PB82-101635

EVALUATION OF ON-SITE WASTEWATER TREATMENT AND DISPOSAL OPTIONS

D. H. Bauer, et al

SCS Engineers
Reston, Virginia

September 1981

U.S. DEPARTMENT OF COMMERCE
National Technical Information Service
NTIS®

PB82-101635

EPA-600/2-81-178
September 1981

EVALUATION OF ON-SITE WASTEWATER TREATMENT AND DISPOSAL OPTIONS

by

David H. Bauer
E. T. Conrad
Donald G. Sherman

SCS ENGINEERS
Reston, Virginia 22091

Contract No. 68-03-2627

Project Officer
Robert P. G. Bowker
Wastewater Research Division
Municipal Environmental Research Laboratory
Cincinnati, Ohio 45268

MUNICIPAL ENVIRONMENTAL RESEARCH LABORATORY
OFFICE OF RESEARCH AND DEVELOPMENT
U.S. ENVIRONMENTAL PROTECTION AGENCY
CINCINNATI, OHIO 45268

TECHNICAL REPORT DATA

(Please read Instructions on the reverse before completing)

1. REPORT NO EPA-600/2-81-178	2. ORD Report	3. RECIPIENT'S ACCESSION NO. PB82 101635
4. TITLE AND SUBTITLE Evaluation of On-Site Wastewater Treatment and Disposal Options		5. REPORT DATE September 1981 6. PERFORMING ORGANIZATION CODE U249023
7. AUTHOR(S) Bauer, D.H., Conrad, E.T., Sherman, D.G.		8. PERFORMING ORGANIZATION REPORT NO
9. PERFORMING ORGANIZATION NAME AND ADDRESS SCS Engineers 11260 Roger Bacon Drive Reston, VA 22090		10. PROGRAM ELEMENT NO. AZB1B 11. CONTRACT/GRANT NO. 68-03-2627
12. SPONSORING AGENCY NAME AND ADDRESS Municipal Enviromental Research Laboratory -Cinti,OH Office of Research and Development U.S. Environmental Protection Agency Cincinnati, Ohio 45268		13. TYPE OF REPORT AND PERIOD COVERED Final: 10/77 - 10/78 14. SPONSORING AGENCY CODE EPA/600/14

15. SUPPLEMENTARY NOTES

Project Officer: Robert P. G. Bowker (513) 684-7620

16. ABSTRACT

A literature review of published and unpublished data was conducted to identify all conceivable alternative on-site systems, including wastewater manipulation, treatment and disposal options. Wastewater manipulation options included flow reduction, wasteload reduction and waste segregation. Treatment options included disinfection, biological, and physical/chemical methods. Disposal options included air, soil and surface water methods, and practical combinations.

Both tested and untested systems were identified, and combinations of the various components were developed. An equipment inventory was then performed to determine the availability of hardware for the systems and system components identified. Data on engineering, economic, and environmental acceptability characteristics were collected.

These systems were evaluated on the basis of performance, operation and maintenance, environmental acceptability, and total annual cost for 15 specific site conditions. Site conditions were defined by soil percolation rate, soil depth, slope, available land area, direct discharge effluent requirements, and net evaporation.

17. KEY WORDS AND DOCUMENT ANALYSIS

a. DESCRIPTORS	b. IDENTIFIERS/OPEN ENDED TERMS	c. COSATI Field/Group
Sewage treatment Sewage disposal Septic tanks	On-site sewage disposal Non-sewered area	13 B

18. DISTRIBUTION STATEMENT Release to Public	19. SECURITY CLASS *(This Report)* unclassified 20. SECURITY CLASS *(This page)* Unclassified	21. 22. PRICE

EPA Form 2220-1 (9-73)

DISCLAIMER

This report has been reviewed by the Municipal Environmental Research Laboratory, U.S. Environmental Protection Agency, and approved for publication. Approval does not signify that the contents necessarily reflect the views and policies of the U.S. Environmental Protection Agency, nor does mention of trade names or commercial products constitute endorsement or recommendation for use.

FOREWORD

The U.S. Environmental Protection Agency was created because of increasing public and government concern about the dangers of pollution to the health and welfare of the American people. Noxious air, foul water, and spoiled land are tragic testimony to the deterioration of our natural environment. The complexity of the environment and the interplay between its components require a concentrated and integrated attack on the problem.

Research and development is that necessary first step in problem solution and it involves defining the problem, measuring its impact, and searching for solutions. The Municipal Enviornmental Research Laboratory develops new and improved technology and systems for the prevention, treatment, and management of wastewater and solid and hazardous waste pollutant discharges from municipal and community sources, for the preservation and treatment of public drinking water supplies and to minimize the adverse economic, social, health, and aesthetic effects of pollution. This publication is one of the products of that research; a most vital communications link between the researcher and the user community.

In recent years, individual on-site wastewater treatment and disposal systems have enjoyed increased attention as technically viable and environmentally sound, cost-effective alternatives to traditional gravity collection and centralized wastewater treatment facilities in rural areas. This renewed interest has spawned considerable research and development of technology applicable to on-site wastewater handling. This report provides an evaluation of both existing and potential on-site wastewater alternatives for the purpose of: defining the application of existing and conceptual wastewater systems, determining the needs for future hardware development, and assessing the desirability of future demonstrations of untested but promising on-site wastewater handling alternatives.

Francis T. Mayo
Director
Municipal Environmental
Research Laboratory

ABSTRACT

A literature review of published and unpublished data was conducted to identify all conceivable alternative on-site systems, including wastewater manipulation, treatment and disposal options. Wastewater manipulation options included flow reduction, wasteload reduction and waste segregation. Treatment options included disinfection, biological, and physical/chemical methods. Disposal options included air, soil and surface water methods, and practical combinations.

Both tested and untested systems were identified, and combinations of the various components were developed. An equipment inventory was then performed to determine the availability of hardware for the systems and system components identified. Data on engineering, economic, and environmental acceptability characteristics were collected.

These systems were evaluated on the basis of performance, operation and maintenance, environmental acceptability, and total annual cost for 15 specific site conditions. Site conditions were defined by soil percolation rate, soil depth, slope, available land area, direct discharge effluent requirements, and net evaporation.

Where site conditions are appropriate, septic tank - conventional soil absorption systems were found to be the least-cost and top-ranked method of on-site wastewater treatment and disposal. Under other conditions, systems incorporating other methods of disposal, such as soil disposal with modified distribution, mounds, evapotranspiration, irrigation, evaporation, or direct discharge, are appropriate. A septic tank normally provides adequate pretreatment for most of these disposal methods. Where irrigation or surface discharge disposal is used, additional treatment, such as that provided by an intermittent sand filter and iodine disinfection, may be required. Use of low pressure membrane filtration where high quality effluent is required also appears promising, based on very limited operating experience.

This report was submitted in fulfillment of Contract No. 68-03-2627 by SCS Engineers under the sponsorship of the U.S. Environmental Protection Agency, Municipal Environmental Research Laboratory. This report covers work performed from October 1977 to October 1978.

CONTENTS

Foreward . . . iii
Abstract . . . iv
Figure . . . vii
Tables . . . viii
Acknowledgments . . . xiii

1. Introduction . . . 1
   Project Objectives and Scope . . . 1
   References . . . 3
2. Conclusions and Recommendations . . . 4
   Project Findings and Conclusions . . . 4
   Recommendations . . . 6
3. System Concept Development and Ranking Criteria . . . 8
   System Concept Development . . . 8
   Component and System Ranking Criteria . . . 10
4. Wastewater Characteristics . . . 14
   References . . . 23
5. Wastewater Manipulation . . . 25
   Flow Reduction . . . 25
   Wasteload Reduction . . . 30
   Wastewater Segregation . . . 43
   References . . . 48
6. Biological Treatment . . . 50
   Aerobic-Suspended and Fixed Growth . . . 50
   Anaerobic-Septic Tank . . . 55
   Anaerobic-Packed Reactor . . . 58
   Lagoons . . . 62
   Biological Treatment Component Comparisons . . . 65
   References . . . 69
7. Physical-Chemical Treatment . . . 72
   General . . . 72
   Media Filtration . . . 72
   Membrane Filtration (Pressure) . . . 80
   Coagulation and Chemical Precipitation . . . 87
   Sorption . . . 90
   Physical-Chemical Component Comparisons . . . 95
   References . . . 99
8. Disinfection Options . . . 103
   General . . . 103
   Chlorine . . . 103
   Iodine . . . 107
   Ozone . . . 111
   Ultraviolet Irradiation . . . 116

CONTENTS
(Continued)

Disinfection Component Comparisons 121
References 125
9. Disposal Options 128
General 128
Atmosphere Disposal 128
Soil Disposal 131
Surface Discharge 143
Combinations 145
Disposal Component Comparisons 148
References 152
10. Comparative Analysis 157
Methodology 157
System Ranking - Hardware and Performance Data Available . . 159
System Rank - Hardware (But No Performance Data) Available . 161
Undeveloped System Concepts 164

Appendices

A. Treatment and Disposal System - Site Condition Tables 168
B. Reuse Water Quality Objectives 215

FIGURE

Number		Page
1	Average Daily Flow Pattern From Eleven Rural Households	21

TABLES

Number		Page
1	Top Ranked Systems-Hardware and Performance Data Available	5
2	On-Site Component Options	9
3	Physical Site Conditions for System	11
4	Component and System Ranking Criteria	13
5	Wastewater Flow from Various Household Sources	15
6	Combined Household Wastewater Characteristics	16
7	Wastewater Constituent Contributions from Various Household Sources	17
8	Blackwater (Toilet Only) Characteristics	18
9	Grey Water Characteristics	19
10	Garbage Disposal Wastewater Characteristics	20
11	Glow and Wasteload Reduction-Except Toilet	26
12	Flow and Wasteload Reduction Toilet	27
13	Wastewater Flow Reduction	28
14	Wasteload Reduction	31
15	Incinerating Toilet Costs	35
16	Composting Toilet Costs	38
17	Costs of Oil Recirculating Toilet System	40
18	Non-Water Carriage Toilet Component Comparison for Components with Sufficient Information	41
19	Non-Water Carriage Toilet Component Comparison for Components with Incomplete Information	42

TABLES
(Continued)

Number		Page
20	Wastewater Segregation Options Matrix	44
21	Wastewater Segregation Option Impact	45
22	Biological Treatment Options	51
23	Aerobic-Suspended Growth Unit (Extended Aeration) Performance	53
24	Aerobic Fixed Growth Unit Performance	54
25	Aerobic Suspended and Fixed Growth Treatment Unit Costs	56
26	Anaerobic Septic Tank Performance	57
27	Anaerobic Septic Tank Treatment Unit Costs	59
28	Anaerobic-Packed Reactor Treatment Unit Performance	61
29	Anaerobic Packed Reactor Treatment Unit Costs	63
30	Lagoon Performance	64
31	Aerobic (Not Aerated) Lagoon Costs	66
32	Biological Treatment Component Comparison for Components with Sufficient Information	67
33	Biological Treatment Component Comparison for Components with Incomplete Information	68
34	Physical-Chemical Treatment Options	73
35	Pressurized Media Filtration Performance	75
36	Pressurized Media Filtration Costs	77
37	Gravity Filtration Unit Performance	79
38	Gravity Filtration Costs	81
39	Ultrafiltration Performance	84
40	Ultrafiltration System Costs	86
41	Coagulation and Chemical Precipitation Performance	89

TABLES
(Continued)

Number		Page
42	Coagulation and Chemical Precipitation Costs	91
43	Sorption Performance	93
44	Sorption Unit Costs	96
45	Physical-Chemical Component Comparison for Components with Sufficient Information	97
46	Physical-Chemical Component Comparison for Components with Incomplete Information	98
47	Disinfection Options	104
48	Dry Feed Chlorine Disinfection Performance	106
49	Chlorination Costs	108
50	Iodine Performance Data for Various Effluent Types	110
51	Cost Estimate for an Iodination Unit for On-Site Wastewater Disinfection	112
52	Ozone Performance Data for Various Effluent Types	114
53	Ozonation System Costs	117
54	Ultraviolet Disinfection Unit Description	119
55	Ultraviolet Disinfection Unit Performance	120
56	Ultraviolet Disinfection System Costs	122
57	Disinfection Component Comparison for Components with Sifficient Information	123
58	Disinfection Component Comparison for Components with Incomplete Information	124
59	Disposal Options	129
60	ET Bed Costs	132
61	Mound Performance Data	136
62	Mound Costs	138

TABLES
(Continued)

Number		Page
63	Modified Distribution Costs	142
64	Irrigation Costs	144
65	Evaporation/Infiltration Lagoon Costs	149
66	Disposal Component Comparison for Components with Sufficient Information	150
67	Disposal Component Comparison for Components with Incomplete Information	151
68	Top Ranked Systems-Hardware and Performance Data Available . . .	160
69	Top Ranked Systems-Hardware Available, Inadequate Performance Data	162
70	Site Condition-System Development Needs Matrix	165
A1	Treatment and Disposal Systems -- Physical Site Condition 1 . . .	169
A2	Treatment and Disposal Systems -- Physical Site Condition 2 . . .	172
A3	Treatment and Disposal Systems -- Physical Site Condition 3 . . .	175
A4	Treatment and Disposal Systems -- Physical Site Condition 4 . . .	178
A5	Treatment and Disposal Systems -- Physical Site Condition 5 . . .	181
A6	Treatment and Disposal Systems -- Physical Site Condition 6 . . .	184
A7	Treatment and Disposal Systems -- Physical Site Condition 7 . . .	187
A8	Treatment and Disposal Systems -- Physical Site Condition 8 . . .	190
A9	Treatment and Disposal Systems -- Physical Site Condition 9 . . .	193
A10	Treatment and Disposal Systems -- Physical Site Condition 10 . .	196
A11	Treatment and Disposal Systems -- Physical Site Condition 11 . .	199
A12	Treatment and Disposal Systems -- Physical Site Condition 12 . .	202
A13	Treatment and Disposal Systems -- Physical Site Condition 13 . .	205
A14	Treatment and Disposal Systems -- Physical Site Condition 14 . .	208

TABLES
(Continued)

Number		Page
A15	Treatment and Disposal Systems -- Physical Site Condition 15 . .	211
A16	Treatment/Reuse Systems for Segregated Waste Streams	214
B1	Reuse Categories and Applications	216
B2	Toilet Flush Water Quality Objectives (a)	217
B3	Utility Grade Water Quality Objectives	218
B4	Body Contact Grade Water Quality Objectives	219

ACKNOWLEDGEMENTS

The conduct of this project was accomplished through the cooperation of EPA, universities, equipment manufacturers, government agencies and SCS personnel. The guidance of Mr. Robert P. G. Bowker, Project Officer, Municipal Environmental Research Laboratory (MERL) of the U.S. EPA, Cincinnati, OH is gratefully acknowledged.

We wish to express our appreciation to the members of the Technical Advisory Committee - Mr. Jack L. Abney, Parrott, Ely and Hurt, Lexington, KY; Dr. William C. Boyle and Mr. Richard J. Otis, University of Wisconsin, Madison, WI; Dr. J. T. Winneberger and Mr. James A. Burgel, Consultants, Berkely, CA; and Mr. Pio Lombardo, Pio Lombardo & Associates, Boston, MA - for their assistance in locating information and reviewing most of this report. The services performed by the Technical Advisory Committee should not be construed as an endorsement of the contents and conclusions of this report. A number of the committee members hold views contrary to the report's assessment and conclusions. The assistance of Kamber Engineering, a subcontractor on the project, is also appreciated.

SCS project participants were Mr. E. T. Conrad, Project Director; Mr. David H. Bauer, Project Manager; and Mr. Donald G. Sherman, Project Engineer.

SECTION 1

INTRODUCTION

The provision of adequate wastewater treatment at a reasonable cost in rural and unsewered areas has become a matter of increasing concern for both public officials and private citizens. According to the 1970 census, 19.5 million housing units or roughly 30 percent of the housing units in the United States dispose of their wastewater through some form of private wastewater treatment system (1). Most of these households use septic tank - soil absorption systems.

Septic tank - soil absorption systems have often been considered a stop-gap measure to be used until municipal wastewater collection and treatment becomes available to unsewered areas. However, two-thirds of the total annual cost of a conventional municipal system is often for the collection sewers. As a result, multiple treatment and disposal systems serving dispersed individual houses or groups of houses (not requiring an extensive collection system) may provide a cost-effective alternative to centralized municipal treatment in rural areas (2).

Sections 201(h) and (j) of the Clean Water Act of 1977 (P.L. 95-217) authorized construction grants funding of privately owned treatment works serving individual homes or groups of homes (or small commercial establishments), provided that a public entity (which will ensure proper operation and maintenance) apply on behalf of a number of such individual systems.

PROJECT OBJECTIVES AND SCOPE

Section 104(q)(1) of P.L. 92-500 directs the EPA Administrator to conduct a program of research and development of alternatives to conventional sewerage and septic tank - soil absorption sytems for rural areas where these traditional approaches are either technically or economically infeasible. Development of alternative on-site systems as part of the resulting EPA Small Flows Research Program and increased system development and promotion in the private sector made this study of the alternatives desirable. The major objectives of this twelve month study were:

- Identify all potential in-the-house and individual home on-site wastewater treatment, handling, reuse, and disposal options. The on-site system unit processes (components) considered included in-the-house water conservation devices, waterless systems, recycle systems, separation systems, and other wastewater manipulation schemes; biological and physical/chemical treatment options; and disposal options.

- Conduct a technological and economic comparative analysis of all manipulation, treatment, and disposal options resulting in a ranking of alternatives and identification of a small number of selected most feasible alternatives.

The data base for the project included both published and unpublished literature and personal interviews. Published literature was first reviewed to extract pertinent data. Where data was lacking or incomplete, individual researchers, sanitarians, and consultants were contacted to obtain available unpublished data. Equipment manufacturers were also contacted to obtain non-proprietary data and to discuss relevant specific topics. Data collection and subsequent system evaluations focus on the following topic areas: (1) performance, (2) operation and maintenance requirements, (3) environmental acceptability, and (4) cost.

Technical ranking criteria and a standard cost baseline were then developed to provide a basis for system evaluation. The ranking criteria used are discussed in the body of the report (see Section 3). The cost estimates are based on manufacturer price quotes, literature data, and standard engineering cost estimation guides. All costs are presented in January 1978 dollars.

For the purposes of this study, on-site wastewater systems are defined as systems which serve a single residential dwelling. Thus, systems serving groups of houses or commercial establishments are specifically excluded, as are pressure or vacuum sewers and similar technologies appropriate for these applications.

This report is intended for use by technical R & D personnel familar with on-site wastewater systems. It is not intended for use by the layman. Specific design information has purposely not been included as this was not the intent of the study. In addition, not all possible wastewater treatment and disposal alternatives have been considered. For example, pit privies, although considered to be primitive by many, are a well known and demonstrated means of waste containment. However, in this study, septic tank - soil absorption systems have been considered a baseline from which other, less conventional alternatives could be evaluated to determine their technical and economic feasibility and to determine whether further demonstration would be justified.

REFERENCES

1. U.S. Department of Commerce, U.S. Bureau of the Census. General Housing Characteristics for the United States and Regions. Current Housing Reports Series H-150-73A, U.S. Government Printing Office, Washington, D.C., 1975. 99p.

2. Otis, R.J., W.C. Boyle, J.C. Converse and E.J. Tyler. On-site Disposal of Small Wastewater Flows. EPA-625/4-77-011, U.S. Environmental Protection Agency, Cincinnati, OH, 1977. 60 p.

SECTION 2

CONCLUSIONS AND RECOMMENDATIONS

PROJECT FINDINGS AND CONCLUSIONS

A review of the available literature on on-site wastewater treatment and disposal systems for single family homes has been conducted. Evaluation of the information collected, based on the ranking criteria and site conditions considered, lead to the development of Table 1 which summarizes the top ranked systems for each of fifteen site conditions. Systems included in Table 1 were generally limited to those with a total annual cost within $250 of the top ranked system for each site condition. As shown, systems were ranked on the basis of performance (5 points maximum), operation and maintenance (5 points maximum), and environmental acceptability (nuisance and hazard) (3 points maximum). Brief discussion of the systems shown is provided in the comments section of Table 1.

Additional conclusions are as follows:

1. Reduction of wastewater flow is particularly desirable where limited land area is available for disposal or relatively expensive disposal options are required, since reduced flow generally permits reduced disposal unit size (and may permit reduced treatment unit size).

2. Flow reduction in the range of 10 to 40 percent (depending primarily on the device used) of the normal household total should be consistently achievable utilizing flow reduction devices for batch-flow sources (i.e., toilet, laundry and dishwasher). The flow reduction achieved from batch-flow sources depends primarily on the specific devices utilized, and secondarily on user habits. Flow reduction achieved on continuous flow sources is highly dependent on user habits and is extremely variable (i.e., showers, sinks).

3. Wastewater reuse is a potential method of flow reduction. However, the cost of treatment for reuse of either combined or segregated waste streams is not typically offset by reduced disposal costs resulting from reduced volume for any of the site conditions considered. Thus, systems incorporating wastewater reuse are not normally economically viable, although they occasionally may be applicable in specific situations (e.g., very limited water availability).

TABLE 1. TOP RANKED SYSTEMS - HARDWARE AND PERFORMANCE DATA AVAILABLE

Site Condition: Number	Site Condition: Description	System	Performance	O & M	Environmental Acceptability	Total	Estimated Total Annual Costs ($)	Comments
1	Acceptable soil depth and percolation available land 372 m² evaporation minus precipitation (EVP PPT) >5 cm/mo	1 Septic tank (ST) conventional soil absorption system (SAS)	4	5	3	12	50	ST SAS system is preferred due to lower cost. Lagoon is the least desirable primarily due to nuisance and potential hazard considerations
		2 Septic tank evapotranspiration/absorption (ETA)	4	4	3	11	300	
		3 Septic tank evapotranspiration/infiltration lagoon	4	4	1	9	250	
2	Shallow (0.3-1.2m) soils with acceptable percolation available land 93-372 m² EVP PPT 5 cm/mo	1 Septic tank mound	3	4	[illegible]	10	50	Variability of ET performance with climate, limited availability of general applicable ET design criteria, possibility that flow reduction will be required (depends on climate) and higher ET costs make either mound system preferable. The relative advantages of mound vs ETA (mounded) systems are uncertain
		2 Septic tank evapotranspiration/absorption (mounded)	4	4	2	10	350	
		3 Flow reduction septic tank evapotranspiration (ET)	3	4		9	450	
3	Acceptable soil depth but marginal percolation; available land 93 m² EVP PPT >5 cm/mo	1 Flow reduction-holding tank off site disposal	4	4	3	10	1200[e]	Marginal soil percolation and very limited available land limit on site disposal
4	Acceptable soil depth and percolation available land <93 m² direct discharge feasible; EVP-PPT >5 cm/mo	1 Flow reduction septic tank-conventional soil absorption system	4	5	3	12	150[c]	Adequate performance of ST SAS system depends on consistent and significant (40 percent) flow reduction which should be achievable (see Section 5 especially Table 13). ST ETA system performance also depends on flow reduction (25 percent). ST SF DIS DD system does not require flow reduction but is more costly and requires significantly more maintenance
		2 Flow reduction-septic tank evapotranspiration/absorption	4	5	2	11	300[c]	
		3 Septic tank sand filter[a] disinfection[b] direct discharge (DD)	4	3	2	9	450	
5	Acceptable soil depth and percolation available land 93-372 m² EVP PPT 5 cm/mo slope 25%	1 Flow reduction-holding tank off-site disposal (by tank truck)	4	3	3	10	200[e]	Topography (slope) limits on site disposal
6	Shallow (0.3-1.2m) soils with marginal percolation available land >372 m² EVP-PPT <2.5 cm/mo	1 Septic tank mound	4	4	2	10	450	ST-mound systems is preferred since it requires less maintenance and is less susceptible to climatic effects
		2 Septic tank sand filter[a] disinfection[b] irrigation	4	3	2	9	550	
7	Very shallow (<0.3 m) soils with marginal percolation available land 372 m² EVP PPT 2.5-5 cm/mo	1 Flow reduction-holding tank off-site disposed (by tank truck)	4	3	3	10	1200[e]	Shallow soil (<0.3m) limits on site disposal
8	Shallow (0.3-1.2 m) soils with marginal percolation available land 93-372 m² EVP PPT <2.5 cm/mo	1 Flow reduction-septic tank mound	4	4	2	10	450[c]	ST-mound preferred due to lower costs and maintenance requirements. Disinfection is assumed to be required for irrigation due to limited land available for disposal (93-372 m²). Flow reduction (10 to 40 percent) is required depending on exact amount of available land
		2 Septic tank sand filter[a] disinfection[b] irrigation	4	3	2	9	550	
9	Very shallow (<0.3 m) soils with marginal percolation available land 93-372 m² EVP PPT <2.5 cm/mo	1 Flow reduction-holding tank-off site disposed (by tank truck)	4	3	3	10	1200[e]	Shallow soil (<0.3m) limits on site disposal
10	Limiting soil percolation available land 93 m² slope >25% direct discharge feasible EVP-PPT 5 cm/mo	1 Septic tank sand filter[a] disinfection[b] direct discharge	4	3	2	9	450	Limiting soil and net ET requires off site disposal. ST SF DIS-DD is cost available and least costly system
11	Limiting soil percolation available land 93-372 m² EVP-PPT 5 cm/mo	1 Septic tank evapotranspiration	3	4	2	9	500	Limiting soil and infeasible direct discharge makes ET disposal the technically and economically preferable alternative. Liner is not required due to tight soils and adequate soil depth. ST is adequate and the least expensive method of pretreatment. Flow reduction not required but should provide significant savings in ET capital cost
12	Limiting soil percolation available land 93-372 m² direct discharge feasible (BOD & SS < 10 mg/l N<10 mg/l) EVP PPT 2.5 cm/mo	1 Septic tank sand filter[a] fixed growth anaerobic reactor (for denitrification) (DEN) disinfection[d] direct discharge	4	[illegible]	2	9	650	Limiting soil and net ET requires off site disposal. Direct discharge is least costly disposal method and ST SF DEN DIS is least costly and at least technically equal to available options. Ability of segregated system to meet the 10 mg/l nitrogen limitation depends on homeowner habits and the resulting wastewater characteristics
		2 Waterless toilet (WT) septic tank sand filter[a] disinfection[b] direct discharge for greywater	[illegible]	[illegible]	1	7	600	
13	Limiting soil percolation available land > 372 m² direct discharge feasible (BOD & SS 10 mg/l N 10 mg/l P 2 mg/l) EVP PPT 2.5 cm/mo	1 Waterless toilet (WT) septic tank sand filter[a] disinfection[b] direct discharge for greywater	3	3	1	7	600	Ability of segregated system to meet the 10 mg/l nitrogen limitation depends on homeowner habits and the resulting wastewater characteristics. Limiting soil and net ET requires off site disposal. Use of phosphorus free detergents should eliminate the need for red mud (not available in many areas) in the segregated system and will at least reduce maintenance requirements and may eliminate red mud from the combined system
		2 Septic tank sand/red mud filter fixed growth anaerobic reactor (for denitrification) disinfection direct discharge	4	3	2	9	700	
14	Shallow (0.3-1.2m) soils with excessive percolation available land 93 m² EVP PPT <2.5 cm/mo	1 Flow reduction - septic tank mound	4	4	2	10	300[c]	Other methods of subsurface disposal require substantially increased levels of pretreatment and therefore significantly higher costs. Flow reduction required is on the order of 15 percent and therefore should be readily achievable
15	Shallow (0.3-1.2m) soils with excessive percolation available land 93-372 m² EVP PPT 2.5 cm/mo	1 Septic tank soil absorption with pressure distribution	4	4	3	11	200	Pressure distribution providing unsaturated flow conditions has been shown to provide the required treatment under these conditions. Alternatives are significantly more costly
		2 Septic tank mound	4	4	2	10	300	
		3 Septic tank sand filter[a] conventional soil absorption system	4	3	3	10	300	

a Covered intermittent or recirculating gravity filter
b Iodine chlorine or ultraviolet (UV) disinfection
c Does not include cost of flow reduction which varies with hardware and percent flow reduction to be achieved
d Iodine or UV disinfection
e Tank truck removal for off site disposal cost assumes 560 l/d (150 gal/day) and $0.005/l ($0.02/gal) hauling and disposal cost
f The following treatment unit options are appropriate extended aeration rotating disks and anaerobic fixed growth reactor
g Numerical values for site conditions are used to define the framework of this generalized analysis but they are not intended as a regulatory guide since significant regional variations occur. See Table 3 for comprehensive site condition descriptions

4. Systems incorporating wastewater segregation options are generally not cost-competitive for any of the site conditions considered, unless segregation is a part of flow reduction and flow reduction in excess of approximately 35 percent of the normal household total is required. However, use of a non-water carriage or recirculating toilet system to control wastewater nitrogen concentrations, or segregation of bath and laundry wastewater from kitchen and toilet wastewater to facilitate denitrification, may be appropriate if nitrogen discharge limitations are applicable.

5. Systems with available hardware and performance data are available at a reasonable cost for the site conditions considered, except 1) where steep slopes prevent area intensive construction and direct discharge is not feasible; 2) where soils have very limited purification capacity, and direct discharge and evapotranspiration disposal are not feasible; or 3) where available land for disposal is very limited, soil percolation is slow and direct discharge is not feasible. In these instances, holding tanks with periodic pump-out may be used, but this is very costly.

6. Septic tanks normally provide adequate pretreatment for all methods of soil disposal (except irrigation), evapotranspiration (ET), and infiltration/evaporation lagoon disposal. Additional pretreatment is required for soil absorption disposal in shallow soils without adequate purification capacity or direct discharge to surface waters.

RECOMMENDATIONS

Demonstration of on-site wastewater systems for which there is available hardware, and further development of treatment requirements and methods are recommended. Specific recommendations for further development of treatment requirements and methods are as follows:

1. Development of effluent quality requirements and treatment methods for on-site irrigation and subsurface disposal in shallow soils with limited purification capacity. Requirements will likely be affected by soil characteristics and available land area;

2. Further development of evaporation equipment which is relatively independent of precipitation (i.e., mechanical evaporator); and

3. Development of a one-step process (i.e., membrane filtration) for on-site applications to provide high quality effluent (including nutrient removal, if necessary) for reuse and/or variety of disposal methods (i.e., direct discharge, irrigation, or subsurface disposal in shallow or excessively permeable soils) would be desirable if future developments indicate the total annual cost would be comparable to currently available alternatives.

Based on the ranking criteria and site conditions considered, it is recommended that the following systems be field tested to obtain definitive performance and cost data, determine operation and maintenance requirements, and assess environmental acceptability:

1. Septic tank - soil absorption with dosing and resting

2. Septic tank - soil absorption with alternating fields

3. Septic tank - covered intermittent or recirculating sand filter - irrigation

4. Septic tank - evaporative lagoon

5. Septic tank - low pressure membrane filtration - irrigation or direct discharge

6. Septic tank - mechanical evaporator (hardware could be made readily available).

SECTION 3

SYSTEM CONCEPT DEVELOPMENT AND RANKING CRITERIA

SYSTEM CONCEPT DEVELOPMENT

The overall purpose of this study was the comparison and evaluation of on-site wastewater alternatives. The first step necessary to accomplish this was the identification of conceivable alternative systems. Identification of alternative systems has been termed "concept development" and includes consideration of those systems and system components currently in use in on-site applications; those which have as yet found application only on a larger scale; and finally, those which are in the developmental or conceptual stage.

System components for both existing and potential on-site wastewater systems logically fall into three general categories:

- manipulation
- treatment
- disposal

In general, wastewater manipulation options include flow reduction, wasteload reduction, and segregation. Treatment options include biological, physical-chemical and disinfection. Disposal may utilize the atmosphere, soil, or surface water or various combinations.

Specific component options considered in developing alternative systems are shown in Table 2. Since the vast majority of wastewater manipulation options are applicable to all treatment/disposal systems, manipulation options and treatment/disposal options were handled separately in developing alternative systems.

In order to ensure consideration of all combinations of treatment and disposal system components, a matrix of the options identified in Table 2 was developed (see Appendix A). Since thousands of combinations of treatment and disposal options are possible, the following criteria were used to identify the more reasonable combinations:

- Treatment systems selected for a disposal method should not provide a higher level of treatment than necessary. For example, if system A can produce a 30/30 BOD/SS effluent, then system A with the addition of a component to achieve a 10/10 effluent is not considered if secondary treatment standards control direct discharge disposal.

TABLE 2. ON-SITE COMPONENT OPTIONS

Manipulation

- flow reduction
- wasteload reduction
- segregation

Treatment

- biological
  - aerobic/anaerobic
  - aerobic
  - anaerobic
  - emergent vegetation
  - undeveloped treatment processes
  - composting
- physical chemical
  - filtration
  - separation
  - coagulation and chemical precipitation
  - sorption
  - oxidation
  - desorption
  - undeveloped treatment processes
  - incineration
- disinfection

Disposal

- air
  - evapotranspiration
  - lined lagoon
  - mechanical
  - thermal
- water
  - direct discharge
- soil
  - "conventional" soil absorption field
  - seepage pit
  - soil absorption field with modified distribution
    - pressure distribution
    - alternating beds
    - dosing & resting
  - soil modification (i.e., mound)
  - irrigation
- combinations
  - evapotranspiration/absorption
  - unlined lagoon
  - lagoon with overflow
- reuse
  - toilet flushing
  - toilet flushing, lawn watering, and car washing
  - lawn sprinkling, bath, shower, toilet flushing, car washing and laundry

- Systems with inherent environmental acceptability limitations are not considered if similar, but more acceptable systems are possible. For example, an anaerobic lagoon is not considered if an aerobic lagoon can accomplish the same objective in a given system.

- Treatment systems are based on compatible components so that unnecessary pre-treatment prior to a specific component is not utilized.

- Treatment systems are based on sanitary engineering principles applicable to on-site conditions.

- Treatment/disposal systems provide adequate environmental protection. For example, disinfection is assumed to be required for direct discharge.

As mentioned previously, the applicability of on-site systems is often limited by variable site-specific conditions. The most significant site conditions are identified in Table 3. As shown, the list is limited to physical conditions. Variable conditions such as regulatory requirements and aesthetic perceptions are not included as site conditions since they are continuously changing and are not relevant to the engineering evaluation of alternatives which was the objective of this study. Since site conditions often occur in combination to limit the applicability of on-site systems, common combinations of site variables were also indicated in Table 3.

For each combination of site conditions the practical on-site systems were identified by first determining the feasible disposal options. The pre-treatment required for each disposal option was then considered in conjunction with the "practicability" criteria listed above to determine the practical system alternatives. Tabulations of the system alternatives identified for each of the 15 site condition combinations shown in Table 3 are provided in Appendix A.

Wastewater manipulation options are discussed in detail in Section 5. In general, the available options are applicable to all treatment and disposal systems, although the degree of applicability depends on specific system and site characteristics. However, specific treatment systems are appropriate for segregated waste streams in some instances -- primarily when reuse is part of the system. Thus, treatment options for segregated waste streams were developed using a matrix format similar to that for combined wastewater treatment and disposal systems (see Appendix A, Table A-16).

COMPONENT AND SYSTEM RANKING CRITERIA

In order to evaluate the alternative systems identified through the concept development process, ranking criteria were developed (see Table 4). The criteria selected represent the characteristics of greatest concern (in addition to cost) for on-site systems.

TABLE 3. PHYSICAL SITE CONDITIONS FOR SYSTEM EVALUATION

Condition No.	Soil Percolation[D]: Excessive[A]	Soil Percolation: Acceptable[B]	Soil Percolation: Marginal[C]	Soil Percolation: Limiting	Available Land[E]: <93 m (<1000 ft)	Available Land: 93-372 m (1000-4000 ft)	Available Land: >372 m (>4000 ft)	Slope[F]: <25%	Slope: >25%	Direct Discharge[H]: Not Feasible	Direct Discharge, Feasible: BOD/SS <30/30	Direct Discharge, Feasible: 10/10 NK10	Direct Discharge, Feasible: 10/10 P<2	Depth to Groundwater/Crevice Bedrock: <0.3m (<1ft)	Depth: 0.3-1.2m (1-4ft)	Depth: >1.2m (>4ft)	EVP-PPT[G], cm/mo (in/mo): <2.5 (<1)	EVP-PPT: 2.5-5 (1-2)	EVP-PPT: >5.5 (>2)
1		X					X	X		*						X			X
2		X				X		X		*					*				X
3			*		*			X		*						X			X
4		X			*			X			*					X			X
5		X				X			*	*						X			X
6			X				X	X		*					*		*		
7			X				X	X		*				*				*	
8			X			X		X		*					*		*		
9			X			X		X		*				*			*		
10				*	*				*		*					X			X
11				*			X	X		*						X			X
12				*		X		X				*			*		*		
13				*			X	X				*	*		*		*		
14	*				*			X		*					*		*		
15	*					X		X		*						X	*		

FOOTNOTES

A. Excessive Representative of coarse, sandy, or creviced soils with inadequate purification capacity.
B. Acceptable. Percolation rate within range considered acceptable by most state or local regulations
C. Marginal May be unacceptable for conventional soil absorption system without design modifications
D. Limiting Considered inadequate for any system relying on soil percolation, e g., tight clay soils.
E. Exclusive of horizontal set-back restrictions.
F. 25% slope considered to be maximum for disposal options requiring "area intensive" construction (i.e., soil absorption field, lagoon, etc.).
G. Evaporation minus precipitation for critical season.
H. Units are mg/l.

* Considered to be a significant limitation or restriction for the specific set of conditions.

X Non-restrictive site condition.

Since concept development included a range of options from proven systems to conceptual and untested unit processes, the ranking criteria are best applied by separating the alternative systems into three categories:

- systems with available hardware and on-site performance data;
- systems with available hardware but incomplete data (if any) on on-site performance; and
- systems without hardware appropriate for on-site application.

Determination of the availability of hardware and performance data for the systems identified required consideration of the specific configurations and process options within the general treatment/disposal categories (such as "aerobic," "filtration," or "separation") used to develop alternative systems. Thus, process options within each treatment/disposal category were grouped according to hardware and performance data availability and then evaluated based on the ranking criteria shown in Table 4 (see Sections 6-9).

The most appropriate and highest ranked process options were then selected for each system. Systems in the first two categories were ranked according to the criteria while systems in the third category were not ranked due to insufficient information. Systems with incomplete performance and O&M data were ranked based on engineering judgment and these rankings are subject to revision when data becomes available. All rankings assume proper equipment installation and operation.

TABLE 4. COMPONENT AND SYSTEM RANKING CRITERIA*

I. Performance. Level and consistency of treatment achieved

Rating	Description
5	High and consistent level of treatment provided
4	Adequate and consistent level of treatment provided
2	Adequate but inconsistent treatment
0	Inadequate and inconsistent treatment

II. O&M Requirements Scheduled service frequency, equipment failure, and hardware complexity

A. Scheduled maintenance frequency rating

Rating	Description
2	≤1/yr
1	2-4/yr
0	>4/yr

B. Equipment failure (requiring unscheduled service) rating

Rating	Description
1	Infrequent (<1/yr)
0	Frequent (>1/yr)

C. Hardware complexity rating

Rating	Description
2	Simple, few or no moving parts, minimal skills required for servicing
1	Moderate, intermediate in mechanical/electrical complexity, servicing may require some degree of skill and/or training
0	Complex, involves sophisticated mechanical or electrical equipment, skilled and trained serviceman required for servicing

III. Environmental Acceptability Freedom from potential hazards+ and nuisances#

Rating	Description
3	No hazard or nuisance
2	No hazard, minor nuisance
1	Limited hazard and/or major nuisance
0	Significant hazard

+ Effluent toxicity, health effects (disease transmission potential), safety (fire, explosion, chemical toxicity)

Odor, vectors, noise, aesthetics, special residuals disposal problems

* Criteria were applied assuming proper installation and operation.

SECTION 4

WASTEWATER CHARACTERISTICS

On-site wastewater quantity and quality characteristics have been reported in the literature by several investigators. Data derived from actual sampling and analysis of on-site wastewater are summarized in tabular form as follows:

Table	Information Presented
5	Wastewater Flow From Various Household Sources
6	Combined Household Wastewater Characteristics (excluding garbage disposal)
7	Wastewater Constituent Contributions from Various Household Sources
8	Blackwater Characteristics
9	Greywater Characteristics
10	Garbage Disposal Characteristics

The data presented in Tables 5-10 are based on mean values reported in the literature (1-10). These values fluctuate widely, depending primarily on individual household occupant habits.

Wastewater flow values used for this study (presented in the next to the last column of Table 5) are based on a weighting of the reported data into similar wastewater generating sources. Factors used to weight the data included distribution of "other" wastewater generation data into kitchen, bathroom, and service sinks; assigning more weight to research based on a larger number of data points; and giving less weight to data based on literature review. Similarly, kitchen wastewater was distributed between sink and dishwashing for those studies which had attributed all kitchen waste to either the sink or the dishwaster.

Wastewater influent to on-site wastewater systems is received intermittently throughout the day according to the general pattern shown in Figure 1 (1). Maximum hourly flows averaging approximately 11.5 lpch (3.0 gpch) generally occur between 7 and 10 a.m. and 5 and 7 p.m. Low flow periods of less than 3.8 lpch (1 gpch) are generally experienced between midnight and 6 a.m. In addition, instantaneous peak flow rates of 30 to 65 lpm (8-17 gpm) are reported to occur periodically throughout the day (9). Seasonal variations of wastewater generation rates are not significant when compared to the variation of wastewater generation rates between households (8).

TABLE 5. WASTEWATER FLOW FROM VARIOUS HOUSEHOLD SOURCES

Source (lpcd)**	Investigator						This Study	
	Cohen and Wallman (6)	Laak (5)	Ligman, Hutzler, and Boyle (4)	Bennett and Linstedt (3)	Witt, Siegrist, and Boyle (2)	SSWMP (8)+	Weighted Value Used in This Study	Percent of Total (excluding garbage disposal, and water softener)
Kitchen, Total#	--	--	--	17.0	28.4	--	22	14
Sink	--	13.6	--	9.8	5.7	--	9	6
Dishwasher*	--	--	13.3	4.2	12.1	18.5	13	8
Garbage Disposal	--	--	--	3.0	10.6	--	--	--
Laundry (machine)	39.8	28.0	37.9	43.9	56.5	39.8	37	23
Bathrooms, Total (w/o toilet)	--	40.1	--	51.8	--	--	45	28
Bath/ shower	23.8	32.2	47.3	32.9	18.5	37.9	33	21
Sink	--	7.9	--	18.9	--	--	12	7
Toilet	65.1	74.9	--	55.6	26.6	34.7	50	31
Fecal	--	--	--	--	7.1	--	--	--
Non-fecal	--	--	--	--	19.5	--	--	--
Water Softener	--	--	--	--	--	10.0	--	--
Other (sinks not included above)	68.3	--	--	--	--	20.6	6	4
TOTAL	197.0	156.6	--	168.0	130.0	161.2	160	100
Greywater	131.9	81.8	--	109.7	92.8	126.5	110	69

* Manual and/or automatic dishwashing

\+ Values represent daily per capita water usage

\# Excluding garbage disposal

** Data have been rounded

TABLE 6. COMBINED HOUSEHOLD WASTEWATER CHARACTERISTICS
(Excluding Garbage Disposal)*

Parameter (g/cap/d)+	Investigator					This Study
	Olsson, Karlgren, and Tullander (7)	Laak (5)	Bennett and Lindstedt (3)	Witt, Siegrist, and Boyle (2)	SSWMP (8)	Weighted Value Used in this Study
BOD_5	45	48.7	34.8	49.5	49.5	48
BOD_5 filtered	--	--	--	30.4	30.4	30
COD	120	119.4	121.5	--	--	120
TOC	--	--	--	32.1	32.1	32
TOC filtered	--	--	--	22.0	22.0	22
TS	130	--	146.3	113.4	113.4	125
TVS	83	--	74.6	63.1	63.1	70
SS	48	--	47.3	35.4	35.4	40
VSS	40	--	41.6	26.6	26.6	31
TKN	12.1	--	6.5	6.1	6.1	6
NH_3-N	--	3.2	--	1.3	1.3	2
NO_3-N	--	0.1	--	0.1	0.1	0.1
NO_2-N	--	--	--	--	--	--
TP	3.8	--	--	4.0	4.0	4
PO_4-P	--	4.0	3.7	1.4	1.4	1.4
Oil and Grease	--	--	--	14.6	--	15
MBAS	--	--	--	--	--	3
flow (lpcd)	131.5	186.7	165.3	119.4	161.2	160

* Also excludes water softeners

+ Data have been rounded

TABLE 7. WASTEWATER CONSTITUENT CONTRIBUTIONS FROM VARIOUS HOUSEHOLD SOURCES* (percent)+

Source / Parameter	Kitchen			Laundry Clothes Washer			Bathroom	Toilet Flush		
	Sink	Automatic Dishwasher	Total*	Wash	Rinse	Total	Bath/ Shower	Fecal	Non-Fecal	Total
BOD_5	17	26	42	22	8	30	6	9	13	22
BOD_5 filtered	15	26	41	23	9	32	6	8	13	21
TOC	16	23	39	24	8	32	5	11	13	24
TOC filtered	19	21	40	25	9	33	5	7	14	22
TS	12	16	28	33	10	43	4	9	16	25
TVS	15	17	32	23	8	31	6	12	19	31
SS	12	15	27	23	9	31	6	18	18	36
VSS	14	17	31	18	7	25	6	19	19	38
TKN	7	8	15	10	2	12	5	25	44	68
NH_3-N	3	4	7	2	1	2	3	47	41	88
NO_3-N	3	6	9	25	15	40	11	9	31	40
TP	11	21	31	40	14	54	1	7	7	14
Ortho-P	13	27	39	29	8	37	2	8	13	22
Grease	16	17	33	13	10	22	22	6	17	23

* Excluding garbage disposal and water softener, and sinks other than kitchen.
\+ Rounded to nearest percent.

Source: Reference 2 and 8.

TABLE 8. BLACKWATER (TOILET ONLY) CHARACTERISTICS

Parameter (g/cap/d)+	Investigator					This Study
	Olsson, Karlgren and Tullander (7)	Laak (5)	Bennett and Linstedt (3)	Witt, Siegrist and Boyle (2)	SSWMP (8)	Weighted Value Used in This Study
BOD_5	20	23.5	6.9	10.7	10.7	15
BOD_5 filtered	--	--	--	6.3	6.3	6
COD	72	67.8	65	--	--	68
TOC	--	--	--	7.7	7.8	8
TOC filtered	--	--	--	4.8	4.8	5
TS	53	--	76.5	28.5	28.5	45
TVS	39	--	55.8	19.7	19.7	30
SS	30	--	36.5	12.8	12.5	20
VSS	25	--	31	10.2	10.2	16
TKN	11	--	5.2	4.1	4.1	5
NH_3-N	--	2.78	--	1.11	1.11	1
NO_3-N	--	0.02	--	0.03	0.03	0.03
NO_2-N	--	--	--	--	--	--
TP	1.6	--	--	0.55	0.55	0.6
PO_4-P	--	2.16	3.1	0.31	0.31	0.3
Oil and Grease	--	--	--	3.35	--	3
MBAS	--	--	--	--	--	--
pH	8.9	--	5.6	--	--	--
Total Bacteria (#/cap/d)	6.2×10^{10}	--	--	--	--	--
Total coliform (#/cap/d)	4.8×10^{9}	--	--	--	--	--
Fecal coliform (#/cap/d)	3.8×10^{9}	--	--	--	--	--
Fecal strep	--	--	--	--	--	--
Flow (lpcd)	8.5*	74.9	55.6	26.6	34.7	50

* Study households equipped with vacuum toilets
\+ Data has been rounded

TABLE 9. GREY WATER CHARACTERISTICS*

Parameter (g/cap/d)++	Investigator							This Study
	Olsson, Karlgren, and Tullander (7)	Hypes (10)	Laak (5)	Ligman, Hutzler, and Boyle (4)+	Bennett and Linstedt (3)	Witt, Siegrist, and Boyle (2)	SSWMP (8)	Weighted Value Used in This Study
BOD_5	25	--	25.2	24.5	27.9	38.8	38.8	33
BOD_5 filtered	--	--	--	--	--	24.1	24.1	24
COD	48	--	51.6	--	56.5	--	--	52
TOC	--	--	--	--	17.8	24.4	24.4	24
TOC filtered	--	--	--	--	--	17.2	17.2	17
TS	77	--	--	70.8	69.8	85	85	80
TVS	44	--	--	--	18.8	43	43	40
SS	18	--	--	15.4	10.8	22.6	22.6	20
VSS	15	--	--	--	10.6	16.5	16.5	15
TKN	1.1	--	--	--	1.3	1.9	1.9	2
NH_3-N	--	--	0.44	--	--	0.16	0.16	0.2
NO_3-N	--	--	0.6	--	--	0.04	0.04	0.05
NO_2-N	trace	--	--	--	--	--	--	--
TP	2.2	--	--	2.7	--	3.43	3.43	3
PO_4-P	--	--	1.8	--	0.6	1.10	1.10	1.1
Oil and Grease	--	--	--	--	--	11.3	--	11
MBAS	--	--	--	--	3.4	--	--	3
pH	--	7.2	--	--	--	--	--	7.2
Total Plate Count (#/cap/d)	7.6×10^{10}#	--	--	--	--	--	--	--
Total coliform (#/cap/d)	1.3×10^{10}#	1.95×10^{7}	--	--	--	6500**	6500**	--
Fecal coliform (#/cap/d)	2.5×10^{9}#	--	--	--	--	550**	550**	--
Fecal strep (#/cap/d)	--	--	--	--	--	94**	94**	--
Flow (lpcd)	121.5*	--	81.8	98.3	109.7	92.8	126.5	110

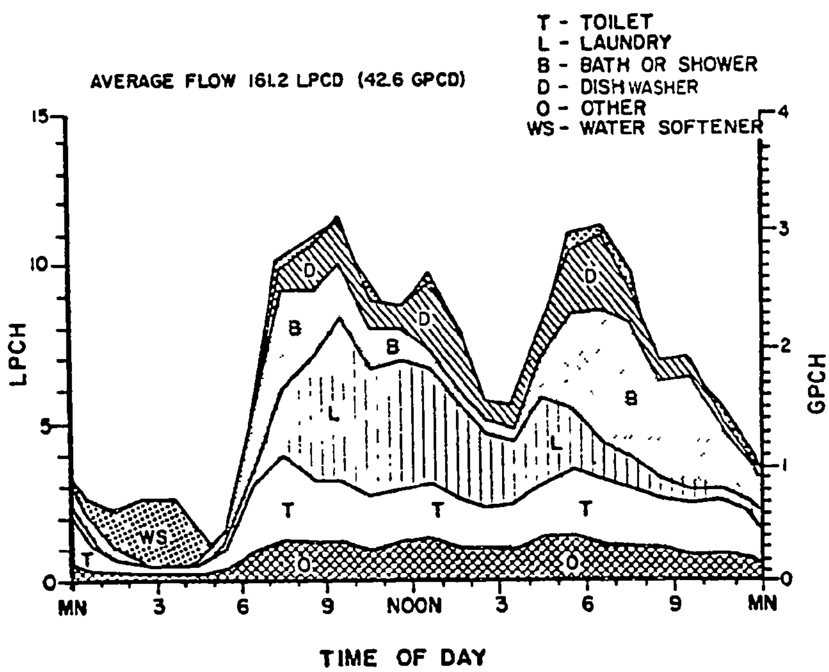
* Excluding garbage disposal and water softener.
\+ Based on bath/shower, dishwashing, and laundry only.
\# Based on kitchen and bath/shower data only.
** Based on laundry and bath/shower data only.
++ Data have been rounded.

TABLE 10. GARBAGE DISPOSAL WASTEWATER CHARACTERISTICS

Parameter (g/cap/d)+	Investigator		This Study		
	Bennett and Linstedt (3)	Witt, Siegrist and Boyle* (2)	Weighted Value Used In This Study		
BOD_5	12.3	10.9	11		
BOD_5	--	2.6	3		
COD	35.6	--	36		
TOC	--	7.3	7		
TOC filtered	--	3.9	4		
TS	32.5	25.8	28		
TVS	22.1	24.0	23		
SS	20.2	15.8	18		
VSS	19.0	13.5	15		
TKN	0.2	0.63	0.5		
NH_3-N	--	0.01	0.01		
NO_3-N	--	trace	trace		
NO_2-N	--	--	--		
TP	--	0.13	0.1		
PO_4-P	0.1	0.09	0.1		
Oil and Grease	--	2.1	2		
MBAS	--	--	--		
pH	6.4	--	6.4		
Total coliform (MPN/100 ml)	--	--	--		
Fecal coliform (MPN/100 ml)	--	--	--		
Fecal strep (MPN/100 ml)	--	--	--		
Flow (lpcd)	3.0	10.6	7		

* Garbage grinders did not receive all meal waste. Study families owned dogs which received table scraps.

\+ Data have been rounded



SOURCE: Reference 1.

FIGURE 1. AVERAGE DAILY FLOW PATTERN FROM ELEVEN RURAL HOUSEHOLDS

It is also important to note that variations of constituent loadings to on-site wastewater treatment systems occur concomitant with variations in wastewater flow from individual household sources throughout the day. Thus, on-site wastewater treatment systems must be able to accommodate considerable long and short-term fluctuations in pollutant as well as hydraulic loadings.

REFERENCES

1. Otis, R.J., W.C. Boyle, J.C. Converse and E.J. Tyler. On-site disposal of small scale wastewater flows. University of Wisconsin, Madison, Small Scale Wastewater Management Project, 1977. 34 p.

2. Witt, M., R. Siegrist, and W.C. Boyle. Rural household wastewater characteristics. In: Proceedings of the National Home Sewage Disposal Symposium, Chicago, Illinois, December 9-10, 1974. American Society of Agricultural Engineers, St. Joseph, Michigan, 1975. pp. 79-88.

3. Bennett, E.R. and K.D. Linstedt. Individual home wastewater characteristics and treatment. Completion Report Series No. 66, Colorado State University, Fort Collins, Environmental Resources Center, 1975.

4. Ligman, K., N. Hutzler, and W.C. Boyle. Household wastewater characteristics. J. Environ. Eng. Div., Am. Soc. Civ. Eng., 100 (EEI): 201-213, February 1974.

5. Laak, R. Relative pollution strengths of undiluted waste materials discharged in household and the dilution waters used for each. In: Manual of Grey Water Treatment Practice, J.T. Winneberger, ed. Monogram Industries, Inc., Santa Monica, California, 1974. pp. 6-16.

6. Cohen, S. and H. Wallman. Demonstration of waste flow reduction from households. EPA-670/2-74-071, General Dynamics Corporation, Groton, Connecticut, September 1974. 111 p. (Available from National Technical Information Services (NTIS) as PB-236 904).

7. Olsson, E., L. Karlgren, and V. Tullander. Household wastewater Report No. 24, National Swedish Institute for Building Research, Stockholm. Sweden, 1:968. 26 p.

8. Small Scale Waste Management Project. Management of small waste flows. Appendix A. Wastewater characteristics and treatment. EPA-600/2-78-173. U.S. Environmental Protection Agency, Cincinnati, Ohio, September 1978. 764 p.

9. Jones, J.E., Jr. Domestic water use in individual homes and hydraulic loading of and discharge from septic tanks. In: Proceedings of the National Home Sewage Disposal Symposium, Chicago, Illinois, December 9-10, 1974. American Society of Agricultural Engineers, St. Joseph, Michigan, 1975. pp. 89-103.

10. Hypes, W. Characterization of typical household greywater. In: Manual of Grey Water Treatment Practice, J.T. Winneberger, ed. Monogram Industries, Inc., Santa Monica, California, 1975. pp. 19-26.

SECTION 5

WASTEWATER MANIPULATION

On-site wastewater treatment systems can be significantly affected by the influent wastewater quantity and characteristics. Wastewater manipulation techniques consisting of flow reduction, wasteload reduction, and/or segregation can be used with both new and existing systems to facilitate and enhance wastewater treatment and disposal, extend system life, reduce system O&M requirements, reduce system capital and O&M costs, and reduce household water consumption.

A summary of generic types of household wastewater flow and wasteload reduction devices for greywater and blackwater generating sources are presented in Tables 11 and 12, respectively. Flow reduction data in Table 11 assumes full open flow for continuous functions and full volume per use for batch functions as baseline conditions.

Additional capital costs included in Tables 11 and 12 are the incremental costs for flow and wasteload reduction devices in excess of the capital costs for conventional (non-flow or -wasteload reducing) equipment. For example, the difference in capital cost between a faucet with an in-line flow restrictor and a conventional faucet is the additional capital cost. Where there is no comparable conventional equipment (i.e., a faucet aerator), the capital cost of the device is considered to be an additional cost. In Table 12, the present worth of the incremental capital costs, including replacement, (amortized over 20 years assuming 7 percent interest, discount, and inflation factors) are added to the annual operation and maintenance costs.

FLOW REDUCTION

Significant water consumption and wastewater flow reductions have been observed without installation of flow reduction devices in several locales as a result of government agency water conservation education programs, and/or a perceived need by household water users (1). The potential savings of flow reduction devices is presented in Tables 11 and 12. Actual performance of many devices depends on user habits. On the other hand, successful performance of some flow and wasteload reduction devices is virtually independent of user habits. Estimates of achievable flow reductions (the amount of water that can actually be saved by a typical household) for various household wastewater sources are presented in Table 13. These estimates are based on data reported in the literature and on engineering judgement, focusing primarily on studies of observed flow reductions demonstrated in household moni-

TABLE 11. FLOW AND WASTELOAD REDUCTION-EXCEPT TOILET

Generic Type	Flow Range*	Dependent On User Habits	Independent of User Habits	Performance: Flow Reduction+ (Percent)	Performance: Wasteload Reduction (Constituents)	Additional Capital Cost Range ($)#: New	Additional Capital Cost Range ($)#: Retrofit
KITCHEN (22 l/cap/d)**							
Sink faucet (9 l/cap/d)	15-30 lpm						
Flow restrictors							
In-line, upstream of faucet		X		30-70	None	1-10	10-25
Incorporated into faucet		X		40-80	None	<1-5	<1-5
Aeration devices		X		40-70	None	<1-5	<1-5
Spray taps		X		30-70	None	7-12	7-12
Cut-off valves		X		60-90	None	10-110	20-140
Specialty faucet systems (pre-set mixing valves, etc)		X		50-90	None	25-80	35-100
Dishwasher (13 l/cap/d)	45-70 l/cycle						
Multi-cycle control		X		10-40	None	50-90	60-100
Ultrasonic (combined with microwave oven)			X	100	BOD, SS, P, O&G	Unknown	Unknown
Garbage disposal (7 l/cap/d)++							
Reduced flow disposal		X		0-40	None	10-20	15-30
Grinder w/centrifuge/ separator			X	95	BOD, SS, O&G	Unknown	Unknown
Eliminate garbage disposal			X	95	BOD, SS, O&G	---	---
LAUNDRY (37 l/cap/d)	100-260 l/cycle						
Automatic washing machine							
Multi-level/cycle control		X		10-40	None	50-75	50-75
Suds-savers		X		10-30	P, BOD, SS	15-25	15-35
Detergents w/low P or filler solids		X		0	P, SS	---	---
Sink faucet (see kitchen)							
BATHROOMS (45 l/cap/d)							
Bath/shower (33 l/cap/d)							
Bathtubs	210 l/use						
Low water volume tub			X	0-30	None	0	0
Showers	20-60 lpm						
Flow restrictions							
In-line, upstream of showerhead		X		40-80	None	1-10	10-35
Incorporated into showerhead		X		10-40	None	5-15	5-15
Compressed air assisted aeration devices		X		60-90	None	260-300	300-500
Cut-off valves		X		60-90	None	10-110	20-140
Specialty faucet systems (pre-set mixing valves, etc.)		X		40-90	None	25-80	35-100
Sink faucets (12 l/cap/d) (see kitchen)							

* Indicate full-open flow rate (continuous functions) or standard water usage per event (batch functions) for conventional fixtures

\+ Indicates percent reduction in flow rate when flowing wide open, or in volume/use. Potential changes in user habits with changing flow rate are not included

\# Capital costs are the incremental costs for flow and wasteload reduction devices in excess of the capital costs for conventional equipment

** Baseline value used for purpose of this study, subject to wide fluctuation (as much ± 50% or more for various functions) in individual homes

++ Not included in kitchen total

TABLE 12. FLOW AND WASTELOAD REDUCTION TOILET

Generic Type	Flow Range	Performance: Dependent on User Habits	Performance: Independent of User Habits	Performance: Flow Reduction* (Percent)	Performance: Wasteload Reduction Selected Constituents	Adequacy	System O&M Requirements: Frequency of Scheduled Maintenance (#/yr)	System O&M Requirements: Hardware Complexity	System O&M Requirements: Equipment Failure (requiring unscheduled service)##	Environmental Acceptability (potential hazards and nuisances)
TOILETS (50 l/cap/d)#	15-20 l/use**									
Water carriage										
Reduced tank flush water volume			X	10-60	none	appears reliable	≤1	simple	infrequent	---
Dual cycle flush		Y		10-30	none	appears reliable	<1	simple	infrequent	---
Compressed air assist flush			X	70-90	none	appears reliable	≤1	moderate	infrequent	---
Flush valve (w/o tank)			X	20-50	none	appears reliable	≤1	moderate	infrequent	---
Vacuum assist flush			X	70-90	none	appears reliable	<1	moderate	frequent	---
Closed-loop recycling toilet systems			X	100	N, SS, BOD, P, microbiological	appears reliable	≥4	moderate-complex	frequent	residuals disposal
Non-water carriage										
Thermal										
Incineration (combustion)			X	100	N, SS, BOD, P, microbiological	appears reliable	>4	moderate	frequent	odor, air emissions, and safety
Evaporation-condensation			X	100	N, SS, BOD, P, microbiological	unknown	unknown	complex	unknown	odor, and residuals disposal
Freezing			X	100	N, SS, BOD, P, microbiological	potentially reliable	>4	moderate	frequent	odor, vectors, and residuals disposal
Oil recirculating			X	100	N, SS, BOD, P, microbiological	potentially reliable	2-4	complex	frequent	odor and residuals disposal
Composting										
Small			X	100	N, SS, BOD, P, microbiological	potentially reliable	>4	moderate	frequent	odor, vectors, residuals disposal, safety and health effects
Large			X	100	N, SS, BOD, P, microbiological	potentially reliable	2-4	simple	infrequent	odor, vectors, residuals disposal, safety and health effects
Holding										
Packaging			X	100	N, SS, BOD, P, microbiological	potentially reliable	4	moderate	frequent	odor, vectors, and residuals disposal

* Indicates percent reduction in full-open flow rate (continuous functions) or standard water usage per event (batch functions) for conventional fixtures

** Based on 1 to 3 toilets per household.

+ Amortized capital cost (in excess of "conventional" equipment) plus annual operation and maintenance costs.

Baseline value used for purposes of this study, subject to wide fluctuations (as much as ± 50% or more for various functions) in individual homes. (Not included in bathroom total).

** Only for conventional fixtures.

Relative to the other devices listed.

++ Amortized capital cost (assuming replacement of existing equipment to reduce flow) plus annual operation and maintenance costs.

TABLE 13. WASTEWATER FLOW REDUCTION

Wastewater Source	Flow Rate: Weighted value used in this study (lpcd)	Estimate of achievable (actual) flow range (lpcd)	Estimate of achievable (actual) flow reduction (percent)*	Reference
Greywater				
Kitchen				
Total	22	14-21	5-35	
Sink	9	6-9	0 30	(5,9)
Dishwasher	13	8-12	10-40	(2,6)
Laundry	37	22-33	10-40	(1,2,6)
Bathroom				
Total	45	17-45	0-60	
Bath/shower	33	3-33	0-70#	(1,3,4,7,8)
Sink	12	7-12	0-40	(5,9)
Other	6	4-6	0-30	(9)
Greywater Total	110	57-105	5-50	
Blackwater				
Toilet	50	0-45	10-100+	(1,4,6,8)
Household Total	160	50-150	5-65	

* Values are rounded.

\+ Achievable reduction is 100% with recycle or non-water carriage toilet.

\# Estimated achievable reduction approaches 70% with compressed air assist showerhead (8).

toring programs, where available (1-10). In many cases, the estimates presented in Table 13 are much lower than the flow reductions listed in Tables 11 and 12. Explanations for some of the apparent discrepancies are:

- Flow ranges and reductions listed in Tables 11 and 12 are based on full open flow, although most conventional continuous flow sources are not regularly operated in this mode.

- User habit changes. Continuous flow source fixtures equipped with flow reducing devices may be operated to actually increase the volume of wastewater generated due to longer duration of usage.

- Inadequate device design. Some batch flow devices may require a second batch operation due to inadequate device performance, or improper operation by user. For example, a reduced volume toilet may be flushed a second time in order to completely clean the bowl.

- Improper device installation. For example, an improperly installed toilet dam may lose its seal and become ineffective.

- Incompatibility of device with existing plumbing. Pipe cloggings may occur due to increased waste solids concentrations and reduced wastewater flow volumes caused by wastewater flow reductions.

- Device removal or circumvention by homeowner.

Overall, the potential exists for significant flow reductions from both continuous and batch flow sources. In general, the most effective flow reducing devices (primarily for batch functions) are those that are virtually independent of user habits. Slightly less effective devices simply require the user to select the reduced flow cycle. For example, reduced flush water volume toilets are virtually assured of wastewater flow reductions (unless additional flushes are required as a result of inadequate flush water velocity) while multi-cycle dishwasher or dual cycle flush toilets require selection of the appropriate cycle to achieve flow reductions. On the other hand, decreases in wastewater quantity directly attributable to installation of flow reducing devices on continuous flow sources have had mixed successes (1, 3, 4, 5), depending primarily on the perceived need for flow reduction. For example, flow reductions as high as 50 percent resulting solely from changes in users habits were reported in California during the summer of 1977.

Since the toilet, laundry, and bath/shower typically generate the largest quantities of household wastewater, installation of flow reducing devices on these sources can have a significant impact on the quantity of wastewater requiring on-site treatment and/or disposal. From the foregoing discussion and the information presented in Tables 11, 12, and 13, it can be seen that installation of flow reducing devices for the toilet, laundry, and dishwasher (batch-flow sources) are most likely to be consistently successful, but are more expensive. Installation of flow reducing devices for the shower (continuous flow source) are not always effective, but most of them are inexpensive. Similarly, installation of flow reducing devices for sink faucets may not always be effective, but they are normally inexpensive. Combined small wastewater flow reductions from individual sink faucets can be significant.

Wastewater reuse is an additional method of flow reduction. On-site wastewater reuse systems generally treat the waste stream from one or more household fixtures to provide the water supply for the same or other water consuming fixtures. Since the operation of wastewater reuse systems is almost completely independent of user habits, their effectiveness in reducing flow is virtually assured. The amount of the flow reductions achieved depends upon the type of reuse system and the household fixtures served.

Reuse water quality criteria are presented in Appendix B. Several of the numerous wastewater reuse options available are describe l in the wastewater segregation section of this chapter as part of Tables 19 and 20 and in Appendix A, Table A-16.

WASTELOAD REDUCTION

As previously indicated in Tables 11 and 12, some flow reduction techniques reduce the mass of waste constituents generated as well as decrease constituent concentrations. These techniques may be used individually, in combination, or in conjunction with segregation of specific household waste generating sources to facilitate on-site wastewater treatment and disposal. Other flow reduction techniques have no effect on the mass of waste constituents (wasteload) requiring treatment and/or disposal, as indicated in Tables 11 and 12, although they increase waste constituent concentrations. These resulting concentration increases primarily affect individual treatment and disposal system component design (size, configuration, etc.); they usually have little impact on the selection of unit processes (component types). In addition to wastewater flow reductions accompanied by wasteload reductions, wasteloads alone may be reduced.

Methods to achieve household wasteload reductions and the constituents affected are described in Table 14. As an example of wasteload reduction methods, both with and without flow reduction, the quantity of phosphorus influent to an on-site treatment system may be reduced by eliminating toilet discharges and the use of high phosphate detergents. The value of these efforts might be to eliminate a specific phosphorus removal treatment step prior to surface discharge. Similarly, elimination of toilet discharges to the treatment system would reduce the input of all constituents considered in Table 14. With the exception of toilet discharges, the methods of wasteload reduction listed in Table 14 are self-explanatory and need no further discussion.

Several methods for eliminating toilet waste discharges (and thereby reducing flow) were identified in Table 12. All but one of these methods involve the use of non-water carriage toilet systems. Descriptions of these

TABLE 14. WASTELOAD REDUCTION

Method	Wasteload Reduced						Accompanied by flow reduction
	BOD	SS	N	P	O&G	Micro-biological	
Eliminate garbage disposal	X	X	X	X	X	X	X
Eliminate use of detergents with phosphorus and/or filler solids+		X		X			
Install laundry "sud-saver"	X			X			X
Eliminate toilet discharges	X	X	X	X	X	X	X

* "X" indicates constituents reduced.

\+ Inert solids added by detergent manufacturers as abrasives to enhance detergent performance.

non-water carriage toilet systems for which there is available on-site hardware and performance information follow.

Incinerating Toilets

Non-water carriage, incinerating toilets can be used to eliminate household blackwater flow and reduce wasteloads by drying and incinerating toilet wastes, as briefly described below.

System Type	System Requirements	Comments
Gas-fired (liquified propane or natural gas)	Toilet bowl, combustion chamber, insulation, ignition source (electric spark plug), air-fuel supply system, flue gas vent and blower, and system controls consisting of cycle activation switch and timer.	Frequent removal of combustion residuals is required. Incomplete combustion of wastes may result in odor problems. Slight potential for explosion or fire hazard.
Oil fired	Same as above	Same as above
Electric (115 or 220 volts AC, or 12 volts DC)	Toilet bowl, combustion chamber, electric heating element, insulation, flue gas vent and blower, and system controls consisting of cycle activation switch and timer.	Frequent removal of combustion residuals is required. Waxed paper bowl liner may be required to be placed in toilet prior to each use.

Gas and oil-fired incinerating toilets require significantly more frequent maintenance (associated with fuel supply and combustion equipment) than electric incinerating toilets. On the other hand, electric incinerating toilets have significantly higher energy costs. Thus, the applicability of the various types of incinerating toilets is largely site dependent.

Performance--

There are a number of commercially available incinerating toilets. However, discussion of performance of these units will be limited to the gas-fired and electric units since oil-fired unit performance data were not readily available.

In general, incinerating toilets are designed to dry and incinerate influent toilet wastes, producing ash which requires subsequent disposal. For gas-fired units, the complete combustion/cooling cycle takes approximately 20 minutes (15 for combustion and 5 for cooling); while electric units normally require approximately 45 minutes (15 for combustion and 30 for cooling). Although the cycle can be interrupted for toilet use, additional combustion cycles without introduction of waste may be required following peak use periods to avoid incomplete waste combustion. (Personal Communication. T. G. Townley. March 19, 1978.)

System O&M Requirements--

Routine removal and disposal of combustion residuals about once a week are necessary for gas-fired incinerating toilets. Residuals removal can be performed using a vacuum cleaner or a dustpan-and-brush if waste incineration is complete. If incineration is incomplete (as has been reported for some units) waste must be scraped from the incineration chamber (11). The toilet bowl must also be wiped clean with a damp cloth at weekly intervals. Periodic cleaning and alignment of the gas-fired burner assembly, adjustment of the air/fuel ratio, and adjustment and/or replacement of spark plugs may be required two to four times per year by a trained technician to maintain combustion efficiency. Frequent unscheduled maintenance necessitated by spark plug fouling, faulty timers, blower motor failure, or corrosion of internal parts may be required (11,12).

Similarly, routine removal and disposal of combustion residuals are required approximately once per week for electric incinerating toilets. Residuals can be removed by a vacuum cleaner or a dustpan-and-brush if waste incineration is complete. As previously mentioned, a waxed paper bowl liner may be required to be placed in the toilet (manufacturer specification) prior to each use. Weekly cleaning of the toilet bowl by wiping with a damp cloth is required. The heating element may require cleaning two to four times per year to maintain combustion efficiency. Ventilation systems, including a blower and piping, need to be cleaned with hot water, soap, and brush approximately two to four times a year. Infrequent, unscheduled repair and maintenance include inspection and replacement of the heater element by a trained technician.

Because positive ventilation is required to discharge flue gases, homes using incinerating toilet may consume additional energy to maintain household temperatures due to heat losses or gains caused by flue gas venting.

Environmental Acceptability--

Although the high operating temperatures of incinerating toilets adequately sterilize the ash produced by incineration of toilet wastes, there are several environmental concerns related to use of incinerating toilets. These are as follows:

- Odor problems resulting from incomplete waste combustion. (Masking agents or catalytic deodorizer may help to alleviate or eliminate the symptoms);
- Slight potential of explosion or fire hazards for gas- or oil-fired incinerating toilets; and

- Air pollution potential of combustion products escaping with flue gases.

Cost--

Capital, operation and maintenance and total annual costs for gas-fired and electric incinerating toilets ae presented in Table 15.

Composting Toilets

Non-water carriage, composting toilets can be used to eliminate household blackwater flow and reduce wasteloads by converting toilet wastes into compost, which may be suitable for land application as a soil conditioner or fertilizer. Types of composting toilets available are:

System Type	System Requirements	Comments
Large composting toilet	Compost tank with toilet stool (typical tank effective volume of 30 to 70 ft^3), and ventilation system. Addition of dry carbon source, such as sawdust, may be required.	Requires large space for composter tank. Tank volume expandable in section fashion for some units. Loading of kitchen wastes allowable and often desirable. Potential odor problems (resulting from excessive liquid loadings), vector problems, and limited fire hazards. Energy may be lost from household through vent .
Small Composting Toilet	Compost tank with toilet stool (typical tank effective volume 0.5-1m^3), and ventilation system. Electric heating element and stirring or leveling on some units.	Occasional odor problems resulting from excessive liquid build-up. Potential insect problems and fire hazard. Energy loss from house through vent may be a problem.

Performance--

Both large and small compost toilets should be capable of producing relatively stable end products. As a result of the difference in effective compost volumes, large compost toilets rely largely on low rate aerobic biological mechanisms to degrade toilet (and kitchen) wastes, while small

TABLE 15. INCINERATING TOILET COSTS

Capital Cost Item	Design life (yr)	Capital Cost ($) Gas Unit	Capital Cost ($) Electric Unit
Toilet unit	20	600-800	600-800
Installation*	--	200-350	150-250
Total Capital Cost*		$800-1150	$750-1050
Annual O&M Cost Item		**Annual O&M Cost ($) Gas Unit**	**Annual O&M Cost ($) Electric Unit**
Maintenance (@$10/hr)			
Routine		70	70
Unscheduled repairs		20	20
Replacement Parts		15	10
Energy+ & liner (if required) costs		200	300
Total Annual O&M Cost		$305	$400
Annual Cost			
Present worth of the sum of the capital costs amortized over 20 years @ 7% interest, discount, and inflation (factor = 0.09439)*		76-109	71-99
Annual O&M Costs		305	400
Total Annual Cost*		$381-414 ~$380-410	$471-499 ~$470-500

* Lower value is for new construction; higher value is for retrofit applications.

\+ Energy consumption is estimated to be 135 g (0.3 lb) LP gas/use at $0.5/lb for gas units and 1.2 kwh/use at $0.05/kwh for electric units (3).

compost toilets generally depend on thermal dehydration and high-rate aerobic mechanisms to stabilize toilet wastes. Key factors relating to the performance of compost toilets are as follows (Personal Communication. M. Findlay and C. Lindstrom. April 1978.) (13):

Large Compost Toilets	Small Compost Toilets
Long detention time	Short detention time
Microorganisms as well as higher organisms such as arthropods and earthworms predominate	Microorganisms such as bacteria and fungi predominate. Thermal dehydration also takes place
Pathogens are killed by long-term predation, competition, and natural die-off	Pathogens killed by heat and natural die-off
Operating temperature ranges, 20-35°C	Operating temperature ranges, 15 to 55°C

No comparative studies of the long-term reliability of composting units have have been conducted in this country. Studies of the composition of the end product from various compost units indicate that it can be relatively pathogen-free for some commercially available units (13-15). However, the continuous nature of the composting process in the available large composting units provides the potential for short-circuiting and the contamination of stabilized compost by "fresh" waste materials. At least one model of small composting units provides a pasteurizing step immediately before the compost container is emptied. If it is effective, this pasteurizing step would eliminate a potential short-circuiting problem.

The potential for short-circuiting in the large units increases if inadequate liquid absorption capacity is provided. Excess liquid build-up can also cause odors (which may be a particular problem if the ventilation system is inadequately designed or installed) resulting from anaerobic conditions. The relative health effects associated with the potential for liquid build-up and short-circuiting for compost toilets as compared to conventional systems have not be determined.

System Operation and Maintenance Requirements--

Routine system operation and maintenance of large units includes periodic removal and disposal of compost approximately once per year, after initial compost mass development. Also, periodic addition of sawdust or kitchen waste to facilitate the composting process is required approximately 6 to 12 or more times per year. This is desired to prevent the compost mass from becoming compacted, to equalize moisture distribution, and to facilitate system aeration and waste decomposition. Infrequent unscheduled maintenance, consisting of replacement of mechanical equipment (i.e., ventilation fan) and compost mass mixing, removal, or sawdust addition is expected.

For small composting toilets, periodic removal and disposal of compost is required four or more times per year. Periodic mixing of the compost mass by an electric or manual stirrer is also required to facilitate the evaporation and aeration. Unscheduled maintenance and repairs for small composter toilets include infrequent replacement of broken stirrers, corroded heating elements, and ventilation fans, and mixing or removal of compost mass (13).

In addition, energy loss from the house through the toilet ventilation system of both large and small compost toilet systems may increase the energy requirements of a household.

Environmental Acceptability--

Potential factors affecting the environmental acceptability of both large and small composter toilets include odor problems due to occasional anaerobic conditions and inadequate venting, health hazards resulting from inadequate pathogen destruction in the compost mass, fire hazards associated with addition of hot ashes to excessively dry compost mass, and air emission problems. In addition, there may be vector problems associated with inadequate venting of the units and handling of the compost. In general, these potential problems can be minimized if the user is committed to proper management of the compost process.

Costs--

Capital, operation and maintenance, and total annual costs of the compact composting toilet and large composting system are presented in Table 16. Costs for both new homes and retrofit installation are included.

Oil Recirculating Toilets

Non-water carriage, oil recirculating toilets can be used to eliminate household blackwater flow and reduce wasteloads for on-site treatment and disposal. This is accomplished by separating toilet wastes from a recirculating petroleum-base flushing liquid, as briefly described below (Personal Communication. T. Woltanski. January, 1978.) (10,16):

System Type	System Requirements	Comments
Oil recirculating	Toilet bowl, waste separation and storage tank, flushing oil, oil-waste separation and purification system, pump and controls.	Waste separation and holding equipment requires large space. The environmental acceptability of disposal of oil-coated residuals is uncertain. Disinfectant addition may be required to eliminate microbial contamination and degradation of the flushing oil.

TABLE 16. COMPOSTING TOILET COSTS

Capital Cost Item	Design life (yr)	Capital Cost ($) Small	Large+
Compost unit	20	650	1600
Shipping and installation	--	200-400*	700-1500
Total Capital Cost		$850-1050	$2300-3100

Annual O&M Cost Item	Annual O&M Cost ($) Small	Large
Electricity	3[illegible][#]	15[#]
Replacement Parts	15	10
Maintenance requirement @ $8/hr		
Routine	48	24
Unscheduled repairs	24	112
Total Annual O&M Cost	$125	$60

Annual Cost		
Present worth of the sum of the capital costs amortized over 20 years @ 7% interest, discount, and inflation (factor 0.09439)	80-100	217-292
Annual O&M Costs	125	60
Total Annual Cost	205-225 ~$210-230	277-352+ ~$280-350

* Lower value is for new construction; higher value is for retrofit applications.

\+ This assumes one toilet per unit. However, some large units can accommodate additional toilet stools, which would result in significant economies of scale for multiple toilet installations of these units, as compared to single toilet units.

\# Reference (14), $0.04/day for the large unit and $0.09/day for the small unit.

Performance--

Oil recirculating toilets separate and store toilet wastes for subsequent removal and disposal. Performance may be adversely affected by several characteristics, including the following:

- Incomplete separation of aqueous base liquids from the flushing oil due to the formation of oil-water emulsions;
- Deterioration of the flushing oil due to chemical reaction with toilet wastes;
- Bacterial contamination and degradation of the flushing oil. Addition of an oil soluble bactericide disinfectant which is not toxic to toilet users may alleviate this problem; and
- Odors and toilet discoloration due to inadequately purified oil (10,16).

Generally, these problems can be overcome by periodic replacement of the flushing oil.

System Operation and Maintenance Requirements--

Removal and disposal of residuals from the waste storage tank is required annually for a system with a 1900 l (500 gal) storage capacity. Inspection, cleaning, and maintenance of the complex hardware by a skilled serviceman should be performed one to three times per year. This includes addition of a disinfectant and odor and color masking agents, and replacement of exhausted filtration media and flushing oil (50 l (13 gal) per year) (Personal Communication. T. Woltanski. January, 1978.) (10). Frequent unscheduled maintenance of the coalescer and filter assemblies, system pumps and chemical addtion systems (if any) may be required.

Environmental Acceptability--

Flushing oil odor and discoloration are minor nuisances associated with oil recirculating toilets, while flushing oil microbial contamination is a limited hazard. Addition of masking agents and disinfectants should alleviate these problems. However, disposal of oil-coated residuals and exhausted filtration media and flushing oil can be a more severe problem (16).

Costs--

Capital, operation and maintenance, and total annual costs for oil recirculating toilets are presented in Table 17.

Component Comparisons

Non-water carriage toilet component comparisons for units with sufficient on-site performance information and hardware to permit detailed evaluation are presented in Table 18. Component comparisons for units with available on-site

TABLE 17. COSTS OF OIL RECIRCULATING TOILET SYSTEM

Capital Cost Item	Design Life (yr)	Capital Cost ($)
2-toilet oil recirculating system	20	6,000
Shipping and installation	--	700-1,500*
Centrifugal oil pump	10	150
Float Switches	5	140
Total Capital Cost		$6700-$7500

Annual O&M Cost Item	Amount	Unit Cost ($)	Annual O&M Cost ($)
Maintenance required			
Routine	4 hr	12/hr	48
Unscheduled	2 hr	12/hr	24
Residuals removal and disposal	1	50	50
Disinfectant and masking agent refills and filtration media replacement	2/yr	75	150
Flushing oil addition	50 1/yr	1/1	50
Electricity	240 kwh	0.05/kwh	12
Replacement Parts	--	--	50
Total Annual O&M Cost			$344

Annual Cost	
Present worth of the sum of the capital costs amortized over 20 years @ 7% interest, discount and inflation (factor = 0.09439)	$632-708
	$344
Total Annual Cost	$976-1052 ~ $980-1050

* Estimated cost for new and retrofit installation, respectively.

TABLE 18. NON-WATER CARRIAGE TOILET COMPONENT COMPARISON FOR COMPONENTS WITH SUFFICIENT INFORMATION*

Ranking group	Component	Ranking: Performance (5 max.)	Ranking: O&M requirements (5 max.)	Ranking: Environmental acceptability (3 max.)	Ranking: Total (13 max.)	Total annual cost ($): New	Total annual cost ($): Retrofit
A	Small composting	3	3	1	7	210	230
	Large composting	3	4	1	8	280[+]	350[+]
	Incinerating	3	2	1	6	380-470	410-500
B	Oil recirculating	3	2	1	6	980	1050

* For components with sufficient on-site performance information and hardware available to permit detailed evaluation. See Chapter III for explanation of the ranking system.

\+ This assumes one toilet per unit. However, some large units can accommodate additional toilet stools, which would result in significant economies of scale for multiple toilet installations of these units, as compared to single toilet units.

TABLE 19. NON-WATER CARRIAGE TOILET COMPONENT COMPARISON FOR COMPONENTS WITH INCOMPLETE INFORMATION*

Ranking group	Component	Ranking: Performance (5 max.)	Ranking: O&M requirements (5 max.)	Ranking: Environmental acceptability (3 max.)	Total (13 max.)	Range of total annual cost ($): New	Range of total annual cost ($): Retrofit
A	Freezing	3	1	1	5	125-175	150-225
	Packaging	3	1	1	5	---	---

* For components with available on-site hardware, but insufficient on-site performance information. This comparison is based on engineering judgement and is subject to revision when data become available.

hardware but insufficient performance information shown in Table 19 are based on engineering judgment and are subject to revision when data become available.

WASTEWATER SEGREGATION

Isolation or segregation of specific household waste generating sources may be employed independent of or in combination with flow and/or wasteload reduction to facilitate on-site wastewater treatment and disposal. For one or more household waste streams, waste segregation and separate treatment and disposal may result in the following:

- The reduction of the quantity of wastewater requiring on-site treatment or disposal;
- The reduction of treatment and disposal system size, O&M requirements, and capital and O&M costs;
- The extension of system life;
- The reuse of wastewater for non-potable purposes; and
- The simplification, enhancement, or elimination of treatment prior to reuse or disposal.

Matrices of 18 potential waste segregation options and potential impacts are presented in Tables 20 and 21, respectively. This listing is not intended as a complete list of all options. Rather, the segregation options shown are based on systems previously tested by researchers, currently operating systems, and theoretically promising systems (Personal communication. R. Laak. May 1978. and L. Waldorf. April 1978.) (4, 5, 17-21). These matrices systems were developed based on the following principles and assumptions:

- Wastewater will not be reused in the kitchen or for drinking purposes;
- The quantity of wastewater intended for reuse must satisfy intended demands or make-up water must be provided;
- Concentrated waste streams will not be treated for reuse if a sufficient quantity of a more easily treated waste stream is available; and
- Flow reduction will normally be used in conjunction with wastewater segregation. However specific waste streams to which flow reduction is applied and the level of flow reduction achieved is dependent on the method of treatment and disposal selected and thus will be variable. For the mass balances presented in Table 20, it is assumed that the volume of wastewater generated will equal the volume required for reuse.

TABLE 20. WASTEWATER SEGREGATION OPTIONS MATRIX

Segregation Option *	Waste Stream*			Selected Constituents Segregated (percent)+														
				Waste Stream 1					Waste Stream 2					Waste Stream 3				
	1	2	3	BOD	SS	N	P	O&G	BOD	SS	N	P	O&G	BOD	SS	N	P	O&G
a	K,L,B,T#	---	---	100	100	100	100	100	---	---	---	---	---	---	---	---	---	---
b	K,L,B	T	---	80	65	30	85	75	20	35	70	15	25	---	---	---	---	---
c	L	K,B,T	---	30	30	10	55	20	78	70	90	45	80	---	---	---	---	---
d	B	K,L,T	---	5	5	5	<5	20	95	95	95	>95	80	---	---	---	---	---
e	K,L,B	T(K,L,B)**	---	80	65	30	85	75	25	40	100	50	35	---	---	---	---	---
f	L	K,B,T(L)	---	30	30	10	55	20	70	70	100	70	85	---	---	---	---	---
g	B	K,L,T(B)	---	5	5	5	<5	20	95	95	100	100	85	---	---	---	---	---
h	L,B	K,T	---	35	35	15	55	45	65	65	85	45	55	---	---	---	---	---
i	L,B	K,T(L,B)	---	35	35	15	55	45	65	70	100	65	65	---	---	---	---	---
j	B	K,L(B),T(B)	---	5	5	5	<5	20	95	95	100	>95	80	---	---	---	---	---
k	B	K,L	T++	5	5	5	<5	20	70	60	25	85	55	20	35	70	15	25
l	B	L(B)	K,T(B)	5	5	5	<5	20	30	30	15	55	25	65	65	85	45	55
m	B	K,L(B)	T(B)	5	5	5	<5	20	70	60	30	85	55	20	35	70	15	25
n	K	L,B	T(L,B)	40	25	15	30	35	35	35	15	55	45	25	40	85	35	35
o	B	L	K,T(L)	5	5	5	<5	20	30	30	10	55	20	65	65	95	65	60
p	L,B	L(L,B)	K,T(L,B)	35	35	#	#	45	30	30	##	##	20	65	65	##	##	60
q	K	L(K,L,B), B(K,L,B)	T(K,L,B)	40	25	15	30	35	35	40	##	##	50	25	25	##	##	25
r	L	B	K,T(B)	30	30	10	55	20	5	5	5	<5	20	65	65	85	45	55

* 1,2,3 indicate individual or combined waste streams with separate conveyance, treatment, or disposal systems

\+ Approximate mean percentage of mass of selected constituents household total from Tables IV-1 and IV-3. The sum of individual waste stream constituents may total more or less than 100 percent for segregation options incorporated wastewater reuse. Development of Tables V-9 and V-10 is based on principles listed in the text and reuse water quality objectives presented in Appendix B.

\# K = kitchen waste stream without a garbage grinder; L = laundry waste stream, B = bathroom waste stream (excluding toilet), T = toilet waste stream.

** T(KLB) indicates influent to toilet stream is effluent from kitchen-laundry-bath system (following treatment).

++ System may include closed-loop recycle toilet, holding toilet with off-site treatment or disposal, or on-site treatment and disposal.

\#\# Constituent quantity is dependent on treatment system performance and volume of wastewater recycled.

TABLE 21. WASTEWATER SEGREGATION OPTION IMPACT

Segregation Option	Waste Stream			Potential Impacts[+]				Comments
	1	2	3	Reuse Wastewater Within Household	Improve Treatability or Simplify/Eliminate Treatment Required Prior to Reuse or Disposal	Reduce Quantity of Wastewater Requiring a Specific Type of Treatment or Disposal	Reduce Treatment or Disposal System Size, O&M, or Costs	
a	K,L,B,T[*]	---	---	---	---	---	---	Conventional system
b	K,L,B	T	---	2	1,2	1,2	---	On-site treatment and disposal of greywater only required when used in conjunction with closed-loop recycle toilets, non-water carriage toilet, or holding toilet Alternatively, separate treatment followed by recombination of waste streams may facilitate denitrification If required, P-removal from waste stream 1 only may be sufficient
c	L	K,B,T	---	1	1	1,2	---	Reuse of a portion of waste stream 1 may be possible with minimal treatment
d	B	K,L,T	---	1	1	1,2	---	Required treatment of waste stream 1 required prior to disposal (or reuse). (For example, no treatment may be required prior to disposal by irrigation, or only disinfection may be required prior to lawn watering)
e	K,L,B	T(K,L,B)	---	1	1	1,2	1,2	Treatment of all greywater will produce quantity in excess of that required for reuse as toilet flush water Separate treatment, disposal, and/or alternate reuse of excess must be provided.
f	L	K,B,T(L)	---	1	1	1,2	1,2	Does not facilitate treatment of waste stream 1 for reuse as effectively as option g
g	B	K,L,T(B)	---	1	1	1,2	1,2	Reduced treatment of waste stream 1 required prior to reuse. Quantity may be insufficient unless low volume flush toilet is used or make-up water provided
h	L,B	K,T	---	1	1,2	1,2	---	Waste stream 1 may not require N-removal prior to disposal
i	L,B	K,T(L,B)	---	1	1	1,2	1,2	Relatively dilute waste streams treated for reuse If low volume flush toilet is used, separate treatment, disposal, and/or alternate reuse of excess must be provided
j	B	K,L(B), T(B)	---	1	1	1,2	1,2	Reduced treatment of waste stream required prior to reuse Quantity will be insufficient unless very low volume flush toilet is used and/or make-up water is provided

TABLE 21. (CONTINUED)

Segregation Option	Waste Stream* 1	Waste Stream* 2	Waste Stream* 3	Potential Impacts+: Reuse Wastewater Within Household	Potential Impacts+: Improve Treatability or Simplify/Eliminate Treatment Required Prior to Reuse or Disposal	Potential Impacts+: Reduce Quantity of Wastewater Requiring a Specific Type of Treatment or Disposal	Potential Impacts+: Reduce Treatment or Disposal System Size, O&M, or Costs	Comments
k	B	K,L	T	1,3	1,2,3	1,2,3	---	Use of closed-loop recycle or non-water carriage toilet, and segregation of remaining waste streams may allow disposal (or reuse) of waste stream with reduced treatment For systems providing on-site disposal of all waste streams, P-removal (if required) from waste stream 2 only may be sufficient.
l	B	L(B)	K,T(B)	1	1,2	1,2,3	1,2,3	Reduced treatment of waste stream 1 required prior to reuse. Quantity will be insufficient unless very low volume flush toilet is used and/or make-up water is provided. Separate treatment disposal and/or reuse of any excess must be provided. If required, N-removal from waste stream 2 only many be sufficient
m	B	K,L(B)	T(B)	1	1,2	1,2,3	1,2,3	Reduced treatment or waste stream 1 may be required prior to reuse Does not facilitate treatment or disposal as effectively as option 1
n	K	L,B	T(L,B)	2	1,2	1,2,3	2,3	Treatment of entire waste stream 2 will produce quantity in excess of that required for reuse as toilet flush waste. Separate treatment, disposal, and/or alternate reuse of excess must be provided
o	B	L	K,T(L)	1,2	1,2	1,2,3	2,3	Reduced treatment of waste stream 1 required prior to reuse or disposal Quantity of treated waste stream 2 may be insufficient unless low volume flush toilet is used or make-up water provided. Separate treatment, disposal, and/or alternate reuse of any excess must be provided.
p	L,B	L(L,B)	K,T(L,B)	1,2	1,2	1,2,3	1,2,3	"Fresh" water enters recycle system as bathroom waste stream. Concentrated wastes exit with toilet waste stream
q	K	L(K,L,B), B(K,L,B)	T(K,L,B)	1,2	1,2	1,2,3	1,2,3	"Fresh" water enters recycle system as kitchen waste stream Concentrated wastes exit with toilet waste stream
r	L	B	K,T(B)	1,2	1,2	1,2,3	2,3	Reuse of a portion of waste stream 1 may be possible with minimal treatment Reduced treatment of waste stream 2 required prior to reuse Quantity of treated waste stream 2 may be insufficient unless low volume flush toilet is used or make-up water provided. Separate treatment, disposal, and/or reuse of any excess must be provided.

* K = kitchen waste stream without a garbage grinder, L = laundry waste streams, B = bathroom waste stream (excluding toilets), T = toilet waste stream.

\+ Potential impacts (as compared with combined on-site wastewater treatment and/or disposal) affecting waste streams indicated by numbers (1,2,3).

- The entire flow of an individual or combined waste stream utilized for more than one reuse application will be treated to meet water quality objectives of the more stringent of the reuse applications; and

- For the mass balances presented in Table 20, treatment of any waste stream for reuse is assumed to result in 60 percent P removal and 0 percent N removal.

The wastewater segregation options identified in Table 20 can be effective. However, the feasibility of the individual options is dependent on the accompanying treatment and disposal system feasibility, including the successful implementation of wastewater flow and wasteload reduction techniques where utilized; site conditions; and comparative feasibility of combined wastewaster treatment and disposal systems. For example, segregation option G (segregation and treatment of bathroom waste--excluding toilet--for reuse in the toilet) will effectively reduce total household wastwater flow. The feasibility of implementing this segregation option will depend on the cost and performance of system as compared to the alternatives.

In general, segregated systems compare favorably with combined systems only in the following situations:

- When the cost of segregation and treatment of a waste stream for reuse is off-set by reduced treatment and disposal costs;

- When limited land or water availability requires significant flow reductions achieved by reuse, with treatment for reuse facilitated by segregation;

- When off-site disposal (i.e., holding tank with periodic pumpout) of a portion of total household wastewater is desirable due to limited land availability for disposal, reduced level of treatment required, or restrictive on-site environmental quality requirements; or

- When segregation facilitates treatment or containment of specific pollutants, such as nitrogen.

Due to this relatively limited applicability, segregation options are included on a case-by-case basis in the system comparative analysis (see Section 10).

REFERENCES

1. Sharpe, W.E. and P.W. Fletcher. The impact of water saving device installation programs on resource recovery conservation. Research Publication 98, Pennsylvania State University, University Park, Institute for Research on Land and Water Resources, 1977. 44 p.

2. Water conservation devices, residential water conservation. Stock No. 024-000-00837-1, Technology Transfer Water Research Capsule Report, U.S. Department of the Interior, Washington, D.C., Office of Water Research and Technology, 1978. 8 p.

3. Siegrist, R.L., T. Woltanski, and L.E. Waldorf. Water conservation and wastewater disposal. In: Proceedings of the Second National Home Sewage Treatment Symposium, Chicago, Illinois, December 12-13, 1977. American Society of Agricultural Engineers, St. Joseph, Michigan, 1978. pp. 121-136.

4. Cohen, S. and H. Wallman. Demonstration of waste flow reduction from households. EPA-670/2-74-071, General Dynamics Corporation, Groton, Connecticut, September 1974. 111 p. (Available from National Technical Information Service (NTIS) as PB-236 904).

5. Bailey, J.R., R.J. Benoit, J.L. Dodson, J.M. Roby, H. Wallman, and C.L. Swanson. Water flow reduction from households. Water Sewage Works, 122(4):57-66, April 1975.

6. Kuhner, J., D. Luecke, and R. Sharpin. Water use and wastewater and residuals generation in households: potential for conservation. In: Proceedings of the Second National Home Sewage Treatment Symposium Chicago, Illinois, December 12-13, 1977. American Society of Agricultural Engineers, St. Joseph, Michigan, 1978. p. 260-267.

7. Small Scale Waste Management Project. Management of small waste flows. Appendix A. Wastewater characteristics and treatment. EPA-600/2-78-173. U.S. Environmental Protection Agency, Cincinnati, Ohio, September 1978. 764 p.

8. Schatzberg, P., D.F. Jackson, C.M. Kelly, and L.R. Harris. Energy conservation through water resource management--a reduced flow bathing shower. Conference on Water Reuse, Chicago, Illinois, May 4-8, 1975. American Institute of Chemical Engineers, New York. pp. 141-146.

9. Nelson, J.O. North Marin's Little Compendium of Water Saving Ideas. North Marin County Water District, Novato, California, 1976. 273 p.

10. Milne, M. Residential water conservation. Report No. 35, University of California, Davis, California Water Resources Center, 1976. 469 p.

11. Abney, J. Evaluation of 19 on-site waste treatment systems in Southeastern Kentucky. Contract No. CA-8-2575-A, U.S. Environmental Protection Agency. Cincinnati, Ohio, August 1978. 107 p. Draft.

12. Carpenter, J.W., Jr. Individual sewage disposal prototype study. Appalachian Environmental Health Demonstration Project, Corbin, Kentucky, March 1971. 17 p.

13. McKernarn, J.M. and D.S. Morgan. Experiences with the Clivus-Multrum and Mull-Toa toilets in Northern Manitoba; an interim report. Manitoba Department of Northern Affairs, Winnipeg, August 12, 1976. 16 p.

14. Guttormsen, D., O. Lind, T.A. Pedersen, E. Bjerkelnud and S. Leborg. 21 biological toilets-decomposition toilets for cabins and holiday homes. Extract from Consumer Report No. 10, Agricultural College of Norway (no date) 23 p.

15. Flaherty, A. Analysis report. Process Research, Inc., Cambridge, Massachusetts, May 12, 1975. 1 p.

16. SCS Engineers. Technical Advisory Committee meeting minutes. Cincinnati, Ohio, March 23, 1978. 12 p.

17. Withee, C.C. Segregation and reclamation of household wastewater of an individual residence. University of Colorado, Boulder, Department of Civil and Environmental Engineering, 1975. 286 p. (Available from National Technical Information Service (NTIS) as PB-268 881).

18. Duncan, D.L. Individual household recirculating waste disposal system for rural Alaska. J. Water Pollut. Control Fed., 36 (12):1468-1473, 1964.

19. McLaughlin, E.R. A recycle system for conservation of water in residences. Water Sewage Works, 11(4);175-180, April 1968.

20. Bailey, J. and H. Wallman. Flow reduction of wastewater from households. Water Sewage Works, 118(3);168-174, March 1971.

21. Texidyne, Inc. Household water reuse project preliminary report and budget estimate. Clemson, South Carolina, 1977. 30 p.

SECTION 6

BIOLOGICAL TREATMENT

Many biological treatment options may be utilized for on-site wastewater treatment applications to remove COD, BOD, suspended solids, phosphorus, and nitrogen. Biological options are summarized in Table 22. Those with available hardware and on-site performance data are summarized below, except composting which was covered in Section 5.

AEROBIC-SUSPENDED AND FIXED GROWTH

Numerous aerobic suspended and fixed growth process variations have been utilized for municipal wastewater treatment applications. Systems for which on-site hardware and performance information is available include suspended growth extended aeration units, fixed growth rotating disks, and fixed growth packed reactors. Brief descriptions of these major system types are provided below.

System Type	System Requirements	Comments
Suspended Growth-Extended Aeration (may be batch or continuous flow unit)	Process tank, aeration and circulation system, provisions for solids separation and controls. (Pretreatment of grease and gross solids, surge tank, and solids return system may be required).	Periodic pumpout of waste solids is required.
Fixed Growth-Rotating Disks	Process tank, contactor "media" and drive assembly, provisions for solids separation and controls. (pretreatment of grease, and surge tank, may be required).	Periodic pumpout of waste solids is required.
Fixed Growth-Packed Reactor (bio-filter)	Process tank, media for solids separation, and controls. (Pretreatment of grease and and gross solids; surge tanks; and aeration, circulation, or ventilation systems may be required).	Periodic pumpout of waste solids is required.

TABLE 22. BIOLOGICAL TREATMENT OPTIONS

	Performance*		O&M Requirements				
Generic Type	Constituents Affected	Adequacy	Frequency of Scheduled Maintenance (#/yr)	Hardware Complexity	Equipment Failure (requiring unscheduled Service)	Environmental Acceptability (potential hazards and nuisances)	Range of Total Annual Cost ($)**
AEROBIC/ANAEROBIC							
- alternating processes							
.. oxidation ditch	BOD, SS, $NO_3 \rightarrow N_2$	potentially consistent	≥4	moderate	infrequent	odor and aesthetics	400-650
. Bardenpho process	BOD, SS, $NO_3 \rightarrow N_2$	unknown	unknown	complex	unknown		Unknown
pulsed aeration	BOD, SS, $NO_3 \rightarrow N_2$	potentially consistent	≥4	complex	frequent		500-650
AEROBIC							
suspended growth							
oxidation ditch	BOD, SS, [Org N and $NH_3 \rightarrow NO_3$]	appears consistent	2-4	moderate	infrequent	odor and aesthetics	400-700
. extended aeration	BOD, SS, [$NH_3 \rightarrow NO_3$]	potentially consistent	2-4	complex	frequent	—	400-550
fixed (attached) growth							
rotating disks	BOD, SS, [$NH_3 \rightarrow NO_3$]	appears consistent	2-4	moderate	frequent	—	400-650
.. packed reactor	BOD, SS, [$NH_3 \rightarrow NO_3$]	appears consistent	2-4	moderate	frequent	—	400-550
. fluidized bed	BOD, SS, [$NH_3 \rightarrow NO_3$]	potentially consistent	2-4	complex	unknown	—	600-800
ANAEROBIC							
- septic tank	BOD, SS, [Org. N]	consistent	<1	simple	infrequent	—	50-100
- imhoff tank	BOD, SS, [Org. N]	potentially consistent	≤1	simple	infrequent	—	100-200
· suspended growth							
mixed reactor	BOD, SS, [$NO_3 \rightarrow N_2$]	potentially consistent	2-4	moderate	frequent	— -	300-450
· fixed growth							
. rotating disks	BOD, SS, [($NO_3 \rightarrow N_2$)]	unknown	unknown	moderate	unknown		450-650
packed reactor	BOD, SS, [($NO_3 \rightarrow N_2$)] or ($NO_3 \rightarrow N_2$), [BOD, SS]	consistent	1-4	moderate	infrequent	Methanol toxicity	100-400
fluidized bed	BOD, SS, [($NO_3 \rightarrow N_2$)]	unknown	unknown	moderate	unknown		600-800
LAGOON							
- aerobic/anaerobic (facultative)	BOD, SS, [Org N and $NH_3 \rightarrow NO_3$]	potentially consistent	2-4	simple	infrequent	odor, vectors, and aesthetics	150-300
- aerobic							
.. shallow (not aerated) lagoon	BOD, SS [Org N and $NH_3 \rightarrow NO_3$]	appears consistent	2-4	simple	infrequent	odor, vectors, and aesthetics	150-300
suspended growth (aerated) lagoon	BOD, SS, [Org N and $NH_3 \rightarrow NO_3$]	potentially consistent	2-4	moderate	infrequent	odor, vectors, noise and aesthetics	200-500
- anaerobic lagoon	BOD, SS, [Org N and $NO_3 \rightarrow N_2$]	potentially consistent	2-4	simple	infrequent	odor, vectors, and aesthetics	200-400
EMERGENT VEGETATION (fixed, suspended, or floating)	BOD, SS, N [P]	potentially consistent	2-4	simple to moderate	infrequent	harvested plants, odor, vectors and aesthetics	250-500

* Bracketed constituents are secondarily affected. However, systems may be optimized for greater removals/conversions of these constituents.
** Amortized capital cost plus annual operation and maintenance costs.

Hardware alternatives which may be utilized to perform various system functions include the following (1,2):

Functions	Hardware Alternatives
Pretreatment of grease and gross solids	Settling chamber, septic tank, screens, and "hydraulic" comminutors.
Aeration and circulation	Mechanical aerators, compressed or forced air diffusers, natural convection, and fans and blowers.
Solids separation (see Physical-Chemical Treatment Section 7)	Clarifiers (upflow and downflow, batch and continuous), tube and plate settlers, filtration (fabric and media), skimmers.
Solids return	Gravity, air lift pumps, and draft tubes. (Units utilizing filter bags or batch flow hydraulics don't require solids return since they retain solids within the aeration unit.)

Performance

Information and data describing the performance of aerobic suspended and fixed growth treatment units are presented in Tables 23 and 24, respectively (2-11). Conclusions based on the results of these investigations are as follows:

- Suspended growth units normally provide from 70 to 90 percent BOD and SS reductions for combined household wastewater, yielding effluent BOD and SS concentrations in the range of 30-70 mg/l and 40-100 mg/l, respectively, depending on unit configuration, flow type (batch or continuous), method of solids separation and return (if provided), and pretreatment and maintenance provided (2-9);

- Fixed growth units with prior settling produce effluent BOD and SS concentrations in the range of 10-40 mg/l and 10-25 mg/l, respectively. However, data are available only for units tested with municipal or synthetic wastewater and the performance indicated from the data presented cannot be assumed to be representative of on-site installations receiving combined household wastewater;

- Effluent BOD and SS variability normally requires that additional treatment be provided prior to direct discharge disposal; and

TABLE 23. AEROBIC-SUSPENDED GROWTH UNIT (EXTENDED AERATION) PERFORMANCE

Reference	Voell & Vance (3)	McBride (4)	Glasser (5)	Patterson (6)	Tipton (7)	Waldorf (8)	Bernhardt (9)	SSWMP (2)
Influent wastewater	Combined household	Combined household	Combined household	Combined household	Combined household	Combined household	Combined household	Combined household
Pretreatment	Settling chamber	—	Comminution, settling	—	—	—	—	None (batch and continous units), septic tank (continous unit)
Treatment Units (total number of sites)	93	56	5	62	56	10	5	4
Number of different models	2	6	5	7	6	3	4	4
Flow type	Continuous	—	Batch or continuous	Batch or continuous	Batch or continuous	Batch	Batch or continuous	Batch or continuous
Samples (total)	93	>300	124	---	108-393	130	74-06	78-118
Effluent (mg/l)*								
BOD_5	88	60-160	27-70	24-189	33-279	18-54	47	6-55
COD	—	—	—	--	158-501	—	--	71-159
SS	40	90-200	56-104	69-515	41-204	51-321	94	12-65
NH_3-N	—	—	10-73	—	—	—	--	0-7
NO_3-N	—	—	1 0-12.5	—	—	—	—	19-34
TP	—	—	—	4-32	—	—	—	9-32
Fecal coliform†	—	—	—	3 8-6 7	—	3 7-4.9	—	3.1-4 3

* Data ranges presented are mean effluent concentrations extremes for the specific unit types tested, where reported

† Values represent log number per 100 ml

TABLE 24. AEROBIC FIXED GROWTH UNIT PERFORMANCE

Reference	SSWMP (2)	Ahlberg & Kwong (10)	SSWMP, Mason (2, 11)
Influent wastewater	Combined household (synthetic)	Municipal	Combined household (synthetic)
Pretreatment	Septic tank (2.0-4.0 m^3)	Settling chamber	—
Treatment units (total number of sites)	2	1	1
Number of different models	—	1	1
Type of unit	Rotating disk	Rotating disk	Packed reactor+
Flow type	Continuous	Continuous	Continuous
Samples (number)	27-69	—	55-85
Effluent (mg/l)*			
BOD_5	17-38	10	11
COD	51-52	—	53
SS	15-16	13	15
NH_3-N	7	10	1
NO_3-N	31	5	19
TP	32	3.4	36

* Where reported, ranges represent mean effluent concentration extremes for the specific unit types tested.

\+ Also referred to as "submerged media" (2)

- Effluent suspended solids concentrations are highly dependent on solids separation methods utilized (2). For example, units with pumped sludge return operate more effectively than those with gravity return.

Finally, considerable controversy exists regarding the relative performance of some subsequent treatment and disposal units receiving aerobically versus anaerobically treated wastewater. At present, this issue remains unresolved (1,12-14).

System O&M Requirements

Periodic system maintenance consisting of mechanical adjustments of the complex hardware (aerators, solids separation and sludge return mechanisms, timers, pumps, etc.) by skilled servicemen is required two or more times per year. In addition, removal and disposal of accumulated solids is normally required approximately once a year.

Frequent unscheduled maintenance consisting of unclogging undersized pumps, skimmers, and air and sludge return lines, and replacement of faulty mechanical and electrical components has been reported (1, 2). Proper unit design and component hardware may alleviate these problems.

Environmental Acceptability

Reported problems relating to the environmental acceptability of properly operated and installed on-site aerobic suspended and fixed growth treatment units include odors (especially when discharged to a dry ditch) and increased noise levels.

Costs

Capital, operation and maintenance, and total annual costs are estimated in Table 25.

ANAEROBIC-SEPTIC TANK

Traditionally, septic tanks have been utilized in most on-site wastewater treatment systems to remove settleable and floatable solids.

Performance

Documentation of septic tank performance is widely available throughout the literature. Data describing typical septic tank performance is presented in Table 26 (Personal Communication. R. Laak. May 1978.) (2,9,15-18). Conclusions based on these investigations are as follows:

- Effluent BOD and SS concentrations typically range from 120-150 mg/l and 40-70 mg/l, respectively, but can vary over a wider range

TABLE 25 AEROBIC SUSPENDED AND FIXED GROWTH TREATMENT UNIT COSTS

Capital Cost Item		Design Life (yr)	Capital Cost ($)
Aerobic treatment unit including installation		20	2100#
Total Capital Cost			$ 2100
Annual O&M Cost Item	**Amount**	**Unit Cost ($)**	**Annual O&M Cost ($)**
Maintenance			
Routine	8 hr/yr	10/hr	80*
Unscheduled	4 hr/yr	10/hr	40*
Replacement parts (mechanical and electrical)	--	--	40*
Solids removed	1/yr	50	50
Electricity	1500 kwh/yr	0.05/kwh	75
Total Annual O&M Cost			$285
Annual Cost			
Present worth of the sum of the capital costs amortized over 20 years assuming 7% interest, discount, and inflation (factor = 0.09439)			198
Annual O&M Costs			$285
Total Annual Cost			$483 ~$480

* Manufacturers provide service contracts which typically cost $100 to $120 per year, including parts for the first 1 to 2 years.

\+ Life of mechanical components is less than 20 years; cost of replacement parts is included in the annual O&M costs.

\# Price will vary approximately ±$500 depending on location and manufacturer.

TABLE 26. ANAEROBIC SEPTIC TANK PERFORMANCE

Reference	SSWMP (2)	SSWMP (2)	Weibel (15)	Salvato (16)	Bernhardt (9)	Thomas & Bendixen (17)	Laak**	Brandes (18)#	Brandes (18)#
Wastestream	Combined household	Greywater (simulated)	Combined household	Combined household	Combined household	Combined household	Combined household	Blackwater w/ bathroom sink	Combined household w/o laundry
Treatment units (number)	7	2	10	19	4	1	1	1	1
Volume (m^3)	4.7 (3.5-7.6)	3.0 (2.0-4.0)	2.6 (1.7-7 8)	—	1.8	—	4.0	2 8	3 4
Samples (number)	89-155	22-57	44-55	51	18-21	—	47-60	—	—
Effluent (mg/l)*									
BOD_5	138 (57-272)	81 (62-101)	138	140	240	93	120	74	160
COD	327 (208-542)	203 (171-236)	—	—	—	220	200	—	448
SS	49 (34-69)	46 (46-47)	155	101	95	45	39	80	65
TN	45 (27-76)	36 (34-37)	—	36	—	33	—	153	75
NH_3-N	31 (19-46)	1 8 (1 4-2.1)	—	—	—	—	—	141	68
NO_3^--N	0 4 (0.1-0.7)	—	—	—	—	—	—	<0.1	0 1
TP	13 (11-31)	42 (40-44)	—	—	—	—	—	19.2	15.0
Fecal coliform†	5 7 (5.3-6.4)	(4 5-6.6)	—	—	—	—	—	5 6	6.4
Fecal strep†	3.6 (2.4-5.1)	(<2 0-4.3)	—	—	—	—	—	—	—

* Data ranges presented are mean effluent concentration extremes for specific unit types tested.
† Values represent log number per 100 ml.
\# Constituent concentrations are based on sampling of septic tank second compartment supernatant.
** Personal Communication, R. Laak. May 1978.

depending on tank size, configuration (inlets, outlets, shape, etc.), number of compartments, frequency of sludge pumping, and influent wastewater characteristics (2,9,15-18).

System O&M Requirements

Routine system O&M requirements consist of inspection of the sludge level and scum mat approximately every two years, and sludge pumping by an unskilled serviceman when necessary. Pumping is generally required approximately every three to five years to prevent excessive sludge or scum build-up which would cause a deterioration in effluent quality (18,19). Unscheduled maintenance, such as unclogging or replacement of baffles, is required very infrequently.

Environmental Acceptability

No problems relating to the environmental acceptability of on-site septic tank treatment units are reported (2,9,15-18).

Costs

Capital, operation and maintenance, and total annual costs are summarized in Table 27.

ANAEROBIC - PACKED REACTOR

Anaerobic packed reactor (anaerobic "filter") treatment units can be used to remove COD, BOD, and SS from on-site waste streams receiving varying levels of previous treatment (20-22). Alternately, anaerobic packed reactors can provide denitrification of previously nitrified influent waste streams (Personal Communication. R. Laak. May 1978) (23,24). Anaerobic packed reactor system requirements are summarized below:

System Type	System Requirements	Comments
Anaerobic packed reactor for organics and solids removal	Reactor (tank), media, and Wastewater distribution piping.	Primarily for COD, BOD, and SS removal. Periodic media cleaning is required to prevent clogging.
Anaerobic packed reactor for denitrification	Reactor (tank), media, carbon source addition system, wastewater distribution system (including pump, controls and piping).	Primarily for denitrification. Methanol or segregated waste stream may be utilized as carbon source. Infrequent media cleaning is required to prevent clogging.

TABLE 27. ANAEROBIC SEPTIC TANK TREATMENT UNIT COSTS

Capital Cost Item		Design Life (yr)	Capital Cost ($)
Septic tank, including installation		20	400
Total Capital Cost			$ 400
Annual O&M Cost Item	**Amount**	**Unit Cost ($)**	**Annual O&M Cost ($)**
Maintenance			
Routine	0.5 hr/yr	8/hr	4
Unscheduled	--	--	--
Sludge pumping	---*	50	12
Total Annual O&M Cost			$ 16
Annual Cost			
Present worth of the sum of the capital costs amortized over 20 years assuming 7% interest, discount, and inflation (factor = 0.09439)			38
Annual O&M Costs			16
Total Annual Cost			$ 54 ~$ 50

* Once every three to five years.
+ Price may vary approximately ± $150, depending on the manufacturer, material used, and site conditions.

Performance

Data describing the performance of on-site anaerobic packed reactor treatment units are presented in Table 28 (20-23). Based on this information, it is concluded that anaerobic packed reactors used for organics and solids removal perform as follows:

- Units receiving combined wastewater pretreated by a septic tank provide average BOD and SS reductions of approximately 30 and 40 percent, respectively, yielding effluent BOD and SS concentrations in the range of 50-100 mg/l and 20-70 mg/l. Reductions achieved depend on media size, loading rate and unit configuration (20-22); and

- Additional treatment of the effluent from these units will generally be required prior to surface discharge.

In addition to the anaerobic packed reactor for denitrification described in Table 28, system variations are currently being investigated by several researchers (23,24). One of those systems involves the use of greywater septic tank effluent to provide the carbon source for denitrification of blackwater septic tank-sand filter effluent in an upflow anaerobic packed reactor. (Personal Communication. R. Laak. May 1978.) Another variation incorporates the denitrification system (with methanol addition) as part of a subsurface disposal system (24). This system is not a packed reactor per se, but functions on the same basic principles. Based on these investigations and information presented in Table 28, it is concluded that anaerobic packed reactors for denitrification perform as follows:

- The limited data available indicate that units receiving nitrified effluent (septic tank-intermittent sand filter) provide average nitrate reductions of approximately 90 percent, yielding effluent nitrate concentrations consistently less than 7 mg/l (averaging approximately 3 mg/l) if a denitrification carbon source is available.

System O&M Requirements

System O&M requirements for the uncomplicated on-site anaerobic packed reactors consist of periodic media cleaning by an unskilled serviceman approximately every one to three or more years, depending on influent wastewater characteristics. Systems utilizing chemical feed for denitrification will also require periodic chemical refills and adjustment and maintenance of the chemical feed equipment two to four times per year. Unscheduled maintenance is required infrequently.

Environmental Acceptability

Some concerns relating to the environmental acceptability of on-site anaerobic packed reactors for organics and solids removal are reported. On-site anaerobic packed reactors for denitrification utilizing methanol as a

TABLE 28. ANAEROBIC-PACKED REACTOR TREATMENT UNIT PERFORMANCE

Reference		Hamilton (20)	Raman & Chakladar (21)	Winneberger, et al. (22)	Sikora, et al. (23)[+]
Influent wastewater		Combined household	Blackwater	Raw municipal	Combined household
Pretreatment (m^3)		Septic tank (4.2)	Septic tank (2.2-3.9)	Comminution	Septic - sand filter
Treatment unit (number)		1	3	1	1[++]
Media volume (m^3)		3.4	0.4-0.6	0.8	0.8
Media size (cm)		1.9-5.1	0.2-1.9	3.8-6.4	0.9
Media depth (m)		1.9	0.7-1.1	1.5	0.7
Flow type		Upflow	Upflow and downflow-upflow	Upflow	Upflow
Cumulative operation time (months)		2 5	19-26*	—	12
Samples (number)		3-16	5-32	—	--
Characteristics**					
BOD_5	influent	101	188-240	—	—
	effluent	73	52-61	—	1-4
	(removal)	(28)	(67-75)	(--)	(—)
COD	influent	305	465-771	310-431	—
	effluent	236	176-329	117-166	—
	(removal)	(23)	(53-60)	(61-63)	(—)
SS	influent	67	181-812	129-205	—
	effluent	39	50-318	2-47	—
	(removal)	(42)	(65-73)	(77-98)	(negligible change)
TKN	influent	—	—	—	31 3
	effluent	—	—	23	4 2
	(removal)	(—)	(—)	(--)	(87)
NH_3-N	influent	—	—	—	0.7
	effluent	—	—	21	<0 1
	(removal)	—	—	—	(>85)
NO_3-N	influent	—	—	—	28.9
	effluent	—	—	—	3.1
	(removal)	(—)	(—)	(—)	(89)
pH[##]	influent	8.2	7.1-7.8	—	—
	effluent	8.0	6.7-7.5	—	—

* Filter clogging occurred at 19 or more months for units tested
[+] Denitrification start-up data has been deleted.
[#] Also includes nitrate-nitrogen.
[++] Methanol added to packed reactor influent.
** Influent and effluent constitutes concentrations expressed as mg/l unless otherwise noted, removals expressed as percent.
[##] Standard units.

carbon source may require that service personnel wear respirators to avoid inhaling toxic vapors (23). This should pose no threat to the homeowner during normal treatment unit operation, although excess unreacted methanol may cause the effluent to be toxic. Reactors which utilize carbon sources other than methanol (i.e., segregated wastewater) avoid toxicity problems, although excess carbon source addition will still adversely affect effluent quality.

Costs

Capital, operation and maintenance, and total annual costs are estimated in Table 29.

LAGOONS

Lagoons may be utilized for both on-site wastewater treatment and disposal applications. The use of non-discharging lagoons for disposal, such as an infiltration/evaporation lagoon, is discussed in Section 9. System requirements for discharging lagoons are summarized below:

System Type	System Requirements	Comments
• Facultative • Aerobic (not aerated) • Anaerobic	Bermed lagoon, inlet pipe and support, fence, and outlet pipe. Impermeable liner may also be required.	Berm must be designed to prevent surface runoff entering lagoon. Odor, vector, aesthetic, safety, and groundwater quality considerations may affect environmental acceptability.
• Aerated	Aerator is required in addition to the above requirements.	In addition to above comments, noise could be an adverse impact.

Performance

Although hardware suitable for aeration of on-site lagoons exists, no performance data for aerated on-site lagoons were available. Furthermore, detailed data describing on-site wastewater treatment applications of other lagoon systems are largely unavailable. A summary of existing effluent quality data describing aerobic (not aerated) lagoons is provided in Table 30 (25,26).

Conclusions, based on the data presented in Table 30 and other investigations of on-site aerobic (not aerated) lagoons are as follows (25-29):

- Effluent BOD and SS concentrations range from <10-70 mg/l and <2-130 mg/l, respectively (25-27). Thus, additional treatment is normally required prior to surface discharge;

TABLE 29. ANAEROBIC PACKED REACTOR TREATMENT UNIT COSTS

Capital Cost Item	Design Life (yr)	Organics and Solids Removal Unit ($)	Denitrification Unit ($)
Reactor (tank) including excavation and access hatch	20	400	400
Media (crushed stone)	20	75	50
Distribution piping	20	100	100
Methanol pump, controls, and storage tank	10	--	250
Wet well	20	--	300
Pump and controls	10	--	250
Total Capital Costs		$575	$1350

Annual O&M Cost Item	Annual O&M Cost ($)	Annual O&M Cost ($)
Maintenance		
Routine	16	30
Unscheduled	8	10
Residuals disposal (from media cleaning)	75	25
Methanol	--	60
Electricity	--	2
Total Annual O&M Cost	99	127

Annual Cost		
Present worth of the sum of the capital costs amortized over 20 years assuming 7% interest, discount, and inflation (factor = 0.09439)	54	174
Annual O&M Costs	99	127
Total Annual Cost	$153 ~ $150	$301 ~ $300

TABLE 30. LAGOON PERFORMANCE

Reference	Asplen+ (25)	Karikari (26)
Influent wastewater	Combined household (from 2 homes)	Combined household
Pretreatment	Aerobic unit	Septic tank
Treatment unit	Aerobic (non-aerated) lagoon	Aerobic (non-aerated) lagoon
Volume (m^3)	1400	85
Depth (m)	2.1	0.8
Samples (number)	7-20	6-8
Effluent (mg/l)*		
COD	--	308 (164-555)
BOD	17 (3-66)	33 (15-68)
SS	60(<2-130)	--
TS	910 (560-1900)	742 (645-805)
TN	--	33 (11-64)
NO_3-N	0.21 (0.01-0.65)	--
TP	1.94 (0.65-2.6)	--
Dissolved oxygen	10.3 (7.5-13.8)	--
Fecal coliform#	2.2 (<0.5-3.9)	--

* Values within parentheses represent data range.
\# Log #/100 ml.
\+ Non-discharging lagoon designed for infiltration/evaporation disposal.

- Many supposed aerobic lagoons actually function as facultative lagoons with an aerobic layer on the surface (27). This is primarily dependent on the relationship between influent waste quantity, lagoon temperature, surface area, and depth; and

- Lagoon performance has significant seasonal variability which has not been quantified (25,29). Also, growth will adversely effect effluent SS.

<u>System O&M Requirements</u>

Periodic operation and maintenance requirements for the simple aerobic (not aerated) lagoons may consist of removal of accumulated sludge from the lagoon bottom (particularly adjacent to the inlet pipe) once every three to five or more years with a dragline or backhoe (39). Routine maintenance includes trimming vegetation and adding water to maintain the desired depth during the summer (approximately 2 to 4 times per year). Unscheduled maintenance of inlet and outlet pipes is required infrequently.

<u>Environmental Acceptability</u>

Odor, vector, and aesthetic nuisances may affect the environmental acceptability of lagoons. Lagoon configuration utilizing rounded corners and steep interior slopes should help to reduce development of stagnant water and growth of vegetation below the water level, thus reducing odor and vector nuisances. Aesthetics may be improved by screening with plants or fences. Use of impermeable bottom soils or plastic liners should eliminate any threat to groundwater quality, and safety fencing around the perimeter can keep small children and animals out of the area.

<u>Costs</u>

Capital, operation and maintenance, and total annual costs are estimated in Table 31.

BIOLOGICAL TREATMENT COMPONENT COMPARISONS

Biological treatment component comparisons for components with sufficient on-site performance information and hardware available to permit detailed evaluation are presented in Table 32. Comparisons for components with available on-site hardware but insufficient on-site performance information shown in Table 33 are based on engineering judgement and are subject to revision when data become available.

TABLE 31. AEROBIC (NOT AERATED) LAGOON COSTS

Capital Cost Item	Design Life (yr)	Capital Cost ($)
Lagoon including excavation, installation of inlet pipe and support, and seeding of berm	20	1000
Fencing (3 strand barb-wire @ $ 5/m)		150
Total Capital Cost		1150*

Annual O&M Cost Cost Item	Amount	Unit Cost ($)	Annual ($)
Sludge removal	1/10 yr	250	25
Maintenance required			
Routine	4/yr	8/hr	32
Unscheduled	1/yr	8/hr	8
Total Annual O&M Cost			$ 65

Annual Cost	
Present worth of the sum of the capital costs amortized over 20 years assuming 7% interest, discount, and inflation (factor = 0.09439)	109
Annual O&M Costs	65
Total Annual Cost	$ 174

* If a liner is required, total capital cost and the total annual cost are estimated to increase by $700 and $65, respectively.

TABLE 32. BIOLOGICAL TREATMENT COMPONENT COMPARISON FOR COMPONENTS WITH SUFFICIENT INFORMATION*

Ranking Group	Component	Ranking: Performance (5 max.)	Ranking: O&M Requirements (5 max.)	Ranking: Environmental Acceptability (3 max.)	Ranking: Total (13 max.)	Total Annual Cost ($)
A	Septic tank (anaerobic)	4	5	3	12	50-100
B	Packed reactor for denitrification (anaerobic-fixed growth)	4	2	3	9	300-400
	Extended Aeration (aerobic-suspended growth)	4	2	3	9	400-550
	Rotating disks (aerobic-fixed growth)	4	2	3	9	400-550
	Packed reactor (aerobic-fixed growth)	4	2	3	9	400-550
	Packed reactor for organics and solids removal (anaerobic-fixed growth)	3	3	2	8	100-200
	Lagoon - Aerobic-shallow (not aerated)	4	4	1	9	150-300

* For components with sufficient on-site performance information and hardware available to permit detailed evaluation. See Component Ranking Criteria for explanation of the ranking system.

TABLE 33. BIOLOGICAL TREATMENT COMPONENT COMPARISON FOR COMPONENTS WITH INCOMPLETE INFORMATION*

Ranking Group	Component	Ranking: Performance (5 max.)	Ranking: O&M Requirements (5 max.)	Ranking: Environmental Acceptability (3 max.)	Ranking: Total (13 max.)	Total Annual Cost ($)
A	Mixed reactor (anaerobic-suspended growth)	4	2	3	9	300-450
B	Emergent vegetation	4	3	1	8	250-500
	Oxidation ditch (aerobic/anaerobic-alternating process	3	2	1	6	400-650
	Oxidation ditch (aerobic-suspended growth)	4	3	1	8	400-700
	Extended aeration (aerobic/anaerobic-alternating process)	3	1	3	7	500-650
	Lagoon (facultative)+	3	4	1	8	150-300
	Lagoon (aerated)+	4	3	1	8	200-500

* For components with available on-site hardware, but insufficient on-site performance information. This comparison is based on engineering judgement and should be reevaluated when data become available.

\+ These are treatment lagoons for direct discharge.

REFERENCES

1. Hutzler, N.J., L.E. Waldorf, and J. Fancy. Performance of aerobic treatment units. In: Proceedings of the Second National Home Sewage Treatment Symposium, Chicago, Illinois, December 12-13, 1977. American Society of Agricultural Engineers, St. Joseph, Michigan, 1978. pp. 149-163.

2. Small Scale Waste Management Project. Management of small waste flows. Appendix A. Wastewater characteristics and treatment. EPA-600/2-78-173. U.S. Environmental Protection Agency, Cincinnati, Ohio, September 1978. 764 p.

3. Voell, A.T. and R.A. Vance. Home aerobic wastewater treatment systems--experience in a rural county. In: Proceedings, Ohio Home Disposal Conference, Ohio State University, Columbus, January 1974. pp. 26-36.

4. McBride, R.N. Individual home aerobic wastewater treatment systems. Master's thesis, University of Colorado, Boulder, Department of Civil and Environmental Engineering, 1972. 116 p. PB-226 478.

5. Glasser, M.B. Garrett County home aeration wastewater treatment project. Maryland State Department of Health and Mental Hygiene, Baltimore, Bureau of Sanitary Engineering, 1974. 38 p.

6. Patterson, M. Residential sewage disposal survey. Indiana State Board of Health, Indianapolis, March 1977. 11 p.

7. Tipton, D.W. Experience of a county health department with individual aerobic sewage treatment systems. Jefferson County Health Department, Lakewood, Colorado, Environmental Health Division, 1975. 8 p.

8. Waldorf, L.E., Appalachian Regional Commission, Washington, D.C., July 5, 1978. 22 p. (Unpublished data.)

9. Bernhardt, A.P., Wastewater from homes. University of Toronto, Canada, 1967. 173 p.

10. Ahlberg, N.R. and T.S. Kwong. Process evaluation of a rotating biological contactor for municipal waste water treatment. Research Paper No. W2041, Ministry of the Environment, Toronto, Canada, 1974, 37 p.

11. Mason, D.G. A unique biological treatment system for small plants. Presented at 50th Water Pollution Control Federation Conference, Philadelphia, Pennsylvania, October 1977. 15 p.

12. Stockton, E.L. Biological oxidation - a technology assessment. In: Proceedings of the National Home Sewage Disposal Symposium, Chicago, Illinois, December 9-10, 1974. American Society of Agricultural Engineers, St. Joseph, Michigan, 1975. pp. 17-22.

13. McGauhey, P.H. and J.H. Winneberger. A study of methods of preventing failure of septic tank percolation systems. SERL Report No. 65-17. University of California, Berkeley, Sanitary Engineering Research Laboratory, 1965. 31 p.

14. Krebs, J.R. Sizing, design, and application factors in home sewage treatment systems. In: Proceedings of the National Home Sewage Disposal Symposium, Chicago, Illinois, December 9-10, 1974. American Society of Agricultural Engineers, St. Joseph, Michigan, 1975. pp. 182-190.

15. Weibel, S.R., C.P. Straub, and J.R. Thoman. Studies on household sewage disposal systems. Environmental Health Center, Cincinnati, Ohio, 1949. 279 p. (Available from National Technical Information Service (NTIS) as PB-217 671.)

16. Salavato, J.A. Experiences with subsurface sand filters. Sewage Ind. Wastes, 27(8):909-914, August 1955.

17. Thomas, E.R. and T.W. Bendixen. Degradation of wastewater organics in soil. J. Water Pollut. Control Fed., 41(5):808-813, May 1969.

18. Brandes, M. Accumulation rate and characteristics of septic tank sludge and septage. Research Report W63, Ministry of the Environment, Toronto, Canada, February 1977. 20 p.

19. Manual of septic-tank practice. PHS-Pub-256, U.S. Public Health Service, Washington, D.C., Division of Sanitary Engineering Services, 1969. 96 p. (Available from National Technical Information Service (NTIS) as PB-218 226.)

20. Hamilton, J.R. Treatment of septic tank effluent with an anaerobic filter. Master's thesis, University of Washington, Seattle, 1975. 92 p.

21. Raman, V. and N. Chakladar. Upflow filters for septic tank effluents. J. Water Pollut. Control Fed., 44(8):1552-1560, 1972.

22. Winneberger, J.H., W.I. Saad, and P.H. McGauhey. A study of methods of preventing failure of septic tank percolation fields; first annual

report. University of California, Berkeley. Sanitary Engineering Research Laboratory, December 1961. 76 p.

23. Sikora, L.J., J.C. Converse, D.R. Keeney, and R.C. Chen. Field evaluation of a denitrification system. In: Proceedings of the Second National Home Sewage Treatment Symposium, Chicago, Illinois, December 12-13, 1977. American Society of Agricultural Engineers, St. Joseph, Michigan, 1978. pp. 202-207.

24. Andreoli, A., R. Reynolds, N. Bartilucci and R. Forgione. Pilot plant study: nitrogen removal in a modified residential subsurface sewage disposal system. Suffolk County, Department of Health Sciences, Hauppauge, New York, October 1977. 36 p.

25. Asplen, E.W. Evaluation of domestic waste disposal by bermed infiltration ponds 1971-1975. Maryland State Department of Health and Mental Hygiene, Maryland, Environmental Health Administration, July 1976. 15 p.

26. Karikari, T.J., C.E. Beer, and R.J. Smith. Treatment of a residential septic tank effluent in an aerobic lagoon. In: Proceedings of the National Home Sewage Disposal Symposium, Chicago, Illinois, December 9-10, 1974. American Society of Agricultural Engineers, St. Joseph, Michigan, 1975, pp. 144-151.

27. Hines, M.W., E.R. Bennett, and J.A. Hochne. Alternate systems for effluent treatment and disposal. In: Proceedings of the Second National Home Sewage Disposal Symposium, Chicago, Illinois, December 12-13, 1977. American Society of Agricultural Engineers, St. Joseph, Michigan, 1978. pp. 137-148.

28. Witz, R.L. Twenty-five years with the NODAK Waste Disposal System. In: Proceedings of the National Home Sewage Disposal Symposium, Chicago, Illinois, December 9-10, 1974. American Society of Agricultural Engineers, St. Joseph, Michigan, 1975. pp. 168-174.

29. Franks, W. Above ground sewage disposal in rural Saskatchewan. In: Proceedings of the National Home Sewage Disposal Symposium, Chicago, Illinois, December 9-10, 1974. American Society of Agricultural Engineers, St. Joseph, Michigan, 1975. pp. 163-167.

SECTION 7

PHYSICAL-CHEMICAL TREATMENT

GENERAL

Physical-chemical treatment processes may be used for on-site wastewater treatment in conjunction with, or independent of, biological treatment processes. In general, physical-chemical treatment processes may be utilized for the following purposes:

- Reduce wastewater COD, BOD and SS concentrations to lower levels than possible using biological treatment processes alone;
- Remove wastewater constituents such as phosphorus and dissolved inorganic salts which do not respond readily to biological treatment processes; and
- Remove wastewater constituents such as COD, BOD, SS, ammonia, nitrate, and phosphate without using biological treatment processes (1).

Physical-chemical treatment processes and their applicability to on-site wastewater treatment are summarized in Table 34. Those with available hardware and on-site performance data are summarized below.

MEDIA FILTRATION

Pressure Filtration

The use of pressurized media filtration to separate suspended solids and associated wastewater constituents from on-site waste streams is briefly described below:

System Type	System Requirements	Comments
Cartridge	Surge tank pressurization pump, tank, controls, cartridge filter, bypass piping and strainer, check valves.	Frequent cartridge replacement required (when pressure drop across filter becomes excessive).
Diatomaceous Earth	Surge tank, pressurization pump, tank, controls, diatomite filter, recircula-	Backwash water requires disposal periodically.

TABLE 34. PHYSICAL-CHEMICAL TREATMENT OPTIONS

Generic Type	Performance* Selected Constituents Affected	Performance* Adequacy	O&M Requirements: Frequency of Scheduled Maintenance (#/yr)	O&M Requirements: Hardware Complexity	O&M Requirements: Equipment Failure (requiring unscheduled service)	Environmental Acceptability (potential hazards or nuisances)	Range of Total Annual Cost ($)**
FILTRATION							
- media							
.. pressure	SS, [BOD, P]	consistent	2->4	moderate	infrequent	odor of backwash water	150-300
.. gravity	SS, [NH_4 NO_3, BOD]	consistent	≤1-4	simple	infrequent	odors and vectors	100-300
- microstraining	SS [BOD]	potentially consistent	>4	moderate	infrequent	odor	200-400
- membrane							
.. pressure							
. ultrafiltration	SS, [COD, BOD, microbiological]	consistent	2-4	complex	infrequent	disposal of concentrated residuals	400-500
. reverse osmosis	SS, COD, BOD, microbiological	potentially consistent	2-4	complex	unknown	disposal of concentrated residuals	400-600
. electrodialysis	SS, COD, BOD, microbiological	unknown	≥4	complex	unknown	disposal of concentrated residuals	300-600
.. non-pressure							
. fabric	SS [BOD]	consistent	1-4	simple	infrequent	---	25-50
SEPARATION							
- sedimentation							
. clarifiers	SS [BOD]	appears consistent	2-4	moderate	infrequent	odors	100-300
. tube or plate settlers	SS [BOD]	potentially consistent	2-4	moderate-complex	unknown	odors	unknown
- flotation	SS [BOD]	potentially consistent	>4	moderate-complex	unknown	odors	unknown
- centrifuge	SS [BOD]	potentially consistent	>4	complex	unknown	---	unknown
COAGULATION AND CHEMICAL PRECIPITATION	SS, P [COD, BOD, microbiological]	consistent	2-4	moderate	frequent	increased residuals generation	150-300
SORPTION							
- carbon adsorption	COD, BOD [SS]	consistent	1-4	simple - moderate	infrequent	disposal of exhausted media	250-350
- ion exchange	NH_4^+, NO_3^-, PO_4 [SS]	consistent	1-4	simple moderate	infrequent	disposal of exhausted media	300-500
DESORPTION							
- air stripping tower	NH_3	unknown	≥4	moderate	unknown	noise and aesthetics	unknown
OXIDATION							
- chemical	BOD [SS, microbiological]	unknown	≥4	moderate - complex	unknown	effluent toxicity and safety	unknown
- thermal	BOD, SS, microbiological	unknown	≥4	complex	unknown	air emissions	unknown

* Bracketed constituents are secondarily affected.
**Amortized capital cost plus annual operation and maintenance costs.

	tion pump, bypass piping, strainer, check valves, backwash water supply, distribution, collection, and holding or disposal system .	
Single media	Surge tank, pressurization pump, tank, controls, filter media, tank or column, bypass piping, strainer backwash water supply, distribution, collection, and holding or disposal system.	Backwash water requires disposal periodically.
Multiple media	Surge tank, pressurization pump, tank, controls filter media, tank or column, bypass piping strainer, backwash water supply, distribution, collection, and holding or disposal system.	Backwash water requires disposal periodically.

Pressurized media filtration units which require very frequent (more than 4 times per year) backwashing will likely utilize automated backwash systems.

Performance--

Greywater filtration data for various pressurized media filtration systems are given in Table 35 (2,3). Blackwater and combined household wastewater filtration data were unavailable. Furthermore, performance data for some commercially available units were considered proprietary and therefore unobtainable. Conclusions based on available data presented for pressurized media filtration systems are as follows:

- Greywater and bath/laundry suspended solids and turbidity reductions of approximately 40 to 70 percent can be achieved (2,3);
- COD, BOD, and phosphorus removed are the fractions associated with the suspended solids removed (2); and
- Little bacterial removal was observed (2).

It should also be noted that the dual media filtration system performance was less than optimal due to improper selection of media sizes, filter area, and backwash system (2).

System O&M Requirements--

In general, pressurized media filtration systems have moderately complex hardware and require maintenance performed by semi-skilled servicemen.

TABLE 35. PRESSURIZED MEDIA FILTRATION PERFORMANCE **

Reference		Withee (2)	Withee (2)	Cohen & Wallman (3)	Cohen & Wallman (3)	Cohen & Wallman (3)
Waste stream		Greywater	Greywater	Bath and Laundry	Bath and Laundry	Bath and Laundry
Pretreatment		Equalization	Extended aeration and sedimentation	Equalization and chlorine disinfection	Equalization and chlorine disinfection	Equalization and chlorine disinfection
Treatment unit		Dual media (0.9 mm anthracite 0.5 mm sand)	Dual media (0.9 mm anthracite 0.5 mm sand)	Diatomaceous earth	Cartridge (surface-type)	Cartridge (depth-type)
Test period (days)		9	5	86	48	71
Volume processed per run (l)		–	–	17,000	12,600	15,000
Loading rate (m/min)		0.133	0.133	–	–	–
Nominal solids removal size (microns)		–	–	–	15	10
Cumulative filter operation time until run termination (hrs)		8-10	20	–	–	–
Head loss at end of run (psi)		0.9-7 1	0.4	12.4	12.4	12.4
Method of backwash		water, air and water	none	water	none	none
Constituents*						
BOD_5	influent	85	12	–	–	–
	effluent	46	10	–	–	–
	(removal)	(46)	(17)	–	–	–
SS	influent	93	27	–	50-70	90-160
	effluent	67	18	10-45	25-35	35-70
	(removal)	(28)	(33)	–	(40-55)	(60-75)
COD	influent	213	64	–	–	–
	effluent	129	62	53-85	–	–
	(removal)	(39)	(3)	–	–	–
PO_4-P	influent	3.0	18.5	–	–	–
	effluent	2.0	18.8	–	–	–
	(removal)	(33)	(-2)	–	–	–
Turbidity	influent	46+	13+	–	70-90++	90-170++
	effluent	27+	6.6+	15-40++	40-65++	30-95++
	(removal)	(41)	(49)	–	(25-45)	60-80
Coliforms#	influent	6.2	6 3	–	–	–
	effluent	6.2	6.3	–	–	–
	(removal)	(0)	(0)	–	–	–

* Influent and effluent constituent concentrations expressed as mg/l, removals expressed as percent.
\+ Expressed as JTU.
\# Expressed as log no. per 100 ml., source does not indicate whether values are for total or fecal coliforms.
** Typical performance data for units tested.
\++ Expressed as ppm.

Routine adjustment and maintenance of filtration equipment generally is required two to four times per year. Unscheduled maintenance, such as pump repair, media replacement or system controls repair, is required infrequently. Routine O&M requirements for specific systems are as follows:

System Type	System O&M Requirements
Cartridge filters	Require frequent replacement of cartridge elements five to eight or more times per year.
Diatomaceous earth filters	Require continuous recirculation of filter system effluent to maintain the diatomaceous earth coating on the filter surface. Filter backwashing utilizing 30 to 150 l of filter effluent is required every one to three months (Personal Communication. W. Hypes. June 1978) (3). Spent backwash water must be collected and disposed. Also, addition of make-up media (lost during backwashing) is anticipated 2 to 4 times per year.
Single and multiple media filters	Require frequent filter backwashing utilizing 250 l or more of filter effluent (up to 5 percent of filter forward flow) one to four times per month. Spent backwash water must be collected and disposed. Also, addition of make-up media (lost during backwashing) is anticipated two to four times per year (Personal Communication. J. Scandon. June 1978).

Environmental Acceptability--

There appear to be no problems relating to the environmental acceptability of pressurized media filtration system effluents. Although odor problems have been reported with the holding of spent backwash water prior to disposal, proper design of the holding facility should eliminate odor problems (3). The adequacy of landfill disposal of discarded filter media has not been determined, but preliminary indications are that this method is appropriate.

Costs--

Capital, operation and maintenance, and total annual costs are presented in Table 36.

Gravity Filtration

Gravity filtration of on-site wastewater has been accomplished using a variety of configurations, as described below:

TABLE 36

PRESSURIZED MEDIA FILTRATION COSTS*

Capital Cost Item	Design Life (year)	Cost ($) Cartridge	Diatomaceous Earth	Single or Multiple Media
Surge tank	20	150	150	150
Filtration unit and controls	20	125	300	800
Pressurization tank	20	100	100	100
Pressurization pump and controls	10	225	225	225
Pipe system (pipe, valves, check valves, fittings, bypass, strainer)	20	150	250	250
Recirculation pump (very low h.p.)	10	--	75	--
Total Capital Cost		$750	$1100	$1525
Annual O&M Cost Item				
Maintenance required (@ $10/hr)				
Routine		90	50	50
Unscheduled		10	10	10
Filter media		60	6	10
Electricity		5	30	8
Total Annual O&M Cost		$165	$96	$78
Annual Cost				
Present worth of the sum of the capital costs amortized over 20 years @ 7% interest, discount and inflation (factor = 0.09439)		92	132	165
Annual O&M Costs		165	96	78
Total Annual Cost		$257 ~$260	$228 ~$230	$243 ~$240

* Disposal of backwash water is not included. It is assumed that backwash water residuals will be handled in conjunction with residuals from other treatment processes (especially biological).

System Type	System Requirements	Comments
Buried sand filter	Distribution and collection piping; sand and gravel; surge tank and self-priming siphon (or pump and controls).	Conservative application rates are required since routine maintenance of media surface is impractical.
Single stage intermittent sand filter	Surge tank and self-priming siphon (or pump and controls); sand and gravel; two filter beds; distribution and collection piping.	Freezing and odors may limit applicability unless insulated cover or furrowed sand surface is provided.
Recirculating sand filter	Recirculation tank with pump and controls; sand and gravel; distribution and collection piping.	Same as above.
Series intermittent sand filter	Surge tank and self-priming siphon (or pump and controls); sand (2 or more sizes) and gravel; four or more filter beds and distribution and collection piping.	Same as above.

The four systems listed above are all single media downflow filters. Upflow filters are discussed in Section 6. Horizontal filters have also been proposed, but data on their performance are lacking. Gravity multi-media filters have not seen wide application presumably since single-media filters perform adequately for most applications. A variety of media have been tried (4), but sand is most commonly used. Use of mixtures of sand and limestone or "red mud" for phosphorus removal is discussed under SORPTION.

Performance--

Selected on-site sand filter performance data from recent investigations are shown in Table 37. As indicated, the sand filters studied consistently reduced average BOD and SS levels of combined wastewater to less than 10 mg/l and significantly reduced coliform levels by factors of 10^1 to 10^3. Nearly total nitrification (94 to 99 percent conversion of ammonia to nitrate) was observed for intermittent filters receiving septic tank effluent.

Despite the consistently high level of treatment for BOD and SS indicated in Table 37, filter performance depends on several interdependent factors, including:

- Wastewater characteristics;
- Filter characteristics, including temperature and media size, uniformity and depth;

TABLE 37. GRAVITY FILTRATION UNIT PERFORMANCE

Reference		Bowne (5)	Hines & Favreau (6)	Sauer (7)	Sauer (7)	Chowdhry (4)*	Siegrist (8)	Siegrist (8)
Filter type		Recirculating	Recirculating	Intermittent	Intermittent	Intermittent	Intermittent	Intermittent
Pretreatment unit(s)		Septic tank	Septic tank	Septic tank	Aerobic unit	Septic tank	Septic tank	Septic tank
Wastewater type		Combined	Combined	Combined	Combined	Combined	Greywater	Greywater
Type of study		Field	Field	Field	Field	Field	Laboratory	Laboratory
Average loading rate (m/day (gal/day/ft^2))		0.12(3)	0.12(3)	0.2(5)	0.15(3.8)	0 05-0.07 (1.2-1.8)	0.15(3 8)	0.29(7 3)
Constituents† (Average (Range))								
BOD	influent	—	—	123	26	315	62(56-68)**	62(56-68)**
	effluent	4(1-11)	4(1-7)	9	2-4	4(2.2-9.3)	1(1-3)	1(1-3)
SS	influent	—	—	48	48	286	46(41-51)	46(41-51)
	effluent	3(1-6)	5(1-18)	6-9	9-11	6(4.8-9 8)	9(6-16)	13(9-19)
NH_3-N	influent	—	—	19 2	0.4	37	2 1(1 7-2 5)	2 1(1.7-2 5)
	effluent	—	—	0 8-1.1	0.3	0 5(0 2-1 4)	—	—
NO_3-N	influent	—	—	0.3	33 8	0 3	—	—
	effluent	—	—	19.6-20.4	36 8	35 (19-42)	—	—
PO_4	influent	—	—	8.7	28 1	14	34(31-37)	34(31-37)
	effluent	—	—	6.7-7.1	22.6	6(1 8-9 8)	—	—
Fecal Coliform‡ (Average (Range))								
	influent	—	—	5.9×10^5	$1 9 \times 10^5$	$3 5 \times 10^6$	—	—
	effluent	6.7×10^5 ($2 2 \times 10^2$-5×10^6)	1×10^4 (8×10^2-$4 2 \times 10^4$)	0.5×10^3-0.8×10^3	1.3×10^3	<100-7500	—	—
Total Coliform‡ (Average (Range))								
	influent	—	—	$9 0 \times 10^5$	1.5×10^5	84×10^6	—	—
	effluent	—	—	1.3×10^3	$1 3 \times 10^4$	2×10^4 ($1 2 \times 10^3$-$1 1 \times 10^5$)	—	—

* Data presented for 9 filter beds. Values given are average values achieved 85 percent of the time.
† Value in mg/l except as indicated.
‡ MPN/100 ml.
** Log-normalized data.

- Wastewater loading rate; and

- Maintenance.

Thus, improper design, construction or maintenance can result in inconsistent and reduced levels of treatment.

System O&M Requirements--

Routine operation and maintenance requirements of gravity filtration units vary with the system type. Since buried filters are inaccessible for maintenance of the media, O&M requirements consist of annual adjustment and inspection of the self-priming siphon or pump and controls. The other three types of filters require maintenance of the media surface (raking and/or replacement of the top 10 cm (4 in.) of media) 2 to 4 times per year in addition to siphon or pump maintenance requirements. Intermittent filters (effective sand size of 0.4 mm and a uniformity coefficient of 3 to 4) receiving combined wastewater from a septic tank generally require maintenance 4 times per year while filters receiving combined wastewater from an aerobic treatment unit require less frequent maintenance, approximately 2 times per year at loading rates of 0.2 m/day (5 gal/ft^2/day). Less frequent maintenance would be required for lower loading rates. Filters receiving septic tank effluent must be taken out of service for maintenance; therefore two filter beds are required. (Personal Communication. D. K. Sauer. June 1978.)

For all 4 types of systems discussed, the equipment is fairly simple and requires only moderately skilled personnel training to ensure adequate service. Unscheduled maintenance, such as repair of level control apparatus, is required infrequently.

Environmental Acceptability--

The environmental acceptability of gravity filters also depends on system type. Uncovered filter units (typically the intermittent or recirculating system types) have a limited potential for health hazards (including vector problems); nuisance odors (primarily a concern with units receiving anaerobic influent); and undesirable appearance. Covered filters generally present no hazard or nuisance.

Costs--

Capital, operation and maintenance, and total annual costs are shown in Table 38.

MEMBRANE FILTRATION (PRESSURE)

Ultrafiltration

Ultrafiltration as applied to on-site wastewater treatment is a membrane filtration process which depends on a relatively low pressure driving force and a membrane permeable to some wastewater constituents, and impermeable to

TABLE 38. GRAVITY FILTRATION COSTS

Capital Cost Item	Design Life (year)	Installed Cost ($) Intermittent	Recirculating	Buried
Dosing (or recirculation) tank & self-priming siphon	20	200	300+	200+
Pump and controls	10	--	225	225
Filter structure	20	400	400	--
Aggregates:				
• filter sand	20	300	150	800
• pea gravel	20	100	50	--
• coarse gravel	20	100	50	200
Distribution & collection piping	20	200	200	300
Total Capital Costs		$1300*	$1375	$1725
Annual O&M Cost Item				
Maintenance required (@$8/hr)				
Routine (includes replacement sand)		80	80	20
Unscheduled repairs		--	--	--
Electricity		--	10	--
Total Annual O&M Costs		$80	$90	$20
Annual Cost				
Present worth of the sum of capital costs amortized over 20 years @ 7% interest, discount, and inflation (factor = 0.09439)		120	130	190
Annual O&M Costs		80	90	20
Total Annual Cost		$200*	$220	$210

* Cost for units receiving anaerobic effluent; cost of units receiving aerobic effluent is estimated to be $160 due to reduced maintenance frequency.

\+ Does not include siphon.

others. The most common types of ultrafiltration systems are summarized below (9-16).

System Type	System Requirements	Comments
Closed-loop recycle	Feed tank, high capacity low pressure pump and controls, membrane elements.	Membrane deterioration possible. Periodic membrane cleaning required to restore permeate flux. Periodically, concentrate must be bled from system and disposed.
Single pass	Surge tank, high capacity low pressure pump and controls, membrane elements, pressure reduction valve, concentrate holding tank.	Membrane deterioration possible. Periodic membrane cleaning required to restore permeate flux.

Membrane Materials	Properties	Comments
Cellulosic (cellulose moni-, di-, or tri-acetate)	Narrow pH operating range (3.5-7.5), susceptible to aerobic microbiological degradation.	Not likely to be used widely for on-site applications (with the possible exception of treatment of anaerobic waste streams).
Non-cellulosic (proprietary synthetic polymeric formulations)	Broad pH operating range (0.5 to 12.5), resistant to many organic solvents, free chlorine, and both aerobic and anaerobic microbiological degradation.	Most applicable to on-site treatment.

Membrane Configurations	Characteristics	Comments
Spiral wound	Moderate to high operating pressures from 3.5×10^5 to 1.0×10^6 N/m^2 (50-150 psi), low flux rates from 1.2 to 2.4 m/day (30-50 gsfd).	Fair resistance to plugging and good resistance to fouling. Generally operated with turbulent flow regime.
Hollow fiber	Low operating pressures from 1.4 to 3.5×10^5 N/m^2 (20-50 psi), low to high flux rates from 1.2 to 6.1 m/day	Fair resistance to plugging and fouling. May be operated with

	(30-150 gsfd), inside diameters from 0.1 to 1.0 mm (0.004 to 0.04 in.).	laminar or turbulent flow regime. May be backwashed with product.
Tubular	Low to moderate operating pressures from 1.4×10^5 to 6.9×10^5 N/m^2 (20-100psi) low to moderate flux rates from 1.2 to 4.0 m/day (30-100 gsfd), inside diameters from 1.3 to 2.5 cm (0.5 to 1.0 in.).	Excellent resistance to plugging and fouling. Operated with turblent flow regime. May be cleaned chemically or mechanically. Suitable for treatment of highly concentrated wastes with large amounts of suspended materials.

Most ultrafiltration systems employ more than one membrane element and are described as having series, parallel, or tapered membrane arrangements. Closed-loop recycle, non-cellulosic, tubular ultrafiltration membrane systems using either parallel or tapered membrane arrangements appear most suitable for on-site wastewater treatment applications.

Performance--

Ultrafiltration has been used as part of on-site scale investigations for treating toilet wastes for reuse as toilet flush water; treating segregated and combined laundry and shower waste streams for reuse in the same fixtures; and treating combined household wastewater following anaerobic treatment, prior to discharge to a soil absorption system (17-20). Performance of the ultrafiltration units within these systems is described in Table 39.

Conclusions reached by these investigations (17-22) were as follows:

- Ultrafiltration membranes consistently reduce blackwater average SS levels to less than 15 mg/l and reduce fecal coliform levels by factors of 10^4 to 10^7;
- Ultrafiltration membrane systems with molecular weight cut-off $\geq$20,000 have little effect on removal of dissolved solids (phosphates, ammonia, nitrates, etc.) and only affect chemical constituents associated with wastewater solids (18,19,22); and
- Low pressure membrane filtration systems utilizing reverse osmosis membranes with molecular weight cut-offs $\leq$500 are moderately to highly effective in removing BOD, COD, dissolved solids, and bacteria contained in on-site waste streams (19,20).

TABLE 39. ULTRAFILTRATION PERFORMANCE

Reference		Ebower, et al. (17)	Harris & Adams (18)				Poradek (21)	Gollan, et al. (22)	Bhattacharyya (19)		Grethlein (20)
Influent wastewater type		Blackwater	Blackwater	Blackwater	Blackwater	Blackwater	Raw municipal	Hospital waste (graywater)	Laundry*	Shower*	Raw municipal
Operating mode		Batch	Continuous	Continuous	Continuous	Continuous	Batch	—	Continuous	Continuous	Periodic batch and continuous
Membrane type+		Tubular	Hollow fiber	Tubular (cellulosic)	Tubular	Tubular	Tubular	Tubular	Flat sheet	Flat sheet	Tubular (cellulosic)
Membrane area (m^2)		0.33	1.4	2.1	2.1	0.7	—	—	5.1×10^{-3}	5.1×10^{-3}	—
Molecular weight cutoff		—	50,000	20,000	20,000	20,000	20,000	20,000	500	500	—#
Pretreatment		Macerator and wide mesh plastic screen	105 cm mesh vibrating screen**	None**	None**	None**	255 cm mesh screen	40 mesh screen	Fine screen and pre-chlorination	Fine screen and pre-chlorination	Septic tank
Pressure (N/m^2)		3.45×10^5	1.10×10^5	1.59×10^5	2.34×10^5	2.26×10^5	1.38, 3.45×10^5	3.45×10^5	1.5, 6.9×10^5	1.5, 6.9×10^5	3.45, 10.3×10^3
Flux (m/day)		2.65-1.63	6.1-0.9	2.4-0.9	5.1-1.8	8.6-2.4	5.3-1.3	4.9-1.6	1.6-0.2	1.7-0.6	0.5-0.05
Volumetric feed concentration factor		30x	—	—	—	—	2x-10x	—	1x-10x	1x-10x	—
Cumulative operation time (hrs)		90.3	100	100	100	100	—	3000	—	—	3300
Constituents##											
TSS	influent	860	400	3640	3640	5240	200-870	—	—	—	—
	effluent	<5-10	5	12	11	47	—	—	—	—	—
	(rejection)	(>90)	(98.8)	(99.7)	(99.7)	(99.1)	(—)	(>99)	(—)	(99	(—)
TDS	influent	1050	—	—	—	—	—	—	700	240-650	—
	effluent	1650	—	—	—	—	—	—	195	—	—
	(rejection)	(-69)	(—)	(—)	(—)	(—)	(—)	(—)	(72-80)	(39-62)	(—)
BOD_5	influent	—	—	—	—	—	50-110	—	—	—	270
	effluent	—	—	—	—	—	30-70	—	—	—	17
	(rejection)	(—)	(—)	(—)	(—)	(—)	(40-60)	(—)	(—)	(—)	(93)
COD	influent	—	—	—	—	—	200-420	—	—	—	—
	effluent	—	—	—	—	—	100-150	—	—	—	—
	(rejection)	(—)	(—)	(—)	(—)	(—)	(50-60)	(50)	(—)	(—)	(—)
TOC	influent	—	—	—	—	—	—	—	185	75-220	—
	effluent	—	—	—	—	—	—	—	6	20-30	—
	(rejection)	(—)	(—)	(—)	(—)	(—)	(—)	(—)	(97-99+)	(70-86)	(—)
NO_3-N	influent	—	—	—	—	—	—	—	—	—	3 5
	effluent	—	—	—	—	—	—	—	—	—	0 95
	(rejection)	(—)	(—)	(—)	(—)	(—)	(—)	(—)	(—)	(—)	(73)
PO_4-P	influent	—	—	—	—	—	—	—	100	—	33
	effluent	—	—	—	—	—	—	—	2	—	5
	(rejection)	(—)	(—)	(—)	(—)	(—)	(—)	( )	(95-98)	(78-95)	(85)
Conductivity	influent (umho)	—	—	—	—	—	—	—	910	350-840	410
	effluent (umho)	—	—	—	—	—	—	—	405	—	170
	(rejection)	(—)	(—)	(—)	(—)	(—)	(—)	(—)	(50-55)	(35-45)	(59)
Fecal Coliform (log no./100 ml)	influent	5.7-8.1	6.2-8.8	6.1-9.2	6.1-9.2	3.6-9.7	—	—	—	—	—
	effluent	0.0-6.9++	1.6	4.1++	2.2	1.8	1.3-2.0	—	—	—	0
	(rejection)	(1.2-7.8)	(5.9)	(3.6)	(5.5)	(8.5)	(—)	(—)	(—)	(—)	(—)

* Investigations performed using actual and synthetic wastes.
\+ All membranes noncellulosic unless otherwise indicated.
\# Investigations performed using reverse osmosis membranes (pore sizes less than 1.0×10^{-8} m (100 Å)).
** Aerated feed tank.
\++ Membrane or seal failure.
\## Influent and effluent concentrations expressed as mg/l, rejections expressed as percent.

Depending on the specific ultrafiltration system utilized and the method of wastewater disposal or reuse anticipated, additional treatment for removal of BOD, nutrients, bacteria, color, and odor may be required.

System O&M Requirements--

Routine operation and maintenance of complex tubular ultrafiltration membrane systems (estimated at 4 times per year) by highly skilled service personnel consists of maintenance of mechanical components, removal and disposal of concentrated residuals rejected by the membranes, and membrane element inspection. If tubes become clogged, they may be cleaned mechanically with brushes or chemically with solvents, detergents, or other cleaning liquids which do not react with membrane materials. Unscheduled maintenance may be required due to mechanical equipment failures, caused by excessive feed stream concentrated residuals build-up or failure of the membrane or membrane seal. Overall, tubular membrane element life is expected to be approximately 15,000-20,000 hours of operation.

The reported length of membrane operation possible before mechanical or chemical cleaning is required varies substantially from study to study, depending on factors such as membrane material and configuration, influent waste characteristics, bulk velocity of fluid over the membrane surface, flow path channel height, and mode of operation (continuous or intermittent). Some researchers have reported severe clogging by colloids for membranes receiving septic tank effluent (Personal Communication. W. C. Boyle. October 1978). Others have reported adequate membrane flow for 1500 hours of operation of bench-scale membranes receiving septic tank effluent (20) and 15,000 hours of maintenance fee operation for membranes receiving aerobically digested wastewater in on-site applications (Personal Communication. A. Coviello. November, 1977). Thus, it appears that membrane materials, configuration, and operation can be matched with the influent wastewater characteristics to minimize membrane maintenance requirements.

Environmental Acceptability--

Since membrane ultrafiltration is a physical separation process, no toxic substances are generated. In fact, it has been shown that recycled laundry and shower wastes concentrated more than 100-fold are not toxic or irritating to humans when appropriate membrane systems are utilized (19). The applicability of current methods of wastewater sludge disposal for disposal of concentrated residuals has not been determined, although preliminary indications are that these methods are suitable.

Costs--

Capital, operation and maintenance, and total annual costs are presented in Table 40.

TABLE 40

ULTRAFILTRATION SYSTEM COSTS*

Capital Cost Item	Design Life (year)	Capital Cost ($)
Vault for ultrafiltration system including excavation and access hatch	20	500
Ultrafiltration system including feed tank and membrane elements	20	1200
Pump and controls	10	300
Total Capital Cost		$2000

Annual O&M Cost Item	Amount	Unit Cost ($)	Annual O&M Cost ($)
Maintenance requirements			
Routine	6 hr/yr	12/hr	72
Unscheduled	2 hr/yr	12/hr	24
Electricity	800 kwh/yr	0.5/kwh	40
Membrane replacement	1/yr	75/ea	75
Total O&M Costs			$211

Annual Cost	
Present worth of the sum of the capital costs amortized over 20 years @ 7% interest, discount and inflation (factor = 0.09439)	217
Annual O&M Cost	211
Total Annual Cost	$428 ~ $430

* Disposal of concentrate is not included. It is assumed that concentrate is returned to the previous treatment unit in most systems. When ultrafiltration of untreated wastewater is employed, concentrate handling and disposal will cost an estimated $75 annually.

COAGULATION AND CHEMICAL PRECIPITATION

Chemical addition to on-site waste streams may be utilized to enhance settling of colloidal and suspended wastewater solids, to chemically precipitate otherwise soluble wastewater constituents (such as phosphorus), or both. The types of chemicals which may be added for on-site wastewater treatment are described below.

Chemical Type	Purpose	Comments
Polymers (cationic, anionic, or non-ionic)	Coagulation and sedimention of colloidal suspended solids.	Cationic polymers give most favorable results. Not likely to be used if filtration immediately follows coagulation.
Aluminum salts (aluminum sulfate (alum), sodium aluminate, or aluminum chloride)	Coagulation and sedimentation of colloidal suspended solids and/or phosphorus precipitation.	Aluminum salt solutions are corrosive. Not likely to be used if very low effluent SS desired.
Iron salts (ferric chloride, ferric sulfate and ferrous sulfate)	Coagultion and sedimentation of colloidal suspended solids and/or phosphorus precipitation.	Iron salt solutions are highly corrosive and may cause staining. Ferrous sulfate ineffective for coagulation of anaerobic waste streams.
Lime	Coagulation and sedimentation of colloidal suspended solids and/or phosphorus precipitation.	May require considerably higher dosages than aluminum or iron salts. Not likely to be used if low effluent SS desired. Generates more sludge than other chemicals.
Sodium bicarbonate	Buffering of wastewater, sedimentation of colloidal suspended solids	Less effective than the alternatives for SS removal

In addition, combinations of the chemical types also may be utilized. Use of combinations of chemicals generally will serve a combination of the purposes described above for each chemical type.

These chemicals may be added to waste streams in either liquid or solid form. Hardware usually consists of chemical metering pumps or siphons which add a preset quantity of chemical to fixed volume of wastewater. Fixed wastewater volumes are provided using a tipping bucket arrangement (which activates the chemical feed), or by operating the treatment unit in a batch mode (with the chemical feed activated by the same mechanism which operates the batch cycle).

Following chemical addition, mixing and separation must be provided. Mixing may rely on turbulence induced by the waste stream flow and treatment unit configuration, or on mechanical mixing provided by impellers or aeration equipment. Separation generally consists of sedimentation which takes place in the treatment unit following mixing, with additional solids removal occurring in subsequent treatment or disposal components.

Performance

Data describing on-site chemical addition investigations are given in Table 41 (23-29). In general, these investigations have focused on the applicability of the various chemical types and dosages in combination with biological wastewater treatment, with little or no emphasis on chemical addition, mixing, and sedimentation hardware performance. From the data presented the following conclusions are drawn:

- Consistently, catonic polymer or aluminum sulfate addition can provide approximately 50 percent BOD reductions and 70 to 90 percent SS reductions;
- Phosphorus removals in excess of 80 percent, along with substantial fecal coliform reductions, can be achieved with aluminum sulfate addition;
- Significant increases (approximately 300 percent) in sludge generation accompany aluminum sulfate addition. Although sludge density may also be increased, it is not likely to offset the need for additional sludge storage volume (27,28); and
- Sodium bicarbonate appears to provide approximately 75 percent reduction in septic tank effluent suspended solids concentrations based on an extremely small number of samples (26).

In general, conclusions applying to aluminum sulfate addition are likely to apply to the addition of other salts of aluminum and iron, with the possible exception of ferrous sulfate. Ferrous sulfate is generally ineffective as a coagulant in anaerobic waste streams (30-32).

System O&M Requirements

Routine operation and maintenance of coagulation and chemical precipitation systems may vary significantly for different types of hardware. In general, chemical refills, adjustment of feed quantities, and maintenance of the moderately complex mechanical equipment by a semi-skilled technician is

TABLE 41. COAGULATION AND CHEMICAL PRECIPITATION PERFORMANCE

Reference	Winneberger, et al (23)			Winneberger & McGauhey (24)				Hutzler (25)	Laak et al (26)		Brandes (27,28)			Ugrun (29)		
Influent wastewater	Raw municipal			Combined household		Bath and toilet		Simulated combined household	Combined household		Toilet and bathroom sink			Raw municipal		
Pretreatment	Sedimentation, cloth screen comminution by garbage grinder			—		—		Three compartment septic tank (980 l)	—		—			Coarse grid		
Treatment unit	Single compartment septic tank (170 l)			Two compartment septic tank (400 l)		Two compartment septic tank (130 l)		Cylindrical clarification tank (1100 l)	Septic tank		Two compartment septic tank (3400 l)			Presedimentation (1000 l) biological contactor clarification (850 l)	Presedimentation (1100 l) clarification (3100 l)	Presedimentation (1000 l) clarification (800 l)
Detention time (days)	3			5		4-6		1.6	—		9.7			0.5	0.3	0.5
Point of chemical addition	Influent to septic tank			Influent to septic tank		Influent to septic tank		Influent to clarifier	—		Sewer pipe from toilet to septic tank			—	—	—
Mixing	—			—		—		Vortex mixer	—		—			—	-	—
	Test	Test	Control	Test	Control	Test	Control	Test	Test*	Control*	Test	Test	Control	Test	Test	Test
Chemical added	cationic polymer #1	cationic polymer #2	—	cationic polymer #1	—	cationic polymer #1	—	aluminum sulfate	sodium bicarbonate	—	aluminum sulfate	aluminum sulfate	—	aluminum sulfate	aluminum sulfate	aluminum sulfate
Dosage (mg/l)	25	250	—	8	—	8	—	120#	240	—	106-430	430	—	—	—	—
Constituent##																
COD influent	300	303	313	—	—	—	—	221	—	—	—	—	—	—	-	—
COD effluent	136	138	171	—	—	—	—	165	—	—	169	140	—	—	—	—
COD (removal)	(55)	(54)	(43)	(—)	(—)	(—)	(—)	(25)	(—)	(-)	(—)	(—)	(—)	—	—	—
BOD_5 influent	—	—	—	—	—	—	—	107	—	—	—	-	—	366**	[illegible]**	386**
BOD_5 effluent	—	—	—	—	—	—	—	73	240	198	67	83	143	35**	178**	133**
BOD_5 (removal)	(—)	(—)	(—)	(—)	(—)	(—)	(—)	(32)	(—)	(—)	(—)	(—)	(—)	(92)	(56)	(68)
TS influent	—	—	—	—	—	—	—	879	—	—	—	—	—	—	—	—
TS effluent	—	—	—	—	—	—	—	899	767	735	523	565	597	—	—	—
TS (removal)	(—)	(—)	(—)	(—)	(—)	(—)	(—)	(-2)	(—)	(—)	(—)	(—)	(—)	—	—	—
SS influent	218	218	218	—	—	—	—	86	—	—	—	—	—	197	197	197
SS effluent	27	38	52	83	156	41	300	116	26	100	36	25	81	39	46	58
SS (removal)	(88)	(82)	(75)	(—)	(—)	(—)	(—)	(-35)	(—)	(—)	(—)	(—)	(—)	(80)	(77)	(70)
TP influent	—	—	—	—	—	—	—	—	—	—	—	—	—	7.6	7.6	7.6
TP effluent	—	—	—	—	—	—	—	—	—	—	2.8	0.72	19.6	1.5	1.5	2.7
TP (removal)	(—)	(—)	(—)	(—)	(—)	(—)	(—)	(—)	(—)	(—)	(—)	(—)	(—)	(80)	(80)	(55)
Total Coliform (log #/100 ml) effluent	—	—	—	—	—	—	—	—	—	—	5.1	3.9	5.3	—	—	—
pH (standard units) effluent	—	—	—	—	—	—	—	—	7.1	7.0	7.2	7.2	7.9	—	—	—
Sludge accumulation (l/m^3)	—	—	—	—	—	—	—	—	—	—	—	7.2*	1.5	7.7**	7.8**	6.1**

* Samples collected from septic tank liquor. Test samples collected 72 hours after chemical addition.
† Not reported
\# Estimated
** Values reported are BOD_7 (seven day BOD)
†† Includes presedimentation sludge.
\#\# Influent and effluent concentrations expressed as mg/l, removals expressed as percents.

required 2 to 4 times per year. In addition, removal of accumulated sludge directly resulting from coagulation and chemical precipitation is required approximately one to four times per year depending on the chemical used and the system characteristics. Frequent unscheduled maintenance may be required for existing hardware as a result of plugging and malfunctioning of chemical feed equipment. The latter may be caused by the corrosive nature of chemicals stored or by hydraulic overloads.

Environmental Acceptability

The corrosive nature of iron and aluminum salt solutions may create safety problems for those handling the chemicals, but should pose no threat to the homeowner during system operation. Also, effluent dissolved solids (especially iron or aluminum concentrations) may increase substantially, but effluent toxicity should not present any problems. However, staining problems may occur at high effluent iron concentrations.

Cost

Capital, operation and maintenance, and total annual costs are shown in Table 42.

SORPTION

As applied to on-site wastewater treatment, sorption processes involve the accumulation of initially dissolved wastewater constituents on or in solid media. The sorption processes which are currently most applicable to on-site wastewater treatment are briefly described below.

System Type	System Requirements	Comments
Carbon adsorption (activated carbon)	Surge tank, self-priming siphon or pump and controls, carbon adsorption media, media tank or column. (Systems incorporating pressurization and backwashing require additional equipment similar to pressurized media filtration systems).	Media replacement (or regeneration) may be required at frequent intervals for wastes with high organic or solids concentrations.
Ion exchange:		
• clinoptilolite • limestone • "red mud" (bauxite purification by-product)	Surge tank, self-priming siphon or pump and controls. Ion exchange media, media tank or column. (Systems incorporating pressurization and backwashing	Media replacement (or regeneation) may be required at frequent intervals depending on the or-

TABLE 42

COAGULATION AND CHEMICAL PRECIPITATION COSTS

Capital Cost Item	Design Life (years)	Chemical Addition Unit ($)	Chemical Addition Unit with Sedimentation Chamber ($)
Chemical storage and feed unit	10	300	300
Sedimentation chamber	20	---	300
Total Capital Cost		$300	$600

Annual O&M Cost Item	Amount	Unit Cost ($)	Annual O&M Cost ($)
Maintenance requirements			
Routine	6 hr/yr	10/hr	60
Unscheduled	3 hr/yr	10/hr	30
Chemical Costs	4-8 kg/yr	2-10/kg	8-80
Chemical sludge pumping	1/yr	50/pumpout	50
Total Annual O&M Cost			$148-220

Annual Cost	
Present worth of the sum of the capital costs amortized over 20 years @ 7% interest, discount, and inflation (factor = 0.09439)	28- 55
Annual O&M Costs	148-220
Total Annual Cost	$176-275 ~$180-280

• hydroxy-aluminum saturated cationic resins • other synthetic cationic anionic resins	require additional equipment similar to pressurized media filtration systems).	ganic and solids concentration of the wastewater and the exchange capacity of the resin used. "Red mud" is not generally available in parts of the country.

Generally, most on-site sorption process units will receive flow intermittently. Both pressure and gravity application of wastewater can be utilized, with media backwash capabilities frequently accompanying pressure distribution units. In most cases, sorption processes will be preceded by biological or other physical-chemical treatment. Exhausted media will be replaced by media regenerated off-site, or by new media (2,4,33).

A listing of specific wastewater constituents and sorption media which may be utilized to remove them from on-site waste streams are listed below.

Wastewater Constituents	Sorption Media Type
COD, BOD, Cl^-, I^-, $S^=$, and odor producing substances	Activated carbon
NH_4^+	Naturally occurring cationic resins such as the aluminosilicate zeolites (including clinoptilolite) and synthetic resins
NO_3^-	Naturally occurring and synthetic anionic resins
PO_4^{-3}	Naturally occurring anionic resins such as limestone (including calcite and dolomite), activated alumina, "red mud" and synthetic resins

Performance

Data describing on-site sorption unit performance are given in Table 43 (1,2,4,33-36). Several full-scale applications of activated carbon treatment of on-site waste streams exist for which performance information is not readily available. One application involves pressurized, downflow activated carbon treatment of blackwater preceded by anaerobic and aerobic treatment, sedimentation, and ultrafiltration. Following disinfection, the treated blackwater is recycled for toilet flushing (Personal Communication. A.

TABLE 43. SORPTION PERFORMANCE

Reference	Witt (2)	Witt (2)	Witt (2)	Witt (2)	Waldorf (38)	Smith (33)	SSWMP (1)	SSWMP & Siltora (1,36)	Chowdhry (4,34)	Chowdhry (4,34)
Wastestream	Greywater	Greywater	Greywater	Greywater	—	—		Combined household	Combined household	Combined household
Pretreatment	Equalization	Dual media filtration	Aerobic unit & sedimentation, and dual media filtration	Aerobic unit sedimentation	Aerobic unit, 1000 gal holding tank, 0.5 mg/l iodine disinfection with 20 minute contact time	Septic tank	Septic tank & sand filter	Septic tank & sand filter	Septic tank	Septic tank
Treatment Unit	8 x 30 mesh activated carbon (pressurized downflow, with backwashing)	8 x 30 mesh activated carbon (pressurized downflow, with backwashing)	8 x 30 mesh activated carbon (pressurized downflow, with backwashing)	8 x 30 mesh activated carbon (pressurized downflow, with backwashing)	Activated carbon (pressurized downflow, with backwashing)	10 x 20 mesh and 20 x 40 mesh clinoptilolite (upflow and downflow)	limestone (anaerobic, horizontal columns packed with 0.32 cm calcite chips, methanol addition for denitrification	Limestone (anaerobic upflow tank packed with 0.50 cm dolomite chips, methanol addition to influent for denitrification)	Sand and sand-limestone dual media filter (aerobic downflow gravity filter) o upper 38 cm layer sand D_{10}=0.24 mm C_u=1.9 o lower 38 cm layer - 50% mixture sand D_{10}=0.24 mm, C_u= 1.9 and limestone D_{10}=0.29 mm, C_u=3.9)	Sand and sand "red-mud" dual media filter (aerobic, downflow, gravity filter) o upper 38 cm layer sand D_{10}=0.24 mm C_u= 1.9 o lower 38 cm layer - 1:1 mixture sand D_{10}=0.24 mm, C_u=1.9 and "red-mud" (bauxite purification by-product)
Media volume (m^3)	0.089	0.035	0.29	0.085	—	180 x 10^{-6}	4.8 x 10^{-3}	0.76	8.44	8.44
Media depth (m)	2.3	1.1	2.3	1.1	—	0.16	0.96	0.65	0.76	0.76
Media contact time (hr)	0.67	0.33	0.67	0.33	—	0.1	72	12-24	—	—
Loading rate (m/hr)	4.9	4.9	4.9	4.9	—	1.6	0.002#	0.01-0.02	0.002-0.003	0.002-0.003
Flow rate (bed volumes/hr)	1.5	3.0	1.6	3.0		10	0.034#	0.04-0.08	0.003-0.004	0.003-0.004
Capacity at breakthrough	0.5 g COD/g carbon+	0.5 g COD/g carbon+	0.5 g COD/g carbon+	0.5 g COD/g carbon+	—	0.30-0.41 meq NH_4/g clinoptilolite	—	—	—	—
								—	—	—
								—	—	—
Cumulative operation time (days)	3.0	1.5	1.3	0.8	—	1.3	200	300	860	850
Constituents*										
COD influent	186	129	64	62	—	—	—	—	360	360
COD effluent	43	47	19	27	—	—	—	—	<20	<20
COD (removal)	(77)	(64)	(71)	(55)	(--)	(--)	(--)	(--)	(>94)	(>94)
BOD_5 influent	51	46	12	10	—	100	—	1-4	185	185
BOD_5 effluent	17	13	3.5	6	—	80-92	—	—	1	1
BOD_5 (removal)	(66)	(72)	(71)	(40)	(--)	(8-20)	(--)	(--)	(99)	(99)
TS influent	326	264	280	280	—	—	—	—	860	850
TS effluent	269	209	223	261	—	—	—	—	750	755
TS (removal)	(18)	(21)	(20)	(4)	(--)	(--)	(--)	(--)	(12)	(11)
TVS influent	105	88	83	76	—	—	—	—	—	—
TVS effluent	58	51	62	72	—	—	—	—	—	—
TVS (removal)	(45)	(42)	(25)	(5)	(--)	(--)	(--)	(--)	(--)	(--)
TDS influent	318	197	253	262	—	—	—	—	—	—
TDS effluent	275	167	219	247	—	—	—	—	—	—
TDS (removal)	(11)	(15)	(13)	(6)	(--)	(--)	(--)	(--)	(--)	(--)
VDS influent	80	60	61	72	—	—	—	—	—	—
VDS effluent	43	28	48	52	—	—	—	—	—	—
VDS (removal)	(46)	(53)	(21)	(28)	(--)	(--)	(--)	(--)	(--)	(--)
TSS influent	18	67	27	18	—	38	—	(negligible change)	130	130
TSS effluent	—	42	4	22	5	14-23	—		4	3
TSS (removal)	(--)	(37)	(85)	(-22)	(--)	(40-62)	(--)		(97)	(98)
Organic-N influent	2.0	1.2	1.4	0.6	—	7.4	—	—	15.6	15.6
Organic-N effluent	1.5	1.3	2.0	0.5	—	2.8-5.2	—	—	0.5	0.6
Organic-N (removal)	(25)	(-8)	(-43)	(17)	(--)	(30-62)	(--)	(--)	(97)	(96)
NH_3-N influent	0	0	0.25	0.3	—	30	—	0.1	23.6	23.6
NH_3-N effluent	0	0	0.20	0.3	—	0.0-0.3	—	<0.1	0.1	<0.1
NH_3-N (removal)	(--)	(--)	(20)	(0)	—	(>99)	—	(--)	(99)	(>99)
NO_3-N influent	—	—	—	—	—	—	20-80	34	0.1	0.1
NO_3-N effluent	—	—	—	—	—	—	0-0.5	3.7	16.7	18.4
NO_3-N (removal)	(--)	(--)	(--)	(--)	—	(-)	(98-100)	(89)	(--)	(--)
TP influent	14.5	11.0	18.4	18.5	—	—	—	—	9.3, 9.7**	9.3, 9.7**
TP effluent	13.3	9.0	11.8	19.0	—	—	—	—	2.4, 4.5	1.1, 1.7
TP (removal)	(8)	(18)	(36)	(-3)	—	—	—	—	(73, 54)	(88, 82)
PO_4-P influent	1.8	2.0	18.5	18.8	—	—	7-13	10.9##	—	—
PO_4-P effluent	3.3	2.5	13.0	17.0	—	—	0-11	6.8##	—	—
PO_4-P (removal)	(-83)	(-25)	(31)	(10)	—	—	(12-97+)	(36)	—	—

* Influent and effluent constituent concentrations expressed as mg/l, removals expressed as percent

\+ Equilibrium capacity (not breakthrough capacity)

\# Laboratory columns dosed daily with 500 ml of sand-filtered septic tank effluent. Majority of effluent movement through column occurred within one hour of dosing

** Nitrate plus nitrite-nitrogen. Log normal distribution

\++ Values reported for first and second year of testing, respectively

\## Values reported for first 10 months of testing.

Coviello. November 1977). Another application described in Table 43 also produces an effluent which is reused for toilet flushing (35).

Conclusions based on the performance of the sorption processes included in Table 43 and those discussed in the preceding paragraph are as follows:

System Type	Performance
Activated carbon	Consistently provides significant removals of COD (60-75 percent), BOD (40-70 percent), and volatile dissolved solids (30-50 percent) from all waste streams tested (2,35). Suspended solids are removed by carbon acting as a filtration media (2).
Clinoptilolite	Consistently provides significant ammonia removals (>9 percent) from septic tank effluents, with similar results anticipated for other non-nitrified waste streams (33). Suspended solids and organic nitrogen removed by clinoptilolite acting as filtration media (33). Rapid media exhaustion experienced (1).
Limestone	Dual media (sand and sand-limestone mixture) filtration provides significant phosphorus removal (50 percent in the first year of operation) from septic tank effluent in excess of that provided by sand filtration alone. Other sand filter performance characteristics are unaffected. Similar results are anticipated for other influent waste streams suitable for sand filtration (4,34). Large limestone chips provide less significant phosphorus removal from sand filtered (nitrified) septic tank effluent under anaerobic conditions than is provided with the smaller diameter, sand-limestone mixture discussed above (4,34).
"Red mud" (bauxite purification by-product)	Dual media (sand and sand-red mud mixture) filtration consistently provides significant phosphorus removal (70 percent the first year and 60 percent the second year) in excess of that provided by sand filtration alone. Other sand filter performance characteristics are unaffected. Similar results are expected for other influent waste streams suitable for sand filtration (4,34).

Generally, all sorption process efficiencies decline during treatment unit operation (1,2,4,33,34,36,37). Since the rate of decline depends on the wastewater characteristics and sorption media, these two factors must be properly matched to minimize O&M requirements. Additional methods of alleviating the decline include the following:

- Media backwashing;
- Prefiltration; and
- Chemical addition (chlorine, iodine, etc.) to inhibit growth of biological slime.

System O&M Requirements

Routine system O&M requirements consist of media addition or replacement 2 to 12 or more times per year by semi-skilled service personnel, depending primarily on the system design, influent wastewater quality, and media volume and exchange capacity. In addition, routine maintenance of mechanical equipment 1 to 2 times per year is also required. Unscheduled maintenance of the pump and controls and/or media will be required infrequently.

Environmental Acceptability

Sorption unit effluents should not present any environmental problems. Similarly, media regeneration and disposal will take place off-site, and should not pose any special problems.

Cost

Capital cost, operation and maintenance, and total annual costs are presented in Table 44 with the exception of pressurized sorption units equipped with backwash capabilities. Costs for these units are similar to the costs for pressurized media filtration units equipped with backwash capabilities, previously presently in Table 36.

PHYSICAL-CHEMICAL COMPONENT COMPARISONS

Comparisons for physical-chemical components with available hardware and on-site performance information sufficient to permit detailed evaluation are presented in Table 45. Component comparisons for components with available on-site hardware but insufficient on-site performance information shown in Table 46 are based on engineering judgment and are subject to revision when data become available.

TABLE 44

SORPTION UNIT COSTS

Capital Cost Item	Design Life (year)	Capital Cost ($)
Sorption column or tank (including media)	20	600
Surge tank (wet well)	20	200
Pump and controls	10	300
Distribution piping	20	100
Total Capital Cost		$1200

Annual O&M Cost Item	Amount	Unit Cost ($)	Annual O&M Cost ($)
Maintenance required			
Routine	8 hr/yr	10/hr	80
Unscheduled	2 hr/yr	10/hr	20
Sorption media	50-1000 kg/yr	0.15-0.30/kg	80-300
Electricity	200 kwh/yr	0.05/kwh	10
Total Annual O&M Cost			$190-410

Total Annual Cost	
Present worth of the sum of capital costs amortized over 20 years @ 7% interest, discount, and inflation (factor = 0.09439)	141
Annual O&M Cost	190-410
Total Annual Cost	$331-551 ~$330-550

TABLE 45. PHYSICAL-CHEMICAL COMPONENT COMPARISON FOR COMPONENTS WITH SUFFICIENT INFORMATION*

Ranking Group	Component	Ranking: Performance (5 max.)	Ranking: O&M Requirements (5 max.)	Ranking: Environmental Acceptability (3 max.)	Ranking: Total (13 max.)	Total Annual Cost ($)
A	Gravity filtration	5	4	3	12	150-250
	Pressure filtration	4	3	3	10	200-300
	Carbon Adsorption	4	3	3	10	250-350
B	Coagulation and chemical precipitation	4	2	3	9	150-300
	Ultrafiltration	5	2	3	10	400-500
	Ion Exchange	5	2	3	10	450-500

* For components with sufficient on-site performance information and hardware available to permit detailed evaluation. See Section 3 for explanation of the ranking system.

TABLE 46. PHYSICAL-CHEMICAL COMPONENT COMPARISON FOR COMPONENTS WITH INCOMPLETE INFORMATION*

Ranking Group	Component	Ranking: Performance (5 max.)	Ranking: O&M Requirements (5 max.)	Ranking: Environmental Acceptability (3 max.)	Ranking: Total (13 max.)	Annual Cost ($)
B	Clarification	4	3	3	10	100-300
	Microstraining	4	2	3	9	200-400
	Reverse Osmosis	5	2	3	10	400-600

* For components with available on-site hardware, but insufficient on-site performance information. This comparison is based on engineering judgement and should be reevaluated when data become available.

REFERENCES

1. Small Scale Waste Management Project. Management of small waste flows. Appendix A. Wastewater characteristics and treatment. EPA-600/2-78-173. U.S. Environmental Protection Agency, Cincinnati, Ohio, September, 1978. 764 p.

2. Withee, C.C. Segregation and reclamation of household wastewater at an individual residence. University of Colorado, Boulder, Department of Civil and Environmental Engineering, 1975. 286 p. (Available from National Technical Information Service (NTIS) as PB-268 810.)

3. Cohen, S. and H. Wallman. Demonstration of waste flow reduction from households. EPA-670/2-74-071, General Dynamics Corporation, Groton, Connecticut, September 1974. 111 p.

4. Chowdhry, N.A. Septic tank-sand filter systems for treatment of domestic sewage. Publication No. W64, Ontario Ministry of the Environment, Toronto, June 1977. 47 p.

5. Bowne, W.C. Experience in Oregon with Hines-Favreau recirculating sand filter. Presented at the Northwest States Conference on On-Site Sewage Disposal, Seattle, Washington, August 1977. 7 p.

6. Hines, M. and R.E. Favreau. Recirculating sand filters; an alternative to traditional sewage absorption systems. In. Proceedings of the National Home Sewage Disposal Symposium, Chicago, Illinois, December 9-10, 1974. American Society of Agricultural Engineers, St. Joseph, Michigan, 1975. pp. 130-136.

7. Sauer, D.K. Treatment systems required for surface discharge of on-site wastewaters. In: Individual On-Site Wastewater Systems, Proceedings of the Third National Conference, Ann Arbor Science Publishers, Ann Arbor, Michigan. pp. 113-130.

8. Siegrist, R.L. Waste segregation to facilitate on-site wastewater sewage disposal alternatives. In: Proceedings of the Second National Home Sewage Treatment Symposium, Chicago, Illinois, December 12-13, 1977. American Society of Agricultural Engineers, St. Joseph, Michigan, 1978. pp. 271-281.

9. Battacharya, D., K.A. Garrison, and R.B. Grieves. Membrane ultrafiltration waste treatment application for water reuse. Indus. Water Eng. 12(4):6-12, April 1975.

10. Weber, W.J., Jr. Physicochemical processes for water quality control. Wiley-Interscience, New York, 1972. pp. 413-466.

11. Hardwick, W.H. The application of reverse osmosis and ultrafiltration to the purification and treatment of natural waters and effluents. NATO Advanced Study Institute Series E, No. 13. Noordhoff International Publishing Company, Leyden, Netherlands, 1975. pp-435-464.

12. Mahlman, H.A., W.G. Sisson, K.A. Kraus, and J.S. Johnson, Jr. Crossflow filtration in physical-chemical treatment of municipal sewage effluents. EPA-600/2-76-025, Oak Ridge National Laboratory, Tennessee, February 1976. 121 p.

13. Porter, M.C. and A.S. Michaels. Membrane ultrafiltration. Chem. Tech., 1:56-63, January 1971.

14. Guinn, R.M. and W.K. Hendershaw. A comparison of current membrane systems used in ultrafiltration and reverse osmosis. Ind. Water Eng., 13(3):12-15, March 1976.

15. SCS Engineers. Wastewater management for new housing development: advanced wastewater treatment techniques and new development. HUD/RES-1321, Long Beach, California, January 1977. 47 p. (Available from National Technical Information Service (NTIS) as PB-279 778.)

16. Krause, K.A. Cross-flow filtration and axial filtration. Proc. Indus. Waste Conf., 29:1059-1075, 1974.

17. Hoover, P.R., K.J. McNulty, and R.L. Goldsmith. Evaluation of ultrafiltration and disinfection for treatment of blackwater. U.S. Army Mobility Research and Development Command, Fort Belvoir, Virginia, 1977. 47 p.

18. Harris, L.R. and C.M. Adema. Processing of raw sewage by ultrafiltration. Report MAT-77-79, David W. Taylor Naval Ship Research and Development Center, Bethesda, Maryland, 1977. 12 p.

19. Battacharya, D., A.B. Jumawan, Jr., R.B. Grieves, and S.O. Witherup. Ultrafiltration of complex wastewaters; recycling for non-potable use. J. Water Pollut. Control Fed., 50(5):846-86, May 1978.

20. Grethlein, H.E. Anaerobic digestion and membrane separation of domestic wastewater. J. Water Pollut. Control Fed., 50(4):754-763, April 1978.

21. Poradek, J.C. HUD/NASA MIST ultrafiltration test program for application in the MIUS demonstration; draft report. National Aeronautics and Space Administration, Houston, Texas, Lyndon B. Johnson Space Center, 1977. 43 p.

22. Gollan, A.Z., K.J. McNulty, R.L. Goldsmith, M.H. Kleper, and D.C. Grant. Evaluation of membrane separation processes, carbon adsorption, and ozonation for treatment of MUST hospital waste; final report. Abcor, Inc., Wilmington, Massachusetts, Walden Research Division, August 1976. 454 p.

23. Winneberger, J.H., A.B. Menar, and D.H. McGauhey. A study of methods of preventing failure of septic-tank percolation fields; third annual report. SERL Report No. 63-9, University of California, Berkeley, Sanitary Engineering Research Laboratory, December 1963. 82 p.

24. Winneberger, J.H. and D.H. McGauhey. A study of methods of preventing failure of septic-tank percolation fields, fourth annual report. SERL Report No. 65-16, University of California, Berkeley, Sanitary Engineering Research Laboratory, October 1965. 56 p.

25. Hutzler, N.J. Evaluation of on-site treatment devices receiving a controlled simulated waste. Master's Report, University of Wisconsin, Madison, 1974. 138 p.

26. Laak, R., J.J. Kolega, B.J. Cosenza and M.S. Weinberg. Feasibility studies on utilizing sodium bicarbonate with septic tank systems. In: Proceedings of the National Home Sewage Disposal Symposium, Chicago, Illinois, December 9-10, 1974. American Society of Agricultural Engineers, St. Joseph, Michigan, 1975. pp. 202-209.

27. Brandes, M. Phosphorus removal from human wastewater by direct dosing of alum to a septic tank. Research Report W61, Ministry of the Environment, Toronto, Canada, September 1976. 42 p.

28. Brandes, M. Effective phosphorus removal by adding alum to septic tank. J. Water Pollut. Control Fed., 49(11):2285-2296, November 1977.

29. Ulmaren, L. Reningresultat from provning an sma paketerenings-verk vid Akeshous Reningsverk (Purification reports from testing of small package sewage treatment plans at the Akewhov Sewage Treatment Plant). Vatten No. 3, 1971. 362 p.

30. Barkshied, R.D. and H.M. El-Baroudi. Physical-chemical treatment of septic tank effluent. J. Water Pollut. Control Fed., 46(10): 2347-2354, November 1974.

31. Metcalf and Eddy, Inc. Wastewater Engineering; Collection, Treatment, and Disposal. McGraw Hill, New York, 1972. 782 p.

32. SCS Engineers. Review of techniques for treatment and disposal of phosphorus-laden chemical sludges; draft report. Contract No. 68-03-2432, Long Beach, California, February 1978. 451 p.

33. Smith, J.J. The feasibility of using clinoptilolite for removal of ammonia from septic tank effluents. Master's study report. University of Wisconsin, Madison, Department of Civil and Environmental Engineering, 1978. 140 p.

34. Chowdhry, N.A. Domestic sewage treatment by underdrained filter systems. Publication No. 53, Ministry of the Environment, Toronto, Canada, Pollution Control Branch, 1974. 93 p.

35. Waldorf, L.E. The Boyd County Demonstration Project - a system approach to individual rural sanitation (an update). In: Individual On-Site Wastewater Systems, Proceedings of the Third National Conference, Ann Arbor, Michigan, November 1976. Ann Arbor Science Publisher, Ann Arbor, Michigan, 1977. pp. 235-244.

36. Sikora, L.J., J.C. Converse, D.R. Keeney, and R.C. Chen. Field evaluation of a denitrification system. In: Proceedings of the Second National Home Sewage Symposium, Chicago, Illinois, December 12-13, 1977. American Society of Agricultural Engineers, St. Joseph, Michigan, 1978. pp. 202-207.

37. Zarnett, G.D. Sorption capabilities of soils for phosphorus removal. Publication No. S58, Ministry of the Environment, Toronto, Canada, Pollution Control Branch, January 1976. 56 p.

SECTION 8

DISINFECTION OPTIONS

GENERAL

On-site wastewater treatment system effluents may require disinfection prior to disposal by direct discharge, irrigation, or non-potable reuse (e.g. toilet flushing) to meet environmental and/or public health requirements. Disinfection is the selective destruction of disease-causing organisms and can be effected by both physical and chemical agents (1). Disinfection options and their applicability to on-site systems are summarized in Table 47. Those with available hardware and on-site performance data are summarized below, except composting and incineration which were discussed in Section 5.

CHLORINE

Chlorine used as a wastewater disinfectant may be added in several forms as briefly described below.

System Type	System Requirements	Comments
Solid Feed	Pellet or cake storage chamber with flow-through mixing provisions, and contact tank. Surge tank and self-priming siphon (or pump and controls) may be utilized for more accurate dosage control.	Chemical feed malfunction due to "caking" possible. Pellet or cake storage must be refilled periodically.
Solid chemicals to create liquid feed	Surge tank and self-priming siphon (or pump), dry chemical storage and feed device, solution mixer, solution storage and feed tank, feed activation device. (If water supply for solution is household potable water, a cross connection preventer must also be provided.)	Dry chemical storage must be refilled periodically.
Liquid Feed	Surge tank and self-priming siphon (or pump), dry chemical storage and feed tank, feed activation device, and contact tank.	Feed equipment malfunction possible. Liquid solution storage must be filled periodically.

TABLE 47. DISINFECTION OPTIONS

Generic Type	Performance	O&M Requirements: Frequency of Scheduled Maintenance (#/yr)	O&M Requirements: Hardware Complexity	O&M Requirements: Equipment Failure (requiring unscheduled service)	Environmental Acceptability (potential hazards and nuisances)	Range of Annual Cost ($)*
CHEMICAL AGENTS						
- Halogens						
. Chlorine	Consistent	2-4	Simple	Frequent	Toxicity (chlorinated organics)	150-250
Iodine	Consistent	2-4	Simple	Infrequent	Toxicity uncertain	150-250
. Bromine	Potentially consistent	Unknown	Unknown	Unknown	Unknown	250-350
Halogen Mixtures	Potentially consistent	2-4	Simple-moderate	Frequent	Toxicity (halogenated organics)	250-350
- Ozone	Consistent	2-4	Complex	Frequent	Toxicity unknown, safety (for pure oxygen feed)	450-600
- Halogen plus Ozone	Potentially consistent	2-4	Complex	Frequent	Toxicity uncertain	500-650
- Acids and Bases	Potentially consistent	Unknown	Moderate	Unknown	Neutralization required	450-600
- Alcohols	Potentially consistent	Unknown	Moderate	Unknown	Increases effluent BOD	250-450
- Dyes	Ineffective	---	---	---	---	---
- Heavy Metals	Potentially consistent	Unknown	Unknown	Unknown	Toxicity, residuals disposal	450-600
- Hydrogen Peroxide	Ineffective	---	---	---	---	---
- Permanganate	Potentially consistent	Unknown	Unknown	Unknown	Residuals disposal	450-600
- Phenols	Potentially consistent	Unknown	Moderate	Unknown	Effluent toxicity	250-450
- Quaternary Ammonia	Potentially consistent	Unknown	Unknown	Unknown	Toxicity	450-600
- Surfactants	Ineffective	---	---	---	---	---
PHYSICAL AGENTS						
- Irradiation						
Ultraviolet	Consistent	2-4	Moderate	Infrequent	Toxicity unknown	150-250
Gamma ray	Appears consistent	2-4	Complex	Infrequent	Safety	500-700
X-ray	Potentially consistent	Unknown	Moderate	Unknown	Safety	400-600
- Electrochemical	Unknown	--	---	---	---	---
- Thermal						
. Heating	Potentially consistent	2-4	Moderate	Frequent	High effluent temperature	1500+
Freezing	Potentially consistent	--	---	---	---	---
- Ultrafiltration	Potentially consistent	2-4	Moderate	Frequent	Concentrate disposal	250-400
- Ultrasonics	Unknown	--	---	---	---	---
PHYSICAL PLUS CHEMICAL AGENTS						
- Ultraviolet plus ozone+	Appears consistent	2-4	Moderate	Infrequent	Toxicity unknown	150-250
- Ultraviolet plus halogens	Potentally consistent	2-4	Moderate	Frequent	Toxicity (halogenated organics)	300-600

* Amortized capital cost plus annual operation and maintenance costs
\+ Ozone generated by specialized UV lamp

Gas Feed	Gas storage cylinder, regulator, feed equipment with diffuser, and contact tank.	Toxic gases or explosion possible if equipment fails. Gas storage cylinder refilling required periodically. Gaseous feed chlorination not likely to be widely used for on-site applications due to potential hazards.

Premixed liquid solutions or dry solid feed chlorination systems are normally most suitable for on-site applications.

Performance

Currently available dry feed chlorine disinfection units have been shown to provide adequate disinfection of various on-site wastewater treatment system effluents. Specific data describing the performance of these units is shown in Table 48 (2,3). Additional data documenting on-site applications of chlorine disinfection of wastewater were not available.

- Number, type, nature, and condition of organisms that are to be killed;
- Wastewater pH and temperature;
- Presence of oxidizable inorganic and organic substances in wastewater (H_2S, Mn^{+2}, NH_3, amino acids, carbohydrates, proteins, etc.); and
- Presence of microorganisms enmeshed in solid material contained in the wastewater (1,2,4-7).

These variables also affect the amount of contact time and therefore the size of the contact chamber required to achieve the desired level of disinfection (1,4,6,7). Overall, bacteria are readily killed by chlorine disinfection, while viruses are somewhat resistant, and spores and cysts are more resistant (6,8).

Due to the inherent variability of influent wastewater characteristics, on-site systems with flow-proportional chlorine feed (yielding constant chlorine dosages) exhibit a wide range of free and combined chlorine residuals and levels of disinfection. Furthermore, many systems are not capable of achieving uniform (flow-proportional) chlorine dosages, consistent levels of disinfection, or chlorine residual. Thus, overdosing is normally required to ensure that the desired level of disinfection is consistently achieved for systems which are not capable of providing consistent chlorine dosages. As a result, high levels of chlorine residual may be found in the effluent.

TABLE 48. DRY FEED CHLORINE DISINFECTION PERFORMANCE

Parameter	Entering Disinfection Unit From:	Flow* Rate (gpd)	Chlorine Dosage (mg/l)	Contact* Time (hrs)+	Disinfection Unit Performance: Influent Log #/100 ml Mean (95% Conf. Int.)	Effluent Log #/100 ml Mean (95% Conf. Int.)	Reduction of Organism Count: Log Units Mean	Percent Mean#
Fecal Coliform	Septic Tank - Sand Filter	200-400	17-36	9-18	2.8 (2.0-3.7)	0.3 (-0.3-1.1)	2.5	99.7
	Septic Tank - Sand Filter	400-800	7-17	4.5-9	3.7 (2.7-4.7)	1.8 (0.7-2.9)	1.9	98.7
	Aerobic Unit - Sand Filter	100-150	18	14-17	3.3 (3.0-3.6)	0.9 (0.5-1.3)	2.4	99.6
Total Coliform	Septic Tank - Sand Filter	200-400	17-36	9-18	3.1 (2.3-4.0)	0.5 (-0.3-1.2)	2 6	99.7
	Septic Tank - Sand Filter	400-800	7-17	4.5-9	4.2 (3.3-5.1)	2.3 (1.0-3.6)	1.9	98.7
	Aerobic Unit - Sand Filter	100-150	18	14-17	4.2 (3.9-4.3)	1.5 (1.0-2.1)	2.7	99.8
Fecal Strepto-cocci	Septic Tank - Sand Filter	200-400	17-36	9-18	1.8 (1.0-2.2)	0.3 (-0.2-1.8)	1 5	96.8
	Septic Tank - Sand Filter	400-800	7-17	4.5-9	2.3 (1.3-3.0)	1.1 (0.3-2.0)	1 2	93.6
	Aerobic Unit - Sand Filter	100-150	18	14-17	2.7 (2.2-3.1)	0.9 (0.5-1.2)	1 8	98.4
Total Bacteria	Septic Tank - Sand Filter	200-400	17-36	9-18	6.8 (5.9-7.8)	5.0 (4.0-5.9)	1 8	98.4
	Septic Tank - Sand Filter	400-800	7-17	4.5-9	7.7 (7.2-8.1)	7.5 (7.0-7.8)	0.2	37.0
	Aerobic Unit - Sand Filter	100-150	18	14-17	6.8 (6.5-7.1)	5.6 (5.1-6.0)	1.2	93.7
Pseudomonas aeruginosa	Septic Tank - Sand Filter	200-400	17-36	9-18	1.4 (0.7-2.1)	0.3 (--)	1 1	92.1
	Septic Tank - Sand Filter	400-800	7-17	4.5-9	—	--	--	--
	Aerobic Unit - Sand Filter	100-150	18	14-17	2.4 (2.0-3.0)	0.7 (0.3-1.1)	1 7	98.0

\# Percent destruction are unchanged from original source (2). Due to unit conversions, discrepancies have resulted
\+ Chlorine residuals typically varied from 0.1 to 1.0 mg/l. although concentrations as high as 160 mg/l were reported
* Flow rates variations caused contact times to vary.

Source: References 2 and 3.

System O&M Requirements

Routine operation and maintenance of premixed liquid feed chlorination systems consists of chemical refills, adjustment of feed quantity, and maintenance of mechanical components two to four times per year. Currently available dry feed chlorination systems require somewhat less frequent chemical refills, but require more frequent chemical feed chamber cleaning to prevent caking of hypochlorite tablets or pellets. Caking problems can cause the system to provide insufficient chlorine dosages, requiring that the equipment be cleaned and the chemicals replaced at least four times per year. Additional unscheduled feed chamber cleanings will still be required. New feed chamber designs may eliminate this problem.

Environmental Acceptability

Levels of combined chlorine residual as low as 0.05 mg/l have been shown to be toxic to aquatic life in receiving waters (9,10). Since measurement of a free chlorine residual is generally required to demonstrate that adequate disinfection has taken place, chlorine disinfection of on-site wastewater effluents may be environmentally undesirable for surface discharge. However, the relatively small flow volumes from on-site systems may be diluted many fold by the receiving waters, in which case the problem is minimized. Disinfection requirements will be determined by state or local regulatory authorities.

Costs

Capital, operation and maintenance, and total annual costs are shown in Table 49.

IODINE

Iodine application to wastewater effluent provides disinfection, as briefly described below.

System Type	System Requirements	Comments
Solid Feed	Tank for iodine crystal storage and saturated iodine solution, with wastewater flow-through provisions (iodine "saturator"), and contact tank. Surge tank and self-priming siphon (or pump and controls) may be used for more accurate dosage control.	Iodine crystal storage must be refilled periodically.
Liquid	Surge tank and self-priming siphon (or pump), solution storage and feed tank, feed	Feed equipment malfunction possible. Liquid solution storage must

TABLE 49. CHLORINATION COSTS

Capital Cost Item	Design Life (yr)	Initial Capital Cost ($)
Vault for chlorination system including excavation and access hatch	20	$ 400
Chlorination unit	10	200
Contact Chamber	20	100
Total Capital Cost		$ 700

Annual O&M Cost Item	Amount	Unit Cost ($)	Annual O&M Cost ($)
Maintenance requirements			
Routine	4 hr/yr	8/hr	$ 32
Unscheduled repairs	2 hr/yr	8/hr	16
Chemical cost (calcium hypochlorite @ 70% available chlorine)	4.75 kg/yr	2.65/kg	13
Total Annual O&M Cost			$ 61

Annual Cost	
Present worth of the sum of the capital costs amortized over 20 years @ 7% interest, discount, and inflation - (factor = 0.09439)	85
Annual O&M Costs	61
Total Annual Cost	$ 146 ∿ $ 150

activation device, and contact tanks. Systems continuously preparing solution on-site must provide iodine crystal storage and mixing tank, and water supply. If water supply for solution is potable water, a cross connection preventer is required. If pH control is required, a second chemical solution storage and feed tank, and feed activation device must be provided.

be refilled periodically. Liquid solutions not widely available commercially, necessitating solution preparation on-site.

Solid feed iodination systems appear most suitable for on-site iodine wastewater disinfection applications. Factors affecting iodine dosages required to achieve a desired level of disinfection are as follows:

- Number, type, nature, and condition of organisms to be killed;
- Presence of oxidizable inorganic and organic substances in the wastewater; and
- Presence of microorganisms enmeshed in solid material contained in the wastewater (6,11,12).

These variables also affect the amount of contact time and therefore the size of the contact chamber required.

Performance

Limited data indicate that iodine "saturators" provide adequate disinfection of effluent from an aerobic treatment unit followed by a holding tank. Analysis of effluents from iodine contact chambers providing approximately 20 min detention times reportedly revealed only trace fecal coliform counts (Personal Communication. L. Waldorf. April 1978.) Virtually no other documentation of iodine disinfection of on-site wastewater treatment system effluents was found.

Data summarizing a recent study which attempted to achieve target fecal coliform counts of 200/100 ml using various secondary and tertiary municipal wastewater treatment system effluents are presented in Table 50 (12). In general, these investigations revealed a strong linear correlation between wastewater turbidity and iodine dosage required to achieve specific effluent fecal coliform counts (12). Municipal wastewater and on-site water disinfection experience (11) indicate that bacteria are readily killed by iodine disinfection while viruses are somewhat resistant and spores and cysts are more resistant (11,13-18).

Since the solubility of iodine in water nearly doubles as temperature increases from 0 to 20°C, the concentration of iodine contained in the

TABLE 50. IODINE PERFORMANCE DATA FOR VARIOUS EFFLUENT TYPES*

(Contact Time - 45 min)

	Iodine		Wastewater Characteristics					Fecal Coliform Count		Reduction of Coliform Count	
Effluent Type	Dosage Applied (mg/l)	Residual (mg/l)	Turbidity (JTU)	TSS (mg/l)	BOD (mg/l)	NH_3-N (mg/l)	Temp. (C°)	Influent (Log #/100 ml)	Effluent (Log #/100 ml)	(Log units) mean	(Percent) mean
Activated Sludge	9.20 (5.79-11.69)	0.64 (0.18-1.64)	7.0 (5.1-12.0)	20.0 (12.7-29.0)	33.6 (25.0-45.0)	14.2 (10.8-18.5)	14.2 (13.0-15 1)	4.9 (4.1-5.3)	2.2 (0 6-3 1)	2.7	99.75
Dual Media Filtered Activated Sludge	5.49 (4.70-6.32)	0.27 (0.10-0.54)	3.8 (2.7- 5.2)	12.9 (9.3-15.7)	9.7 (6.3-15.6)	17.3 (16.0-19.0)	20.0 (19.0-21 1)	4.9 (3.7-5.5)	2 5 (1 0-3.1)	2 4	98.57
Rotating Film Contactor Nitrified Effluent	3.96 (1.84-5.80)	0.65 (0.24-1.50)	2.1 (1.8- 2.3)	6.3 (3.3- 8.7)	9.5 (5.9-14.5)	0.6 (0.9- 2.0)	23.6 (22.4-25.0)	4 2 (3.7-4.6)	3 0 (1 6-3 6)	1.2	81 6
Activated Sludge Nitrified Effluent	2.81 (2.81)	0.26 (0.22-0.30)	1.2 (0.9- 1.6)	2.4 (1.1- 3.6)	3.5 (3.0- 4.0)	0.0 (0.0)	13.6 (13.0-14.2)	2.6 (2.0-3.0)	1 4 (1.0-1 7)	1.2	94.91

* Numbers of parentheses indicate range of data.

Source. Reference 12.

saturated iodine solution feed tank is highly dependent on the wastewater temperature (11,19,20). Thus, flow-proportional feed of a constant strength iodine solution is difficult to achieve. To cope with this and the variability of influent wastewater constituents reacting with iodine, overdosing may be required to consistently achieve adequate levels of disinfection. Manual or automatic control of flow through iodine saturators could reduce the degree of overdosing resulting from increased iodine solubility at higher temperatures (11).

System O&M Requirements

Routine system maintenance (2 to 4 times per year) and chemical refills (once every 1 to 2 years) are required for iodine disinfection systems. As part of the routine maintenance, it may be necessary to adjust the valves controlling flow through the iodine saturator (as discussed above), and to redistribute iodine crystals within the saturator if flow "channelization" through the saturator occurs. Unscheduled maintenance, such as adjustment of the iodine dosage or pump maintenance, is infrequent (Personal Communication. L. Waldorf. April 1978.).

Environmental Acceptability

Although iodine generally does not react with organics present in wastewater to form carcinogens, the toxicity to aquatic life of free iodine residuals and wastewater constituents oxidized by iodine is uncertain (11,18,21). Slight overdosing of effluents intended for reuse should not be a problem (e.g., toilet staining should not occur) (22).

Costs

Capital, operation and maintenance, and total annual costs are shown in Table 51.

OZONE

Use of ozone as a wastewater disinfectant is briefly described below.

System Type	System Requirement	Comments
Injection of ozone generated from pure oxygen gas cylinders	Surge tank, self-priming siphon (or pump), oxygen gas cylinders and regulator, ozone generator controls, ozone injection and contact device and cooling water supply (optional).	Explosion hazard with pure oxygen gas cylinder failure. Gas storage cylinder replacement (refilling) required periodically.
Injection of ozone gener-	Surge tank, self-priming siphon (or pump), ozone generator,	Ozone generators utilizing air as an oxygen

TABLE 51. COST ESTIMATE FOR AN IODINATION UNIT FOR ON-SITE WASTEWATER DISINFECTION

Capital Cost Item	Design Life (yr)	Initial Capital Cost ($)
Vault for iodination system including excavation and access hatch	20	$ 400
Iodinator, (iodine saturator) 8-lb unit	10	300
Contact Chamber	20	100
Total Capital Cost		$ 800

Annual O&M Cost Item	Amount	Unit Cost ($)	Annual O&M Cost ($)
Maintenance Required			
Routine	3 hr/yr	8/hr	$ 24
Unscheduled repairs	1 hr/yr	8/hr	8
Chemical (crude iodine)	2.5 kg/yr	16/kg	40
Total Annual O&M Cost			$ 72

Annual Cost	
Present worth of the sum of the capital costs amortized over 20 years @ 7% interest, discount, and inflation - (factor = 0.09439)	$ 104
Annual O&M Costs	72
Total Annual Cost	$ 176 ~ $ 180

ated from oxygen in ambient air	controls, ozone injection and contact device, and cooling water supply (optional).	source without air preparation equipment require more frequent maintenance and reduce service life.
Injection of ozone generated from oxygen contained in pretreated ambient air	Same as above, with addition of air filter and heatless air dryer.	Air dryer desiccant cartridge refills required periodically.

Air feed ozone generators with or without air preparation equipment are available and appear suitable for on-site wastewater disinfection applications. Dosages required to achieve a desired level of disinfection depend on several factors including:

- Number, type, nature, and condition of organisms that are to be killed;
- Presence of reactive inorganic and organic substances present in the wastewater;
- Presence of microorganisms enmeshed in solid material contained in the wastewater; and
- Method of ozone injection into and contact with the wastewater.

Performance

Virtually no data are available in the literature documenting performance of on-site ozone wastewater disinfection units. Data summarizing a recent study which attempted to achieve target fecal coliform counts of 200/100 ml, using various secondary and tertiary municipal wastewater treatment system effluents are presented in Table 52 (12). These and other investigations revealed the following trends:

- There is a strong correlation (quadratic) between wastewater turbidity and ozone dosage required to achieve specific effluent fecal coliform counts (12);
- Time required for bacterial kill is short, with most bacteria killed within the first three minutes of contact (12,23);
- Dissolved COD, nitrite, and TOC are the primary wastewater constituents that reduce the effectiveness of ozone as a disinfectant. The method of ozone injection and contact is also significant (24,25); and

TABLE 52. OZONE PERFORMANCE DATA FOR VARIOUS EFFLUENT TYPES*

(Contact Time - 1.6 min)

		Wastewater Characteristics					Fecal Coliform Count		Reduction of Coliform Count	
Effluent Type	Ozone Dosage (mg/l)	Turbidity (JTU)	TSS (mg/l)	BOD (mg/l)	NH_3-N (mg/l)	Temp. (C°)	Influent (Log #/100 ml)	Effluent (Log #/100 ml)	(Log Units) Mean	(Percent) Mean
Activated Sludge	13.41 (10.60-14.65)	7.0 (5.1-12.0)	20.0 (12.7-29.0)	33.6 (25.0-45.0)	14.2 (10.8-18.5)	14.2 (13.0-15.1)	4.9 (4.1-5.3)	2 6 (1 3-3 2)	2 3	99 34
Dual Media Filtered Activated Sludge	4.28 (2.94-5.02)	3.8 (2.7-5.2)	12.9 (9.3-15.7)	9.7 (6.3-15.6)	17.3 (16.0-19.0)	20.0 (19.0-21.1)	4.9 (3.7-5.5)	2 4 (2 0-2 7)	2.5	99.02
Rotating Film Contactor Nitrified Effluent	3.58 (2.96-4.04)	2.1 (1.8-2.3)	6.3 (3.3-8.7)	9.5 (5.9-14.5)	0.6 (0.9-2.0)	23.6 (22.4-25.0)	4.2 (3.7-4 6)	2 0 (1 5-2 2)	2 2	99.30
Activated Sludge Nitrified Effluent	3.66 (3.33-4.92)	1.2 (0.9-1.6)	2.4 (1.1-3.6)	3.5 (3.0-4.0)	0.0 (0.0)	13.6 (13.0-14.2)	2 6 (2.0-3 0)	1 1 (0 7-1 5)	1 5	92.02

* Numbers of parentheses indicate range of data.

Source: Reference 12.

- Ozone residuals dissipate to zero within approximately three minutes of injection into the wastewater (12,23,24). Thus, pathogenic regrowth and/or recontamination is possible (6). Additional disinfection may be required if disinfected wastewater is to be stored prior to reuse or recycle. This may be achieved by continuously recirculating the wastewater through the disinfection system, recirculating it immediately prior to reuse, or by the addition of a secondary, residual producing disinfectant.

Although the method of ozone injection into and contact with the wastewater affects the overall efficiency of the disinfection process, performance of the various ozone injection and contact systems for on-site application is largely untested or proprietary in nature.

System Requirements

Routine system maintenance is required two to four times per year if ozone is generated by electrical current. This maintenance consists of cleaning precipitated material (if any) from the ozone generator tubes, and replacing the air dryer desiccant cartridges (if system is so equipped). Generators utilizing air-fed oxygen without air preparation equipment require significantly more frequent maintenance (4 or more times per year) and have a potentially reduced service life since moisture in the air can combine with oxides of nitrogen formed in the generator to produce highly corrosive nitric acid. Additionally, cooling water may be required. Highly skilled personnel are required to maintain these ozone disinfection systems. Frequent unscheduled maintenance, such as desiccant replacement or generator adjustment, is anticipated.

If ozone is generated by UV light, routine replacement of the UV lamp is required annually. This maintenance can be performed by an unskilled serviceman. Infrequent unscheduled maintenance such as desiccant replacement or generator adjustment, is anticipated.

Environmental Acceptability

The explosive potential of pure oxygen feed systems, when considered along with both the positive and negative factors relating to their use (increased ozone generation rates versus frequent gas refills) is likely to inhibit their wide acceptance for on-site applications.

Generally, ozone disinfection is not thought to produce any lasting residual compounds toxic to higher life forms (although additional research is presently being conducted) (6,10,23,25). Since free ozone injected into wastewater dissipates rapidly, ozone disinfection of on-site wastewater treatment system effluents with dosage levels required to ensure adequate disinfection (including possible "overdosing") should be acceptable for direct discharge (providing other discharge requirements are met). However, unreacted ozone gas may destroy adjacent vegetation and other oxidizable materials as a result of prolonged low-level oxidant exposure. (Personal Communication. W. C. Boyle. May 1978.).

Costs

Capital, operation and maintenance, and total annual costs are shown in Table 53.

ULTRAVIOLET IRRADIATION

The use of ultraviolet irradiation to disinfect on-site wastewater effluent is briefly described below.

System Types	System Requirements	Comments
Thin film (thin wastewater layer thickness, high UV intensity, short detention time)	Surge tank, self-priming siphon (or pump), ultraviolet disinfection unit (with lamp emitting UV radiation of 254 nm), and controls.	Periodic UV lamp quartz sleeve cleaning and occasional lamp replacement required. Automatic lamp sleeve wiper systems are available which should reduce the frequency (but not eliminate) cleaning and improve UV radiation transmission between cleanings.
Thick film (thick wastewater layer thickness, low UV intensity, long detention time)	Surge tank, self-priming siphon (or pump), ultraviolet disinfection unit (with lamp emitting UV radiation of 254 nm), and controls.	Same as above, except lamp may not have quartz sleeve. Lamp may require more frequent replacement. Relatively large irradiation chamber required as part of disinfection unit.

Thin film UV disinfection systems appear to be more practical for on-site applications than thick film systems. The dosage of UV irradiation required to achieve a desired level of disinfection depends on several factors, including:

- Nature, type, number and condition of organisms that are to be killed;

- UV lamp intensity;

TABLE 53. OZONATION SYSTEM COSTS

Capital Cost Item	Design Life (yr)	Initial Capital Cost ($)
Vault for ozone generator including excavation and access hatch	20	$ 400
Ozone generation system including tube type generator, controls, air preparation package (filters, compressor and dryer), and injection system and contact chamber	10	1800
Surge tank and self-priming siphon (or pump)	10	200
Total Capital Cost		$ 2400*

Annual O&M Cost Item	Amount	Unit Cost ($)	Annual O&M Cost ($)
Electricity (ozone generator, pumps, compressor and dryer)	160 kwh/yr	0.05 kwh/yr	$ 8
Maintenance			
Routine	4 hr/yr	12/hr	48
Unscheduled	2 hr/yr	lw/hr	24
Water	9100 gal/yr	0.001/gal	9
Desiccant cartridge	1/five yr	75/ea	15
Total Annual O&M Cost			$ 104

Annual Cost	
Present worth of the sum of the capital costs amortized over 20 years @ 7% interest, discount, and inflation - (factor = 0.09439)	415
Annual O&M Cost	104
Total Annual Cost	$ 519 ∿ $ 520

*Price will vary depending primarily on the manufacturer and location. UV generation of ozone will be significantly less expensive (an estimated $150 - $200 total annual cost), but the capacity of current units (single lamp) requires some previous removal of pathogenic organisms. Data on multi-lamp performance was not available.

- Wastewater layer thickness and distance from the UV lamp;
- Wastewater transmissivity; and
- Wastewater detention (exposure) time and flow pattern within the disinfection unit (2,6,25-29).

Performance

Currently available UV disinfection units appear to be capable of providing consistently high levels of disinfection provided that routine maintenance is performed. Data describing the performance of specific on-site thin film UV disinfection units are shown in Tables 54 and 55 (2). Additional data documenting on-site wastewater applications of UV disinfection were not available. It should be noted that these investigations did not present data detailing wastewater transmissivity or power per unit area actually received by the wastewater. In general, these and other investigations revealed:

- Mean log coliform reductions are inversely proportional to wastewater flow rates and directly proportional to wastewater transmissivity (25);
- Suspended solids concentrations as high as 35 mg/l and flow rates as great as 25 l/min (6.5 gpm) did not significantly affect the level of disinfection achieved (2); and
- Wastewater transmissivity is most significantly decreased by the presence of turbidity, color, dissolved organics, and iron (6,28,30).

Overall, bacteria and viruses are most readily killed, while spores and cysts require somewhat higher levels of UV energy and detention times (28). It should be noted that pathogenic regrowth or recontamination of UV disinfected wastewater is possible since UV irradiation does not produce a residual capable of providing long-term disinfection. Additional disinfection may be required if disinfected wastewater is to be stored prior to reusing or recycling. This may be achieved by continuously recirculating the wastewater through the disinfection system, recirculating it immediately prior to reuse, or by the addition of a secondary residual-producing disinfectant.

System O&M Requirements

Periodic manual cleaning (at least 3 times per year) of accumulated materials is required to restore transmissivity of the UV lamp and/or the quartz sleeve surrounding the UV lamp to its initial level for systems in which the equipment is in contact with the wastewater. Cleaning is required more frequently for systems which receive wastewater intermittently, but operate the UV lamp continuously. Automatic mechanical wiper systems for cleaning UV lamp sleeves are commercially available, and their use should reduce the frequency of periodic manual cleanings to twice or less per year. (Personal Communication. D. Sauer. Feb. 1978.) However, operation of

TABLE 54. ULTRAVIOLET DISINFECTION UNIT DESCRIPTION

Unit	Intensity Watts o @ 2,537 A	Effective Length (cm)	Disinfection Chamber		
			Wastewater Film Thickness (cm)	Quartz Sleeve O.D. (cm)	Chamber Wall I.D. (cm)
A	15	75	2.5	2.4	7.3
B	10.2	30.5	1.0	5.6	7.6

SOURCE: (2)

TABLE 55. ULTRAVIOLET DISINFECTION UNIT PERFORMANCE

Parameter	Disinfection Unit Letter (VIII-11a)	Wastewater Enters Unit From	Flow Rate (l/min)	Detention Time (sec)	Estimated Theoretical Power Per Unit Area (Design)* (W sec/cm²)	Disinfection Unit Performance: Influent Log #/100 ml mean	Effluent Log #/100 ml mean	Reduction of Organism Count: Log Units mean	Percent mean
Fecal Coliform	A	aerobic unit - sand filter	15	11	75,000	0 88	<0.0	>0 88	>8 6
	A	septic tank - sand filter	15	11	75,000	2.94	-0.11	3 05	99.91
	A	aerobic unit (submerged media)	7.5 -15	11- 22	75,000- 150,000	4 85 (3.52-6 0)	1 45 (-0 43-2.78)	3.40 (2 16-6.40)	99.96
	B	ultrafiltration (blackwater only)	0.19- 0.57	70-220	750,000-2,500,000	4 4** (0 3 -5.5)	2 8** (0 0 -5 1)	1 6** (0 -4 8)	97 3** (0 -100)
Total Coliform	A	aerobic unit - sand filter	15	11	75,000	1 53	<0.0	>1 53	>97
	A	septic tank - sand filter	15	11	75,000	3 07	0 01	3 06	99 91
Fecal Streptococci	A	aerobic unit - sand filter	15	11	75,000	1 31	-0 17	1.48	96 7
	A	aerobic unit - sand filter	15	11	75,000	2 56	-0.21	2 77	99 8
	A	aerobic unit (submerged media)	7.5 -15	11- 22	75,000- 150,000	4 01 (3 36-5 33)	0.70 (-0 70-2 90)	3 31 (1 67-4 14)	99 95
Total Bacteria	A	aerobic unit (submerged media)	7.5 -15	11- 22	75,000- 150,000	8 85 (8 37-9 46)	5.58 (3.93-7 07)	3 27 (2 13-4.14)	99 95
Pseudomonas aeruginosa	A	aerobic unit (submerged media)	7 5 -15	11- 22	75,000- 150,000	4 26 (3 11-6 4)	0 94 (0 30-2 73)	3 32 (-0 43-5 08)	99.95
Poliovirus 1	A	septic tank - sand filter	15 liter batch	11	75,000	4 6++	<0 0++	>4 6	>99 997

* Wastewater transmissivity and power per unit area actually received were not measured
** Median of data presented
++ Units = log PFU/ml.

Source (2)

currently available lamp cleaning equipment requires a source of air or water pressure, and results in additional capital and O&M costs. Development of electrically operated wiper systems could potentially provide adequate lamp sleeve cleaning at reduced capital and O&M costs.

Periodic lamp replacement (approximately every 7,500 hours of continuous operation) is required for all UV disinfection systems. More frequent replacement is required if the output is reduced to an unacceptable level due to "solarizing" of the lamp surface. In general, occasional unscheduled service (such as lamp cleaning) one or more times per year can be expected for on-site UV disinfection systems.

Environmental Acceptability

Generally, ultraviolet disinfection is not thought to produce any lasting residual compound toxic to higher life forms, although additional research is presently being conducted (25). Thus, UV disinfected wastewater should be acceptable for direct discharge, providing other discharge requirments are met.

Costs

Capital, operating and maintenance, and total annual costs for on-site UV disinfection systems are shown in Table 56.

DISINFECTION COMPONENT COMPARISONS

Disinfection comparisons for components with available hardware and sufficient on-site performance information to permit detailed evaluation are presented in Table 57. Comparisons for components with available on-site hardware but insufficient on-site performance information shown in Table 58 are based on engineering judgment and should be reevaluated when data become available.

TABLE 56. ULTRAVIOLET DISINFECTION SYSTEM COSTS

Capital Cost Item	Design Life (yr)	Initial Capital Cost ($)
Vault for UV disinfection unit including excavation and access hatch	20	$ 400
UV disinfection unit and controls	10	550
Surge tank and self-priming siphon (or pump)	10	200
Total Capital Costs		$1150

Annual O&M Item	Amount	Unit Cost ($)	Annual O&M Cost ($)
Electricity	65 kwh/yr	0.05/kwh	$ 3
Maintenance			
Routine	3 hr/yr	8/hr	24
Unscheduled	1 hr/yr	8/hr	8
UV lamp replacement	1/five yr	75/ea	15
Total Annual O&M Costs			$ 50

Annual Cost	
Present worth of the sum of the capital costs amortized over 20 years @ 7% interest, discount, and inflation - (factor = 0.09439)	179
Annual O&M Costs	50
Total Annual Costs	$ 229 ∿ $ 230

TABLE 57. DISINFECTION COMPONENT COMPARISON FOR COMPONENTS WITH SUFFICIENT INFORMATION*

Ranking Group	Component	Component Ranking Factor Ratings: Performance (5 max.)	O&M Requirements (5 max.)	Environmental Acceptability (3 max.)	Total (13 max.)	Total Annual Cost ($)
A	Ultraviolet	5	3	3	11	230
	Chlorine	4	3	1	8	150
	Iodine	4	4	2	10	180
B	Ozone	5	2	1	8	520

* For components with sufficient on-site performance information and hardware available to permit detailed evaluation. See Component Ranking Criteria for explanation of the ranking system.

TABLE 58. DISINFECTION COMPONENT COMPARISON FOR COMPONENTS WITH INCOMPLETE INFORMATION*

Ranking Group	Components	Component Ranking Factor Ratings: Performance (5 max.)	O&M Requirements (5 max.)	Environmental Acceptability (3 max.)	Total (13 max.)	Range of Annual Cost($)
A	Ultraviolet plus ozone+	5	3	3	11	150-250
B	Halogen mixtures	4	3	1	8	250-350
	Gamma ray	5	2	1	8	500-700
	Ultraviolet plus halogens	5	2	2	9	300-600
	Halogen plus ozone	5	1	1	7	500-650
C	Heating	5	2	3	10	1500+

* For components with available on-site hardware, but insufficient on-site performance information. This comparison is based on engineering judgement and is subject to revision when data becomes available.

\+ Ozone generated by specialized UV lamp.

REFERENCES

1. Metcalf and Eddy, Inc. Wastewater Engineering: Collection, Treatment and Disposal. McGraw-Hill, New York, 1972. pp. 353-363.

2. Small Scale Waste Management Project. Management of small waste flows. Appendix A. Wastewater characteristics and treatment. EPA-600/2-78-173. U.S. Environmental Protection Agency, Cincinnati, Ohio, September 1978. 764 p.

3. Sauer, D.K. Dry feed chlorination of wastewater on-site. University of Wisconsin, Madison, Small Scale Waste Management Project, 1976. 16 p.

4. Clark, J.W., W. Veissman, and M.J. Hammer. Water Supply and Pollution Control. 2d. ed. International Textbook Company, Scranton, Pennsylvania, 1972. 674 p.

5. General Electric Corporation. Water recovery and solid waste processing for aerospace and domestic applications. Volume II. Final report. GE Document No. 73SD 4236, Valley Forge Space Center, Philadelphia, Pennsylvania, 1973. pp K1-K8.

6. Weber, W.J., Jr. Physicochemical Processes for Water Quality Control. Wiley-Interscience, New York, 1972. pp. 413-456.

7. Fair, G.M., J.C. Geyer, and D.A. Okum. Water and Wastewater Engineering. Wiley, New York, 1966-68. 2 vols.

8. Pelczar, M.J., Jr. and R.D. Reid. Microbiology. 2d. ed. McGraw-Hill, New York, 1965. 670 p.

9. Zillich, J.A. Toxicity of combined chlorine residuals to freshwater fish. J. Water Pollut. Control Fed., 44:212, 1972.

10. Ward, R.W., R.D. Giffin, G.M. DeGraeve, and R.A. Stone. Disinfection efficiency and residual toxicity of several wastewater disinfectants. EPA-600/2-76-156, Municipal Environmental Research Laboratory, Cincinnati, Ohio. 146 p. (Available from National Technical Information Service (NTIS) as PB-262 245.)

11. Cook, B. Iodine dispenser for water supply disinfection. Equipment Development and Test Report 7400-1, U.S. Forest Service, San Dimas, California, Equipment Development Center, January 1976. 21 p.

12. Budde, P.E., P. Nehm, and W.C. Boyle. Alternatives to wastewater disinfection. J. Water Pollut. Control Fed., 49(10):2144-2156, October 1977.

13. Chang, S.L. and J.C. Morris. Elemental iodine as a disinfectant for drinking water. Ind. Eng. Chem. 45(5);1009-1012, 1953.

14. Gershenfeld, L. Iodine as a vircidal agent. J. Am. Pharm. Soc., Sci. Ed., 44(3): 177-182, 1955.

15. Black, A.P., R.N. Kinman, W.C. Thomas, Jr., G. Freund, and E.D. Bird. Use of iodine for disinfection. J. Am. Water Works Assoc., 57(11): 1401-1421, 1965.

16. Cramer, W.N., K. Kawata, and C.W. Kruse. Chlorination and iodination of poliovirus and f2. J. Water Pollut. Control Assoc., 48(1):61-76, January 1976.

17. Berg, G. S.L. Chang, and E.K Harris. Devitalization of microrganisms by elemental iodine. I. Dynamics of the devitilization of enteroviruses by elemental iodine. Virology, 22:469-481, 1964.

18. Cook, B. Using iodine to disinfect water supplies. In: Individual Onsite Wastewater Systems; Proceedings of the Fourth National Conference, Ann Arbor, Michigan, October 1977. Ann Arbor Science Publishers, Ann Arbor, Michigan, 1978. pp. 217-226.

19. Allen, T.L. and R.M. Keefer. The formation of hypoiodous acid and hydrated iodine cation by the hydrolysis of iodine. J. Am. Chem. Soc., 77:2957-2960, 1955.

20. Hughes, W.L. The chemistry of iodination. Am. N.Y. Acad. Sci., 70(1):3-18, August 30, 1957.

21. Morgan, D.P. and J.P. Karpen. Test of chronic toxicity of iodine as related to purification of water. U.S. Armed Forces Med. J., 4:725-728, 1953.

22. Sax, N.I. Dangerous Properties of Industrial Materials. 4th ed. Van Nostrand Reinhold, New York, 1975. 1258 p.

23. Ghan, H.B., C.L. Chen, and R.P. Miele. The significance of water quality of wastewater disinfection with ozone. In: International Ozone Institute Disinfection Symposium Proceedings, Chicago, Illinois, June 2-4, 1976. pp. 46-65.

24. Nebel, C., R.D., Gottschling, R.L. Hutchison, T.J. McBride, D.M. Taylor, J.L. Pavoni, M.E. Tittlebaum, H.E. Spencer, and M.

Fleischman. Ozone disinfection of industrial-municipal secondary effluents. J. Water Pollut. Control Fed., 45(12):2493-2507, December 1973.

25. U.S. Environmental Protection Agency. Technology transfer notes. Environmental Research Center, Cincinnati, Ohio, October 1977. 10 p.

26. Huff, C.B., H.F. Smith, W.D. Boering and N.A. Clarke. Study of ultraviolet disinfection of water and factors in treatment efficiency. Public Health Rep., 80(8):695-705, 1965.

27. Berg, G. Removal of viruses from sewage effluent and waters. Bull. W.H.O. 49:451-460, 1973.

28. Nazy, R. Water sterilization by ultraviolet radiation. Research Report BL-R-6-1059-3023-1, Westinghouse Electric Company, Pittsburgh, Pennsylvania, Lanys Division, 1955.

29. Municipal Wastewater Reuse News No. 2. American Water Works Research Foundation, Denver, Colorado, November, 1977.

30. Hoover, P.R., K.J. McNalty, and R.L. Goldsmith. Evaluation of ultrafiltration and disinfection for treatment of black water. U.S. Army Mobility Equipment Research and Development Command, Fort Belvoir, Virginia, 1977. 47 p.

SECTION 9

DISPOSAL OPTIONS

GENERAL

On-site wastewater treatment system effluents may be discharged to the atmosphere, surface water, soil or combinations. Soil disposal, in the form of a "conventional" soil absorption field, is by far the most common and accepted on-site disposal method. However, site-specific limitations often make other methods of disposal necessary or desirable. Disposal options and their applicability to on-site systems are summarized in Table 59. The options with available on-site hardware and performance data are discussed below, except incineration which was covered in Section 5.

ATMOSPHERE DISPOSAL

As shown in Table 59, atmosphere disposal may be accomplished by a variety of means. However, evapotranspiration (ET) is the only method listed with available on-site hardware and performance information which discharges exclusively to the atmosphere. Mechanical evaporator pilot studies have been conducted, and additional hardware development is planned. Evaporative lagoons are generally unlined, and are discussed under COMBINATIONS of disposal methods.

Evapotranspiration

ET disposal is most likely to be used in situations where direct discharge or soil disposal is not feasible and adequate net evaporation potential is available. The primary ET configuration options are indicated below.

System Type	System Requirements	Comments
Built to existing grade	Distribution piping, impervious liner, gravel, sand (with appropriate capillary rise characteristics), and selected vegetation (tolerant of moisture extremes).	Aesthetically most acceptable. Evapotranspiration must exceed precipitation in all months or storage facilities are required.
Mounded	Same as above.	Mounded to reduce precipitation infiltration; effectiveness is variable. Eva-

TABLE 59. DISPOSAL OPTIONS

Generic Type	Performance: Selected Constituents Affected	Performance: Adequacy	O&M Requirements: Frequency of Scheduled Maintenance (#/yr)	O&M Requirements: Hardware Complexity	O&M Requirements: Equipment Failure (requiring unscheduled service)	Environmental Acceptability (potential hazards and nuisances)	Range of Total Annual Cost ($)*
AIR							
- evapotranspiration (lined)	BOD, SS, N, P, microbiological	consistent	≤ 1	simple	infrequent		300-700+
- lined evaporation lagoon	BOD, SS, N, P, microbiological	potentially consistent	2-4	simple	infrequent	odor and aesthetics	200-350
- mechanical evaporation	BOD, SS, N, P, microbiological	potentially consistent	>4	moderate	unknown	aesthetics	600
- thermal evaporation	BOD, SS, N, P, microbiological	potentially consistent	>4	moderate - complex	unknown	air emissions	1000
SOIL							
- soil absorption							
.. "conventional"	SS, BOD, P, N microbiological	consistent	0	simple	infrequent	groundwater quality impacts	50-150
. modified distribution	SS, BOD, P, N microbiological	consistent	≤ 1	simple	infrequent	groundwater quality impacts	100-250
.. soil modification	SS, BOD, P, N microbiological	consistent	≤ 1	simple	infrequent	groundwater quality impacts	200-450
- irrigation							
. drip	SS, BOD, P, N microbiological	potentially consistent	2-4	simple	unknown	odors, health effects, aesthetics	100-200
.. spray	SS, BOD, P, N microbiological	consistent	2-4	simple	unknown	odors, health effects, aesthetics	150-250
.. overland flow	SS, BOD, P, N microbiological	potentially consistent	2-4	simple	unknown	odors, health effects, aesthetics	100-200
SURFACE WATER							
- direct discharge	none	consistent	≤ 1	simple	infrequent	BOD and SS < 30 mg/l, stream water quality, and effluent toxicity	10-50
COMBINATIONS							
- evapotranspiration/ absorption	SS, BOD, P, N microbiological	consistent	≤ 1	simple	infrequent	groundwater quality impacts	200-350
- unlined lagoons	SS, BOD, P, N microbiological	consistent	2-4	simple	infrequent	odor, aesthetics and groundwater quality impacts	150-300
- lagoon w/overflow	SS, BOD, P, N microbiological	consistent	2-4	moderate	infrequent	BOD and SS $\leq$ 30 mg/l stream water quality, effluent toxicity, odor and groundwater quality impacts	200-350

*Amortized capital cost plus annual operation and maintenance costs Does not include cost of pretreatment.

		potranspiration must exceed precipitation in all months or storage facilities are required.
Covered	Same as above, plus transparent covering.	Designed to expand the climate range for which ET disposal is feasible.

Additional options incorporating other methods of disposal, such as unlined ET beds, are discussed under COMBINATIONS.

Performance--

The performance of ET beds depends primarily on appropriate sizing, which depends on local ET potential. In addition, appropriate selection of cover vegetation and the use of sand with adequate capillary rise characteristics are important. A variety of methods are available for estimation of ET potential, including:

- Blaney-Criddle method (1)
- Jensen-Haise method (2)
- Penman method (3)
- Priestley and Taylor method (4)

However, the accuracy of these methods in predicting ET varies with location (5,6). Thus, use of these methods for determining ET bed size will result in variable performance. In addition, there are significant differences of opinion between researchers on the effects of advection, wastewater heat, biological heat production, wastewater quality and vegetation cover on ET rates (5,7,8). Thus, field data are currently recommended for optimal ET bed design.

Field data on determination of ET rates are currently rather limited, although additional field investigations are currently in progress.(Personal Communication. H.J. Pence, F.G. Longry, L. Pasaren, and K. Lomax. December 1977, April 1978, February 1978, and February 1978, respectively.) Data from 21 months of testing in Colorado and observation of field installations in Colorado and elsewhere, indicate that ET disposal is effective. However, the reported range of climatic conditions in which ET is effective varies considerably (Personal Communication. H.T. Pence. December 1977) (7,8,). Data from Colorado indicate that provision of necessary wastewater storage capacity is impractical in areas where evaporation does not exceed precipitation by at least 5 cm (2 in.) in every month of the year (8).

Salt accumulation occurs in ET beds as a result of dissolved solids contained in the wastewater applied. Observations of ET beds which have been in operation for 5 years indicate no major problems associated with salt accumulation. Salt accumulation is particularly pronounced at the surface of the ET bed during dry periods (although it is redistributed by rainfall) and could potentially have an adverse effect on vegetation after a long period of use (8).

System O&M Requirements--

Routine maintenance of a properly designed and constructed ET disposal unit is normally required only if wastewater is pumped to the ET unit. Pump and level control inspection and adjustment is normally required annually. Unscheduled maintenance, such as repair of level control apparatus, is required infrequently.

Environmental Acceptability--

Depending on specific system characteristics, including the vegetation utilized, the size of the system and the extent of site grading required, visual aesthetics may be a problem for some installations. Otherwise, ET disposal generally presents no nuisance or hazard.

Costs--

Capital, operation and maintenance, and total annual costs are shown in Table 60 for an ET bed without provisions for long-term storage.

SOIL DISPOSAL

On-site disposal of wastewater to the soil may be accomplished by use of a "conventional" soil absorption field (also called "leach field." "disposal field" or "drainfield"); a variety of soil modification techniques (i.e., mounds); modified distribution approaches (i.e., dosing and resting or pressure distribution); or irrigation. In certain areas where groundwater is deep, especially in some western states, seepage pits are used instead of a "conventional" soil absorption field. The function of each of these soil disposal methods normally is to provide treatment as well as disposal of the wastewater applied. In general, soil disposal is considered to perform adequately if it absorbs all the wastewater applied, provides an acceptable degree of treatment before the wastewater reaches the groundwater, and has a reasonably long life (approximately 20 yrs) (9).

Conventional Soil Absorption Fields

The characteristics of conventional soil absorption field configuration options are indicated below.

System Type	System Requirements	Comments
Trench system	Distribution piping and aggregate.	Most common type of on-site disposal.
Bed system	Distribution piping and aggregate.	Applicability generally limited to sites with rela-

TABLE 60. ET BED COSTS*

Capital Cost Item	Amount	Design Life (yr)	Installed Unit Cost ($)	Capital Cost ($)
Sand	260 m^3	20	7.5/m^3	1,950
Plastic liner	475 m^2	20	1.1/m^2	520
Distribution piping	190 m	20	4/m	760
Gravel	30 m^3	20	7.5m^3	225
Excavation	290 m^3	20	1.1/m^3	320
Pump and controls	1	10	250	250
Pumping Chamber	1	20	300	300
				$4,325
Total Capital Cost				$4,325

Annual O&M Cost Item	Amount	Unit Cost ($)	Annual O&M Cost ($)
Maintenance required			
Routine	2 hr	10/hr	20
Unscheduled repairs	0.5 hr	10/hr	5
Total Annual O&M Cost			$25

Annual Cost	
Present worth of the sum of the capital costs amortized over 20 years @ 7% interest, discount and inflation (factor = 0.09439)	432
Annual O&M Cost	25
Total Annual Cost	$457
	~ $460

* Costs are presented for 465 m^2 (5,000 ft^2), 0.6 m (2 ft) deep ET bed (the size typically required for a residence in Boulder, Co.). Availability and therefore the cost of appropriate sand is a significant variable. It addition, provision of storage capacity for extended periods will significantly increase the cost. Bed size varies substantially with climate.

tively coarse grained soils since the permeability of these soils is not adversely affected by construction practices.

Specific characteristics vary widely, including:

- Aggregate size;
- Type of distribution piping;
- Trench or bed dimensions and overall size; and
- Trench configurations (i.e., continuous, parallel, etc.).

Performance--

Studies of conventional soil absorption field longevity and ability to accept wastewater indicate that field performance depends on a variety of site specific factors, including:

- Soil percolation rate;
- Depth of unsaturated soil;
- Slope;
- Soil type;
- Design and construction practices;
- Influent wastewater characteristics; and
- Hydraulic loading rate (10-21).

Although effective removal of all wastewater contaminants in the soil system is important for the protection of groundwater quality (and surface water quality where groundwater and surface water contact), public health concerns center primarily on the effectiveness of the soil in removing the bacteria, viruses, phosphorus and nitrogen. Detailed discussion of the factors affecting the removal of these constituents in the soil system are available in the literature (12,22,23).

In general, the extent to which pathogens are removed by soil depends on several factors, including:

- Soil moisture;
- Soil texture;
- Soil type;
- Soil temperature;
- pH;
- Biological interactions; and
- Application rates.

Unsaturated flow conditions, higher temperatures, finer soil particle size and development of a clogging mat at the infiltrative surface all tend to facilitate pathogen removal. Coarse-grained soils generally have the lowest capacity for pathogen removal. However, laboratory studies indicate effective pathogen removal is achieved in 0.6 m (2 ft) of coarse-grained soil following development of a biological mat. Under saturated flow conditions without the biological mat, adequate pathogen removal may not be realized (23).

Ammonia is oxidized to nitrate under aerobic soil conditions, except in some fine textured soils where ammonia is retained by complexing with the soil. Nitrates are generally mobile and free to percolate through the soil and into the groundwater, although denitrification in the soil will occur under some conditions. Dilution is the principal means of alleviating harmful nitrate concentrations in the underlying groundwater. In the areas where the density of soil absorption fields is high and/or other sources of nitrate input to the groundwater are significant, nitrate contamination of the groundwater may be a problem.

In general, "conventional" soil absorption fields have been shown to perform well at sites in soils with measured percolation rates less than 24 min/cm (<60 min/in.); with a depth to groundwater or bedrock of at least 0.9 m (3 ft), and with level or gently sloping topography (9). However, many systems which provide adequate treatment and disposal have also been installed under a wide variety of other conditions (Personal Communication. J. Abney and J.T. Winneberger. March 1978.).

System O&M Requirements--

Maintenance of a properly designed and constructed conventional soil absorption field is normally not required. However, rehabilitative maintenance (i.e., "regeneration") or replacement will be required for "failing" systems. Regeneration, such as treatment with hydrogen peroxide, or replacement may be accomplished by an unskilled laborer under the direction of a trained and experienced supervisor.

Environmental Acceptability--

A properly designed and constructed soil absorption field preceded by pre-treatment for removal of settleable and floatable solids, generally presents no hazard or nuisance. However, nitrate contamination of groundwater may be a problem in regions with a high density of soil absorption systems. The density level at which soil absorption systems may pose a health hazard is dependent on soil and groundwater characteristics and has not been quantified. Where nitrate contamination of groundwater is the primary concern, a reduction in nitrogen loading could be accomplished by pretreatment or segregation and containment of blackwater.

Costs--

The principal factors determining the capital cost of a soil absorption field include the size, trench width, trench depth and aggregate costs. Costs have been reported to range from \$10.75-\$22.60/m^2 (\$1.00-\$2.10/ft^2) (24). For the purposes of this study, a value of \$16/m^2 (\$1.50/ft^2) will be used for cost estimation purposes. Thus for a range of soil absorption field size of 35 to 93 m^2 (375 to 1000 ft^2), the capital cost is $560 to $1500. Annual O & M costs are considered to be negligible. Based on a 20 year service life for the absorption field, the total annual cost range is $53 to $142.

Soil Modification Absorption Fields

In many areas of poor site suitability for conventional subsurface disposal (shallow, permeable soils over creviced or porous bedrock; permeable soils with seasonally high groundwater; or, in some cases, slowly permeable soils), additional satisfactory soil material may be provided in order to achieve proper treatment of the wastewater and provide a controlled infiltration rate to the native soil. The most common approaches to soil modification with subsurface application are briefly described below:

System Type	System Requirements	Comments
Mound with bed distribution	Pumping chamber, pump and controls (or dosing siphon if site topography is appropriate), sand, gravel, and distribution piping.	For sites with excessively or moderately permeable soils (with high groundwater or shallow creviced or porous bedrock).
Mound with trench distribution	Same as above.	For sites with slowly permeable soils.

Site specific characteristics, particularly soil type, soil depth, soil percolation rate, and slope, will determine important design features such as bed or trench dimensions, trench spacing, and overall disposal area dimensions (23, 25-27).

In areas which would be suitable for conventional subsurface disposal except for shallow groundwater, it may be possible to artificially divert the groundwater to lower the water table. At such sites where diversion is effective, conventional soil absorption systems could be used. (Personal Communication. J. Abney. October 1978.)

Performance--

In general, modified soil treatment and disposal systems are considered to perform satisfactorily if surface seepage is absent and groundwater quality is protected. Mound designs developed in Wisconsin (23, 25-27) have been used to construct several hundred mounds in the state. (Personal Communication. J. Harkin. May 1978.) Performance data for four prototype mound field installations based on a preliminary design are presented in Table 61. As shown, the mounds generally achieved significant reductions in BOD, COD, total nitrogen and coliform levels (28,29). However, seepage was observed at two of the mounds despite actual loading rates being significantly below the design

TABLE 61. MOUND PERFORMANCE DATA

	BOD	COD	NH_4	NO_3	Total N	Fecal Coliform	Fecal Streptococcus	Total Coliforms
	mg/l					numbers/ml*		
Mound I								
Influent*	141(19)**	323(20)	42(13)	2.5(15)	58(11)	3,900(22)	3(21)	19,000(23)
Seepage at toe of mound	12(1)	166(2)	0.4(2)	1.5(2)	3.7(2)	0.5(4)	1.5(10)	2.4(7)
Not detected+	--	--	--	--	--	5	1	0
Mound II								
Influent*	107(19)	249(20)	34(15)	5(16)	50(13)	5,900(21)	46(2[illegible])	39,000(20)
Seepage at toe of mound*	11(1)	140(3)	2.7(3)	2.3(3)	6.2(3)	5.8(2)	0.8(3)	9.7(4)
Not detected	--	--	--	--	--	5	3	3
Mound III								
Influent*	97(19)	217(19)	33(11)	0.5(13)	40(10)	12,000(20)	240(18)	59,000(19)
Liquid within mound at toe	13(4)	57(3)	0(2)	17(2)	18(2)	1.0(9)	0.6(6)	17(6)
Not detected	--	--	--	--	--	0	2	0
Mound V								
Influent*	90 ± 35	256 ± 80	56 ± 9	<1	--	2,500(14)#	100(13)#	37,000(15)#
Collection - dike	0	42	2 ± 1++	54 ± 6++	--	5(7) <0.02(4)	1.8(9) <0.02(3)	54(13)

* Geometric mean values are reported.
\+ Not detected (ND) indicates the number of bacteriological samples with negative results i.e., <0.1 organisms/ml.
\# Median values obtained from log-probability graphs.
** Numbers in parentheses indicate the number of samples.
\++ Values reported for May sampling as NH_4-N and NO_3-N + NO_2-N. Values for December were significantly different (30 ppm NO_3, 6 ppm NH_4).

Source Ref. 28 and 29.

loading rates. Seepage was attributed to a lack of surface soil plowing and uneven distribution of flow.

More recently constructed mounds based on an improved design have provided improved levels of treatment and significantly reduced the occurrence of seepage (due in large part to improved methods of soil preparation prior to construction and use of pressure- distribution systems). Mound designs developed in Pennsylvania and North Dakota have also been successfully used for on-site wastewater treatment and disposal. However, quantitative data on their performance has not yet been assembled. (Personal Communication. J. Harkin. May 1978.)

System O&M Requirements--

Operation and maintenance requirements of mounds or similar modified soil treatment and disposal methods are limited to the pump and associated controls which are normally required to lift wastewater from preceding buried treatment units into the elevated mound. Routine maintenance is required annually for pump and control inspection and preventive maintenance. Unscheduled maintenance, such as repair of level control equipment, is required infrequently. Necessary maintenance can normally be performed by semi-skilled personnel.

Environmental Acceptability--

A properly designed and constructed mound preceded by appropriate pre-treatment (i.e., septic tank), generally presents no hazard or nuisance. Occasionally, the appearance of a mound may be objectionable to a homeowner, but this can normally be minimized through landscaping. In certain areas, nitrate contamination of groundwater by mound systems may be a concern. However, the land area requirements of mound systems normally preclude their use in high density areas. In addition, nitrogen removal could be accomplished by pretreatment or segregation, if required to protect groundwater quality.

Since mounds rely on the underlying topsoil in addition to the imported fill material to provide the necessary degree of wastewater treatment, the pathogen content of seepage from a mound would pose a health hazard. However, mounds are designed to prevent seepage and experience in Wisconsin indicates that seepage has occurred at only a very few of the several hundred mounds constructed based on the Wisconsin design. Where seepage has occured, improper fill material was used, except in one instance. (Personal Communication. J. Harkin & R.J. Otis. May and October, 1978.)

Costs--

Capital, operation and maintenance, and total annual costs are shown in Table 62 for the three most common mound applications.

TABLE 62. MOUND COSTS

Capital cost item	Design life (yrs)	Installed Unit Cost($)	Mound over shallow excessively permeable soils*	Mound over shallow moderately permeable soils*	Mound over slowly permeable soils*
Piping	20	4/m	150	175	200
Pump and controls	10	250	250	250	250
Pumping chamber	20	300	300	300	300
Aggregates:					
Sand	20	$7.5/m^3$	1,200	1,600	3,000
Gravel	20	$7.5/m^3$	200	200	200
Equipment rental	—	—	200	200	200
Total Capital Cost			$2,300	$2,725	$4,150
Annual O&M Cost Item					
Maintenance requirements					
Routine (at $10/hr)			20	20	20
Unscheduled repairs (at $10/hr)			5	5	5
Electricity (at $0.05/kwh)			2	2	2
Total Annual O&M Cost			$27	$27	$27
Annual Cost					
Present worth of the sum of the cost amortized over 20 years @ 7% interest, discount and inflation (factor = 0.09439)			240	281	415
Annual O&M Cost			22	22	22
			$262	$303	$437
Total Annual Cost			~$260	~ $300	~ $440

* Based on designs provided in ref. 25-29 on sites with zero percent slope.

Soil Absorption Fields with Modified Distribution

In an effort to increase the loading rate of soil absorption fields and to improve the treatment provided, several modified distribution systems have been developed, as described below:

System Type	System Requirements	Comments
Pressure distribution	Pumping chamber, pump and controls, and distribution piping (appropriately sized and perforated).	Applicable to mounds as well as "conventional" systems. Most often used to improve treatment by maintaining unsaturated flow conditions. Achieves dosing and resting and provides a flexible dose/rest schedule.
Dosing and resting	Dosing tank, self-priming siphon and distribution piping (pump may be required in place of siphon, depending on site topography).	Resting period is usually several hours to a day. Intended to increase the quantity of wastewater absorbed per unit area and/or the life of the absorption field. Allows biochemical oxidation of clogging mat during rest cycle.
Alternating fields	Dosing tank, self-priming siphon and distribution piping (pump may be required in place of siphon, depending on site topography).	Resting period generally ranges from several months to one year. Intended to increase the quantity of wastewater absorbed per unit area and/or increase the life of the absorption field. Allows biochemical oxidation of clogging mat during rest cycle.
Proprietary systems	Varies with manufacturer; most utilize concrete chambers or cells of various configurations.	Effectiveness generally unproven; some system have poor performance record.

Performance--

Pressure distribution systems have been shown to achieve uniform wastewater distribution throughout a soil absorption field (23). Uniform distribution can provide unsaturated flow conditions and correspondingly improved treatment, which is particulary important in coarse-grained soils where adequate treatment under saturated conditions may not be achieved prior to the development of the clogging mat (30).

Uniform distribution may also be important in a dosing and resting distribution system, depending on the soil characteristics, although adequately uniform distribution may be achievable through the use of siphons and gravity piping systems. The magnitude of potential performance advantages (decreased field size and/or extended life) of dosing and resting as compared to conventional absorption fields is unclear. Some laboratory studies report improved infiltration rates with intermittent wastewater application (31-34). Other laboratory studies indicate that a greater wastewater volume is absorbed through continuous ponding (35) or that decreased infiltration is obtained with short-term alternating aerobic-anaerobic conditions (33). Data from the first 10-months of an ongoing field study indicate that daily dosing of wastewater to an experimental soil absorption field prevented development of a clogging mat, while data from other sites indicate that clogging would normally have been expected (36).

Potential performance improvements associated with dosing and resting systems are unclear not only as a result of conflicting study conclusions, but also because of the following factors:

- An insufficient number of long-term field studies have been conducted;
- Laboratory methods differ from study to study;
- Most laboratory studies utilize columns with impervious sides, thus ignoring the side wall infiltration and aeration of field systems, and making extrapolation of laboratory data to the field particularly suspect;
- Wide variations in the resting periods investigated;
- Failure of many investigations to report the total quantity of wastewater absorbed over extended periods; and
- Differences in soil texture and structure.

System O&M Requirements--

Routine operation and maintenance requirements of modified distribution systems are limited to annual inspection and preventive maintenance of the dosing siphon or pump and control mechanisms. Unscheduled maintenance of the pump or siphon is required infrequently. Both siphon and pump system maintenance require semi-skilled maintenance personnel.

Environmental Acceptability--

The environmental acceptability of soil absorption fields with modified distribution is at least comparable to a conventional field. In the event that a modified distribution approach improves treatment in excessively permeable soils or improves the performance of a "failing" field, the environmental acceptability is improved.

Costs--

Capital, operation and maintenance, and total annual costs are shown in Table 63 for alternating fields, gravity dosing and resting, and dosing and resting with pressure distribution.

Irrigation

On-site disposal of wastewater by irrigation has been practiced on a limited basis using the specific options described below.

System Type	System Requirements	Comments
Spray irrigation	Pump and controls, pumping chamber distribution piping, sprinkler heads and drain check valves.	Open or forest land may be used. Pretreatment required varies with location.
Drip irrigation	Pump and controls, pumping chamber distribution piping (appropriately sized and perforated for uniform application) and drain check valves.	Distribution system may be buried or exposed. Most applicable to landscaped areas.

Both types of irrigation systems provide both wastewater treatment and disposal. Design and operation characteristics are generally dependent on the same characteristics described above for conventional soil absorption fields. In addition, runoff control must be included.

Performance--

Quantitative data on on-site irrigation disposal system performance were not available. In certain areas (e.g., Kentucky), spray irrigation of settled aerobic effluent, both with and without filtration and disinfection, from combined wastewater systems has been practiced for at least five years. These systems are reportedly functioning well. Specifically, no runoff is observed from systems with application rates of less than 1.0 cm (0.4 in.) per day and soil samples reportedly indicate fecal coliform removal within the top 0.3 m (1 ft) of soil. (Personal Communication. P. Cuffe. May 1978.)

Drip irrigation systems are significantly less common, and the on-site performance of these systems is even less well documented than for spray systems. However, experience with larger applications indicates adequate on-site performance is likely.

For both types of irrigation systems, extended periods (several weeks) of sub-freezing temperatures may result in runoff due to freezing of the soil surface and temporary loss of infiltration capacity.

TABLE 63. MODIFIED DISTRIBUTION COSTS

Capital Cost Item	Design Life (yrs)	Alterating fields	Dosing and resting w/gravity distribution	Dosing and resting w/pressure distribution
Conventional SAS	20	840-2250+	560-1500*	560-1500*
Alternating valves	20	150	--	--
Dosing chamber	20	-	250	250
Dosing siphon	10	-	150	-
Pump and controls	10	-	-	250
Total Capital Cost		$990-2400	$960-1900	$1060-2000
Annual O&M Cost Item				
Maintenance requirements				
Routine (at $10/hr)		10	10	20
Unscheduled repairs (at $10/hr)		-	5	5
Electricity (at $0.05/kwh)		-	-	5
Total Annual O&M Cost		$10	$10	$30
Annual cost				
Present worth of the sum of the capital cost amortized over 20 years @ 7% interest, discount and inflation (factor = 0.09439)		93-226	105 194	123-212
Annual O&M Cost		10	15	30
		$103-236	$120-209	$153-242
Total Annual Cost		~$100-240	~$120-210	~$150-240

* Based on a cost of $16/m² ($1.50/ft²) of trench and a range of trench size required of 35 to 93 m² (375 to 1000 ft²).

** Based on a cost of $16/m² ($1.50/ft²) of trench and a range of trench size required of 53 to 140 m² (563 to 1500 ft²). Range of trench size required will vary with local requirements. For comparison purpose it is assumed that each field is 75% as large as a conventional soil absorption field.

System O&M Requirements--

Equipment associated with irrigation systems is moderately complex, and thus requires that operation and maintenance personnel have some training. Routine preventive maintenance of the pump and control mechanisms is required on an annual basis. Infrequent unscheduled repairs may be required as a result of pump or controls breakdown, check valve malfunction or similar mechanical failures. (Personal Communication. P. Culfe. May 1978.) Spray and drip irrigation systems are slightly more likely to require unscheduled maintenance resulting from sprinkler-head or ejector valve clogging.

Environmental Acceptability--

The environmental acceptability of irrigation is highly variable depending on several factors, including:

- Irrigated wastewater quality;
- Site topography;
- Depth to groundwater;
- Soil characteristics;
- Available buffer areas; and
- Type of cover crop.

Irrigation systems which apply a disinfected aerobic effluent to open fields or woodlands reportedly present no nuisance or hazard, especially if application is performed at night (to minimize potential for human contact). However, the potential for odors, health effects and undesirable appearance is significantly greater than for subsurface disposal.

Spray or surface drip irrigation of non-disinfected effluents may occasionally be acceptable if large buffer areas are available and access is restricted to reduce the potential health hazards.

Costs--

Capital, operation and maintenance and total annual costs are shown in Table 64.

SURFACE DISCHARGE

Direct discharge of on-site treatment system effluent is a disposal option if an appropriate receiving water is available. If a receiving water is available, the level of treatment required may vary depending on local regulations, stream water quality requirements and other site-specific conditions. For the purposes of this study, it is assumed that on-site treatment system effluent disposed by surface discharge must at least meet secondary treatment standards of 30 mg/l BOD and SS and have coliform levels less than 230 #/100 ml. Depending on site-specific conditions, more stringent BOD and SS discharge requirements and/or limitations on N and P discharges may be applicable.

TABLE 64. IRRIGATION COSTS

Capital Cost Item	Design life (yrs)	Costs ($) Spray irrigation	Drip irrigation
Distribution piping	20	450	450
Pump and controls (or siphon)	10	250	250
Pumping chamber	20	300	300
Sprinkler heads and/or miscellaneous hardware	10	100	50
Site preparation (berms and grading)	20	--	--
Total Capital Cost		$1,100	$1,050
Annual O&M Cost Item		Annual O&M Cost ($)	
Maintenance requirements			
Routine (at $10/hr)		50	35
Unscheduled repairs (at $10/hr)		20	10
Electricity (at $0.05/kwh)		5	5
Total Annual O&M cost		$75	$50
Annual Cost			
Present work of the sum of the capital costs amortized over 20 years @ 7% interest, discount and inflation (factor = 0.09439)		135	120
Annual O&M Cost		75	50
Total Annual Cost ($)		$210	$170

The performance, operation and maintenance requirements, and environmental acceptability of surface discharge disposal are predominantly dependent on the preceding treatment system. These characteristics of on-site treatment options are identified in Sections 5-8. Operation and maintenance requirements associated specifically with surface discharge disposal may include infrequent routine or unscheduled cleaning of the effluent pipe, and pump maintenance, if gravity conveyance to the receiving water is not practical. For the subsequent cost estimate it is assumed that gravity conveyance is used. In addition, monitoring will likely be required, but the parameters and frequency will vary with applicable regulations.

Surface discharge of on-site treatment system effluent is currently used for disposal at several locations in Kentucky, as well as in other areas of the country. Monitoring data reportedly indicates that some preceding treatment systems can provide effluent which meets secondary discharge requirements. (Personal Communication. L.E. Waldorf and J.W. Leake. May 1978.) In addition, no maintenance has been required on the gravity conveyance systems used for surface discharge.

The cost of surface discharge conveyance systems depends on site-specific factors such as the distance to the receiving water, the ease of excavation, labor rates, and depth of excavation required. Assuming an average trench depth of 1 m (3 ft), and a length of 18 m (60 ft), the estimated capital cost is $180. Amortized at 7 percent interest over 20 years, the annual cost is $18. O&M costs associated with conveyance are insignificant. Monitoring costs will be highly variable.

COMBINATIONS

As shown in Table 59, some methods of on-site wastewater disposal use combinations of air, water and/or soil disposal. The combination disposal methods most frequently used are evapotranspiration/absorption, unlined evaporative lagoons and lined or unlined lagoons with discharge to surface waters. Lagoons which discharge to surface waters are discussed in Section 6.

Evapotranspiration/Absorption

Evapotranspiration/absorption (ETA) disposal of on-site wastewater in unlined evapotranspiration disposal systems, as briefly described below, is in use at several thousand locations in North America (8). In addition, "conventional" soil absorption systems may use ET as well as absorption for on-site wastewater disposal, especially if shallow trenches are used.

System Type	System Requirements	Comments
ETA	Distribution piping, gravel, sand (with appropriate capillary rise properties), top soil and selected vegetation (tolerant of moisture extremes).	Avoids possible salt accumulation problems; may be used where net ET is negative in some months without pro-

viding storage capacity; and generally requires less land area than ET disposal

Performance--

Quantitative data on the performance of ETA disposal were not available. Since ET and soil disposal can perform adequately under appropriate climate and soil conditions, respectively, it is anticipated that ETA disposal will also perform adequately if soil percolation rates, net ET potential, sand characteristics (with the necessary capillary rise characteristics) and vegetation cover are appropriately coordinated in the design. The presence of thousands of functioning systems also indicates that ETA disposal can perform adequately; however, the extent of evapotranspiration in combined disposal systems has not been determined (8).

Field data on ET rates is desirable for design of ETA disposal units to ensure adequate performance. A careful analysis of the potential relative contributions from ET and soil absorption is required in the design of such a system. If winter net ET rates are negligible, designing to maximize ET may not be justified.

System O&M Requirements--

Routine maintenance of a properly designed and constructed ETA disposal unit is normally required only if wastewater is pumped to the ETA disposal unit. Pump and level control inspection and adjustment is normally required annually. Unscheduled maintenance, such as repair of level control apparatus, is required infrequently.

Environmental Acceptability--

ETA disposal generally presents no nuisance or hazard. Depending on specific system characteristics, including the vegetation utilized, size of the system, and height of mound (if that configuration is employed), visual aesthetics may be a problem for some installations. Otherwise, ETA disposal appears environmentally acceptable.

As with soil disposal, nitrate contamination of groundwater may be a concern in some instances, depending on site-specific factors such as the density of systems, aquifer and soil characteristics and depth to groundwater.

Costs--

Capital, operation and maintenance, and total annual costs per unit area are approximately the same as those for ET disposal (shown in Table 60). However, the size and thus the cost, of an ETA disposal unit will be less than an ET unit for the same climatic conditions. The cost difference will be primarily a function of the soil percolation rate. In general, the capital and total annual costs of most ETA installations is in the range of $1,500 to $3,000, and $200 to $350, respectively.

Lagoons

As metioned in Section 6, lagoons may be utilized for both on-site wastewater treatment and disposal applications. System requirements for lagoons designed for disposal by evaporation and soil absorption are summarized below:

System Type	System Requirements	Comments
Evaporation/ Infiltration lagoon	Bermed lagoon, inlet pipe and support, and fence	Berm must designed to permit surface runoff from entering lagoon. Odor, vector, aesthetic, safety and groundwater quality considerations may affect environmental acceptability.

Performance--

Quantitative data on the performance of evaporation/infiltration lagoons were not available. However, several investigations have reported that this type of lagoon provides adequate treatment and disposal of on-site wastewater when pretreatment with a septic tank is provided (38-40). In all cases, adequate disposal depends on soil characteristics, net evaporation and proper lagoon sizing. Adequate treatment depends primarily on soil and groundwater characteristics and groundwater depth.

System O&M Requirements--

Routine maintenance includes trimming vegetation and adding water to maintain the desired water depth during the summer (approximately 2 to 4 times per year). Maintenance may also include sludge removal from the lagoon. The frequency of sludge removal will depend on the pretreatment provided, wastewater characteristics, lagoon design, and operation and maintenance. In general, sludge removal is anticipated to be required very infrequently (every five or more years). Unscheduled maintenance, such as repair of the inlet pipe or berms, is required very infrequently.

Environmental Acceptability--

Odor, vector, and aesthetic nuisances may affect the environmental acceptability of lagoons. Lagoon configuration utilizing rounded corners and steep interior slopes should help to reduce development of stagnant water and growth of vegetation below the water level, thus reducing odor and vector nuisances. Aethetics may be improved by screening with plants or fences. A fence is advisable in any case to keep small children and animals out of the area. As with other soil disposal methods, groundwater quality may be adversely affected if the lagoon design or location is inappropriate.

Cost--

Capital, operation and maintenance, and total annual costs are estimated in Table 65.

DISPOSAL COMPONENT COMPARISONS

Disposal comparisons for components with available hardware and sufficient on-site performance information to permit detailed evaluation are presented in Table 66. Comparisons for components with available on-site hardware but insufficient on-site performance information shown in Table 67 are based on engineering judgment and are subject to revision when data become available.

TABLE 65. EVAPORATION/INFILTRATION LAGOON COSTS

Capital Cost Item	Design Life (yr)	Capital Cost ($)
Lagoon, including excavation installation of inlet pipe and support, and seeding of berm	20	1000-2500*
Fencing (at $5/m)	20	150-350
Total Capital Cost		$1150-2850
Annual O&M cost Item	**Unit cost ($)**	**Annual O&M Cost ($)**
Maintenance required		
Routine	8/hr	32
Unscheduled	0.5/hr	4
Total Annual O&M cost		$ 36
Annual Cost		
Present worth of the sum of the capital costs amortized over 20 years assuming 7% interest, discount and inflation (factor=0.09438)		108-269
		36
Total Annual Cost		$144-305 ~$140-310

* In general, these lagoons range from 93 to 260m^2 (1000 to 3000 ft^2) and cost approximately \$10.75/m^2 (\$1.00/ft^2), depending on climate, soil infiltration capacity, and the quantity of wastewater handled.

TABLE 66

DISPOSAL COMPONENT COMPARISON FOR COMPONENTS WITH SUFFICIENT INFORMATION*

Ranking Group	Component	Ranking: Performance (5 max.)	Ranking: O&M Requirements (5 max.)	Ranking: Environmental Acceptability (3 max.)	Ranking: Total (13 max.)	Total Annual Cost ($)
A	Conventional soil absorption	4	5	3	12	50-150
	Pressure distribution soil absorption	4	4	3	11	150-240
	Soil modification absorption (mound)	4	4	2	11	260-440
	Evapotranspiration/absorption	4	4	2	10	200-350
B	Evaporation/Infiltration lagoon	4	4	1	9	140-310
	Irrigation (disinfected effluent)	3	4	2	9	170-210
	Evapotranspiration	3	5	2	10	460

* For components with sufficient on-site performance information and hardware available to permit detailed evaluation. Section 3 for explanation of the ranking system. Costs do not include pretreatment.

TABLE 67

DISPOSAL COMPONENT COMPARISON FOR COMPONENTS WITH INCOMPLETE INFORMATION*

Ranking Group	Component	Performance (5 max.)	Ranking: O&M Requirements (5 max.)	Environmental Acceptability (3 max.)	Total (13 max.)	Total Annual Cost ($)
A	Alternating fields	4	5	3	12	100-240
	Dosing & resting soil absorption (w/no pumping)	4	4	3	11	120-240
	Evaporation lagoon (lined)	4	4	2	10	200-350
	Mechanical evaporation	4	3	2	9	600+

* For components with available on-site hardware, but insufficient on-site performance information. This comparison is based on engineering judgement and should be reevaluated when data becomes available. Costs do not include pretreatment.

REFERENCES

1. Blaney, H.F. and W.D. Criddle. Determining consumptive use and irrigation water requirements. Technical Bulletin 1275, U.S. Department of Agriculture, Washington, D.C. 1962. 59 p.

2. Jensen, M.E. and H.R. Haise. Estimating evapotranspiration from solar radiation. J. Irrig. Drainage Div., Am. Soc. Civ. Eng., 89 (IR 4): 15-41, 1963.

3. Jensen, M.E., H.G. Collins, R.D. Burman, A.E. Gibbs, and A.I. Johnson. Consumptive use of water and irrigation water requirements. Technical Report. Irrig. Drainage Div., Am. Soc. Civ. Eng., New York, New York, 1974. 215 p.

4. Priestly, C.H.B. and R.J. Taylor. On the assessment of surface heat flux and evaporation using large-scale parameters. Mon. Weather Rev., 100:81-92, 1972.

5. Tanner, C.B. and J. Bouma. Influence of climate on subsurface disposal of sewage effluent. University of Wisconsin, Madison, Small Scale Waste Management Project, 1975. 16 p.

6. Hasfurther, V.R., D.H. Foster, and G.D. Lloyd. Sizing an evapotranpiration waste disposal system for summer operation. In: Proceedings of the Second National Home Sewage Treatment Symposium, Chicago, Illinois, December 12-13, 1977. American Society of Agricultural Engineers. St. Joseph, Michigan, 1978. pp. 175-184

7. Bernhardt, A.P. Treatment and disposal of wastewater from homes by soil infiltration and evapotranspiration. University of Toronto Press, Toronto, Canada, 1973. 173 p.

8. Bennett, E.R. Sewage disposal by evaporation transpiration; draft final report. EPA Grant No. R803871-01-0, University of Colorodo, Boulder, 1978. 170 p.

9. Otis, R.J., G.D. Plews, and D.H. Patterson. Design of conventional soil absorption trenches and beds. In: Proceedings of the Second National Home Sewage Disposal Symposium, Chicago, Illinois. December 12-13, 1977. American Society of Agricultural Engineers, St. Joseph, Michigan, 1978. pp. 86-99.

10. Hill, D.E. and C.R. Frink. Longevity of septic tank systems in Connecticut soils. Bulletin 747, Connecticut Agricultural Experiment Station, New Haven, 1974. 22 p.

11. Clayton, J.W. An analysis of septic tank survival data from 1952 to 1972 in Fairfax County, Virginia. J. Environ. Health, 36(6):562-567, 1974.

12. Tyler, E. J., R. Laak, E. McCoy, and S.S. Sandhu. The soil as a treatment system. In: Proceedings of the Second National Home Sewage Treatment Symposium, Chicago, Illinois, December 12-13, 1977. American Society of Agricultural Engineers, St. Joseph, Michigan, 1978. pp. 22-37.

13. Viraraghaven, T. and R. G. Warnock. Groundwater quality adjacent to a septic tank system. J. Am. Water Works Assoc., 65(11):611-614, November 1976.

14. Robeck, G.G., J.M. Cohen, W.J. Sayers, and R.L. Woodward. Degradation of ABS and other organics in unsaturated soils. J. Water Pollut. Control Fed., 35(10):1225-1236. October 1963.

15. Pitt, W.A.J. Jr. Effects of septic tank effluent on groundwater quality, Dade County, Florida; an interim report. Ground Water, 12(6):353-355, 1974.

16. Guan, E.L., H.R. Sweet, and J.R. Illian. Subsurface sewage disposal and contamination of groundwater in East Portland, Oregon. Ground Water, 12(6):356-368, 1974.

17. Reneau, R.B., Jr., and D.E. Pettry. Movement of coliform bacteria from septic tank effluent through selected coastal plain soils of Virginia. J. Environ. Qual. 4(1):41-44, 1975.

18. Reneau, R.B., Jr. and D.E. Pettry. Movement of methylene blue active substances from septic tank effluent through two coastal plain soils. J. Environ. Qual., 4(3):370-375, 1975.

19. Reneau, R.B., Jr., J.H. Elder, Jr., D.E. Pettry, and C.W. Weston. Influence of soils on bacterial contamination of a watershed from septic sources. J. Environ. Qual. 4(2):249-252, 1975.

20. Schwartz, W.A. and T.S. Bendixen. Soil system for liquid waste treatment and disposal; environmental factors. J. Water Pollut. Control Fed., 42(4):624-630, April 1970.

21. Walker, W.G., J. Bouma, D.R. Keeney, and F.R. Magdoff. Nitrogen transformations during subsurface disposal of septic tank effluent in sands. II. Groundwater quality. J. Environ. Qual., 2(4):521-525, 1973.

22. Miller, F.P. and D.C. Wolf. Renovation of sewage effluents by the soil. In: Individual Onsite Wastewater Systems; Proceedings of the Second National Conference, Ann Arbor, Michigan, November 1975. Ann Arbor Science Publishers, Ann Arbor, Michigan, 1977. pp. 89-118.

23. Small Scale Waste Management Project. Management of small waste flows. Appendix B. Soil absorption of wastewater effluents. EPA-600/2-78-173. U.S. Environmental Protection Agency, Cincinnati, Ohio, September 1978. 764 p..

24. Machmeier, R.E. Design criteria for soil treatment systems. Scientific Journal Series Paper No. 9358, Minnesota Agricult. Experiment Station, St. Paul, 1975. 21 p.

25. Converse, J.C., R.J. Otis, J. Bouma, W. Walker, J. Anderson and D. Stewart. Design and construction procedures for mounds in slowly permeable soils with or without seasonally high water tables. University of Wisconsin, Madison, Small Scale Waste Management Project, March 1976. 19 p.

26. Converse, J.C., R.J. Otis, J. Bouma, W. Walker, J. Anderson and D. Stewart. Design and construction procedures for fill systems in permeable soils with shallow creviced or porous bedrock. University of Wisconsin, Madison, Small Scale Waste Management Project, March 1976. 17 p.

27. Converse, J.C., R.J. Otis, J. Bouma, W. Walker, J. Anderson and D. Stewart. Design and construction procedures for fill systems in permeable soils with high water tables. University of Wisconsin, Madison, Small Scale Waste Management Project, March 1976. 17 p.

28. Bouma, J., J.C. Converse, R.J. Otis, W.G. Walker, and W.A. Ziebell. Mound system for on-site disposal of septic tank effluent in slowly permeable soils with seasonally perched water tables. J. Environ. Qual., 4(3):382-388, 1975.

29. Bouma, J., J.C. Converse, and F.R. Magdoff. A mound system for disposal of septic tank effluent in shallow soils over creviced bedrock. In: Proceedings of the International Conference on Land for Waste Management, Agricultural Institute of Canada, Ottawa, 1973. pp. 367-378.

30. Converse, J.C., J.L. Anderson, W.A. Ziebell, and J. Bouma. Pressure distribution to improve soil absorption systems. In: Proceedings of the National Home Sewage Disposal Symposium, Chicago, Illinois, December 9-10, 1974. American Society of Agricultural Engineers, St. Joseph, Michigan, 1975. pp. 104-115.

31. McGauhey, P.H. and J.H. Winneberger. A study of methods of preventing failure of septic-tank percolation systems. SERL Report No. 65-17,

University of California, Berkeley, Sanitary Engineering Research Laboratory, 1965. 31 p.

32. McGauhey, P.H. and R.B. Krone. Soil mantle as a wastewater treatment system; final report. SERL Report No. 67-11, University of California, Berkeley, Sanitary Engineering Research Laboratory 1967. 153 p.

33. Thomas, R.E., W.A. Schwartz, and T.W. Bendixen. Soil chemical changes and infiltration rate reduction under sewage spreading. Soil Sci. Am. Proc. 30(5):641-646, 1966.

34. Bendixen, T.W., M. Berk, J.P. Sheehy, and S.R. Weibel. Studies on household sewage disposal systems. Part II. Environmental Health Center, Cincinnati, Ohio, 1950. 94 p.

35. Kropf, F.W., R. Laak and K.A. Healey. Equilibrium operation of subsurface absorption systems. J. Water Pollut. Control Fed., 49(9): 2007-2016, 1977.

36. Bouma, J., J.C. Converse, and F.R. Magdoff. Dosing and resting to improve soil absorption beds. Trans. Am. Soc. Agric. Eng., 17(2): 295-298, 1974.

37. Hines, M.W., E.R. Bennett, and J.A. Hoehne. Alternate systems for effluent treatment and disposal. In. Proceedings of the Second National Home Sewage Treatment Symposium, Chicago, Illinois, December 12-13, 1977. American Society of Agricultural Engineers, St. Joseph, Michigan, 1978. pp. 137-148.

SECTION 10

COMPARATIVE ANALYSIS

METHODOLOGY

The approach used to develop on-site wastewater treatment and disposal systems and the technical ranking criteria used in the comparative analysis of these systems are described in Section 3. The systems developed according to this approach for each of the 15 site conditions (see Table 3) considered are presented in Appendix A. The methodology used to evaluate the systems identified and the resulting conclusions are presented here.

As discussed in Section 3, alternative systems are evaluated in three separate categories:

- Systems with available hardware and on-site performance data;
- Systems with available hardware but incomplete (if any) on-site performance data; and
- Systems without hardware appropriate for on-site application, which therefore require further development.

Systems in the first two categories are evaluated using technical criteria and the total annual cost (rounded to the nearest $50). Technical ranking of systems in the first category was based on operating experience, while ranking of systems in the second category was based on engineering judgment and is subject to revision when data become available. System concepts requiring further development are discussed qualitatively.

Comparative evaluation of the systems presented in Appendix A was based primarily on the component comparisons developed in Sections 5-9. First, the top-ranked components (both those with available hardware and performance data, and those with only available hardware) were identified from the component comparisons in Sections 5-9 for each of the general component categories (i.e., filtration, aerobic biological treatment, disinfection, etc.) used in the Appendix A matrices. Next, the top-ranked components in each general category were used to define each system alternative (A,B,C, etc.) identified in the matrices. These systems were then reviewed to identify the top ranked systems (five or less) for each site condition. For systems with the same technical ranking, those with a total annual cost of $250 more than the least expensive system were not generally included as top-ranked systems.

Some systems were identified for which there was available hardware and performance data for all of the system components, but not for the system as a whole. In these instances, engineering judgment of component compatability was used to determine whether the system should be considered to have available performance data. Systems employing components shown to be adaptable to various influent wastewater characteristics were generally classed as having available performance data. Where less was known about the impacts of influent wastewater characteristics on one or more system components, the systems were considered to have inadequate performance data.

System ranking was based on the concept that a system would get the ranking of the lowest ranked component for each of the ranking criteria unless the combination of components in the system improved their performance, O&M requirements and/or environmental acceptability. For example, ranking of a system consisting of a septic tank followed by low pressure membrane filtration with direct discharge disposal was as follows:

	Ranking Criteria				
Components	Performance	O&M	Environmental Acceptability	Total	Annual Cost ($)
Septic tank	4	5	3	12	50
Low pressure membrane filtration	5	2	3	10	430
Direct discharge	-	-	-	-	20
System Total	5	2	3	10	$500

As shown, the system receives an O&M ranking of 2 since the combination of components does not reduce the O&M requirements of the membrane filtration unit. However, the system gets a performance ranking of 5 since it consistently provides a level of treatment significantly superior to the normal direct discharge requirements of 30 mg/l BOD and SS, as a result of the membrane filtration unit.

Estimated costs are generally based on the cost data presented in Sections 5-9. However, simple addition of the total annual costs for each system component to obtain the total cost of a system was often inappropriate for two reasons. First, specific equipment such as vaults, surge tanks, and pumps included in component cost estimates may be duplicated unnecessarily for some systems. Similarly, equipment in addition to that specified in component cost estimates may be required for some systems. In these instances, the sum of the component costs was adjusted to reflect appropriate equipment modifications.

Secondly, the sum of annual O&M labor requirements for components assembled into a system is sometimes inappropriate (usually too high) for the system as a whole. In these instances, the O&M requirements have been adjusted to more accurately reflect the total system.

SYSTEM RANKING - HARDWARE AND PERFORMANCE DATA AVAILABLE

The top-ranking systems identified with available hardware and performance data are described in Table 68. For the site conditions considered, the following general conclusions are drawn from Table 68:

- Septic tank - conventional soil absorption field is the top-ranked and least cost system where site characteristics permit its use.
- Where shallow soils (0.3-1.2 m) are encountered which would not provide adequate treatment for a conventional soil absorption field, septic tank - mound systems are the top-ranked and least cost systems if adequate land area is available. Flow reduction may be used to minimize area requirements and cost.
- Use of flow reduction - holding tank - off-site disposal is the top-ranked and least cost system only where topography prevents "area intensive" construction and direct discharge is not feasible, or where depth to bedrock or groundwater is less than 0.3m (1 ft) and direct discharge and ET disposal are not feasible. Even with flow reduction, costs are very high.
- ET disposal (with septic tank pretreatment) is top ranked and least cost system where disposal to the soil and direct discharge are not feasible, and EVP-PPT is greater than 5 cm/mo (2 in/mo).
- Disposal by direct discharge is the top-ranked method where soil and ET disposal are not feasible, or where limited land area is available for disposal and sufficient flow reduction is not feasible. The top-ranked and least cost tretment for direct discharge is a septic tank - covered intermittent or recirculating gravity sand filter - disinfection pretreatment system if nutrient discharges are not limited. If nitrogen discharge is limited (<10 mg/l) and 10 mg/l BOD and SS is required, a septic tank - covered intermittent or recirculating gravity sand filter - fixed growth anaerobic reactor - disinfection is the top-ranked treatment system. If phosphorus is also limited (<2 mg/l), use of the same system with a sand/"red mud" filter substituted for the sand filter and/or elimination of phosphate detergents is the top ranked treatment system. Nitrogen may also be significantly reduced through the use of a non-water carriage or recirculating toilet system, but variable household wastewater characteristics make consistent achievement of effluent nitrogen concentrations <10 mg/l uncertain.
- Septic tank - soil absorption with pressure distribution systems are the top-ranked and least cost systems where soils are excessively permeable.

TABLE 68. TOP RANKED SYSTEMS - HARDWARE AND PERFORMANCE DATA AVAILABLE

Number	Description	System	Performance	O & M	Environmental Acceptability	Total	Estimated Total Annual Costs ($)	Comments
1	Acceptable soil depth and percolation available land 372 m² evaporation minus precipitation (EVP-PPT) 5 cm/mo	1 Septic tank (ST) conventional soil absorption system (SAS)	4	5	3	2	150	ST SAS system is preferred due to lower cost lagoon is the least desirable primarily due to nuisance and potential hazard considerations
		2 Septic tank evapotranspiration/absorption (ETA)	4	4	3	11	300	
		3 Septic tank evapotranspiration/infiltration lagoon	4	4		4	250	
	Shallow (0 3 1 2m) soils with acceptable percolation available land 93 372 m² EVP PPT 5 cm/mo	1 Septic tank mound	4	4	2	10	350	Variability of ET performance with climate limited availability of general applicable design criteria possibility that flow reduction will be required (depends on climate) and higher costs make either mound system preferable The relative advantages of mound & ETA (mounded) systems are uncertain
		2 Septic tank evapotranspiration/absorption (mounded)	4	4	2	0	350	
		3 Flow reduction septic tank evapotranspiration (ET)	3	4	2	9	450[c]	
3	Acceptable soil depth but marginal percolation available land 93 m²; EVP PPT >5 cm/mo	1 Flow reduction-holding tank off site disposal	4	4	3	10	1200[e]	Marginal soil percolation and very limited available land limit on site disposal
4	Acceptable soil depth and percolation; available land <93 m² direct discharge feasible EVP-PPT >5 cm/mo	1 Flow reduction-septic tank conventional soil absorption system	4	5	3	12	150[c]	Adequate performance of ST SAS system depends on consistent and significant (40 percent) flow reduction which should be achievable (see Section 5 especially Table 13) ST ETA system performance also depends on flow reduction (25 percent) ST SF DIS DD system does not require flow reduction but is more costly and requires significantly more maintenance
		2 Flow reduction-septic tank evapotranspiration/absorption	4	5	2	11	300[c]	
		3 Septic tank-sand filter[a] disinfection[b] direct discharge (DD)	4	3	2	9	450	
5	Acceptable soil depth and percolation available land 93 372 m² EVP PPT 5 cm/mo slope 25%	1 Flow reduction holding tank off site disposal (by tank truck)	4	3	3	10	1200[e]	Topography (slope) limits on site disposal
6	Shallow (0 3-1 2m) soils with marginal percolation available land >372 m² EVP-PPT <2 5 cm/mo	1 Septic tank -mound	4	4	2	10	450	ST-mound systems is preferred since it requires less maintenance and is less susceptible to climatic effects
		2 Septic tank sand filter[a] disinfection[b] irrigation	4	3	2	9	550	
7	Very shallow (<0 3 m) soils with marginal percolation available land >372 m² EVP-PPT 2 5 cm/mo	1 Flow reduction- holding tank off site disposed (by tank truck)	4	3	3	10	1200[e]	Shallow soil (<0 3m) limits on-site disposal
8	Shallow (0 3 1 2 m) soils with marginal percolation available land 93 372 m² EVP-PPT <2 5 cm/mo	1 Flow reduction septic tank mound	4	4	2	10	450[c]	ST-mound preferred due to lower cost and maintenance requirements Disinfection is assumed to be required for irrigation due to limited land available for disposal (93 372 m²) Flow reduction (10 to 40 percent) is required depending on exact amount of available land
		2 Septic tank sand filter[a] disinfection[b] irrigation	4	3	2	9	550	
9	Very shallow (<0 3 m) soils with marginal percolation available land 93 372 m² EVP PPT< 2 5 cm/mo	1 Flow reduction holding tank off site disposed (by tank truck)	4	3	3	10	1200[e]	Shallow soil (<0 3m) limits on-site disposal
10	Limiting soil percolation available land< 93 m² slope >25% direct discharge feasible EVP-PPT 5 cm/mo	1 Septic tank sand filter[a]- disinfection[d] direct discharge	4	3	2	9	450	Limiting soil and net ET requires off site disposal ST SF DIS-DD is best available and least costly system
11	Limiting soil percolation available land 93 372 m² EVP-PPT> 5 cm/mo	1 Septic tank evapotranspiration	3	4	2	9	500	Limiting soil and infeasible direct discharge makes ET disposal the technically and economically preferable alternative Liner is not required due to tight soils and adequate soil depth ST is adequate and the least expensive method of pretreatment Flow reduction not required but should provide significant savings in ET capital cost
12	Limiting soil percolation available land 93 372 m² direct discharge feasible (BOD & SS 10 mg/l N<10 mg/l EVP PPT <2 5 cm/mo	1 Septic tank sand filter[a] fixed growth anaerobic reactor (for denitrification) (DEN) disinfection[d] - direct discharge	4	3	2	9	650	Limiting soil and net ET requires off site disposal Direct discharge is least costly disposal method and ST SF DEN-DIS is least costly and at least technically equal to available options Ability of segregated system to meet the 10 mg/l nitrogen limitation depends on homeowner habits and the resulting wastewater characteristics
		2 Waterless toilet (WT) septic tank & sand filter[a] disinfection[b] - direct discharge for greywater	3	3	1	7	600	
13	Limiting soil percolation available land > 372 m² direct discharge feasible (BOD & SS 10 mg/l N<10 mg/l P 2 mg/l) EVP PPT 2 5 cm/mo	1 Waterless toilet (WT) septic tank- sand filter[a] disinfection[b] direct discharge for greywater	3	3	1	7	600	Ability of segregated system to meet the 10 mg/l nitrogen limitation depends on homeowner habits and the resulting wastewater characteristics Limiting soil and net ET requires off site disposal Use of phosphorus free detergents should eliminate the need for red mud (not available in many areas) in the segregated system and will at least reduce maintenance requirements and may eliminate "red mud" from the combined system
		2 Septic tank sand/ red mud" filter fixed growth anaerobic reactor (for denitrification) disinfection direct discharge	4	3	2	9	700	
14	Shallow (0 3-1 2m) soils with excessive percolation available land< 93 m²; EVP PPT< 2 5 cm/mo	1 Flow reduction septic tank mound	4	4	2	10	300[c]	Other methods of subsurface disposal require substantially increased levels of pretreatment and therefore significantly higher costs Flow reduction required is on the order of 15 percent and therefore should be readily achievable
15	Shallow (0 3-1 2m) soils with excessive percolation available land 93-372 m² EVP-PPT 2 5 cm/mo	1 Septic tank-soil absorption with pressure distribution	4	4	3	11	200	Pressure distribution providing unsaturated flow conditions has been shown to provide the required treatment under these conditions Alternatives are significantly more costly
		2 Septic tank mound	4	4	2	10	300	
		3 Septic tank sand filter[a] conventional soil absorption system	4	3	3	10	300	

a Covered intermittent or recirculating gravity filter
b Iodine chlorine or ultraviolet (UV) disinfection
c Does not include cost of flow reduction which varies with hardware and percent flow reduction to be achieved
d Iodine or UV disinfection
e Tank truck removal for off site disposal cost assumes 560 l/d (150 gal/day) and $0 005/l ($0 02/gal) hauling and disposal cost
f The following treatment unit options are appropriate extended aeration rotating disks and anaerobic fixed growth reactor
g Numerical values for site conditions are used to define the framework of this generalized analysis but they are not intended as a regulatory guide since significant regional variations occur See Table 3 for comprehensive site condition descriptions

- Flow reduction (10-40 percent) often permits the use of systems which are technically superior to and less costly than other alternatives, and which would otherwise not be feasible due to site condition limitations, such as limited available land.

- Systems incorporating wastewater segregation options are not top-ranked for any of the site conditions considered unless segregation is a part of flow reduction or nitrogen limitations must be met.

SYSTEM RANKING - HARDWARE (BUT NO PERFORMANCE DATA) AVAILABLE

The top ranked systems identified with available hardware but inadequate performance data are described in Table 69. Since adequate data on the field performance of these systems for the site conditions considered is not available, rankings are based on engineering judgment. Field testing of these systems prior to widespread application is recommended. For the site conditions considered, the following general conclusions are drawn from Table 69.

- Systems utilizing potential methods of increasing the long-term loading rate (m/day) for a subsurface disposal field (e.g., dosing and resting or alternating fields) are the top-ranked and least cost systems where soils are not limiting, but limited area is available for disposal. Even where septic tank - conventional soil absorption systems are applicable, systems using dosing and resting may be preferred if they increase the system life and reduce the total annual cost.

- Where shallow (0.3-1.2m) soils are encountered, septic tank - covered intermittent or recirculating gravity sand filter - coventional soil absorption, or chemical addition - septic tank - conventional soil absorption systems may be alternatives to available systems. Documentation that such systems provide adequate treatment is still required.

- Septic tank - mechanical evaporator systems have the most general applicability, although they are only rarely appear to be the least cost of the top-ranked alternatives. Costs are uncertain since hardware is not currently commercially available. Applicability is limited in colder climates unless wastewater storage is provided at additional cost.

- Septic tank - evaporation lagoon systems are the top-ranked and least cost systems where soils are marginally permeable and very shallow (<0.3 m), and ET and direct discharge disposal are not feasible. Septic tank - sand filter pretreatment is the top-ranked least cost system. However, the adequacy of lagoon performance requires documentation. Land requirements and the need for disinfection also need to be determined.

TABLE 69. TOP RANKED SYSTEMS - HARDWARE AVAILABLE, INADEQUATE PERFORMANCE DATA

Site Condition: Number	Site Condition: Description[g]	System	Performance	O & M	Environmental Acceptability	Total	Estimated Total Annual Costs ($)	Comments
1	Acceptable soil depth and percolation, available land > 372 m², evaporation minus precipitation (EVP-PPT) > 5 cm/mo	1. Septic tank - soil absorption with dosing and resting	4	4	3	11	200	Performance data needed to determine whether dosing and resting or alternating fields can increase disposal field life and/or reduce size requirements, and if so, at what relative costs
		2. Septic tank - soil absorption with alternating fields	4	4	3	11	200	
2	Shallow (0.3-1.2m) soils with acceptable percolation, available land 93-372 m², EVP-PPT > 5 cm/mo	1 Septic tank - sand filter[a]-conventional soil absorption system	4	3	3	10	300	Effect of chemical addition (increased TDS) on the disposal field (potential for precipitation) needs to be determined, as does the adequacy of ST-SF or chemical addition-ST pretreatment for disposal in <1 2 m (4 ft) of soil
		2 Chemical addition - septic tank - conventional soil absorption system	4	2	3	9	300	
3	Acceptable soil depth, but marginal percolation, available land < 93 m², EVP-PPT > 5 cm/mo	1 Flow reduction - septic tank - soil absorption with dosing and resting	4	4	3	11	150[f]	Limited available land area requires flow reduction for soil disposal Ability of dosing and resting to provide acceptable performance is questionable, due partly to significant flow reduction (50%) required, but low cost makes it attractive. Mechanical evaporator limited in colder climates unless wastewater storage is provided at additional cost, flow reduction could reduce costs.
		2 Septic tank - mechanical evaporator[h]	4	3	3	10	600	
4	Acceptable soil depth and percolation, available land < 93 m², direct discharge feasible, EVP-PPT > 5 cm/mo	1 Flow reduction - septic tank-soil absorption with dosing and resting	4	4	3	11	150[f]	Ability of dosing and resting system to provide acceptable performance is somewhat questionable, due partly to flow reduction required (40%) but the low cost is attractive
5	Acceptable soil depth and percolation, available land 93-372 m², EVP-PPT > 5 cm/mo, slope > 25%	1. Septic tank - mechanical evaporator[h]	4	3	2	9	600	Topography (>25 percent) limits excavation to tanks and similar small structures. Mechanical evaporator limited in colder climates unless wastewater storage is provided at additional costs, flow reduction could reduce costs.
6	Shallow (0.3-1.2 m) soils with marginal percolation, available land > 372 m², EVP-PPT < 2 5 cm/mo	1. Septic tank - sand filter[a] - soil absorption with alternating fields	4	3	3	10	350	Effect of chemical addition (increased TDS) on the disposal field (potential for precipitation) needs to be determined, as does the effectiveness of ST-SF and chemical addition-ST pretreatment for disposal in <1 2 m (4 ft) of soil Performance data needed to determine to what extent dosing and resting or alternating fields increase infiltration in soils with marginal percolation.
		2 Septic tank - sand filter[a] - soil absorption with dosing and resting	4	3	3	10	350	
		3. Chemical addition - septic tank - soil absorption with dosing and resting	4	2	3	9	350[f]	
		4. Septic tank - sand filter[a] - irrigation	4	3	1	8	400	
7	Very shallow (<0.3 m) soils with marginal percolation, available land > 372 m², EVP-PPT 2.5-5 cm/mo	1. Septic tank - lined evaporative lagoon	4	4	1	9	300	Design criteria for evaporation lagoons are needed as well as assessment of management requirements and environmental acceptability Ability of ST-ST effluent to protect groundwater when irrigated on shallow but marginally permeable soils needs testing Flow reduction might make evaporator or membrane filtration systems cost competitive Low pressure membrane filtration will likely be applicable only if ST-SF effluent does not adequately protect groundwater quality
		2. Septic tank - sand filter[a] - irrigation	4	3	1	8	400	
		3. Septic tank - mechanical evaporator[h]	4	3	2	9	400	
		4 Septic tank - low pressure membrane filtration[g] - irrigation	4	3	3	10	600	
8	Shallow (0 3-1 2 m) soils with marginal percolation, available land 93-372 m², EVP-PPT < 2 5 cm/mo	1. Septic tank - sand filter[a]-soil absorption with alternating fields	4	3	3	10	350	Ability of ST-SF effluent to protect groundwater when applied to shallow but marginally permeable soils and effectiveness of dosing and resting and alternating fields in marginal soils needs testing Flow reduction might make evaporator or membrane filtration systems cost competitive Low pressure membrane filtration will likely be applicable only if ST-SF effluent does not adequately protect groundwater quality
		2 Septic tank - sand filter[a] - soil absorption with dosing and resting	4	3	3	10	350	
		3 Septic tank - sand filter[a] - irrigation	4	3	2	8	400	
		4 Septic tank - mechanical evaporator[h]	4	3	2	9	600	
		5. Septic tank - low pressure membrane filtration[g] - soil absorption with dosing and resting	4	3	3	10	550	
9	Very shallow (<0.3 m) soils with marginal percolation, available land 93-372 m², EVP-PPT < 2 5 cm/mo	1 Septic tank - sand filter[a] - irrigation	4	3	1	8	400	Ability of ST-SF effluent to protect groundwater when irrigated on shallow but marginally permeable soils needs testing Flow reduction might make evaporator or membrane filtration systems cost competitive Low pressure membrane filtration will likely be applicable only if ST-SF effluent does not adequately protect groundwater quality
		2 Septic tank - mechanical evaporator[h]	4	3	2	9	600	
		3 Septic tank - low pressure membrane filtration[g] - irrigation	4	3	3	10	600	

TABLE 69. (CONTINUED)

Site Condition Number	Site Condition Description[g]	System	Performance	O & M	Environmental Acceptability	Total	Estimated Total Annual Costs ($)	Comments
10	Limiting soil percolation; available land < 93 m², slope > 25%; direct discharge feasible; EVP-PPT > 5 cm/mo	1. Chemical addition - sedimentation - direct discharge	4	2	3	9	500	Flow reduction might make evaporator cost competitive. Other pretreatment options for direct discharge which look promising appear significantly more costly.
		2. Septic tank - low pressure membrane filtration[e] - direct discharge	4	2	3	9	500	
		3. Septic tank - mechanical evaporator[b]	4	3	2	9	600	
11	Limiting soil percolation; available land 93-372 m², EVP-PPT > 5 cm/mo	1. Septic tank - evaporative lagoon	4	4	1	9	250	Substantial flow reduction might make evaporator cost competitive. Design criteria for evaporative lagoons are needed, as well as assessment of management requirements and environmental acceptability.
		2. Septic tank - mechanical evaporator[b]	4	3	2	9	400	
12	Limiting soil percolation; available land 93-372 m², direct discharge feasible (BOD & SS = 10 mg/l, NO3 mg/l; EVP-PPT <2.5 cm/mo	1. Septic tank - low pressure reverse osmosis[b] - direct discharge	5	2	3	10	500	Limited testing of these systems appear promising. Alternatives are significantly more expensive and likely not superior technically. Low pressure reverse osmosis and evaporator costs subject to significant variation; flow reduction could help significantly to reduce costs.
		2. Bath & laundry - septic tank; Kitchen & toilet - septic tank-sand filter[a] - fixed growth anaerobic reactor (for denitrification) - disinfection[d] - direct discharge	4	3	2	9	400	
		3. Septic tank - mechanical evaporator[b]	4	3	1	7	600	
13	Limiting soil percolation, available land >372 m², direct discharge feasible (BOD & SS = 10 mg/l; NO3 mg/l; P<2 mg/l), EVP-PPT <2.5 cm/mo	1. Septic tank - low pressure reverse osmosis[b] - direct discharge	5	2	3	10	500	Limited testing of these systems promising. Alternatives are significantly more expensive and likely not superior technically. Low pressure reverse osmosis and evaporator costs subject to significant variation; flow reduction could help significantly to reduce costs.
		2. Septic tank - clinoptilolite - sand and [illegible] filter - disinfection[d] - direct discharge	4	2	3	9	600	
		3. Septic tank - mechanical evaporator[b]	4	3	2	9	400	
14	Shallow (0.3-1.2 m) soils with excessive percolation; available land <93 m²; EVP-PPT <2.5 cm/mo	1. Septic tank - sand filter[a] - conventional soil absorption system	4	3	3	10	300	Alternatives are very limited. Evaporator costs subject to significant variation; flow reduction could help significantly to reduce costs.
		2. Septic tank - mechanical evaporator[b]	4	3	2	9	400	
15	Shallow (0.3-1.2 m) soils with excessive percolation; available land 93-372 m²; EVP-PPT <2.5 cm/mo	1. Septic tank - sand filter[a] - conventional soil absorption system	4	3	3	10	300	Environmental acceptability of irrigation on undisinfected effluent and
		2. Septic tank - sand filter[a] - irrigation	4	3	1	8	300	SI-SF pretreatment for soils with excessive percolation need testing.
		3. Septic tank - mechanical evaporator	4	3	2	9	400	Flow reduction could help make evaporator cost competitive.

[a] Covered intermittent or recirculating gravity filter.
[b] No membrane necessary to remove nitrogen and/or phosphorus.
[c] Does not include cost of flow reduction, which varies with hardware and percent flow reduction to be achieved.
[d] Iodine or UV disinfection.
[e] Either ultrafiltration (UF) or reverse osmosis (RO) membranes may be used, although UF are more likely to be used due to generally lower cost and more advanced development for on-site applications.
[f] The following treatment unit options are equally appropriate: extended aeration, rotating disks, and anaerobic fixed growth reactor.
[g] Numerical values for site conditions are used to define the framework of this generalized analysis, but they are not intended as a regulatory guide since significant regional variations occur.
[h] Hardware is not available, but could be put in production in less than one year.
[i] Systems are ranked based on engineering judgment (since performance data was not available), and are subject to revision when data become available.

- Disposal by direct discharge is the least cost method where soil and ET disposal are not feasible, or where limited land area is available for disposal and flow reduction is not feasible. Low pressure membrane filtration appears to be a promising method of treatment. If nutrient discharges are not limited, ultrafiltration (UF) membranes are the most appropriate. If nutrient discharges are limited (N < 10 ppm; P < 2 ppm), reverse osmosis (RO) membranes are the most appropriate.

- Segregation of bath and laundry wastes from kitchen and toilet wastes to facilitate nitrogen removal appears promising. Additional field testing is required.

- Flow reduction (generally 10-40 percent) occasionally permits the use of subsurface disposal systems where available land area is very limited but soils have acceptable percolation characteristics and purification capacity. Where more extensive flow reduction is required, reuse for toilet, laundry and/or bath to maximize flow reduction is appropriate.

The relative importance of field-testing the systems with available hardware but without performance data depends primarily on the technical adequacy and total annual cost of systems with proven performance. Comparison of the systems in Tables 68 and 69 based on these technical and economic considerations leads to the recommendation that the following systems have priority for field testing:

- Septic tank - soil absorption with dosing and resting;

- Septic tank - soil absorption with alternating fields;

- Septic tank - covered intermittent or recirculating sand filter - irrigation;

- Septic tank - evaporative lagoon;

- Septic tank - low pressure membrane filtration (UF or RO) - irrigation (for sites with very shallow soils) or direct discharge; and

- Septic tank - mechanical evaporator.

UNDEVELOPED SYSTEM CONCEPTS

The impact of the specific characteristics of each site condition evaluated in this study (see Table 3) on the on-site wastewater treatment and disposal alternatives and the most promising system concepts for further development to improve the alternatives are summarized in Table 70. The relative improvement in on-site wastewater alternatives to be derived from the needs shown in Table 70 depends on a variety of factors, including:

TABLE 70. SITE CONDITION - SYSTEM DEVELOPMENT NEEDS MATRIX

Site Condition	System Development Needs*
1	Site conditions are appropriate for septic tank - conventional soil absorption systems. Thus, development of new systems is best focused on methods of increasing the long term loading rate (m/day) of the absorption field (thereby reducing site requirements and cost), including (1) absorption field design modifications (i e., dosing and resting or alternating fields) and (2) modified pretreatment
2	Shallow soils (0.3 to <1.2 m) which would not provide adequate treatment capacity for a conventional septic tank - soil absorption system require more extensive pretreatment than a septic tank provides. Thus, determination of the level of pretreatment required and development of methods to provide the required pretreatment is desirable.
3	Marginally permeable soils and very limited land area available for disposal make development of methods to increase the loading rate (m/day) desirable, including. (1) absorption field design modifications (i.e., dosing and resting) and (2) modified pretreatment. Methods of evaporation which are not land-intensive would also improve on currently available system alternatives. Methods of achieving consistent flow reduction are also desirable. Development of minimum pretreatment requirements for irrigation would help maximize this option Improved treatment methods which provide effluent suitable for extensive reuse are desirable.
4	Very limited land area available for disposal and feasibility of direct discharge are the controlling site characteristics New system development should focus on methods of increasing the long term loading rate of the absorption field and improved methods of treatment for direct discharge. Methods of evaporation which are not land-intensive would also improve on currently available system alternatives. Methods of achieving consistent flow reduction are also desirable. Development of minimum pretreatment requirements for irrigation would help maximize this option.
5	Steep slope prevents "area intensive" construction (i.e , mounds, ET, soil absorption, lagoon, etc.) Thus, evaporation equipment is most promising. This can be facilitated by flow reduction Methods of irrigation could be tested, but significant runoff is anticipated.
6	Marginally permeable and shallow (0.3 to <1.2 m) soils and very low net ET rate are the controlling site characteristics. Thus, evaporation disposal which is relatively independent of precipitation, requirements and methods of pretreatment for conventional soil absorption disposal, design modifications for increasing the long term loading rate, and identification of minimum pretreatment requirements for irrigation are appropriate for development.
7	Very shallow soils (<0.3 m) prevent subsurface disposal (at current levels of understanding) and net ET rate of 2.5 to 5 cm/mo minimum in every month prevents ET disposal. Irrigation, evaporative lagoons and mechanical (or similar) evaporation disposal methods appear feasible Pretreatment methods and requirements for these disposal methods, and subsurface disposal of high quality effluent (i e., low pressure membrane filtration) are appropriate for development.
8	Marginally permeable and shallow (0.3 to <1.2 m) soils and very low net ET rate are the controlling site characteristics. Thus, evaporation disposal which is relatively independent of precipitation, requirements and methods of pretreatment for conventional soil absorption disposal, design modifications for increasing the long term loading rate, and identification of minimum pretreatment requirements for irrigation are appropriate for development. Methods of achieving consistent flow reductions are also desirable.

TABLE 70. (CONTINUED)

Site Condition	System Development Needs*
9	Very shallow soils (<0.3 m) prevents subsurface disposal (at current levels of understanding), and very low net ET rate and limited available land (<372 m^2) prevents ET or evaporative lagoon disposal. Irrigation and mechanical (or similar) evaporation disposal methods are feasible. Pretreatment methods and requirements for these disposal methods, and subsurface disposal of high quality effluent (i.e., from low pressure membrane filtration) are appropriate for development.
10	Tight clay soils prevent soil disposal and very limited available land area (<93 m^2) limits evaporation disposal to methods which are not land-intensive. Thus, direct discharge and mechanical (or similar) evaporation are the top ranked disposal options. Improved methods of treatment for direct discharge are appropirate for development.
11	Tight clay soils prevent soil disposal and direct discharge is not feasible. Thus, evaporation is the top ranked disposal option. Methods of evaporation and necessary pretreatment could be improved, especially design criteria for ET, maintenance requirements of evaporative lagoons, and equipment for mechanical evaporation.
12	Tight clay soils prevent soil disposal and very low net ET rate make direct discharge (and possibly mechanical evaporation) the most practical disposal option. Methods of nitrogen removal appropriate for development include biological (alternating aerobic-anaerobic anaerobic processes) and physical/chemical (RO, sorption and desorption processes) treatments methods and waste segregation load reduction.)
13	Tight clay soils preventing soil disposal and a very low net ET rate make direct discharge (and possibly mechanical evaporation) the most practical disposal option. Methods of nitrogen removal appropriate for development include biological (alternating aerobic-anaerobic and anaerobic processes) and physical/chemical (RO, sorption and desorption processes) treatment methods, and waste segregation (load reduction). Methods of phosphorus removal for development include chemical addition (and associated hardware) and improved sorption media.
14	Excessively permeable and shallow (0.3 to <1.2 m) soils require improved effluent quality for subsurface disposal. Thus, determination of the level of pretreatment required and development of methods to provide the required pretreatment are desirable. Improved hardware for mechanical evaporation might make it a viable option.
15	Excessively permeable soils require unsaturated flow to provide adequate treatment of septic effluent disposal by soil absorption. More complete treatment prior to soil disposal or mechanical evaporation are alternatives for development.

* System development needed to improve on available system alternatives

- Technical adequacy and total annual cost of currently available options for each site condition;

- Relative frequency of occurrence of the various site conditions; and

- Extent of additional development required.

Comparison of the limitations on system alternatives for each site condition and the development needs identified with the factors listed above provides the following conclusions:

- Development of additional alternatives for site conditions 1, 2, 6, 8, 14, 15 is a relatively low priority since existing hardware with proven or promising performance and reasonable costs is available;

- Development of effluent quality requirements and treatment methods for on-site irrigation and subsurface disposal in shallow soils is desirable. Requirements will likely be affected by soil characteristics and available land area;

- Further development of evaporation equipment which is relatively independent of precipitation (i.e., mechanical evaporator) is desirable; and

- Development of a one-step process (i.e, membrane filtration) for on-site applications to provide high quality effluent (including nutrient removal, if necessary) for reuse and/or a variety of disposal methods (i.e., direct discharges, irrigation or subsurface disposal in shallow or excessively permeable soils) would be desirable if future developments indicate that the cost would be comparable to currently available alternatives.

APPENDIX A

TREATMENT AND DISPOSAL SYSTEM - SITE CONDITION TABLES

Tables A-1 through A-15 are matrices of on-site wastewater treatment/disposal system alternatives for each of the 15 site conditions considered in this study. Numbers in the matrices under the treatment section indicate the order of the treatment units and the X's which appears in the disposal section indicate the disposal options for the treatment unit(s) specified. For example, in Table A-1, the alternatives for system A include an anaerobic treatment unit (i.e. septic tank) followed by evapotranspiration disposal, conventional soil absorption, modified distribution soil absorption, soil modification or evapotranspiration/absorption disposal.

Table A-16 summarizes optional treatment and reuse systems for segregated waste streams. Numbers treatment section of the matrix indicate the order of the treatment units and the X's in the waste stream and reuse sections indicate the waste streams and types of reuse which are applicable to the treatment system specified.

TABLE A1. TREATMENT AND DISPOSAL SYSTEMS PHYSICAL SITE CONDITION 1

	Treatment**														Disposal															
	Biological					Physical-Chemical									Air					Soil				Combinations				Reuse		
Systems*	Aerobic-Anaerobic	Aerobic	Anaerobic	Emergent Vegetation	"Black Box"**	Filtration	Separation	Chemical Addition	Adsorption	Ion Exchange	Oxidation	Desorption	"Black Box"**	Disinfection	Evapotranspiration	Lined Lagoon	Mechanical	Thermal	Direct Discharge	Conventional SAS#	Modified Distribution	Soil Modification (i.e., mound)	Irrigation	Evapotranspiration/Absorption	Unlined Lagoon	Lagoon with Overflow	Off-site Disposal##	Toilet Flushing	Toilet Flushing, Lawn Watering and Car Washing	Lawn Sprinkling, Bath Shower, Toilet Flushing, Car Washing and Laundry
A			1												x					x	x	x		x						
B							2	1							x		x			x	x	x		x						
C			2					1							x					x	x	x		x						
D				1											x					x	x	x	x	x						
E							1								x		x			x	x	x		x						
F				N	O	N		E								x	x	x							x		x			
G			1			2								3									x					x	x	
H						2	1																x					x	x	x
I		2					1,3							4									x					x	x	
J		2				4	1,3							5									x					x	x	
K		3					1,4	2						5									x					x	x	
L			2			3		1						4									x					x	x	
M				1		2								3									x					x	x	
N				1			2							3									x					x	x	
O						3	2	1						4									x					x	x	
P				1			2																x							
Q							2					1		3									x					x	x	x
R				1		2																	x							
S			1			2																	x							
T			2			3		1															x							
U						3	2	1															x							
V			2				1,3																x							
W			2			4	1,3																x							
X			1			2			3					4									x					x	x	
Y		2					1,3		4					5									x					x	x	
Z			2			3		1	4					5									x					x	x	
AA							2		3			1		4									x					x	x	
BB			3				1,4	2	5					6									x					x	x	x

TABLE A1 (Continued)

	Treatment**														Disposal															
	Biological					Physical-Chemical									Air					Soil				Combinations				Reuse		
Systems*	Aerobic-Anaerobic	Aerobic	Anaerobic	Emergent Vegetation	"Black Box"**	Filtration	Separation	Chemical Addition	Adsorption	Ion Exchange	Oxidation	Desorption	"Black Box"**	Disinfection	Evapotranspiration	Lined Lagoon	Mechanical	Thermal	Direct Discharge	Conventional SAS#	Modified Distribution	Soil Modification (i.e., mound)	Irrigation	Evapotranspiration/Adsorption	Unlined Lagoon	Lagoon with Overflow	Off-site Disposal##	Toilet Flushing	Toilet Flushing, Lawn Watering and Car Washing	Lawn Sprinkling, Bath Shower, Toilet Flushing, Car Washing and Laundry
CC						3	2	1	4					5									x					x	x	
DD			1,3			2,4			5					6									x					x	x	x
EE		2				3	1		4					5									x					x	x	
FF		2	3			4	1		5					6									x					x	x	
GG		2				3	1			4				5									x					x	x	x
HH			1			2				3				4									x					x	x	x
II			2			3		1		4				5									x					x	x	x
JJ						3	2	1		4				5									x					x	x	x
KK					1		2								x					x	x	x	x	x						
LL													1		x		x			x	x	x	x	x				x	x	x
MM					2		1,3								x					x	x	x	x	x						
NN					1										x		x			x	x	x	x	x						
OO							1						2		x		x			x	x	x	x	x				x	x	x
PP								1					2		x		x			x	x	x	x	x						
QQ								1					2	3									x					x	x	x
RR						2							1		x		x			x	x	x	x	x						
SS						2							1	3									x					x	x	x
TT					2		1,3							4									x					x	x	x
UU					2		1							3									x					x	x	x
VV					1		2							3									x					x	x	x
WW					1									2									x					x	x	x
XX							1						2	3									x					x	x	x

TABLE A1. FOOTNOTES

+ Indicates that the lagoon provides the type of biological treatment indicated.

* Order in which systems appear does not imply ranking.

++ Numbers which appear in the body of the table indicate the order of treatment units in a system.

** Indicates unknown process capable of providing the treatment required (either singly or in combination with other specified processes) for the disposal option(s) indicated under given site conditions. Although it is recognized that new disposal options are possible no "black box" is included for disposal options since it would not be possible to specify the pretreatment required for an unknown disposal method.

\# Soil Absorption System.

\#\# For example, a holding tank with periodic pumping.

TABLE A2. TREATMENT AND DISPOSAL SYSTEMS -- PHYSICAL SITE CONDITION 2

	Treatment**														Disposal															
	Biological					Physical-Chemical									Air					Soil				Combinations				Reuse		
Systems*	Aerobic-Anaerobic	Aerobic	Anaerobic	Emergent Vegetation	"Black Box"**	Filtration	Separation	Chemical Addition	Adsorption	Ion Exchange	Oxidation	Desorption	"Black Box"**	Disinfection	Evapotranspiration	Lined Lagoon	Mechanical	Thermal	Direct Discharge	Conventional SAS#	Modified Distribution	Soil Modification (i.e., mound)	Irrigation	Evapotranspiration/Absorption	Unlined Lagoon	Lagoon with Overflow	Off-site Disposal##	Toilet Flushing	Toilet Flushing, Lawn Watering and Car Washing	Lawn Sprinkling, Bath Shower, Toilet Flushing, Car Washing and Laundry
A			1												x							x		x						
B							2	1							x		x					x		x						
C			2					1							x							x		x						
D				1											x							x	x	x						
E							1								x		x					x		x						
F				N O N E												x	x	x							x		x			
G			1			2								3									x					x	x	
H						2	1																x					x	x	x
I		2					1,3							4									x					x	x	
J		2				4	1,3							5									x					x	x	
K		3					1,4	2						5									x					x	x	
L			2			3		1						4									x					x	x	
M				1		2								3									x					x	x	
N				1			2							3									x					x	x	
O						3	2	1						4									x					x	x	
P				1			2													x	x		x							
Q											1			3									x					x	x	x
R				1		2														x	x		x	x						
S			1			2														x	x		x	x						
T			2			3		1												x	x		x	x						
U						3	2	1												x	x		x	x						
V			2				1,3													x	x		x	x						
W			2			4	1,3													x	x		x	x						
X			1			2			3					4									x					x	x	
Y		2					1,3		4					5									x					x	x	
Z			2			3		1	4					5									x					x	x	
AA							2		3		1			4									x					x	x	
BB			3				1,4	2	5					6									x					x	x	x

TABLE A2 (Continued)

Systems*	Treatment**														Disposal																
	Biological					Physical-Chemical									Air					Soil				Combinations					Reuse		
	Aerobic-Anaerobic	Aerobic	Anaerobic	Emergent Vegetation	"Black Box"**	Filtration	Separation	Chemical Addition	Adsorption	Ion Exchange	Oxidation	Desorption	"Black Box"**	Disinfection	Evapotranspiration	Lined Lagoon	Mechanical	Thermal	Direct Discharge	Conventional SAS#	Modified Distribution	Soil Modification (i.e., mound)	Irrigation	Evapotranspiration/Absorption	Unlined Lagoon	Lagoon with Overflow	Off-site Disposal##	Toilet Flushing	Toilet Flushing, Lawn Watering and Car Washing	Lawn Sprinkling, Bath Shower, Toilet Flushing, Car Washing and Laundry
CC						3	2	1	4					5									x					x	x	x
DD			1,3			2,4			5					6									x					x	x	x
EE		2				3	1		4					5									x					x	x	
FF		2	3			4	1		5					6									x					x	x	
GG		2				3	1			4				5									x					x	x	x
HH			1			2				3				4									x					x	x	x
II			2			3		1		4				5									x					x	x	x
JJ						3	2	1		4				5									x					x	x	x
KK					1		2								x					x		x	x	x						
LL													1		x		x			x		x	x	x				x	x	x
MM					2		1,3								x					x		x	x	x						
NN					1										x		x			x		x	x	x						
OO							1						2		x		x			x		x	x	x				x	x	x
PP								1					2		x		x			x		x	x	x						
QQ								1					2	3									x					x	x	x
RR							2						1		x		x			x		x	x	x						
SS							2						1	3									x					x	x	x
TT						2		1,3						4									x					x	x	x
UU						2		1						3									x					x	x	x
VV						1		2						3									x					x	x	x
WW						1								2									x					x	x	x
XX								1					2	3									x					x	x	x

TABLE A2. FOOTNOTES

+ Indicates that the lagoon provides the type of biological treatment indicated.

* Order in which systems appear does not imply ranking.

++ Numbers which appear in the body of the table indicate the order of treatment units in a system.

** Indicates unknown process capable of providing the treatment required (either singly or in combination with other specified processes) for the disposal option(s) indicated under given site conditions. Although it is recognized that new disposal options are possible no "black box" is included for disposal options since it would not be possible to specify the pretreatment required for an unknown disposal method.

Soil Absorption System.

For example, a holding tank with periodic pumping.

TABLE A3. TREATMENT AND DISPOSAL SYSTEMS
PHYSICAL SITE CONDITION 3

	Treatment**														Disposal															
	Biological					Physical-Chemical									Air					Soil				Combinations				Reuse		
Systems*	Aerobic-Anaerobic	Aerobic	Anaerobic	Emergent Vegetation	"Black Box"**	Filtration	Separation	Chemical Addition	Adsorption	Ion Exchange	Oxidation	Desorption	"Black Box"**	Disinfection	Evapotranspiration	Lined Lagoon	Mechanical	Thermal	Direct Discharge	Conventional SAS#	Modified Distribution	Soil Modification (i.e., mound)	Irrigation	Evapotranspiration/Absorption	Unlined Lagoon	Lagoon with Overflow	Off-site Disposal##	Toilet Flushing	Toilet Flushing, Lawn Watering and Car Washing	Lawn Sprinkling, Bath, Shower, Toilet Flushing, Car Washing and Laundry
A			1												x*						x*	x*		x*						
B							2	1							x*		x				x*	x*		x*						
C			2					1							x*						x*	x*		x*						
D				1											x*						x*	x*	x	x*						
E							1								x*		x				x*	x*		x*						
F				N O N E												x	x	x							x		x			
G			1			2								3									x					x	x	
H						2	1																x					x	x	x
I		2					1,3							4									x					x	x	
J		2				4	1,3							5									x					x	x	
K		3					1,4	2						5									x					x	x	
L			2			3		1						4									x					x	x	
M				1		2								3									x					x	x	
N				1			2							3									x					x	x	
O						3	2	1						4									x					x	x	
P				1			2																x							
Q											1			3									x					x	x	x
R				1		2																	x							
S			1			2																	x							
T			2			3		1															x							
U						3	2	1															x							
V			2				1,3																x							
W			2			4	1,3																x							
X			1			2			3					4									x					x	x	
Y		2					1,3		4					5									x					x	x	
Z			2			3		1	4					5									x					x	x	
AA							2		3		1			4									x					x	x	
BB			3				1,4	2	5					6									x					x	x	x

TABLE A3 (Continued)

	Treatment**														Disposal																	
	Biological					Physical-Chemical									Air					Soil				Combinations				Reuse		
Systems*	Aerobic -Anaerobic	Aerobic	Anaerobic	Emergent Vegetation	"Black Box"**	Filtration	Separation	Chemical Addition	Adsorption	Ion Exchange	Oxidation	Desorption	"Black Box"**	Disinfection	Evapotranspiration	Lined Lagoon	Mechanical	Thermal	Direct Discharge	Conventional SAS#	Modified Distribution	Soil Modification (i.e., mound)	Irrigation	Evapotranspiration/ Absorption	Unlined Lagoon	Lagoon with Overflow	Off-site Disposal##	Toilet Flushing	Toilet Flushing, Lawn Watering and Car Washing	Lawn Sprinkling, Bath, Shower, Toilet Flushing, Car Washing and Laundry
CC						3	2	1	4					5									x					x	x	
DD			1,3			2,4			5					6									x					x	x	x
EE		2				3	1		4					5									x					x	x	
FF		2	3			4	1		5					6									x					x	x	
GG		2				3	1			4				5									x					x	x	x
HH			1			2				3				4									x					x	x	x
II			2			3		1		4				5									x					x	x	x
JJ						3	2	1		4				5									x					x	x	x
KK					1		2								x*						x*	x*	x	x						
LL													1		x*		x				x*	x*	x	x*				x	x	x
MM					2		1,3								x*						x*	x*	x	x*						
NN					1										x*		x				x*	x*	x	x*						
OO							1						2		x*		x				x*	x	x	x				x	x	x
PP								1					2		x*		x				x*	x*	x	x*						
QQ								1					2	3									x					x	x	x
RR							2						1		x*		x				x*	x*	x	x*						
SS							2						1	3									x					x	x	x
TT						2		1,3						4									x					x	x	x
UU						2		1						3									x					x	x	x
VV						1		2						3									x					x	x	x
WW						1								2									x					x	x	x
XX								1					2	3									x					x	x	x

TABLE A3. FOOTNOTES

+ Indicates that the lagoon provides the type of biological treatment indicated.

* Order in which systems appear does not imply ranking.

++ Numbers which appear in the body of the table indicate the order of treatment units in a system.

** Indicates unknown process capable of providing the treatment required (either singly or in combination with other specified processes) for the disposal option(s) indicated under given site conditions. Although it is recognized that new disposal options are possible no "black box" is included for disposal options since it would not be possible to specify the pretreatment required for an unknown disposal method.

Soil Absorption System.

For example, a holding tank with periodic pumping.

• Applicable only if used in conjunction with other disposal methods not affected by the 1000 ft^2 available land limitation, such as mechanical or thermal evaporation, off-site disposal, drip irrigation, etc.

TABLE A4. TREATMENT AND DISPOSAL SYSTEMS -- PHYSICAL SITE CONDITION 4

	Treatment**														Disposal															
	Biological					Physical-Chemical									Air					Soil				Combinations				Reuse		
Systems*	Aerobic -Anaerobic	Aerobic	Anaerobic	Emergent Vegetation	"Black Box"**	Filtration	Separation	Chemical Addition	Adsorption	Ion Exchange	Oxidation	Desorption	"Black Box"**	Disinfection	Evapotranspiration	Lined Lagoon	Mechanical	Thermal	Direct Discharge	Conventional SAS#	Modified Distribution	Soil Modification (i.e., mound)	Irrigation	Evapotranspiration/ Absorption	Unlined Lagoon	Lagoon with Overflow	Off-site Disposal##	Toilet Flushing	Toilet Flushing, Lawn Watering and Car Washing	Lawn Sprinkling, Bath Shower, Toilet Flushing, Car Washing and Laundry
A			1												x*					x*	x*	x*		x						
B							2	1							x*		x			x*	x*	x*		x						
C			2					1							x*					x*	x*	x*		x						
D				1											x*					x*	x*	x*	x	x						
E							1								x*		x			x*	x*	x*		x						
F				NONE												x	x	x							x	x	x			
G			1			2								3					x				x					x	x	
H						2	1												x				x					x	x	x
I		2					1,3							4					x				x					x	x	
J		2				4	1,3							5					x				x					x	x	
K		3					1,4	2						5					x				x					x	x	
L			2			3		1						4					x				x					x	x	
M				1		2								3					x				x					x	x	
N				1			2							3					x				x					x	x	
O						3	2	1						4					x				x					x	x	
P				1			2																x							
Q							2				1			3					x				x					x	x	x
R				1		2																	x							
S			1			2																	x							
T			2			3		1															x							
U						3	2	1															x							
V			2				1,3																x							
W			2			4	1,3																x							
X		1				2								3												x+	x	x		
Y		1					2							3												x+	x	x		
Z		2				3		1						4												x+	x	x		
AA		2					3	1						4												x+	x	x		
BB			1			2			3					4					x				x				x	x		
CC		2					1,3		4					5					x				x				x	x		

TABLE A4 (Continued)

Systems*	Treatment**														Disposal															
	Biological					Physical-Chemical									Air					Soil				Combinations				Reuse		
	Aerobic-Anaerobic	Aerobic	Anaerobic	Emergent Vegetation	"Black Box"**	Filtration	Separation	Chemical Addition	Adsorption	Ion Exchange	Oxidation	Desorption	"Black Box"**	Disinfection	Evapotranspiration	Lined Lagoon	Mechanical	Thermal	Direct Discharge	Conventional SAS#	Modified Distribution	Soil Modification (i.e., mound)	Irrigation	Evapotranspiration/ Absorption	Unlined Lagoon	Lagoon with Overflow	Off-site Disposal##	Toilet Flushing	Toilet Flushing; Lawn Watering and Car Washing	Lawn Sprinkling, Bath Shower, Toilet Flushing, Car Washing and Laundry
DD			2			3		1	4					5					x				x					x	x	
EE							2		3		1			4					x				x					x	x	
FF			3				1,4	2	5					6					x				x					x	x	x
GG						3	2	1	4					5					x				x					x	x	
HH			1,3				2,4		5					6					x				x					x	x	x
II		2					3	1	4					5					x				x					x	x	
JJ		2	3			4	1		5					6					x				x					x	x	
KK		2				3	1			4				5					x				x					x	x	x
LL			1			2				3				4					x				x					x	x	x
MM			2			3		1		4				5					x				x					x	x	x
NN						3	2	1		4				5					x				x					x	x	x
OO					1		2								x'					x	x'	x'	x	x						
PP													1		x'		x		x	x	x'	x'	x	x				x	x	x
QQ					2		1,3								x'					x	x'	x'	x	x						
RR					1										x'		x			x	x'	x'	x	x						
SS							1						2		x'		x		x	x	x'	x'	x	x				x	x	x
TT								1					2		x'		x			x	x'	x'	x	x						
UU								1					2	3					x				x					x	x	x
VV						2							1		x'		x			x	x'	x'	x	x						
WW						2							1	3					x				x					x	x	x
XX					2		1,3							4					x				x					x	x	x
YY					2		1							3					x				x					x	x	x
ZZ					1		2							3					x				x					x	x	x
AAA					1									2					x				x					x	x	x
BBB							1						2	3					x				x					x	x	x

TABLE A4. FOOTNOTES

+ Indicates that the lagoon provides the type of biological treatment indicated.

* Order in which systems appear does not imply ranking.

++ Numbers which appear in the body of the table indicate the order of treatment units in a system.

** Indicates unknown process capable of providing the treatment required (either singly or in combination with other specified processes) for the disposal option(s) indicated under given site conditions. Although it is recognized that new disposal options are possible no "black box" is included for disposal options since it would not be possible to specify the pretreatment required for an unknown disposal method.

Soil Absorption System.

For example, a holding tank with periodic pumping.

• Applicable only if flow reduction and/or off-site disposal of a portion of the total wastewater are used to reduce disposal area requirement.

TABLE A5. TREATMENT AND DISPOSAL SYSTEMS -- PHYSICAL SITE CONDITION 5

	Treatment**														Disposal															
	Biological					Physical-Chemical									Air					Soil				Combinations				Reuse		
Systems*	Aerobic -Anaerobic	Aerobic	Anaerobic	Emergent Vegetation	"Black Box"**	Filtration	Separation	Chemical Addition	Adsorption	Ion Exchange	Oxidation	Desorption	"Black Box"**	Disinfection	Evapotranspiration	Lined Lagoon	Mechanical	Thermal	Direct Discharge	Conventional SAS#	Modified Distribution	Soil Modification (i.e., mound)	Irrigation	Evapotranspiration/ Absorption	Unlined Lagoon	Lagoon with Overflow	Off-site Disposal##	Toilet Flushing	Toilet Flushing, Lawn Watering and Car Washing	Lawn Sprinkling, Bath Shower, Toilet Flushing, Car Washing and Laundry
A							2	1									x													
B							1										x													
C				N O	N	E											x	x									x			
D			1			2								3									x					x	x	
E						2	1																x					x	x	x
F		2					1,3							4									x					x	x	
G		2				4	1,3							5									x					x	x	
H		3					1,4	2						5									x					x	x	
I			2			3		1						4									x					x	x	
J				1		2								3									x					x	x	
K				1			2							3									x					x	x	
L						3	2	1						4									x					x	x	
M				1			2																x							
N							2				1			3									x					x	x	x
O				1		2																	x							
P			1			2																	x							
Q			2			3		1															x							
R						3	2	1															x							
S			2				1,3																x							
T			2			4	1,3																x							
U			1			2			3					4									x					x	x	
V		2					1,3		4					5									x					x	x	
W			2			3		1	4					5									x					x	x	
X							2		3		1			4									x					x	x	
Y			3				1,4	2	5					6									x					x	x	x
Z						3	2	1	4					5									x					x	x	
AA			1,3			2,4			5					6									x					x	x	x
BB		2				3	1		4					5									x					x	x	
CC		2	3			4	1		5					6									x					x	x	

TABLE A5 (Continued)

	Treatment**														Disposal															
	Biological					Physical-Chemical									Air					Soil				Combinations				Reuse		
Systems*	Aerobic -Anaerobic	Aerobic	Anaerobic	Emergent Vegetation	"Black Box"**	Filtration	Separation	Chemical Addition	Adsorption	Ion Exchange	Oxidation	Desorption	"Black Box"**	Disinfection	Evapotranspiration	Lined Lagoon	Mechanical	Thermal	Direct Discharge	Conventional SAS#	Modified Distribution	Soil Modification (i.e., mound)	Irrigation	Evapotranspiration/ Absorption	Unlined Lagoon	Lagoon with Overflow	Off-site Disposal##	Toilet Flushing	Toilet Flushing, Lawn Watering and Car Washing	Lawn Sprinkling, Bath Shower, Toilet Flushing, Car Washing and Laundry
DD		2				3	1			4				5									x					x	x	x
EE			1			2				3				4									x					x	x	x
FF			2			3		1		4				5									x					x	x	x
GG						3	2	1		4				5									x					x	x	x
HH													1				x						x					x	x	x
II					1												x						x							
JJ							1						2				x						x					x	x	x
KK								1					2				x						x							
LL								1					2	3									x					x	x	x
MM						2							1				x						x							
NN						2							1	3									x					x	x	x
OO					2		1,3							4									x					x	x	x
PP					2		1							3									x					x	x	x
QQ					1		2							3									x					x	x	x
RR					1									2									x					x	x	x
SS							1						2	3									x					x	x	x

TABLE A5. FOOTNOTES

+ Indicates that the lagoon provides the type of biological treatment indicated.

* Order in which systems appear does not imply ranking.

++ Numbers which appear in the body of the table indicate the order of treatment units in a system.

** Indicates unknown process capable of providing the treatment required (either singly or in combination with other specified processes) for the disposal option(s) indicated under given site conditions. Although it is recognized that new disposal options are possible no "black box" is included for disposal options since it would not be possible to specify the pretreatment required for an unknown disposal method.

Soil Absorption System.

For example, a holding tank with periodic pumping.

TABLE A6. TREATMENT AND DISPOSAL SYSTEMS · PHYSICAL SITE CONDITION 6

Systems*	Treatment** – Biological: Aerobic-Anaerobic	Aerobic	Anaerobic	Emergent Vegetation	"Black Box"**	Treatment** – Physical-Chemical: Filtration	Separation	Chemical Addition	Adsorption	Ion Exchange	Oxidation	Desorption	"Black Box"**	Disinfection
A			1											
B							2	1						
C			2					1						
D				1										
E							1							
F				N	O	N	E							
G			1			2								3
H						2	1							
I		2					1,3							4
J		2				4	1,3							5
K		3					1,4	2						5
L			2			3		1						4
M				1		2								3
N				1			2							3
O						3	2	1						4
P				1			2							
Q											1			3
R				1		2								
S			1			2								
T			2			3		1						
U						3	2	1						
V			2				1,3							
W			2			4	1,3							
X			1			2			3					4
Y		2					1,3		4					5
Z			2			3		1	4					5
AA							2		3		1			4
BB			3				1,4	2	5					6

Systems*	Disposal – Air: Evapotranspiration	Lined Lagoon	Mechanical	Thermal	Direct Discharge ·	Soil: Conventional SAS#	Modified Distribution	Soil Modification (i.e., mound)	Irrigation	Combinations: Evapotranspiration/Absorption	Unlined Lagoon	Lagoon with Overflow	Off-site Disposal##	Reuse: Toilet Flushing	Toilet Flushing, Lawn Watering and Car Washing	Lawn Sprinkling, Bath Shower, Toilet Flushing, Car Washing and Laundry
A							x	x								
B			x				x	x								
C							x	x								
D							x	x	x							
E			x				x	x								
F			x	x							x		x			
G									x					x	x	
H									x					x	x	x
I									x					x	x	
J									x					x	x	
K									x					x	x	
L									x					x	x	
M									x					x	x	
N									x					x	x	
O									x					x	x	
P							x		x							
Q									x					x	x	x
R							x		x							
S							x		x							
T							x		x							
U							x		x							
V							x		x							
W							x		x							
X									x					x	x	
Y									x					x	x	
Z									x					x	x	
AA									x					x	x	
BB									x					x	x	x

TABLE A6 (Continued)

	Treatment**														Disposal															
	Biological					Physical-Chemical									Air					Soil				Combinations				Reuse		
Systems*	Aerobic -Anaerobic	Aerobic	Anaerobic	Emergent Vegetation	"Black Box"**	Filtration	Separation	Chemical Addition	Adsorption	Ion Exchange	Oxidation	Desorption	"Black Box"**	Disinfection	Evapotranspiration	Lined Lagoon	Mechanical	Thermal	Direct Discharge	Conventional SAS#	Modified Distribution	Soil Modification (i.e., mound)	Irrigation	Evapotranspiration/ Absorption	Unlined Lagoon	Lagoon with Overflow	Off-site Disposal##	Toilet Flushing	Toilet Flushing, Lawn Watering and Car Washing	Lawn Sprinkling, Bath Shower, Toilet Flushing, Car Washing and Laundry
CC						3	2	1	4					5									x					x	x	
DD			1,3			2,4			5					6									x					x	x	x
EE		2				3	1		4					5									x					x	x	
FF		2	3			4	1		5					6									x					x	x	
GG		2				3	1			4				5									x					x	x	x
HH			1			2				3				4									x					x	x	x
II			2			3		1		4				5									x					x	x	x
JJ						3	2	1		4				5									x					x	x	x
KK					1		2														x	x	x							
LL													1				x				x	x	x					x	x	x
MM					2		1,3														x	x	x							
NN					1												x				x	x	x							
OO							1						2				x				x	x	x					x	x	x
PP								1					2				x				x	x	x							
QQ								1					2	3									x					x	x	x
RR							2						1				x				x	x	x							
SS							2						1	3									x					x	x	x
TT						2		1,3						4									x					x	x	x
UU						2		1						3									x					x	x	x
VV						1		2						3									x					x	x	x
WW						1								2									x					x	x	x
XX								1					2	3									x					x	x	x

TABLE A6. FOOTNOTES

* Order in which systems appear does not imply ranking.

++ Numbers which appear in the body of the table indicate the order of treatment units in a system.

** Indicates unknown process capable of providing the treatment required (either singly or in combination with other specified processes) for the disposal option(s) indicated under given site conditions. Although it is recognized that new disposal options are possible no "black box" is included for disposal options since it would not be possible to specify the pretreatment required for an unknown disposal method.

\# Soil Absorption System.

\## For example, a holding tank with periodic pumping.

TABLE A7. TREATMENT AND DISPOSAL SYSTEMS
PHYSICAL SITE CONDITION 7

	Treatment**														Disposal															
	Biological					Physical-Chemical									Air					Soil				Combinations				Reuse		
Systems*	Aerobic-Anaerobic	Aerobic	Anaerobic	Emergent Vegetation	"Black Box"***	Filtration	Separation	Chemical Addition	Adsorption	Ion Exchange	Oxidation	Desorption	"Black Box"***	Disinfection	Evapotranspiration	Lined Lagoon	Mechanical	Thermal	Direct Discharge	Conventional SAS	Modified Distribution	Soil Modification (i.e., mound)	Irrigation	Evapotranspiration/Absorption	Unlined Lagoon	Lagoon with Overflow	Off-site Disposal#	Toilet Flushing	Toilet Flushing, Lawn Watering and Car Washing	Lawn Sprinkling, Bath Shower, Toilet Flushing, Car Washing and Laundry
A			1																		x	x		x						
B							2	1									x				x	x		x						
C			2					1													x	x		x						
D				1																	x	x	x	x						
E							1										x				x	x		x						
F				N	O	N	E									x	x	x							x					
G			1			2								3									x					x	x	
H						2	1																x					x	x	x
I		2					1,3							4									x					x	x	
J		2				4	1,3							5									x					x	x	
K		3					1,4	2						5									x					x	x	
L			2			3		1						4									x					x	x	
M				1		2								3									x					x	x	
N				1			2							3									x					x	x	
O						3	2	1						4									x					x	x	
P				1			2														x		x							
Q											1			3									x					x	x	x
R				1		2															x		x	x						
S			1			2															x		x	x						
T			2			3		1													x		x	x						
U						3	2	1													x		x	x						
V			2				1,3														x		x	x						
W			2			4	1,3														x		x	x						
X			1			2			3					4									x					x	x	
Y		2					1,3		4					5									x					x	x	
Z			2			3		1	4					5									x					x	x	
AA							2		3		1			4									x					x	x	
BB			3				1,4	2	5					6									x					x	x	x

TABLE A7 (Continued)

	Treatment**														Disposal															
	Biological					Physical-Chemical									Air					Soil				Combinations				Reuse		
Systems*	Aerobic-Anaerobic	Aerobic	Anaerobic	Emergent Vegetation	"Black Box"**	Filtration	Separation	Chemical Addition	Adsorption	Ion Exchange	Oxidation	Desorption	"Black Box"**	Disinfection	Evapotranspiration	Lined Lagoon	Mechanical	Thermal	Direct Discharge	Conventional SAS#	Modified Distribution	Soil Modification (i.e., mound)	Irrigation	Evapotranspiration/ Absorption	Unlined Lagoon	Lagoon with Overflow	Off-site Disposal##	Toilet Flushing	Toilet Flushing, Lawn Watering and Car Washing	Lawn Sprinkling, Bath Shower, Toilet Flushing, Car Washing and Laundry
CC						3	2	1	4					5									x					x	x	
DD			1,3			2,4			5					6									x					x	x	x
EE		2				3	1		4					5									x					x	x	
FF		2	3			4	1		5					6									x					x	x	
GG		2				3	1			4				5									x					x	x	x
HH			1			2				3				4									x					x	x	x
II			2			3		1		4				5									x					x	x	x
JJ						3	2	1		4				5									x					x	x	x
KK					1		2														x	x	x	x						
LL													1				x				x	x	x	x				x	x	x
MM					2		1,3														x	x	x	x						
NN					1												x				x	x	x	x						
OO							1						2				x				x	x	x	x				x	x	x
PP								1					2				x				x	x	x	x						
QQ								1					2	3									x					x	x	x
RR							2						1				x				x	x	x	x						
SS							2						1	3									x					x	x	x
TT						2		1,3						4									x					x	x	x
UU						2		1						3									x					x	x	x
VV						1		2						3									x					x	x	x
WW						1								2									x					x	x	x
XX								1					2	3									x					x	x	x

TABLE A7. FOOTNOTES

* Order in which systems appear does not imply ranking.

++ Numbers which appear in the body of the table indicate the order of treatment units in a system.

** Indicates unknown process capable of providing the treatment required (either singly or in combination with other specified processes) for the disposal option(s) indicated under given site conditions. Although it is recognized that new disposal options are possible no "black box" is included for disposal options since it would not be possible to specify the pretreatment required for an unknown disposal method.

\# Soil Absorption System.

\## For example, a holding tank with periodic pumping.

TABLE A8. TREATMENT AND DISPOSAL SYSTEMS --
PHYSICAL SITE CONDITION 8

	Treatment**														Disposal															
	Biological					Physical-Chemical									Air					Soil				Combinations				Reuse		
Systems*	Aerobic -Anaerobic	Aerobic	Anaerobic	Emergent Vegetation	"Black Box"**	Filtration	Separation	Chemical Addition	Adsorption	Ion Exchange	Oxidation	Desorption	"Black Box"**	Disinfection	Evapotranspiration	Lined Lagoon	Mechanical	Thermal	Direct Discharge	Conventional SAS#	Modified Distribution	Soil Modification (i.e., mound)	Irrigation	Evapotranspiration/ Absorption	Unlined Lagoon	Lagoon with Overflow	Off-site Disposal##	Toilet Flushing	Toilet Flushing, Lawn Watering and Car Washing	Lawn Sprinkling, Bath Shower, Toilet Flushing, Car Washing and Laundry
A			1																		x·	x·								
B							2	1									x				x·	x·								
C			2					1													x·	x·								
D				1																	x·	x·	x							
E							1										x				x·	x·								
F				N O	N E												x	x							x		x			
G			1			2								3									x					x	x	
H						2	1																x					x	x	x
I		2					1,3							4									x					x	x	
J		2				4	1,3							5									x					x	x	
K		3					1,4	2						5									x					x	x	
L			2			3		1						4									x					x	x	
M				1		2								3									x					x	x	
N				1			2							3									x					x	x	
O						3	2	1						4									x					x	x	
P				1			2														x·		x							
Q											1			3									x					x	x	x
R				1		2															x·		x							
S			1			2															x·		x							
T			2			3		1													x'		x							
U						3	2	1													x'		x							
V			2				1,3														x'		x							
W			2			4	1,3														x'		x							
X			1			2			3					4									x					x	x	
Y		2					1,3		4					5									x					x	x	
Z			2			3		1	4					5									x					x	x	
AA							2		3		1			4									x					x	x	
BB			3				1,4	2	5					6									x					x	x	x

TABLE A8 (Continued)

Systems*	Treatment**														Disposal															
	Biological					Physical-Chemical									Air					Soil				Combinations				Reuse		
	Aerobic-Anaerobic	Aerobic	Anaerobic	Emergent Vegetation	"Black Box"**	Filtration	Separation	Chemical Addition	Adsorption	Ion Exchange	Oxidation	Desorption	"Black Box"**	Disinfection	Evapotranspiration	Lined Lagoon	Mechanical	Thermal	Direct Discharge	Conventional SAS‡	Modified Distribution	Soil Modification (i.e., mound)	Irrigation	Evapotranspiration/Absorption	Unlined Lagoon	Lagoon with Overflow	Off-site Disposal††	Toilet Flushing	Toilet Flushing, Lawn Watering and Car Washing	Lawn Sprinkling, Bath, Shower, Toilet Flushing, Car Washing and Laundry
CC						3	2	1	4					5									x					x	x	
DD			1,3			2,4			5					6									x					x	x	x
EE		2				3	1		4					5									x					x	x	
FF		2	3			4	1		5					6									x					x	x	
GG		2				3	1			4				5									x					x	x	x
HH			1			2				3				4									x					x	x	x
II			2			3		1		4				5									x					x	x	x
JJ						3	2	1		4				5									x					x	x	x
KK					1		2														x	x	x							
LL													1				x				x	x	x					x	x	x
MM					2		1,3														x	x	x							
NN					1												x				x	x	x							
OO							1						2				x				x	x	x					x	x	x
PP								1					2				x				x	x	x							
QQ								1					2	3									x					x	x	x
RR							2						1				x				x	x	x							
SS							2						1	3									x					x	x	x
TT						2		1,3						4									x					x	x	x
UU						2		1						3									x					x	x	x
VV						1		2						3									x					x	x	x
WW						1								2									x					x	x	x
XX								1					2	3									x					x	x	x

TABLE A8. FOOTNOTES

+ Indicates that the lagoon provides the type of biological treatment indicated.

* Order in which systems appear does not imply ranking.

++ Numbers which appear in the body of the table indicate the order of treatment units in a system.

** Indicates unknown process capable of providing the treatment required (either singly or in combination with other specified processes) for the disposal option(s) indicated under given site conditions. Although it is recognized that new disposal options are possible no "black box" is included for disposal options since it would not be possible to specify the pretreatment required for an unknown disposal method.

Soil Absorption System.

For example, a holding tank with periodic pumping.

• Applicable only if flow reduction and/or off-site disposal of a portion of the total wastewater are used to reduce disposal area requirement.

TABLE A9. TREATMENT AND DISPOSAL SYSTEMS
PHYSICAL SITE CONDITION 9

	Treatment**														Disposal															
	Biological					Physical-Chemical									Air					Soil				Combinations				Reuse		
Systems*	Aerobic-Anaerobic	Aerobic	Anaerobic	Emergent Vegetation	"Black Box"**	Filtration	Separation	Chemical Addition	Adsorption	Ion Exchange	Oxidation	Desorption	"Black Box"**	Disinfection	Evapotranspiration	Lined Lagoon	Mechanical	Thermal	Direct Discharge	Conventional SAS#	Modified Distribution	Soil Modification (i.e., mound)	Irrigation	Evapotranspiration/ Absorption	Unlined Lagoon	Lagoon with Overflow	Off-site Disposal##	Toilet Flushing	Toilet Flushing, Lawn Watering and Car Washing	Lawn Sprinkling, Bath Shower, Toilet Flushing, Car Washing and Laundry
A							2	1									x													
B				1																			x							
C							1										x													
D				N O N E													x	x									x			
E			1			2								3									x					x	x	
F						2	1																x					x	x	x
G		2					1,3							4									x					x	x	
H		2				4	1,3							5									x					x	x	
I		3					1,4	2						5									x					x	x	
J			2			3		1						4									x					x	x	
K				1		2								3									x					x	x	
L				1			2							3									x					x	x	
M						3	2	1						4									x					x	x	
N				1			2																x							
O							2				1			3									x					x	x	x
P				1		2																	x					x	x	
Q			1			2																	x							
R			2			3		1															x							
S						3	2	1															x							
T			2				1,3																x							
U			2			4	1,3																x							
V			1			2			3					4									x					x	x	
W		2					1,3		4					5									x					x	x	
X			2			3		1	4					5									x					x	x	
Y							2		3		1			4									x					x	x	
Z			3				1,4	2	5					6									x					x	x	x

TABLE A 9 (Continued)

	Treatment**														Disposal															
	Biological					Physical-Chemical									Air					Soil				Combinations				Reuse		
Systems*	Aerobic -Anaerobic	Aerobic	Anaerobic	Emergent Vegetation	"Black Box"**	Filtration	Separation	Chemical Addition	Adsorption	Ion Exchange	Oxidation	Desorption	"Black Box"**	Disinfection	Evapotranspiration	Lined Lagoon	Mechanical	Thermal	Direct Discharge	Conventional SAS#	Modified Distribution	Soil Modification (i.e., mound)	Irrigation	Evapotranspiration/ Absorption	Unlined Lagoon	Lagoon with Overflow	Off-site Disposal##	Toilet Flushing	Toilet Flushing, Lawn Watering and Car Washing	Lawn Sprinkling, Bath Shower, Toilet Flushing, Car Washing and Laundry
AA						3	2	1	4					5									x					x	x	
BB			1,3			2,4			5					6									x					x	x	x
CC		2				3	1		4					5									x					x	x	
DD		2	3			4	1		5					6									x					x	x	
EE		2				3	1			4				5									x					x	x	x
FF			1			2				3				4									x					x	x	x
GG			2			3		1		4				5									x					x	x	x
HH						3	2	1		4				5									x					x	x	x
II					1		2																x							
JJ													1				x						x					x	x	x
KK					2		1,3																x							
LL					1												x						x							
MM							1						2				x						x					x	x	x
NN								1					2				x						x							
OO								1					2	3									x					x	x	x
PP							2						1				x						x							
QQ							2						1	3									x					x	x	x
RR						2		1,3						4									x					x	x	x
SS						2		1						3									x					x	x	x
TT						1		2						3									x					x	x	x
UU						1								2									x					x	x	x
VV								1					2	3									x					x	x	x

TABLE A9. FOOTNOTES

* Order in which systems appear does not imply ranking.

++ Numbers which appear in the body of the table indicate the order of treatment units in a system.

** Indicates unknown process capable of providing the treatment required (either singly or in combination with other specified processes) for the disposal option(s) indicated under given site conditions. Although it is recognized that new disposal options are possible no "black box" is included for disposal options since it would not be possible to specify the pretreatment required for an unknown disposal method.

\# Soil Absorption System.

\## For example, a holding tank with periodic pumping.

TABLE A10. TREATMENT AND DISPOSAL SYSTEMS -- PHYSICAL SITE CONDITION 10

	Treatment**														Disposal															
	Biological					Physical-Chemical									Air					Soil				Combinations				Reuse		
Systems*	Aerobic-Anaerobic	Aerobic	Anaerobic	Emergent Vegetation	"Black Box"**	Filtration	Separation	Chemical Addition	Adsorption	Ion Exchange	Oxidation	Desorption	"Black Box"**	Disinfection	Evapotranspiration	Lined Lagoon	Mechanical	Thermal	Direct Discharge	Conventional SAS	Modified Distribution	Soil Modification (i.e., mound)	Irrigation	Evapotranspiration/Absorption	Unlined Lagoon	Lagoon with Overflow	Off-site Disposal#	Toilet Flushing	Toilet Flushing, Lawn Watering and Car Washing	Lawn Sprinkling, Bath Shower, Toilet Flushing, Car Washing and Laundry
A							2	1									x													
B							1										x													
C				N	O	N	E										x	x							x		x			
D			1			2								3					x									x	x	
E						2	1												x									x	x	x
F		2					1,3							4					x									x	x	
G		2				4	1,3							5					x									x	x	
H		3					1,4	2						5					x									x	x	
I			2			3		1						4					x									x	x	
J				1		2								3					x									x	x	
K				1			2							3					x									x	x	
L						3	2	1						4					x									x	x	
M							2				1			3					x									x	x	x
N		1				2								3														x	x	
O		1					2							3														x	x	
P		2				3		1						4														x	x	
Q		2					3	1						4														x	x	
R			1			2			3					4					x									x	x	
S		2					1,3		4					5					x									x	x	
T			2			3		1	4					5					x									x	x	
U							2		3		1			4					x									x	x	
V			3				1,4	2	5					6					x									x	x	x
W						3	2	1	4					5					x									x	x	
X			1,3			2,4			5					6					x									x	x	x
Y		2				3	1		4					5					x									x	x	
Z		2	3			4	1		5					6					x									x	x	

TABLE A10 (Continued)

Systems*	Treatment**														Disposal																	
	Biological					Physical-Chemical									Air					Soil				Combinations				Reuse		
	Aerobic-Anaerobic	Aerobic	Anaerobic	Emergent Vegetation	"Black Box"**	Filtration	Separation	Chemical Addition	Adsorption	Ion Exchange	Oxidation	Desorption	"Black Box"**	Disinfection	Evapotranspiration	Lined Lagoon	Mechanical	Thermal	Direct Discharge	Conventional SAS†	Modified Distribution	Soil Modification (i.e., mound)	Irrigation	Evapotranspiration/Absorption	Unlined Lagoon	Lagoon with Overflow	Off-site Disposal‡	Toilet Flushing	Toilet Flushing, Lawn Watering and Car Washing	Lawn Sprinkling, Bath Shower, Toilet Flushing, Car Washing and Laundry
AA		2				3	1			4				5					x				x					x	x	x
BB			1			2				3				4					x				x					x	x	x
CC			2			3		1		4				5					x				x					x	x	x
DD						3	2	1		4				5					x				x					x	x	x
EE													1				x		x				x					x	x	x
FF					1												x						x							
GG							1						2				x		x				x					x	x	x
HH								1					2				x						x							
II								1					2	3					x				x					x	x	x
JJ						2							1				x						x							
KK						2							1	3					x				x					x	x	x
LL					2		1,3							4					x				x					x	x	x
MM					2		1							3					x				x					x	x	x
NN					1		2							3					x				x					x	x	x
OO					1									2					x				x					x	x	x
PP							1						2	3					x				x					x	x	x

TABLE A10. FOOTNOTES

* Order in which systems appear does not imply ranking.

++ Numbers which appear in the body of the table indicate the order of treatment units in a system.

** Indicates unknown process capable of providing the treatment required (either singly or in combination with other specified processes) for the disposal option(s) indicated under given site conditions. Although it is recognized that new disposal options are possible no "black box" is included for disposal options since it would not be possible to specify the pretreatment required for an unknown disposal method.

Soil Absorption System.

For example, a holding tank with periodic pumping.

TABLE A11. TREATMENT AND DISPOSAL SYSTEMS -- PHYSICAL SITE CONDITION 11

	Treatment**														Disposal																
	Biological					Physical-Chemical									Air					Soil				Combinations				Reuse		
Systems*	Aerobic-Anaerobic	Aerobic	Anaerobic	Emergent Vegetation	"Black Box"**	Filtration	Separation	Chemical Addition	Adsorption	Ion Exchange	Oxidation	Desorption	"Black Box"**	Disinfection	Evapotranspiration	Lined Lagoon	Mechanical	Thermal	Direct Discharge	Conventional SAS#	Modified Distribution	Soil Modification (i.e., mound)	Irrigation	Evapotranspiration/ Absorption	Unlined Lagoon	Lagoon with Overflow	Off-site Disposal##	Toilet Flushing	Toilet Flushing, Lawn Watering and Car Washing	Lawn Sprinkling, Bath Shower, Toilet Flushing, Car Washing and Laundry
A			1												x															
B							2	1							x		x													
C			2					1							x															
D				1											x															
E							1								x		x													
F			N O N E													x	x	x							x		x			
G			1			2								3														x	x	
H						2	1																					x	x	x
I		2					1,3							4														x	x	
J		2				4	1,3							5														x	x	
K		3					1,4	2						5														x	x	
L			2			3		1						4														x	x	
M				1		2								3														x	x	
N				1			2							3														x	x	
O						3	2	1						4														x	x	
P							2				1			3														x	x	x
Q			1			2			3					4														x	x	
R		2					1,3		4					5														x	x	
S			2			3		1	4					5														x	x	
T							2		3		1			4														x	x	
U			3				1,4	2	5					6														x	x	x
V						3	2	1	4					5														x	x	
W			1,3			2,4			5					6														x	x	x
X		2				3	1		4					5														x	x	
Y		2	3			4	1		5					6														x	x	
Z		2				3	1			4				5														x	x	x

TABLE A11 (Continued)

	Treatment**														Disposal															
	Biological					Physical-Chemical									Air					Soil				Combinations				Reuse		
Systems*	Aerobic-Anaerobic	Aerobic	Anaerobic	Emergent Vegetation	"Black Box"**	Filtration	Separation	Chemical Addition	Adsorption	Ion Exchange	Oxidation	Desorption	"Black Box"**	Disinfection	Evapotranspiration	Lined Lagoon	Mechanical	Thermal	Direct Discharge	Conventional SAS	Modified Distribution	Soil Modification (i.e. mound)	Irrigation	Evapotranspiration/ Absorption	Unlined Lagoon	Lagoon with Overflow	Off-site Disposal	Toilet Flushing	Toilet Flushing, Lawn Watering and Car Washing	Lawn Sprinkling, Bath Shower, Toilet Flushing, Car Washing and Laundry
AA			1			2				3				4														x	x	x
BB			2			3		1		4				5														x	x	x
CC						3	2	1		4				5														x	x	x
DD					1		2								x															
EE													1		x		x											x	x	x
FF					2		1,3								x															
GG					1										x		x													
HH							1						2		x		x											x	x	x
II								1					2		x		x													
JJ								1					2	3														x	x	x
KK							2						1		x		x													
LL							2						1	3														x	x	x
MM						2		1,3						4														x	x	x
NN						2		1						3														x	x	x
OO						1		2						3														x	x	x
PP						1								2														x	x	x
QQ								1					2	3														x	x	x

TABLE A12. FOOTNOTES

+ Indicates that the lagoon provides the type of biological treatment indicated.

* Order in which systems appear does not imply ranking.

++ Numbers which appear in the body of the table indicate the order of treatment units in a system.

** Indicates unknown process capable of providing the treatment required (either singly or in combination with other specified processes) for the disposal option(s) indicated under given site conditions. Although it is recognized that new disposal options are possible no "black box" is included for disposal options since it would not be possible to specify the pretreatment required for an unknown disposal method.

Soil Absorption System.

For example, a holding tank with periodic pumping.

TABLE A13. TREATMENT AND DISPOSAL SYSTEMS -- PHYSICAL SITE CONDITION 13

	Treatment**														Disposal															
	Biological					Physical-Chemical									Air					Soil				Combinations				Reuse		
Systems*	Aerobic -Anaerobic	Aerobic	Anaerobic	Emergent Vegetation	"Black Box"**	Filtration	Separation	Chemical Addition	Adsorption	Ion Exchange	Oxidation	Desorption	"Black Box"**	Disinfection	Evapotranspiration	Lined Lagoon	Mechanical	Thermal	Direct Discharge	Conventional SAS†	Modified Distribution	Soil Modification (i.e., mound)	Irrigation	Evapotranspiration/ Absorption	Unlined Lagoon	Lagoon with Overflow	Off-site Disposal‡	Toilet Flushing	Toilet Flushing, Lawn Watering and Car Washing	Lawn Sprinkling, Bath Shower, Toilet Flushing, Car Washing and Laundry
A							2	1									x													
B							1										x													
C				NONE													x	x									x			
D			1			2								3														x	x	
E						2	1																					x	x	x
F		2					1,3							4														x	x	
G		2				4	1,3							5														x	x	
H		3					1,4	2						5														x	x	
I			2			3		1						4														x	x	
J				1		2								3														x	x	
K				1			2							3														x	x	
L						3	2	1						4														x	x	
M							2				1			3														x	x	x
N				1		2													x									x	x	x
O		1				2				3				4													x+	x	x	
P		1					2			3				4													x+	x	x	
Q		2	3			4		1						5													x+	x	x	
R		2	3			4	4	1						5													x+	x	x	
S			1			2			3					4														x	x	
T		2					1,3			4				5					x									x	x	
U			2			3		1	4					5														x	x	
V	3					5	2,4	1						6					x				x					x	x	x
W			2,4			3		1						5					x				x					x	x	x
X		3	5				2,4	1						6					x				x					x	x	x
Y		3	5				1,4	2						5					x				x					x	x	x
Z			3	1			4	2						4					x				x					x	x	x
AA		3	4				2,5	1						6					x				x					x	x	x
BB		3	4				1,5	2						6					x				x					x	x	x
CC			1			3				2				4					x				x					x	x	x

TABLE A11. FOOTNOTES

* Order in which systems appear does not imply ranking.

++ Numbers which appear in the body of the table indicate the order of treatment units in a system.

** Indicates unknown process capable of providing the treatment required (either singly or in combination with other specified processes) for the disposal option(s) indicated under given site conditions. Although it is recognized that new disposal options are possible no "black box" is included for disposal options since it would not be possible to specify the pretreatment required for an unknown disposal method.

Soil Absorption System.

For example, a holding tank with periodic pumping.

TABLE A12. TREATMENT AND DISPOSAL SYSTEMS
PHYSICAL SITE CONDITION 12

	Treatment**														Disposal															
	Biological					Physical-Chemical									Air					Soil				Combinations				Reuse		
Systems*	Aerobic-Anaerobic	Aerobic	Anaerobic	Emergent Vegetation	"Black Box"**	Filtration	Separation	Chemical Addition	Adsorption	Ion Exchange	Oxidation	Desorption	"Black Box"**	Disinfection	Evapotranspiration	Lined Lagoon	Mechanical	Thermal	Direct Discharge	Conventional SAS#	Modified Distribution	Soil Modification (i.e., mound)	Irrigation	Evapotranspiration/ Absorption	Unlined Lagoon	Lagoon with Overflow	Off-site Disposal##	Toilet Flushing	Toilet Flushing, Lawn Watering and Car Washing	Lawn Sprinkling, Bath Shower, Toilet Flushing, Car Washing and Laundry
A							2	1									x													
B							1										x													
C				N O N E													x	x									x			
D			1			2								3														x	x	
E						2	1																					x	x	x
F		2					1,3							4														x	x	
G		2				4	1,3							5														x	x	
H		3					1,4	2						5														x	x	
I			2			3		1						4														x	x	
J				1		2								3														x	x	
K				1			2							3														x	x	
L						3	2	1						4														x	x	
M							2				1			3														x	x	x
N				1		2													x									x	x	x
O		1				2				3				4													x+	x	x	
P		1					2			3				4													x+	x	x	
Q		2	3			4		1						5													x+	x	x	
R		2	3			4	4	1						5													x+	x	x	
S			1			2			3					4														x	x	
T		2					1,3			4				5					x									x	x	
U			2			3		1	4					5														x	x	
V	2					4	1,3							5					x				x					x	x	x
W			1,3			2								4					x				x					x	x	x
X		2	4			5	1,3							6					x				x					x	x	x
Y			2	1		3								4					x				x					x	x	x
Z			2	1			3							4					x				x					x	x	x
AA		2	3			4	1							5					x				x					x	x	x
BB			1			3				2				4					x				x					x	x	x

TABLE A12 (Continued)

	Treatment**														Disposal															
	Biological					Physical-Chemical									Air					Soil				Combinations				Reuse		
Systems*	Aerobic-Anaerobic	Aerobic	Anaerobic	Emergent Vegetation	"Black Box"**	Filtration	Separation	Chemical Addition	Adsorption	Ion Exchange	Oxidation	Desorption	"Black Box"**	Disinfection	Evapotranspiration	Lined Lagoon	Mechanical	Thermal	Direct Discharge	Conventional SAS#	Modified Distribution	Soil Modification (i.e., mound)	Irrigation	Evapotranspiration/ Absorption	Unlined Lagoon	Lagoon with Overflow	Off-site Disposal##	Toilet Flushing	Toilet Flushing, Lawn Watering and Car Washing	Lawn Sprinkling, Bath, Shower, Toilet Flushing, Car Washing and Laundry
CC							2			3	1			4					x									x	x	x
DD			3			4	1	2		5				6					x									x	x	x
EE						3	2	1		4				5					x									x	x	
FF			1,3			2,4								5					x									x	x	x
GG		2				3	1		4					5														x	x	
HH		2	3			4	1		5					6														x	x	
II		2				3	1			4				5					x									x	x	x
JJ			1			2				3				4					x									x	x	x
KK			2			3		1		4				5					x									x	x	x
LL						3	2	1		4				5					x									x	x	x
MM													1				x		x									x	x	x
NN					1												x													
OO							1						2				x		x									x	x	x
PP								1					2				x													
QQ								1					2	3					x									x	x	x
RR						2							1				x													
SS						2							1	3					x									x	x	x
TT					2		1,3							4					x									x	x	x
UU					2		1							3					x									x	x	x
VV					1		2							3					x									x	x	x
WW					1									2					x									x	x	x
XX							1						2	3					x									x	x	x

TABLE A13 (Continued)

Systems*	Treatments**														Disposal															
	Biological					Physical-Chemical									Air					Soil				Combinations				Reuse		
	Aerobic -Anaerobic	Aerobic	Anaerobic	Emergent Vegetation	"Black Box"**	Filtration	Separation	Chemical Addition	Adsorption	Ion Exchange	Oxidation	Desorption	"Black Box"**	Disinfection	Evapotranspiration	Lined Lagoon	Mechanical	Thermal	Direct Discharge	Conventional SAS†	Modified Distribution	Soil Modification (i.e., mound)	Irrigation	Evapotranspiration/ Absorption	Unlined Lagoon	Lagoon with Overflow	Off-site Disposal††	Toilet Flushing	Toilet Flushing, Lawn Watering and Car Washing	Lawn Sprinkling, Bath Shower, Toilet Flushing, Car Washing and Laundry
DD							2			3	1			4					x									x	x	x
EE			3			4	1	2		5				6					x									x	x	x
FF						3	2	1		4				5					x									x	x	
GG			1,3			2,4								5					x									x	x	x
HH		2				3	1		4					5														x	x	
II		2	3			4	1		5					6														x	x	
JJ		2				3	1			4				5					x									x	x	x
KK			1			2				3				4					x									x	x	x
LL			2			3		1		4				5					x									x	x	x
MM						3	2	1		4				5					x									x	x	x
NN													1				x		x									x	x	x
OO					1												x													
PP							1						2				x		x									x	x	x
QQ								1					2				x													
RR								1					2	3					x									x	x	x
SS						2							1				x													
TT						2							1	3					x									x	x	x
UU					2		1,3							4					x									x	x	x
VV					2		1							3					x									x	x	x
WW					1		2							3					x									x	x	x
XX					1									2					x									x	x	x
YY							1						2	3					x									x	x	x

TABLE A13. FOOTNOTES

\+ Indicates that the lagoon provides the type of biological treatment indicated.

* Order in which systems appear does not imply ranking.

++ Numbers which appear in the body of the table indicate the order of treatment units in a system.

** Indicates unknown process capable of providing the treatment required (either singly or in combination with other specified processes) for the disposal option(s) indicated under given site conditions. Although it is recognized that new disposal options are possible no "black box" is included for disposal options since it would not be possible to specify the pretreatment required for an unknown disposal method.

\# Soil Absorption System.

\## For example, a holding tank with periodic pumping.

TABLE A14. TREATMENT AND DISPOSAL SYSTEMS PHYSICAL SITE CONDITION 14

	Treatment**														Disposal															
	Biological					Physical-Chemical									Air					Soil				Combinations				Reuse		
Systems*	Aerobic-Anaerobic	Aerobic	Anaerobic	Emergent Vegetation	"Black Box"**	Filtration	Separation	Chemical Addition	Adsorption	Ion Exchange	Oxidation	Desorption	"Black Box"**	Disinfection	Evapotranspiration	Lined Lagoon	Mechanical	Thermal	Direct Discharge	Conventional SAS#	Modified Distribution	Soil Modification (i.e., mound)	Irrigation	Evapotranspiration/Absorption	Unlined Lagoon	Lagoon with Overflow	Off-site Disposal##	Toilet Flushing	Toilet Flushing, Lawn Watering and Car Washing	Lawn Sprinkling, Bath Shower, Toilet Flushing, Car Washing and Laundry
A			1																			x								
B							2	1									x					x								
C			2					1														x								
D				1																		x	x							
E							1										x					x								
F				N	O	N	E									x	x	x												
G			1			2								3									x					x	x	
H						2	1																x					x	x	x
I		2					1,3							4									x					x	x	
J		2				4	1,3							5									x					x	x	
K		3					1,4	2						5									x					x	x	
L			2			3		1						4									x					x	x	
M				1		2								3									x					x	x	
N				1			2							3									x					x	x	
O						3	2	1						4									x					x	x	
P				1			2													x	x		x							
Q											1			3									x					x	x	x
R				1		2														x	x		x							
S			1			2														x	x		x							
T			2			3		1												x	x		x							
U						3	2	1												x	x		x							
V			2				1,3													x	x		x							
W			2			4	1,3													x	x		x							
X			1			2			3					4									x					x	x	
Y		2					1,3		4					5									x					x	x	
Z			2			3		1	4					5									x					x	x	
AA							2		3		1			4									x					x	x	
BB			3				1,4	2	5					6									x					x	x	x

TABLE A14 (Continued)

	Treatment**														Disposal															
	Biological					Physical-Chemical									Air					Soil				Combinations				Reuse		
Systems*	Aerobic-Anaerobic	Aerobic	Anaerobic	Emergent Vegetation	"Black Box"**	Filtration	Separation	Chemical Addition	Adsorption	Ion Exchange	Oxidation	Desorption	"Black Box"**	Disinfection	Evapotranspiration	Lined Lagoon	Mechanical	Thermal	Direct Discharge	Conventional SAS†	Modified Distribution	Soil Modification (i.e., mound)	Irrigation	Evapotranspiration/ Absorption	Unlined Lagoon	Lagoon with Overflow	Off-site Disposal††	Toilet Flushing	Toilet Flushing, Lawn Watering and Car Washing	Lawn Sprinkling, Bath Shower, Toilet Flushing, Car Washing and Laundry
CC						3	2	1	4					5									x					x	x	
DD			1,3			2,4			5					6									x					x	x	x
EE		2				3	1		4					5									x					x	x	
FF		2	3			4	1		5					6									x					x	x	
GG		2				3	1			4				5									x					x	x	x
HH			1			2				3				4									x					x	x	x
II			2			3		1		4				5									x					x	x	x
JJ						3	2	1		4				5									x					x	x	x
KK					1		2													x	x	x	x							
LL													1				x			x	x	x	x					x	x	x
MM					2		1,3													x	x	x	x							
NN					1												x			x	x	x	x							
OO							1						2				x			x	x	x	x					x	x	x
PP								1					2				x			x	x	x	x							
QQ								1					2	3									x					x	x	x
RR							2						1				x			x	x	x	x							
SS							2						1	3									x					x	x	x
TT						2		1,3						4									x					x	x	x
UU						2		1						3									x					x	x	x
VV						1		2						3									x					x	x	x
WW						1								2									x					x	x	x
XX								1					2	3									x					x	x	x

TABLE A14. FOOTNOTES

\+ Indicates that the lagoon provides the type of biological treatment indicated.

* Order in which systems appear does not imply ranking.

++ Numbers which appear in the body of the table indicate the order of treatment units in a system.

** Indicates unknown process capable of providing the treatment required (either singly or in combination with other specified processes) for the disposal option(s) indicated under given site conditions. Although it is recognized that new disposal options are possible no "black box" is included for disposal options since it would not be possible to specify the pretreatment required for an unknown disposal method.

\# Soil Absorption System.

\## For example, a holding tank with periodic pumping.

TABLE A15. TREATMENT AND DISPOSAL SYSTEMS -- PHYSICAL SITE CONDITION 15

	Treatment**														Disposal															
	Biological					Physical-Chemical									Air					Soil				Combinations				Reuse		
Systems*	Aerobic -Anaerobic	Aerobic	Anaerobic	Emergent Vegetation	"Black Box"**	Filtration	Separation	Chemical Addition	Adsorption	Ion Exchange	Oxidation	Desorption	"Black Box"**	Disinfection	Evapotranspiration	Lined Lagoon	Mechanical	Thermal	Direct Discharge	Conventional SAS#	Modified Distribution	Soil Modification (i.e., mound)	Irrigation	Evapotranspiration/ Absorption	Unlined Lagoon	Lagoon with Overflow	Off-site Disposal##	Toilet Flushing	Toilet Flushing, Lawn Watering and Car Washing	Lawn Sprinkling, Bath Shower, Toilet Flushing, Car Washing and Laundry
A			1																		x	x								
B							2	1									x				x	x								
C			2					1													x	x								
D				1																	x	x	x							
E							1										x				x	x								
F				N	O	N	E									x	x	x												
G			1			2								3									x					x	x	
H						2	1																x					x	x	x
I		2					1,3							4									x					x	x	
J		2				4	1,3							5									x					x	x	
K		3					1,4	2						5									x					x	x	
L			2			3		1						4									x					x	x	
M				1		2								3									x					x	x	
N				1			2							3									x					x	x	
O						3	2	1						4									x					x	x	
P				1			2													x	x		x							
Q											1			3									x					x	x	x
R				1		2														x	x		x							
S			1			2														x	x		x							
T			2			3		1												x	x		x							
U						3	2	1												x	x		x							
V			2				1,3													x	x		x							
W			2			4	1,2													x	x		x							
X			1			2			3					4									x					x	x	
Y		2					1,3		4					5									x					x	x	
Z			2			3		1	4					5									x					x	x	
AA							2		3		1			4									x					x	x	
BB			3				1,4	2	5					6									x					x	x	x

TABLE A15 (Continued)

	Treatment**														Disposal															
	Biological					Physical-Chemical									Air					Soil				Combinations				Reuse		
Systems*	Aerobic - Anaerobic	Aerobic	Anaerobic	Emergent Vegetation	"Black Box"**	Filtration	Separation	Chemical Addition	Adsorption	Ion Exchange	Oxidation	Desorption	"Black Box"**	Disinfection	Evapotranspiration	Lined Lagoon	Mechanical	Thermal	Direct Discharge	Conventional SAS#	Modified Distribution	Soil Modification (i.e., mound)	Irrigation	Evapotranspiration/ Absorption	Unlined Lagoon	Lagoon with Overflow	Off-site Disposal##	Toilet Flushing	Toilet Flushing, Lawn Watering and Car Washing	Lawn Sprinkling, Bath Shower, Toilet Flushing, Car Washing and Laundry
CC						3	2	1	4					5									x					x	x	
DD			1,3			2,4			5					6									x					x	x	x
EE		2				3	1		4					5									x					x	x	
FF		2	3			4	1		5					6									x					x	x	
GG		2				3	1			4				5									x					x	x	x
HH			1			2				3				4									x					x	x	x
II			2			3		1		4				5									x					x	x	x
JJ						3	2	1		4				5									x					x	x	x
KK					1		2													x	x	x	x							
LL													1				x			x	x	x	x					x	x	x
MM					2		1,3													x	x	x	x							
NN					1												x			x	x	x	x							
OO							1						2				x			x	x	x	x					x	x	x
PP								1					2				x			x	x	x	x							
QQ								1					2	3									x					x	x	x
RR							2						1				x			x	x	x	x							
SS							2						1	3									x					x	x	x
TT						2		1,3						4									x					x	x	x
UU						2		1						3									x					x	x	x
VV						1		2						3									x					x	x	x
WW						1								2									x					x	x	x
XX								1					2	3									x					x	x	x

TABLE A15. FOOTNOTES

+ Indicates that the lagoon provides the type of biological treatment indicated.

* Order in which systems appear does not imply ranking.

++ Numbers which appear in the body of the table indicate the order of treatment units in a system.

** Indicates unknown process capable of providing the treatment required (either singly or in combination with other specified processes) for the disposal option(s) indicated under given site conditions. Although it is recognized that new disposal options are possible no "black box" is included for disposal options since it would not be possible to specify the pretreatment required for an unknown disposal method.

Soil Absorption System.

For example, a holding tank with periodic pumping.

TABLE A16. TREATMENT/REUSE SYSTEMS FOR SEGREGATED WASTE STREAMS*

	Waste Stream			Treatment														Reuse		
				Biological					Physical-Chemical											
System⁺	Grey Water	Laundry and Bath/Shower, Laundry Only, or Bath Only	Toilet Only	Aerobic - Anaerobic	Aerobic	Anaerobic	Emergent Vegetation	"Black Box"**	Filtration	Separation	Chemical Addition	Adsorption	Ion Exchange	Oxidation	Desorption	"Black Box"**	Disinfection	Toilet Flushing	Toilet Flushing, Lawn Watering and Car Washing	Lawn Sprinkling, Bath, Shower, Toilet Flushing, Car Washing and Laundry
A	X								2	1							3	X	X	
B	X								2	1		3					3	X	X	X
C	X								4	1, 3	2						5	X	X	X
D	X									1, 3	2	4					5		X	
E	X								2	1		3	4				5			X
F									2	1			3				4		X	X
G		X							1								2	X	X	
H		X							1									X	X	X
I		X							1			2					3		X	
J		X							1			2	3				4			X
K		X							1											
L		X				X			1, 3			4					5			X
M			X		2	1			3			4					5	X		
N			X		2	1			3				4				5	X		
O				1					2				3				4	X		
P	X	X														1		X	X	X
Q	X	X						2		1, 3							4	X	X	X
R	X	X														1	2	X	X	
S	X	X														1	2			X
T	X	X									1					2	3	X	X	
U	X	X									1					2	3			X
V	X										1		3			2	4			X

FOOTNOTES:

* Includes only treatment systems unique to segregated waste streams The treatment/disposal system tables for each site variable indicate the treatment systems applicable prior to reuse of combined wastewater Many of the systems on Table 1 are also applicable to segregated waste streams

** Indicates unknown process capable of providing the treatment required (either singly or in combination with other specified processes) for the reuse option(s) indicated

⁺ Order in which systems appear does not imply ranking

APPENDIX B

REUSE WATER QUALITY OBJECTIVES

For the purposes of this study, reuse water quality objectives are required to determine the level of wastewater treatment necessary prior to onsite reuse. Considerable variation exists for reuse water quality characteristics at existing reuse sites; reuse water quality criteria recommended by several national and international organizations; and reuse water quality criteria enacted by various legislative bodies. Despite the variations, protection of public health and environmental and aesthetic acceptability have generally been the guiding principles.

To ensure protection of public health, reuse water quality recommendations and requirements generally have been based on the likelihood of human contact and/or ingestion of reuse water. Some form of bacteriological measurement (usually the number of coliform organisms per 100 ml) is used as an indicator of health hazard potential. Physical and chemical water characteristics are also indicators of safety hazards and toxicity danger of the reuse water, as well as indicators of environmental and aesthetic suitability of reuse applications.

Categories used to describe reuse applications for this study are based on the considerations shown in Table B-1 (1). Tables B-2, B-3, and B-4 present the water quality objectives used in this study for reuse catagories B, C, and D, respectively. These water quality objectives were estimated based on the data presented and the judgment of the project team. In general, the specific values selected are weighted means of the data presented. Thus, the adequacy of these values requires further demonstration before they can be used outside of the context of this report.

TABLE B-1. REUSE CATEGORIES AND APPLICATIONS*

Category	Consideration	Reuse Type	Application for On-Site Reuse Systems
A	Risk of limited contact with reuse water is unlikely	Aesthetic lakes (boating, fishing and swimming not allowed)	None
B	Risk of limited contact with reuse water is significant, but ingestion is unlikely	Recreational lakes with boating & fishing (but swimming not allowed), toilet flushing	Toilet flushing grade: Toilet flushing reuse
C	Risk of full body contact with reuse water is significant, limited ingestion is likely	Irrigation of (i.e., golf courses, athletic fields, and parks), park fountains, car washing	Utility grade: Lawn watering, irrigation, car and house washing, and toilet flushing reuses
D	Full body contact with reuse water is assumed, limited ingestion is likely	Recreational lakes with boating, fishing, and swimming allowed. (potable reuse not allowed)	Body contact grade: Laundry, shower, lawn watering, irrigation, car & house washing, and toilet flushing reuses
E	Potable reuse assumed	Full potable reuse	Uncertain

* Adapted from Reference 1.

TABLE B-2. TOILET FLUSH WATER QUALITY OBJECTIVES (a)

	Recreational lakes (with boating and fishing) Santee County, CA (b,e) (2,3)	Recreational lakes (with boating and fishing) Lancaster, CA (b,c,f) (2,3)	Toilet flushing (d,g) Tokyo, Japan (4)	Toilet flushing(c) — (1)	Proposed for this study - Toilet flushing grade —
BOD	3.5	0.4 (5-10)	(20)	(30)	(20)
COD	41	35 (45-75)	(40)		
SS	5-10	5 (10)	(30)		(20)
TDS	1,150	544 (500-650)	(5,000)		
Total Coliform/ 100 ml		<2.2 (0-2.2)		(240)	(240)
Turbidity (TU)	5	1.5 (3-10)		(25)	(25)
Color (S.U.)			(no disagreeable color)		(no disagreeable color)
Odor (S.U.)			(no disagreeable odor)	(non-offensive)	(non-offensive)
Floatable O&G				(not visible)	(not visible)
pH (S.U.)	7.7	6.15 (6.5-7.0)	(6.5-9.0)		(6.5-9.0)
NH_3-N	0.36	1.0 (0.1-15.0)	(20)		
Organic-N		1.7 (1-3)			
NO_2-N	0.01				
NO_3-N	1.0	1.9 (1-4)			
TKN		4.6 (3-20)			
PO_4		0.21 (0.1-0.5)			
TP	3.6	0.29			
Chlorides			(400)		
Chlorine Residues	0	3 4 (0.5-2.5)			
ABS		(7-15)	(2)		
MBAS		(2-4)			
Na	207	158			
K		16			
Boron		0.74 (0.8-1.4)			
SAR		(5-7)			
Total Alkalinity as $CaCO_3$	240	65 (74-140)			
Total Hardness as $CaCO_3$	400	68 (86-110)	(400)		
CO_2	2.4	68 (1)			
Arsenic		0			
Chromium		0			
Copper		0.04			
Iron		0.22	(1)		
Manganese		0.03			
Selenium		0			
Zinc		0.24			

(a) Units - mg/l unless otherwise noted
(b) Data represents locally existing water quality characteristics unless otherwise noted
(c) Numbers shown in parentheses represent locally required water quality
(d) Tokyo Metropolitan Government, tentative criteria
(e) Coliform limitation is State requirement
(f) Lahontan Regional Water Quality Control Board Requirements. Coliform limitation of 2.2 is State requirement
(g) Flash point of non-aqueous recycle fluid 73.3°C (minimum)
Numbers shown in parentheses represent locally recommended water quality criteria
Toxicity Oral LD50 > 500 mg/kg
Acute eye irritation - no irritation
Primary skin irritation - mild or slight irritation at 72 hrs
Dermal LD50 > 20,000 mg/kg
Inhalation LD50 > 20 mg/l
Foam: None

TABLE B-3. UTILITY GRADE WATER QUALITY OBJECTIVES

	Irrigation (spraying of golf courses, parks, parkways, and commercial landscape) (b) St. Petersburg, FL (8)	Irrigation/lawn watering of grade school and college campus Calabasas, CA (Las Virgenes Municipal Water District) (b) (2)	Irrigation (spraying of golf course) Fort Carson, CO (b) (2)	Irrigation (of golf course) Las Vegas, NV (Clark County Plant) (f) (2)	Irrigation (athletic field and landscape watering) toilet flushing, car washing (b)(c)(g) Grand Canyon Village, AZ (2)	Irrigation (of landscape and crops) (c)(d)(h) U.S. Virgin Islands (5)	Toilet flushing, car washing, lawn sprinkling, aesthetic ponds, park fountains, et al (c)(d)(i) Japan (4)	Lawn sprinkling, non-crop irrigation car and house washing, fire-fighting, and toilet flushing ("Class 2 utility class") (e)(j) (1)	Proposed for this study - Lawn watering, irrigation, car and house washing, and toilet flushing
BOD	3.8	3	12	19	5-10(10)	(10)	(10)	(30)(d)	(15)
COD							(20)		
SS	2.0	1	17	22	10(10)	(10)	(5)	(30)(d)	(15)
TS							(500)		
TDS		870		1,550	616	(1,200)			
Total coliform/ 100 ml	<1	2.2			0(200)		(0)	(240)	(23)(k)
Fecal coliform/ 100 ml						(2.2)			
Total bacteria/ 100 ml							(10,000)		
Turbidity (TU)	2.0						(5)		
SO_4	48.0	267							
Chlorides	182	112		350	200	(600)	(200)		
Chlorine Residual	1.5				-	-	(0 2)		
ABS							(1 0)		
MBAS		0.34							
Boron		0.77							
Total Hardness as $CaCO_3$							(200)		
Copper	0.002	0.014							
Iron	0.150						(0 5)		
Manganese	0.017						(0.5)		
Color (S.U.)							(10)		(no disagreeable color)
Odor (S.U.)				Sign.	Chlorine		(not unpleasant)	(non-offensive)	(non-offensive)
Floatable O&G								(not visible)	(not visible)
pH (S.U.)	7.2	7.8	7.5	7.6		(6.7-8.5)	(5.8-8.6)	(6-9)(d)	(5.5-8.5)
NH_3-N	14.5	0							
Organic-N	2.5	2.2							
NO_2-N	0.56	0.07							
NO_3-N	0.78	13.2							
PO_4	4 8	32.8					(0.5)		
Zinc	0.063	0.056							
Lead	<0.012	0.022							
Cadmium	<0.002	0.003							
Nickel		0.031							
Fluoride	0.32	0.36							
Phenol	0.006	0.034							

(a) Units - mg/l unless otherwise noted
(b) Data represents locally existing water quality unless otherwise noted
(c) Numbers shown in parentheses represent locally required water quality requirements
(d) Numbers shown in parentheses represent locally recommended water quality
(e) Based on EPA secondary treatment requirements
(f) Salt accumulations in soil occurred due to high TDS and low precipitation
(g) High chlorine residual maintained to discourage human consumption
(h) Effluent standards for U.S. Virgin Islands
(i) Japan Housing Corporation proposed water quality standards for reclaimed use
(j) NSF proposed criteria (not adopted)
Flash point of non-aqueous recycle fluid 73.3°C (minimum)
Toxicity Oral LD50 > 500 mg/kg
Acute eye irritation - no irritation
Primary skin irritation - mild or slight irritation at 72 hrs
Dermal LD50 > 20,000 mg/kg
Inhalation LC60 > 20 mg/l
Foam: None
(k) Specific number selected based on Standard Methods analytical procedure

TABLE B-4. BODY CONTACT GRADE WATER QUALITY OBJECTIVES

	Recreational (lake allowing body contact) Indian Creek Res., Alpine County, CA (b,c,f) (2,3)	Potable reuse Windhoek, South West Africa (b,c,g) (2,4)	Laundry, shower, lawn sprinkling, non-crop irrigation, car & house washing, fire-fighting & toilet flushing ("Class 3 - body contact (not drinking) class") (d,h) (1)	National Interim Primary Drinking Water Regulations (c,i) (7)	Proposed for this study - Body contact grade laundry, shower, lawn sprinkling, irrigation, car & house washing, fire-fighting and toilet flushing
BOD	0.7-3.2 (5)	0.6 (6)	(30) (e)		(10)
COD	12.0-28.7 (30)	14 (10)			
SS	0 (2)		(30) (e)		(10)
TDS	250	940 (500)			
Total coliform/ 100 ml	2 (2.2)	0 (1)	(1)	(1)	(<2.2)
Turbidity (TU)	0.3-0.6 (5)	4 (5)	(1)	(1)	(1)
Color (S.U.)		8 (5)			(no disagreeable color)
Odor (S.U.)		(none)	(non-offensive)		(non-offensive)
Floatable Oil			(not visible)		(not visible)
pH (S.U.)	6.9-8.4 (6.5-8.5)	7.6 (7.0-8.5)	(6-9) (e)		(6.4-8.5)
NH_3-N	23.0-36.0				
Albuminoid-N	0.1-1.3	0.2 (0.5)			
NO_2-N	0.01-0.07	[illegible]			
NO_3-N	0.1-0.9	9	(10)	(10)	(10)
TKN		0.8 (1.0)			
PO_4		0.016			
TP	0.17-0.41				
SO_4	15-34	126 (200)			
Chlorides	20	68 (300)			
Chlorine Residual	0.6-2.2	0.5			
ABS		0.7 (0.5)			
MBAS	0.19-0.45 (0.5)				
Na	5	76			
K		19			
Total Alkalinity as $CaCO_3$	107-[illegible]				
Total Hardness as $CaCO_3$	110-166				
Arsenic	0.005		(0.05)	(0.05)	(0.05)
Barium			(1.0)	(1.0)	(1.0)
Chromium	0.003		(0.05)	(0.05)	(0.05)
Copper	0.015	(0.05)			
Iron	0.003	(0.1)			
Manganese	0.002	(0.05)			
Selenium	0.005		(0.01)	(0.01)	(0.01)
Silver	0.005		(0.05)	(0.05)	(0.05)
Zinc	0.005				
Lead			(0.05)	(0.05)	(0.05)
Cadmium			(0.010)	(0.010)	(0.010)
Mercury			(0.002)	(0.002)	(0.002)
Fluoride			2.4 @ 12°C 1.4 @ 32°C	2.4 @ 12°C 1.4 @ 32°C	

(a) Units mg/l unless otherwise noted
(b) Data represents locally existing water quality
(c) Numbers shown in parentheses represent locally required water quality
(d) Numbers shown in parentheses represent locally recommended water quality criteria
(e) Based on EPA secondary treatment requirements
(f) Plant effluent from South Tahoe, CA. Coliform limitation is State requirement
(g) Plant effluent is diluted 7.5 to 1 with fresh water before distribution to meet standards (standards listed are WHO "Acceptable Drinking Water Standards") (8)
(h) NSF proposed criteria (not adopted)
Flash point of non-aqueous recycle fluids 73.3°C (minimum)
Toxicity: Oral LD50 > 500 mg/kg
Acute eye irritation - no irritation
Primary skin irrigation - mild or slight irritation at 72 hrs
Dermal LD50 > 20,000 mg/kg
Inhalation LD50 > 20 mg/l
Foam: none
Standards (7) for organic chemical and radioactivity are also included
(i) Regulations also include standards for organic chemicals and radioactivity (7).

REFERENCES

1. NSF. Proposed national sanitation foundation standard for wastewater recycle and water conservation devices. National Sanitation Foundation, Ann Arbor, Michigan. (Portions of these standards were not adopted.) 1977.

2. Schmidt, C. J. and E. V. Clements. Demonstrated Technology and Research Needs for Reuse of Municipal Wastewater, EPA-670/2-75-038. U.S. Environmental Protection Agency, Cincinnati, Ohio. 1975.

3. CA-DOH. Wastewater Reclamation Criteria, California Administrative Code, title 22, Division 4, Environmental Health, State of California, Department of Environmental Health, Berkeley, California. 1975.

4. AWWA Research Foundation. Municipal Wastewater Reuse News, No. 4, January 1978.

5. AWWA Research Foundation. Municipal Wastewater Reuse News, No. 3, December 1977.

6. World Health Organization. International Standards for Drinking Water, Third Edition, Geneva, Switzerland. 1971.

7. EPA. National Interim Primary Drinking Water Regulations. EPA-570/9-76-003, U.S. Environmental Protection Agency, Washington, DC. 1976.

8. AWWA Research Foundation. Municipal Wastewater Reuse News, No. 5, February 1978.