	183
Test Procedures	183
References	184
8. PREAPPLICATION TREATMENT AND STORAGE	186
Pollutant Removal in Ponds	188
BOD and Solids Removal in Lagoons	188
Nitrogen Removal in Lagoons	191
Example 8-1: Nitrogen Removal in Facultative Ponds	192
Phosphorus Removal in Lagoons	194
Pathogen Removal in Lagoons	194
Example 8-2: Pathogen Removal in Facultative Ponds	196
Metals and Trace Organic Removal in Lagoons	197
Design of Storage Ponds	197
Storage Calculation Method	199
Storage for Overland Flow	202
Operation of Storage Ponds	207
Physical Design and Construction	207
References	208
9. TRANSMISSION AND DISTRIBUTION SYSTEMS	211
Pumping Stations	211
Transmission Pumping	211
Distribution Pumping	213

Tailwater Pumping	214
Forcemains	216
Distribution Systems	216
Surface Distribution	216
Sprinkler Distribution	217
Design Considerations	218
Surface Distribution	221
Ridge and Furrow Distribution	221
Graded Border Distribution	226
Example 9-1: Establish Preliminary Design Criteria for a Graded Border System	229
Surface Distribution for Overland Flow	231
Surface Distribution for Rapid Infiltration	232
Sprinkler Distribution	233
Solid Set Systems	234
Example 9-2: Establish Preliminary Design Criteria for Solid Set Sprinkler System	237
Solid Set Forest Systems	239
Solid Set Overland Flow Systems	241
Move-Stop Sprinkler Systems	242
Continuous Move Systems	244
Example 9-3: Establish Preliminary Design Criteria for Reel Type Traveling Gun System	248
References	252
10. PROCESS DESIGN—SLOW RATE SYSTEMS	254
System Types	254
Maximum Hydraulic Loading Rate, L_w	255
Example 10-1: Determine Minimum Land Area Based on Hydraulic Loading Criteria	256
Design Percolation Rate, P_w	256
Design Precipitation Rate, P_r	260
Design Evapotranspiration Rate ET	260
Hydraulic Loading Rate Based on the LDP	261
Design Modification for Supplemental Nitrogen	263
Example 10-2: Determine Allowable Hydraulic Loading if Nitrogen is the LDP	264
LDP for Materials Other than Nitrogen	265
Monthly Water Balance and Hydraulic Loading Rate for Final Design, L_{wD}	267
Example 10-3: Establish the Design Hydraulic Loading L_{wD}	269
Land Area Determination	271
Example 10-4: Field Area Determination	272
Buffer Zone Requirements	273
Storage Requirements	273
Crop Selection	273
Distribution System	274
Application Scheduling	274

Example 10-5: Determine Design Hydraulic Loading and Field Area for an Industrial Operation in the North Central U.S.	275
Toxic and Hazardous Wastes	282
References	283
11. PROCESS DESIGN—OVERLAND FLOW SYSTEMS	284
System Concept and Components	284
Site Characteristics	284
System Configuration	285
Performance Standards and System Capabilities	287
Design Procedures	288
BOD	289
Example 11-1: Determine the Wastewater Application Rate for an Operational OF System	290
Example 11-2: Find the Required Slope Length for Various Levels of Preapplication Treatment	292
Suspended Solids	294
Nitrogen	294
Phosphorus	297
Other Constituents	297
Land Area Requirements	297
Example 11-3: Determine Treatment Area for the System Described in Example 11-2	298
Application Period	298
Application Schedule	299
Winter Operation vs Storage	299
Storage for Rainfall Runoff	301
Physical Features and Construction Details	302
Runoff Collection	302
Distribution Systems	303
Site Grading	304
Vegetation	305
Combination Systems	306
Example 11-4: Evaluate the Feasibility of an Overland Flow-Rapid Infiltration Combination	307
References	309
12. PROCESS DESIGN—RAPID INFILTRATION SYSTEMS	312
Treatment Requirements	313
Nitrification	313
Nitrogen Removal	314
Phosphorus Removal	315
Hydraulic Loading Rate	316
Design Infiltration Rate	316
Wet/Dry Ratio	316
Design Hydraulic Loading Rate	317
Example 12-1: Hydraulic Loading Rate	319
Land Requirements	319

Hydraulic Loading Cycle	319
Number of Basin Sets	320
Application Rate	321
Example 12-2: Discharge Capacity	322
Cold Weather Operation	322
Drainage	324
Subsurface Drainage to Surface Waters	324
Example 12-3: Subsurface Drainage	325
Underdrains	326
Recovery Wells	327
References	327
13. COST AND ENERGY CONSIDERATIONS	330
Costs	330
Transmission	331
Pumping	331
Preapplication Treatment	331
Storage	331
Field Preparation	332
Distribution	333
Recovery	337
Land	340
Land Application of Sludge	340
Benefits	341
Energy Requirements	342
Pumping	342
Land Treatment of Wastewater	342
Land Application of Sludge	343
Energy Conservation	343
References	344
14. OPERATION, MAINTENANCE AND MONITORING	346
Slow Rate Systems	346
Staffing Requirements	347
General Skills	348
Special Skills	348
Process Control and Monitoring	348
Storage Ponds	353
Application Site Monitoring	355
Maintenance Procedures	363
Overland Flow	369
Crop Management	364
Rapid Infiltration	365
Sludge Systems	366
Monitoring Requirements	366
Application Scheduling on Agricultural Sites	366
Sludge Use on Disturbed Land	367
Application Methods	368

References	369
15. SMALL SCALE SYSTEMS AND INNOVATIVE CONCEPTS	371
Onsite Septic Tank Systems	372
Design Loading	374
Example 15-1: Determine Application Bed Area for a 1,000 gpd Flow	376
Groundwater Mounding	376
Example 15-2: Determine Mound Height After 10 Years	378
Soil Mound Systems	380
Rehabilitation of Onsite Systems	382
Small Scale Land Treatment	383
Site Identification	384
Final Site Selection and Investigation	386
Facility Design	387
Innovative Concepts	392
Wastewater Systems	392
References	396
16. LAND APPLICATION OF SLUDGE	398
Site and Process Evaluation	399
Agricultural Utilization	400
Nitrogen Limits	401
Metal Limitations	401
Phosphorus Limitations	402
Sludge Loading Determination	402
Land Area Determination	404
Example 16-1: Determine Land Area for Application of Digested Municipal Sludge	405
Monitoring and Application Scheduling	408
Forest Utilization	408
Forest Application Scheduling	409
Sludge Loading for Forest Sites	410
Example 16-2: Determine Land Area for Application of Digested Municipal Sludge in an Established Forest	411
Site Reclamation	412
Sludge Application Rates	414
Example 16-3: Determine Land Area for Application of Digested Sludge for Land Reclamation	414
Restoration Site Monitoring	416
Soil Treatment Systems	416
References	418
CONVERSION FACTORS	419
INDEX	420

Introduction to Land Application As a Treatment Concept

PURPOSE OF THE BOOK

It is the purpose of this book to present the criteria and procedures needed for the complete design of land treatment systems for municipal and industrial wastes. Prior to 1970 land treatment was seldom used by the engineering profession to solve waste treatment problems. In the decade 1970-80 the concept became reestablished in the spectrum of reliable technologies available for wastewater treatment. A considerable research effort has not only established the treatment capability and reliability of land treatment but has also shown that the capital and operating costs and energy usage can be significantly less than for the more familiar mechanical systems. Many of the standard engineering design textbooks still mention land treatment only in passing, if at all. This book is intended to fill that gap.

HISTORICAL BACKGROUND

Disposal of wastes to the land has been an accepted and recognized cultural practice since time began. Stabilization and assimilation of body wastes in the soil are complete, and problems do not occur with low-density, migratory populations of people or animals. The higher density conditions that can cause problems

have been documented since biblical times (1), and these problems require a technology for management rather than random disposal. Application of wastes to the land emerged as a technology with the centralization of people in towns and cities. The earliest system documented in the literature was Bunzlau, Germany (2) where a sewage irrigation system was in operation for over 300 years, commencing in 1531. A system in the vicinity of Edinburgh, Scotland began operation around 1650 (2). The value of the wastewater as a fertilizer for vegetable and other crop production was well recognized.

LAND APPLICATION IN NORTH AMERICA

By the mid 19th century land application of wastes was considered to be the safest and most reliable method for waste disposal by the technical experts and regulatory officials of the time. The connection between contaminated water and disease was recognized, although the causative agents were not identified, so waste discharge to water supplies was avoided. The first comprehensive reviews of wastewater disposal in the U.S. were by George Rafter of the U.S. Geological Survey. In a series of reports (3)(4)(5) from 1894 to 1899 he reviewed the status of wastewater treatment in the U.S. and in Europe. Most of the 143 sewage treatment facilities in the U.S. and Canada as of 1899 (3) were land treatment systems (See Table 1-1). Rafter drew the following conclusions (direct quotations):

- The most efficient purification of sewage can be attained by its application to land.
- On properly managed sewage farms the utilization of sewage is not prejudicial to health.
- Sewage may be purified by broad irrigation at all seasons of the year at any place where the mean annual temperature

- of the coldest month is not lower than about 20° to 25° F.
- From the experience gained abroad it is clear that we may successfully cultivate almost any of the ordinary agricultural productions of the United States on sewage farms, due regard being had in every case to the special conditions required for each particular crop.
 - Sewage utilization should go hand in hand with purification. When operated with reference to all the necessary conditions, a proper degree of purification may be attained as well as satisfactory utilization.
 - The proper method of utilizing sewage is, for purposes of irrigation, be means which do not differ, except in matters of detail, from those of ordinary irrigation as practiced abroad for centuries.

Table 1.1: Some Early Land Treatment Systems in the U.S.

Location	Date Started	Area (acres)
Boulder, CO	1890	—
Calumet City, MI	1888*	12
Woodland, CA	1889*	240
Fresno, CA	1891*	4,000
San Antonio, TX	1895	4,000
Vineland, NJ	1901*	14
Lubbock, TX	1915*	—
South Framingham, MA	1889	—

*System still in use.

Current Status

The use of land treatment began to decline soon after Rafter published these conclusions, and by the 1960's the concepts were almost forgotten. By the time discussion again began in the early 70's many of his conclusions were the subject of bitter debate and controversy. Jewell and Seabrook (2) traced the history of the development and the long, but temporary, decline. Among the

factors identified for the decline were: pressures for alternative land uses, overloading due to incomplete technical understanding, and the development of the germ theory, with the use of chlorine as an effective disinfectant which made it "safe" to discharge partly treated sewage to waterways.

The focus shifted almost completely to "modern methods of sewage treatment" by the early 1920's, and design criteria for trickling filters, activated sludge, etc. were all available. A considerable effort has been expended in the past 50 years to improve the efficiency and understanding of these "modern methods" but the basic design criteria are still about the same as they were in the beginning. By the late 60's it was recognized that there was more to pollution than BOD and suspended solids and it was decided that a strong federal role and funds would be needed to clean up the nation's waterways. Federal legislation, commencing with the Clean Water Act of 1972 (PL 92-500) proposed a "zero discharge" concept and encouraged a reuse and recovery philosophy. Land application of wastewater is the only way to achieve all of those goals and the concept was reborn. It was not accepted at the time as a technology by much of the engineering profession and regulatory community. As a result, a very significant research and development effort was undertaken to reconfirm the conclusions that were so obvious to Rafter and to develop criteria for reliable and cost effective design, construction and operation. Table 1-2 demonstrates the recent increase in the number of land treatment systems.

Table 1.2: U.S. Municipalities Using Land Treatment

Year	Number of Systems
1940	340
1945	422
1957	461
1962	401
1968	512
1972	571
1981	1,180

In Rafter's time sewage treatment systems were typically found only at the larger, more sophisticated metropolitan centers that could not discharge to an ocean, and land treatment was the preferred method. Except in special circumstances it is unlikely that land treatment would be the preferred method of treatment for the very large metropolitan centers that exist today. The costs and the jurisdictional problems in developing a single very large system would be difficult to overcome. However, there are no technical constraints on the size of a system and, as will be shown in the remaining chapters of this book, land treatment can be a viable and cost effective choice for many industries, for small towns and moderately large cities and for portions of large metropolitan areas.

The design approach for land treatment systems is essentially empirical; that is, observation of successful performance followed by derivation of criteria and mathematical expressions that describe overall performance. Criteria for all of the wastewater treatment processes in use today were developed this way. Use of the criteria in this book should produce reliable, cost-effective, and conservative designs for municipal and industrial wastes.

REFERENCES

1. Deuteronomy, 23:12-14.
2. Jewell, W.J. and Seabrook, B.L., A History of Land Application as a Treatment, USEPA 430/9-79-012, USEPA, OWPO, Wash., D.C., (1979).
3. Rafter, G.W. and Baher, M.N., Sewage Disposal in the United States, 598 pg., (1894).
4. Rafter, G.W., Sewage Irrigation. Water Supply and Irrigation Papers, USGS Rpt. 3, USGPO, Washington, D.C., (1897).
5. Rafter, G. W., Sewage Irrigation. Part II, Water Supply and Irrigation Papers, USGS Rpt. 22, USGPO, (1899).

Basic Technology and Design Approach

CONCEPTS

Land treatment is defined as the controlled application of wastes onto the land surface to achieve a specified degree of treatment through natural physical, chemical, and biological processes within the plant-soil-water matrix. The basic wastewater concepts include: Slow Rate (SR), Rapid Infiltration (RI) and Overland Flow (OF). The titles were adopted to reflect the rate of water movement and the flow path within the process. In some earlier texts the term "irrigation" was often used to describe the slow rate process. The present term was chosen to focus attention on wastewater treatment rather than on irrigation of crops. In addition to these basic wastewater processes there are criteria presented in later chapters for combination systems, wetlands and other innovative technologies, large scale septic tank/soil systems, and land application of sludge.

Site Characteristics

The desirable site characteristics for the three wastewater processes are given in Table 2-1. These are not limits to be adhered to rigorously, but rather typical ranges based on successful experience.