EPA-600/2-77-053b
December 1977

HANDLING AND DISPOSAL OF SLUDGES FROM COMBINED SEWER OVERFLOW TREATMENT

Phase II - Impact Assessment

by

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Contract No. 68-03-0242

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FOREWORD

The 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 that 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 problems, measuring its impact, and searching for solutions. The Municipal Environmental 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.

This report documents the results of an assessment of the effort that the United States will have to exert in the area of sludge handling and disposal if, in fact, full-scale treatment of combined sewer overflows is to become a reality.

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ABSTRACT

This report documents the results of an assessment of the effort that the United States will have to exert in the area of sludge handling and disposal if, in fact, full-scale treatment of combined sewer overflows (CSO) is to become a reality. The results indicate that nationwide an average yearly sludge volume of 156×10^6 cu m (41.5×10^9 gal.) could be expected from CSO if complete CSO treatment were achieved. This compares to a raw primary sludge volume of 60.9×10^6 cu m (16.1×10^9 gal.). However, the average solids concentration in CSO sludge is about 1% compared to 2-7% in raw primary sludges. This is due to the high volume, low solids residuals generated by treatment processes employing screens. The sludge volume generated and the reported characteristics of the sludge vary widely, depending on the type of treatment process used. The most notable differences from raw primary sludge were the high grit and low volatile solids content in CSO residuals plus their intermittent generation.

Evaluation of the effect of bleed/pump-back of CSO sludge on the hydraulic, solids and/or organic loadings to the dry-weather plant indicated that overloading would occur in most instances. Disregarding grit accumulation in sewers plus other transport problems, it was established that solids loadings to the secondary clarifier were limiting and required 8-22 day bleed/pump-back periods. There may also be a toxic danger to dry-weather treatment plant biological processes.

The most promising treatment trains were found to include possible grit removal, lime stabilization, optional gravity thickening, optional dewatering and land application or landfill. Land application systems can be considered as viable alternatives for CSO treatment and disposal. The cost of the collection-transportation and/or equalization system may be the crucial factor in disallowing the alternative of direct application of raw CSO. If CSO treatment is employed by a city, land spreading of CSO sludges should be evaluated. Public health concerns dictate sludge stabilization before disposal and pollutant loading limitations based on nitrogen and heavy metal concentrations. An environmentally safe rate of application was determined as 19.0 metric tons/ha/yr (8.5 tons/ac/yr).

Preliminary economic evaluation indicated that lime stabilization, storage, gravity thickening, and land application was the most cost-effective treatment system. Costs for overall CSO sludge handling depend on the type of CSO treatment process, volume and characteristics of the sludge and the size of the CSO area, among other considerations. Estimates indicate that first investment capital costs range from \$447-10,173/ha (\$181-4129/ac) with annual costs of \$139-1630/ha (\$56-660/ac). It is recommended that the use of grit removal, lime stabilization and gravity thickening, plus dewatering, be further investigated to establish specific design criteria related to CSO sludge.

This report was submitted in partial fulfillment of Contract No. 68-03-0242 under the sponsorship of the Municipal Environmental Research Laboratory, Office of Research and Development, U.S. Environmental Protection Agency. Work was completed in February 1976.

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ACKNOWLEDGEMENTS

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SECTION I

CONCLUSIONS

1. Nature of the Problem

   a. It is established that 33 percent of the sewered population or approximately 36.2 x 10^6 people are served by combined sewers. This service is approximately 1.23 x 10^6 ha (3.03 x 10^6 acres) and is mainly concentrated in the Northeast and Great Lakes regions of the country.

   b. Assuming an average annual rainfall of 91.4 cm (36 in.) and that 50 percent of the rainfall results in overflow, then the yearly combined sewer overflow (CSO) is 5.6 x 10^9 cu m (1.5 x 10^{12} gal.).

      Similarly, the annual dry weather flow for the combined sewer population served is 6.3 x 10^9 cu m (1.7 x 10^{12} gal.), assuming 473 ℓ (125 gal.) per capita per day.

   c. The volume of sludge generated from CSO treatment is dependent upon many factors including area served, rainfall and type of CSO treatment method used. The sludge volume generated will range from 0.6 to 6 percent of the CSO volume treated, depending on the CSO treatment process utilized.

   d. There have been six state-of-the-art processes proposed for treating combined sewer overflows. If it is assumed that the total combined sewer overflow volume is treated by each technique, the following volumes and solids concentrations of CSO residuals may be estimated, assuming 70 percent solids removal:

      storage-sedimentation: 50.4 x 10^6 cu m (13.3 x 10^9 gal.), 1.7% solids
      microscreening: 336 x 10^6 cu m (88.8 x 10^9 gal.), 0.7% solids
      screening/dissolved air flotation: 268 x 10^6 cu m (71.1 x 10^9 gal.), 0.84% solids
      dissolved air flotation: 33.6 x 10^6 cu m (8.8 x 10^9 gal.), 2.75% solids
      contact stabilization: 196.1 x 10^6 cu m (51.8 x 10^9 gal.), 1.0% solids
      trickling filtration: 39.2 x 10^6 cu m (10.3 x 10^9 gal.), 3.2% solids

e. The average yearly volume of CSO sludge is estimated to be 156 x 10^6 cu m (41.5 x 10^9 gal.) compared to an annual primary sludge volume of 60.9 x 10^6 cu m (16.2 x 10^9 gal.). However, the average percent solids in CSO sludge is 1.04 percent compared to a primary sludge with 2-7 percent solids. The low value for CSO sludge can be attributed to the high volume-low solids residuals generated by backwash of the screening processes used.

f. Comparison of per capita CSO sludge values with the per capita dry weather values over a 365 days per year period indicates that the values are comparable. However, the magnitude of the CSO disposal problem on a per unit time basis is six times greater when it is recognized that overflows occur only 60 times per year.

g. The characteristics of CSO sludges vary widely depending upon the CSO treatment method utilized. A comparison of quality with dry weather primary sludges indicates that the volatile solids content of CSO sludge is significantly lower than that found in most primary sludge. In other parameters, the ranges of reported values overlapped. Generally, nutrient concentrations and fecal coliform counts were lower for CSO sludges than for raw primary sludges. Metal concentrations varied widely; however, in general, nickel concentrations were higher and lead concentrations were lower in CSO sludges compared to raw primary.

h. Differences in CSO sludge characteristics compared to dry-weather sludge most pertinent to further handling are the high grit and low volatile sludge concentration, the lower average percent solids, the variable volume of sludges produced and their intermittent generation.

2. *Alternatives for Handling and Disposal of CSO Generated Residues*

Alternatives for handling CSO treatment sludges include (a) bleed/pump-back to the dry-weather facilities, (b) dewatering at parallel facilities at the dry-weather plant or at central facilities separate from the dry-weather plant and (c) dewatering at on-site facilities.

a. Bleed/pump-back of CSO treatment sludges to the dry-weather facilities.
   (1) The more excess capacity available at the dry-weather plant, due to built-in safety factors for expansion, the more feasible bleed/pump-back of CSO sludges.
   (2) This procedure would involve the lowest costs due to reduced transportation and use of existing dry-weather facilities for handling. However, this alternative has inherent disadvantages which make the procedure generally not applicable.
   (3) Bleed/pump-back will not be possible unless sufficient scouring velocity can exist in the individual sewer interceptors to prevent accumulation of grit in the lines. Excessive grit deposition in the sewer can cause odor, septicity, and blockage problems and if flushed to the plant, adversely affect normal operation.

(4) The bleed/pump-back of CSO sludges or the residuals from on-site dewatering will have an effect both on the dry-weather treatment plant and the sludge handling facilities. These impacts can be considered separately.
(5) Impact of bleed/pump-back of CSO sludges on the dry-weather treatment plant has been evaluated with respect to hydraulic, solids (primary and secondary), organic and toxic materials loadings to the various processes. Bleed/pump-back of the sludge over a 24 hour period although desirable from a standpoint of limited storage and reduction in septicity, is not possible in most instances.
(6) The limiting factor to consider is the solids loading to the final clarifier. Calculations indicate that bleed/pump-back periods of 8-22 days are necessary depending upon the CSO treatment method involved.
(7) Bleed/pump-back of CSO treatment sludges directly to the dry-weather sludge handling facilities over a 24 hour period will overwhelmingly overload these facilities hydraulically, solids wise and organically. These gross overloads will be expected to detrimentally affect the dewatering and stabilization performance and treatment efficiency of the dry-weather sludge handling facilities. The down-grading in treatment efficiency would be manifested in poorly stabilized sludge for disposal and grossly deteriorated thickener effluents, filtrates, supernatants, etc. for recirculation back to the dry weather treatment plant.
(8) Disadvantages of bleed/pump-back also include the adverse effect on the operation and efficiency of the dry-weather plant caused by loading the plant at excessive levels constantly and the difficulty in storing CSO residuals without stabilization for any excessive length of time.

b. Dewatering CSO treatment sludges at parallel facilities at the dry-weather plant or at central facilities separate from the dry-weather plant.
   (1) Transportation and potential space problems limit the applicability of parallel facilities or central locations.

c. Dewatering at on-site Facilities.

   Handling of CSO treatment sludges in the dry-weather plant or in additional parallel facilities at the dry-weather plant or in separate facilities at the dry-weather plant do not appear to be generally feasible, therefore it is indicated that CSO sludges will have to be treated separately at the on-site facilities.
   (1) Evaluation of sludge handling processes from the standpoint of the high grit and low volatile content of CSO sludges along with the variable and intermittent generation reduces the number of processes applicable for CSO sludge handling.
   (2) Preliminary screening on the basis of CSO sludge characteristics and known information about the processes, indicates that the

following processes may be generally applicable:

conditioning:	chemical treatment
thickening:	gravity thickening
stabilization:	lime stabilization
	anaerobic digestion
dewatering:	vacuum filtration
	centrifugation
disposal:	land application
	landfill

(3) Combinations of the above processes yields approximately ten potential treatment schemes. Examination indicated that bleed/pump-back of dilute residuals from on-site dewatering to the dry-weather plant appears to be practical and warrants further consideration where applicable.

Further evaluation of stabilization techniques indicates that anaerobic digestion is more costly and difficult to operate than lime stabilization and therefore this process was not considered for further study.

(4) Four sludge handling alternatives were then developed for CSO sludge handling:
(a) Lime stabilization → gravity thickening → vacuum filtration → landfill
(b) Lime stabilization → gravity thickening → vacuum filtration → land application
(c) Lime stabilization → gravity thickening → land application
(d) Lime stabilization → land application

Preliminary indications are that the flow scheme utilizing lime stabilization plus gravity thickening and then land application is the most cost effective for CSO sludge handling on a generalized basis.

(5) The logistics of operating and maintaining multiple CSO solids handling plants (5,10,100) at different locations throughout a city are formidable but not insurmountable. Similar, if not greater logistics would be required for multiple CSO treatment facilities from which the sludges to be handled are derived.

3. Costs for Handling and Disposing of CSO Generated Sludges.

It is emphasized that all costs presented are generalized and should not be applied to individual situations.

a. To establish generalized CSO sludge impact, the cities served by combined sewers were evaluated. Of the total 259 cites, it was found that about 12.5 percent had CSO areas of 405 ha (1000 ac) or less, 47.5 percent had areas from 405-4050 ha (1000-10000 ac), 35 percent had CSO area from 4050-16,188 ha (10000-40 000 ac) and about 5 percent had larger areas. From this information, four generalized CSO areas were chosen for further cost evaluation.

b. The generalized costs for CSO sludge satellite treatment assuming 50 percent of rainfall is CSO and that either contact stabilization or dissolved-air flotation was used for treatment, are presented below:

CSO area		Annual Cost ($)	$/acre/yr
ha	acres		
203	500	$0.105 - 0.330 \times 10^6$	210 - 660
2,307	5,700	$0.36 - 1.96 \times 10^6$	64 - 345
10,118	25,000	$2.24 - 10.38 \times 10^6$	77 - 415
24,282	60,000	$3.33 - 26.1 \times 10^6$	56 - 435

c. For four example cities, cost estimates were prepared for handling and disposing of their sludges if complete CSO treatment is achieved (for New Providence the cost is for treating increased sanitary sewer flows due to wet weather sewer infiltrations). The four treatment schematics [see Conclusion 2.c.(4)] were evaluated and a cost range is included.

City	CSO area		Annual Cost (range)
	ha	ac	
Milwaukee, WI	7,006	17,300	$\$1.49 - 2.53 \times 10^6$
San Francisco	12,150	30,000	$\$1.19 - 2.11 \times 10^6$
Kenosha, WI	539	1,331	$\$0.21 - 0.46 \times 10^6$
New Providence, NJ	0	0	$\$0.09 - 0.15 \times 10^6$

d. The economic impact of treating CSO sludges nationwide using one of the treatment systems evaluated would range from $\$169 \times 10^6$ - $\$1,720 \times 10^9$ annually with initial capital costs estimated to range from $\$548 \times 10^6$ - $\$12.5 \times 10^9$.

4. Land Application for Disposal of CSO Raw Waste and of CSO Treatment Sludges.

a. General

(1) Land application systems can be considered as viable alternatives for waste treatment and disposal. The feasibility of land application of CSO wastes may be evaluated under various conditions. This development would provide a rational screening method which should lead to; 1) the identification of

specific limiting factors, 2) an indication of the public health and legal constraints in using land application and 3) site locations that combine the required characteristics for safe pollutant management.

(2) For most land application systems, vast numbers of design possibilities are available to suit specific site characteristics, treatment requirements and overall project objectives. The scope of factors that are commonly considered in the design process include: a) preapplication treatment requirements; b) storage requirements; c) climatic factors; d) pollutional loading constraints: e) land area requirements; f) crop selection and management; g) system components; h) site monitoring program; and i) cost-effectiveness.

b. Handling CSO Raw Waste

(1) An alternative to the treatment of CSO and the resultant problems of sludge handling and disposal is direct application of the raw CSO to the land. Land area requirements necessary for a safe rate of application, as controlled by liquid loading limitations, are 34.4×10^6 ℓ of CSO/ha/yr (3.6×10^6 gal./ac/yr).

(2) The cost of the collection - transport and/or equalization system may be the crucial factor in disallowing land disposal of raw CSO as an alternative to other CSO treatment methods. It may be feasible to use land disposal in cities which have relatively small CSO areas and have land available in close proximity to the city, but cities with large CSO areas, even if the land is available, may find that the cost of the collection - transport system might be prohibitive.

(3) Considering the hydraulic loading limit and if the land required for actual disposal is 70 percent of the entire disposal site, nationwide disposal of raw CSO would require a total land area of 323,560 ha (587,300 acres), inclusive of that required for buffer zones and storage and pre-treatment facilities.

c. Handling CSO Treatment Sludges

(1) If CSO treatment is employed by a city, one viable alternative to the disposal of CSO sludges can be by landspreading application. Three management options would be available: 1) landspreading a dilute sludge (1% solids); 2) landspreading a thickened sludge (4-6% solids) and 3) landspreading a dewatered sludge (>12% solids).

(2) If regulations require CSO sludges to be treated prior to land application, lime stabilization appears to be a promising

preapplication treatment process because of its flexibility and effectiveness, in terms of both cost and performance.

(3) In transporting CSO sludges, it appears that truck transportation of either liquid or dewatered sludge is the most desirable alternative in CSO areas with significant volumes of sludge to be handled. Truck transportation of dewatered sludges might prove to be the more desirable alternative if transporting and storing costs are greater than the additional thickening-dewatering costs.

(4) For field area requirements, the nitrogen content is the limiting loading factor for application of CSO sludges. An environmentally safe rate of application was assumed as 18.9 metric tons/ha/yr (8.5 tons/ac/yr). This is lower than the average range of 22 to 45 metric tons/ha/yr (10-20 tons/acre/yr) reported in the literature for disposal of municipal sludges. This discrepancy is a result of differences in waste characteristics (i.e. nutrients and metals).

(5) For sludge application to non-agricultural lands (e.g. strip mine reclamation), higher loading rates may be allowable but the migration of pollutants through the soil must be closely monitored.

(6) Considering the loading limit established for nitrogen and the fact that, on the average, the land required for actual disposal is 70 percent of a disposal site; nationwide disposal of CSO sludges would require 117,760 ha (290,760 acres) of land, including that required for buffer zones and pre-treatment facilities.

SECTION II

RECOMMENDATIONS

1. A CSO sludge treatment system consisting of nonvolatile solids removal, lime stabilization, gravity thickening, optional sludge dewatering and land application appears promising. However, since several aspects are experimental, it is recommended that the swirl concentrator and or other suitably available equipment be assessed with respect to its applicability for grit removal from CSO sludges and further investigation and demonstration of lime stabilization for application to CSO sludges and to establish basic design and operating criteria be pursued. In addition, the applicability of further thickening and dewatering be investigated to establish feasibility and obtain basic design criteria.

2. It is recommended that further information on the effect of lime on sludges which may be applied to land be established. Particular attention should be given to the effect on crop growth, physical characteristics of the soil and uptake of toxic materials. This information can then be utilized to modify current design criteria for land application of CSO sludges.

SECTION III

INTRODUCTION

The discharge of untreated sanitary and stormwater overflows from combined sewers to receiving waters during and after heavy rains is an important source of impairment of water. These storm generated discharges constitute a high degree of pollutional load to water courses as measured by the usual standards of biochemical oxygen demand, solids, coliform organisms, and nutrients.

The pollutional contribution of storm generated discharges is of national significance, and the magnitude of the problem is illustrated by the fact that more than 1300 U.S. communities serving 36.2 million people have combined sewer systems which provide one collection system for both sanitary sewage and stormwater runoff (1). Sufficient information has been accumulated to confirm that the combined sewer overflow problem is of major importance and is growing worse with increasing urbanization, economic expansion, and water demands (1,2,9).

Various alternatives have been proposed for dealing with the problems of storm generated discharges. There appear to be four possible methods of eliminating or minimizing the problems. These are:

1. Construction of larger interception sewers and expansion of treatment capacity.
2. Construction of separate sewers.
3. Construction of holding tanks with provisions to bleed/pump-back flows into the sewer system after the storm.
4. Treatment of the storm generated discharges at various possible locations.

Each of these techniques has advantages and disadvantages when utilized for CSO abatement at individual locations. Construction of larger interceptors throughout the country appears to be a formidable undertaking. Normal design capacity for interceptors is between 1.5 and 5.0 times the dry weather flow (3)(4). During a storm, the flow in a combined sewer may increase from 50 to 100 times the dry weather flow (3). It is apparent that enlarging the interceptors to handle the great increase in anticipated stormwater flow will have to be accompanied by enlargement of present sewage treatment plants which must treat the interceptor flow. The cost of this construction undertaking would be in the multibillion dollar range. In addition, there are monetary losses which would have to be borne by communities, individuals, businesses and industrial establishments as a result of extensive physical inconveniences occuring during construction.

It has been estimated that providing complete separation of storm and sanitary sewers throughout the country would cost 48 billion dollars (1967 prices)(1). In addition, the monetary losses to communities, individuals, etc. as a result of separation would be considerable. Separation of the sewers may not completely solve the problem, for studies indicate that there is the distinct probability that separated stormwater may require treatment under some circumstances (9).

The holding tank concept is being used as a method of handling storm generated discharges. This method has met with limited success because of the cost of tank installation, the economic and physical limitations of holding capacity, and the need for returning the flow to the interceptor system for treatment after the storm subsides. In many locations, an overloaded condition exists at the treatment plant for several days after a major runoff event and any additional runoff in excess of holding tank capacity is discharged to the receiving waters.

The fourth alternative for dealing with storm generated discharges is the treatment of the discharge itself. Promising physical, physical-chemical, and biological methods have been proposed for treating storm generated discharges. Many of these concepts have been demonstrated or are planned for demonstration by the U.S. Environmental Protection Agency (5,6,7).

As with most wastewater treatment processes, treatment of combined sewer overflow will result in residuals which contain, in concentrated form, the objectionable contaminants present in the raw combined sewer overflow. However, handling the disposal of the residual sludges from the combined sewer overflow treatment systems have been generally neglected, thus far, in favor of the problems associated with the treatment of the discharge itself. Sludge handling and disposal should be considered an integral part of the combined sewer overflow treatment because it will significantly affect the efficiency and cost of the total treatment system.

The objective of this report, then, is to attempt a rough quantification of the effort the United States will have to exert in the future, in the area of sludge handling and disposal, if full-scale treatment of combined sewer overflow is to become a reality. The results of this report will contribute to a better understanding of the problem and will aid in the development of future planning and research needs. It may be found, in fact, that the potential problem of handling the sludges from combined sewer overflow treatment may be greater than the problem of treatment itself. Also, the disposal of these residual solids is only going to compound the disposal problem now caused by the solids from dry-weather treatment plants.

Therefore, alternative techniques for handling combined sewer overflow sludges have been presented in this report. The first section defines the magnitude of the problems associated with combined sewer overflow treatment residuals and the unique characteristics of the sludge itself. After the problem has been defined, several handling methods are identified and evaluated. One method involves bleed/pump-back of the CSO sludge to the dry-weather treatment plant. This technique has the advantage of utilizing existing transportation systems, but has inherent difficulties such as grit deposition and potential solids overload at the treatment plant. If bleed/ pump-back is not feasible, then the sludge must be treated with separate facilities. These facilities may be located at the dry-weather treatment plant, at a separate central location or at satellite locations throughout the area served by combined sewers. Evaluation of the existing sludge handling processes indicate that traditional solids treatment trains may not be generally applicable due to the different characteristics and intermittent nature of the CSO sludge. However, the use of lime for stabilization, plus thickening and possibly dewatering, and then land application for disposal appears to be a viable treatment system for CSO sludges. The economics of various treatment schemes for both actual cities and specific CSO areas have been calculated and are presented. In this way, the magnitude of the problem can be defined and a preliminary assessment of the impact can be made.

SECTION IV

MAGNITUDES AND CHARACTERISTICS OF SLUDGES PRODUCED BY NATIONWIDE TREATMENT OF COMBINED SEWER OVERFLOWS

INTRODUCTION

The problems associated with treatment or handling of any type of sludge are formidable. The recent increased emphasis on sludge handling has created more interest in this aspect of wastewater treatment. With regard to treatment of combined sewer overflow sludges, however, the most feasible handling techniques are just beginning to be developed. Before the problem can be adequately addressed, it is beneficial to define, as much as possible, the volumes of sludges to be produced and their associated characteristics. To do this, it is necessary to make general assumptions regarding many aspects of CSO treatment systems. But it must be emphasized at this point that the characteristics and flow volumes presented herein are generalizations and do not reflect individual CSO sludge systems. Definition of qualities and quantities of sludges resulting from individual processes is dependent upon the treatment system utilized, pretreatment and location of the CSO site, among many other factors. Specific applications and design of sludge handling techniques should be developed individually for each site. However, for the purpose of defining the magnitude and severity of the problems associated with handling various CSO sludges, a basic overall approach is necessary. The ranges of values for CSO sludges have also been compared to generalized dry-weather sludge volumes and characteristics. The basis for the generalizations and the result of the quantifications have been included in this section of the report.

COMBINED SEWER OVERFLOW VOLUMES

In order to estimate the total volume of combined sewer overflow and its associated sludges, it is necessary to establish many variables which affect CSO before it is possible to accurately assess the overall situation. Among the pertinent considerations are: the area served by combined sewers; land use; rainfall volumes; number of overflows; type of treatment utilized; population of area; etc. It is necessary to evaluate the effect of these, and other pertinent variables, in order to prepare a generalized potential volume of CSO and associated sludges.

The sewered population of the United States as projected from 1962 data is 125,770,000 (1). Of this total, 36,236,000 or 29 percent of the sewered population is served by combined sewers. The combined sewer service area totals 1,226,745 ha (3,029,000 acres) (1). Figure 1 shows the distribution of combined sewers throughout the United States (10). It can be seen that the most concentrated use of combined sewers is in the Northeast and Great Lakes regions of the country.

Figure 2 shows the distribution of the median annual precipitation throughout the United States (11). The annual median precipitation across the Northeast and Great Lakes regions of the country where combined sewers are used extensively ranges from 63.5 to 114.3 cm (25-45 in.). A selected average value for the purpose of further calculations is 91.4 cm (36 in.).

Using 1,226,745 ha (3,029,000 acres), an average yearly rainfall of 91.4 cm (36 in.) and assuming 50 percent of the rainfall results in overflow, the yearly volume of combined sewer overflow in the United States would be 5.6×10^9 cu m (1.5×10^{12} gal.).

Table 1 gives the sludge volumes produced, the percent solids of the sludges produced by various combined sewer overflow treatment processes that have been investigated (12), and the calculated sludge volume if treated by the selected CSO treatment processes based on a total yearly combined sewer overflow volume of 5.6×10^9 cu m (1.5×10^{12} gal.).

TABLE 1. TOTAL U.S. SLUDGE VOLUMES AND PERCENT SLUDGE SOLIDS PRODUCED BY VARIOUS CSO TREATMENT PROCESSES (12)

Treatment process	Volume of sludge as percent of volume treated	Sludge percent solids	Sludge volumes produced cu m
Storage with settling	0.3	1.74	50.4×10^6
Microscreening	6.0	0.70	336.2×10^6
Screening/dissolved-air flotation	4.8	0.84	269.0×10^6
Dissolved-air flotation	0.6	2.75	33.6×10^6
Contact stabilization	3.5	1.00	196.1×10^6
Trickling filter	0.7	3.20	39.2×10^6

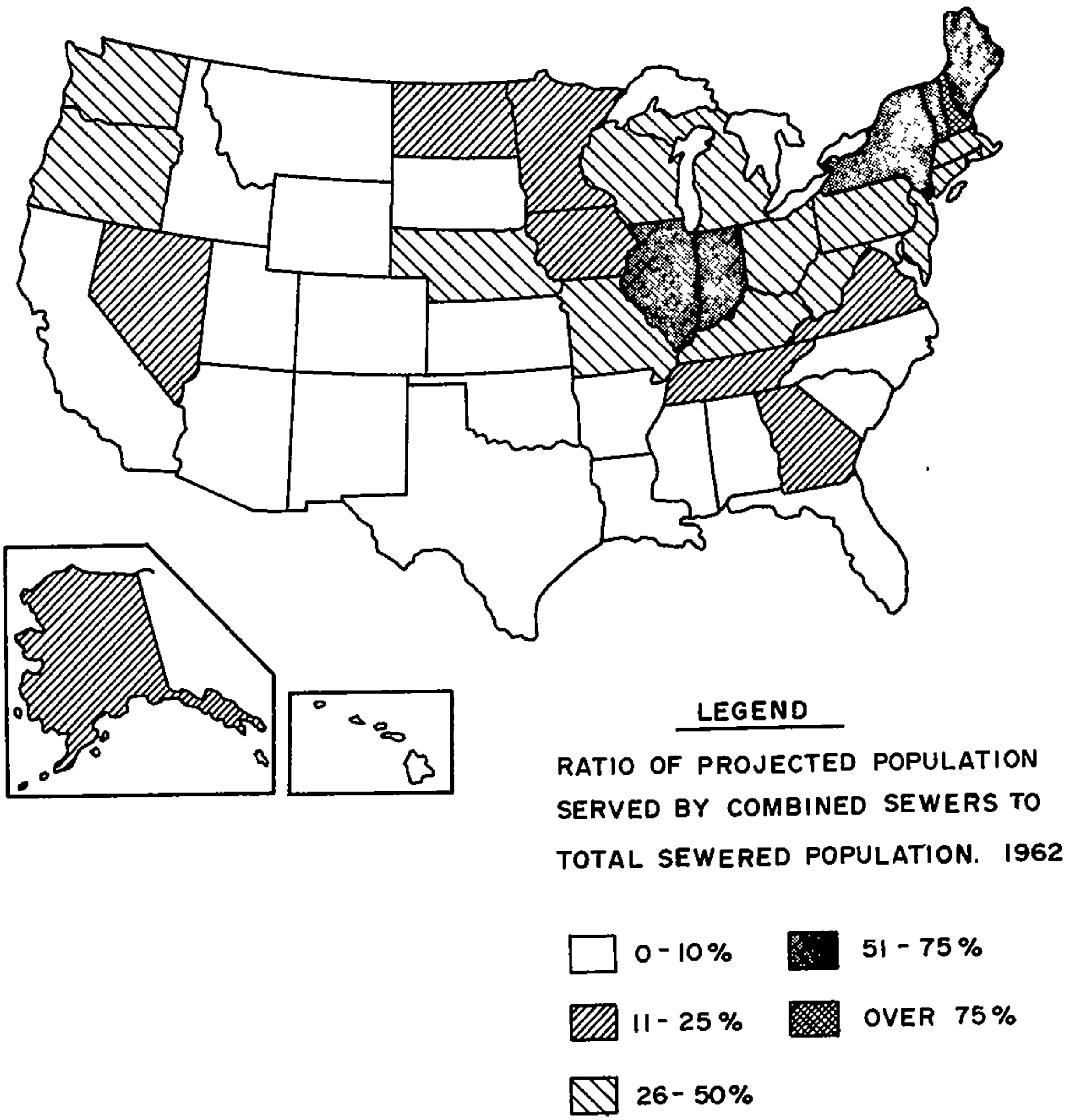


Figure 1. Relative use of combined sewers by states (10).

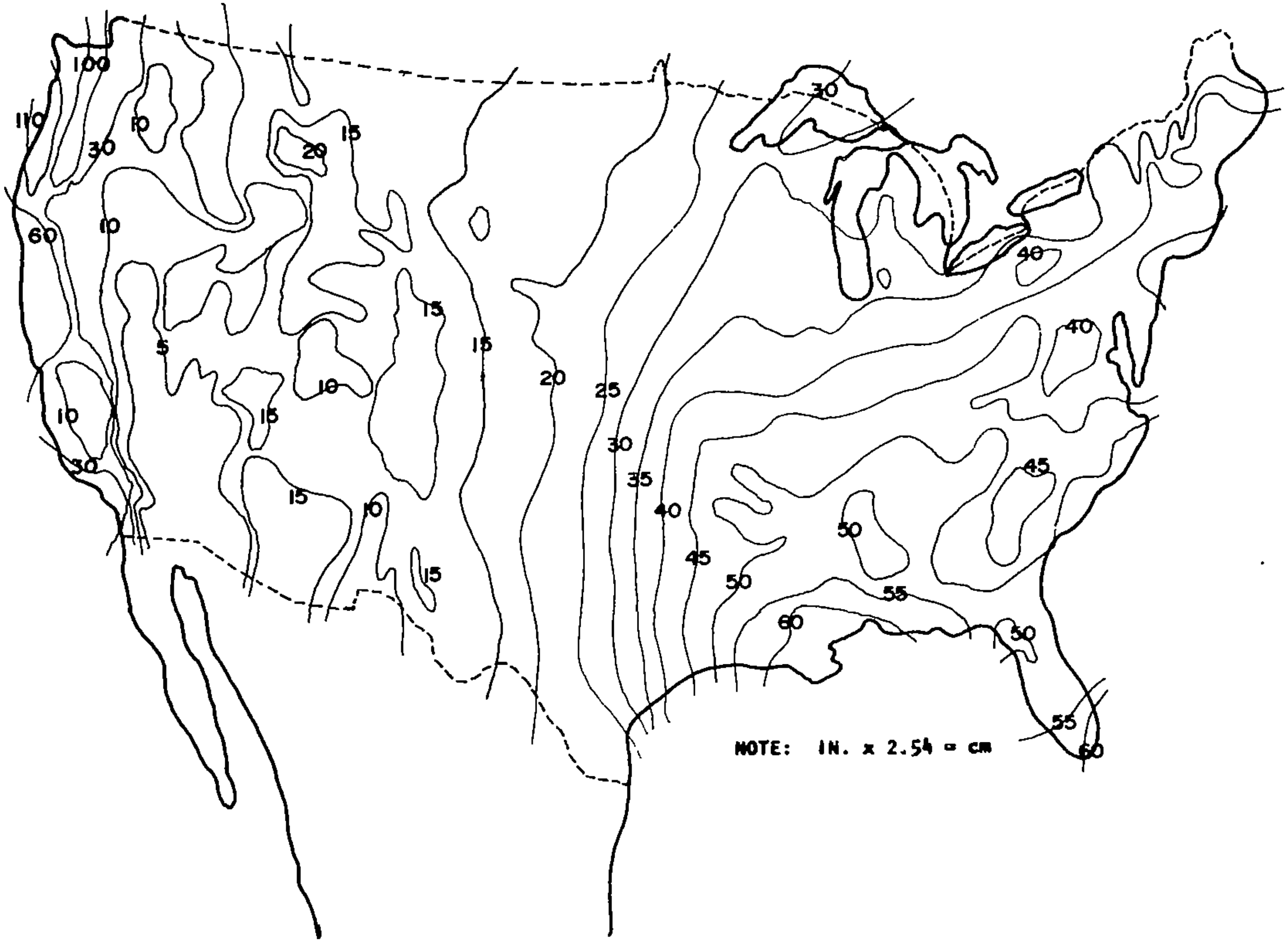


Figure 2. United States median annual precipitation (11).

Assuming an equal mix of the various treatment methods, an average yearly sludge volume resulting from treatment of all combined sewer overflows nationwide would be 156.8×10^6 cu m (41.45×10^9 gal.), or 2.8 percent of the volume treated. The average percent solids of the sludge would be 1.04. This value compared to an estimated 125,000,000 cu m (33.0×10^9 gal.) of primary and secondary sludges generated annually (13). The average solids concentration of the dry-weather sludge is approximately 2-3%. The average value for CSO sludge solids concentration is lower because of the high volume - low solids residuals that are generated by the screening processes, microscreening (6% of volume treated at 0.7% solids) and screening/dissolved-air flotation (4.8% of the volume treated at 0.84% solids).

Another approach to comparison of dry-weather sludge and wet weather sludge is to use population equivalent factors. Table 2 shows a comparison between total flow, sludge volume and solids mass based on the population served.

TABLE 2. POPULATION EQUIVALENT COMPARISONS (14)

Parameter	Units	Dry-weather population equivalent	CSO 365 days/yr	CSO 60 days/yr
Flow: raw waste	gal./capita-day	125	111	679
Flow: sludge only	gal./capita-day	2.65	3.10	18.90
Solids loading	lb/capita-day	0.44	0.27	1.64

gal. x 3.785 = ℓ
lb x 0.454 = kg

As can be seen the population equivalents for CSO sludge are approximately equal to that for dry-weather treatment plant design when considered on the basis of 365 days per year. However, the average number of combined sewer overflows annually is 60 so that the actual loading is more than six times greater than typical design data.

The preceding calculations were based on the sludge volume and solids data reported for the various processes in the literature (12). On the average, the processes achieved a suspended solids (SS) removal of 70 percent. Differences in the removal efficiences and/or the sludge concentrations produced will result in corresponding changes in the final sludge volumes. Table 3 shows the different sludge volumes that will be generated at varying treatment efficiences and sludge concentrations if the nationwide combined sewer

TABLE 3. CSO SLUDGE VOLUMES FOR VARYING TREATMENT EFFICIENCIES AND SLUDGE CONCENTRATIONS

Volume Treated = 5.6×10^9 cu m (1.5×10^{12} gal./year)
Influent SS = 409 mg/l

Percent SS removal achieved	Sludge volume produced at:							
	0.5% solids		1.0% solids		2.0% solids		3.0% solids	
	cu m x 10^{-6}	MGx10^{-3}	cu m x 10^{-6}	MGx10^{-3}	cu m x 10^{-6}	MGx10^{-3}	cu m x 10^{-6}	MGx10^{-3}
50	228.6	(60.4)	114.3	(30.2)	57.2	(15.1)	38.2	(10.1)
55	252.1	(66.6)	126.0	(33.3)	63.2	(16.7)	42.0	(11.1)
60	274.4	(72.5)	137.4	(36.3)	68.5	(18.1)	45.8	(12.1)
65	298.3	(78.8)	149.1	(39.4)	74.6	(19.7)	49.6	(13.1)
70	320.5	(84.7)	160.1	(42.3)	79.9	(21.1)	53.4	(14.1)
75	344.0	(90.9)	171.8	(45.4)	85.9	(22.7)	57.2	(15.1)
80	366.4	(96.8)	183.2	(48.4)	91.6	(24.2)	60.9	(16.1)
85	389.9	(103.0)	195.0	(51.5)	97.7	(25.8)	65.1	(17.2)
90	412.5	(109.0)	205.9	(54.4)	102.9	(27.2)	68.9	(18.2)
95	436.0	(115.2)	218.0	(57.6)	109.0	(28.8)	72.7	(19.2)

overflow volume is treated. The values are based on an average combined sewer overflow SS concentration of 409 mg/l (9); and it should also be noted that the volumes are based on the SS removal. Biological treatment methods such as contact stabilization and trickling filters will also produce solids by conversion of dissolved organic matter to biological cell mass; and any chemical addition that is employed in the selected treatment process will also add solids. These additional solids can increase the final sludge volume.

From Table 3, it can be seen that as the treatment efficiency is improved the volume of sludge that must be handled will increase. However, whenever a thicker sludge can be produced the residual sludge volume will be reduced.

CSO TREATMENT SLUDGE CHARACTERISTICS

There are significant differences in the chemical and physical characteristics of sludges which are generated by various CSO treatment methods. Tables 4, 5 and 6 (12) indicate the reported sludge characteristics from biological, physical and chemical treatment systems. Even within these more specific categories, there are large differences in the qualities which result.

Biological treatment sludges show the highest volatile fraction, about 60 percent, while the physical and physical/chemical treatment processes produce sludges with a 25 to 48 percent volatile fraction. The BOD, total organic carbon, dissolved organic carbon, total phosphorus, and total Kjeldahl nitrogen concentrations vary widely as the solids concentrations vary. The soluble nitrogen forms; ammonia, nitrites, and nitrates, are, for the most part, low in concentration except for the trickling filter secondary sludge which has a very high content. The sludge densities range from 1.005 to 1.07 with an average value of 1.026. The pH of the sludges ranges from 5.2 to 7.9. The low value of 5.2 was found for the dissolved-air flotation process in San Francisco where alum addition is used to facilitate the flotation process. As would be expected with higher volatile solids, the biological sludges have the greatest fuel values. The biological sludges have an average fuel value of 3515 cal/gm (6333 BTU/lb) while the other sludges have an average value of 2032 cal/gm (3661 BTU/lb). Among the PCB's and various pesticides, the PCB's are generally of the highest concentration. Zinc is usually the heavy metal of highest concentration in the sludges, with the concentration of lead also being fairly high.

COMPARISON OF CSO SLUDGES TO DRY-WEATHER FLOW SLUDGES

In order to more fully understand both the magnitude and the uniqueness of the problems associated with treatment and handling of CSO sludges, it is valuable to compare CSO sludges to dry-weather flow sludges. The most direct comparison which can be drawn is between undigested primary sludge and CSO sludge. Although the solids concentration of waste activated sludge most closely resemble CSO sludge solids concentrations, the actual biomass characteristics are different since grit removal and primary sedimentation have preceded the process and removed the more easily separated materials. These

TABLE 4. CHARACTERISTICS OF CSO SLUDGES FROM PHYSICAL TREATMENT PROCESSES (12)

Parameter	Units	Storage sedimentation (Milwaukee, WI)	Storage sedimentation (Cambridge, MA)	Microscreening (Philadelphia, PA)
Total solids	mg/l	18,900	126,900	8,660
Suspended solids	mg/l	17,400	110,000	7,000
Total volatile solids	mg/l	9,150	57,500	2,520
Volatile suspended solids	mg/l	8,425	41,400	1,755
BOD	mg/l	2,200	12,000	-
TOC	mg/l	7,250	16,200	1,032
Dissolved organic carbon	mg/l	55	946	-
Total phosphorus (as P)	mg/l	109.1	293.4	11.5
Total kjeldahl nitrogen (as N)	mg/l	56	28	46
Ammonia (as N)	mg/l	4.1	3.2	-
NO_2 (as N)	mg/l	0.15	0.4	-
NO_3 (as N)	mg/l	1.7	0.5	-
Specific gravity	--	1.015	1.06	1.05
pH	--	6.4	5.7	7.4
Total coliforms	#/100 ml	-	210,000,000	-
Fecal coliforms	#/100 ml	-	2,800,000	-
Fuel value	cal/gm	-	2,721	1,791
PCB's	μg/kg dry	47	6,570	ND
pp'DDD	μg/kg dry	ND	ND	ND
pp'DDT	μg/kg dry	ND	170	ND
Dieldrin	μg/kg dry	20	58	ND
Zinc	mg/kg dry	799	946	1,189
Lead	mg/kg dry	2,063	1,261	2,448
Copper	mg/kg dry	201	757	200
Nickel	mg/kg dry	159	126	289
Chromium	mg/kg dry	243	260	52
Mercury	mg/kg dry	2.7	0.01	2.1

ND = None Detected

TABLE 5. CHARACTERISTICS OF CSO SLUDGES FROM PHYSICAL/ CHEMICAL TREATMENT PROCESSES (12)

Parameter	Units	Screening/ dissolved-air flotation (Racine, WI)	Dissolved-air flotation (Milwaukee, WI)	Dissolved-air flotation (San Francisco, CA)
Total solids	mg/l	9,769	42,700	24,000
Suspended solids	mg/l	8,433	41,900	22,500
Total volatile solids	mg/l	3,596	11,350	9,400
Volatile suspended solids	mg/l	3,340	10,570	8,850
BOD	mg/l	1,100	3,200	1,000
TOC	mg/l	260	6,050	1,600
Dissolved organic carbon	mg/l	60	340	67
Total phosphorus (as P)	mg/l	39.2	149	166
Total kjeldahl nitrogen (as N)	mg/l	112	517	375
Ammonia (as N)	mg/l	6.3	12.5	7.5
NO_2 (as N)	mg/l	<0.1	<0.1	0.02
NO_3 (as N)	mg/l	<0.1	<0.1	0.1
Specific gravity	--	1.01	1.07	1.014
pH	--	6.9	7.2	5.2
Total coliforms	#/100 ml	40,000	6,400,000	6,300,000
Fecal coliforms	#/100 ml	1,400	220,000	17,000
Fuel value	cal/gm	1,961	1,359	1,950
PCB's	µg/kg dry	603	775	113
pp'DDD	µg/kg dry	ND	225	29
pp'DDT	µg/kg dry	ND	TR	96
Dieldrin	µg/kg dry	24	9	192
Zinc	mg/kg dry	1,638	855	708
Lead	mg/kg dry	1,023	164	1,583
Copper	mg/kg dry	481	248	367
Nickel	mg/kg dry	251	173	<83
Chromium	mg/kg dry	251	150	1,667
Mercury	mg/kg dry	2.3	2.1	3.9

ND = None Detected TR = Trace (<0.2 µg/l on wet basis)

TABLE 6. CHARACTERISTICS OF CSO SLUDGES FROM BIOLOGICAL TREATMENT PROCESSES (12)

Parameter	Units	Contact stabilization (Kenosha, WI)	Trickling filter (New Providence, NJ) primary	Trickling filter (New Providence, NJ) secondary
Total solids	mg/l	8,527	2,010	25,500
Suspended solids	mg/l	8,300	1,215	25,070
Total volatile solids	mg/l	5,003	1,120	15,500
Volatile suspended solids	mg/l	5,225	780	14,770
BOD	mg/l	1,700	728	11,200
TOC	mg/l	3,400	700	13,000
Dissolved organic carbon	mg/l	29	220	710
Total phosphorus (as P)	mg/l	194	22	436
Total kjeldahl nitrogen (as N)	mg/l	492	65	6
Ammonia (as N)	mg/l	42	9	180
NO_2 (as N)	mg/l	0.055	0.02	0.02
NO_3 (as N)	mg/l	0.065	0.11	0.09
Specific gravity	--	-	1.005	1.013
pH	--	7.9	-	-
Total coliforms	#/100 ml	1,200,000	3,400,000	1,000,000
Fecal coliforms	#/100 ml	79,000	44,000,000	1,300,000,000
Fuel value	cal/gm	3,446	3,585	3,583
PCB's	µg/kg dry	767	547	-
pp'DDD	µg/kg dry	93	ND	-
pp'DDT	µg/kg dry	TR	ND	-
Dieldrin	µg/kg dry	88	ND	-
Zinc	mg/kg dry	7,154	697	1,294
Lead	mg/kg dry	528	<498	353
Copper	mg/kg dry	1,454	995	1,020
Nickel	mg/kg dry	528	995	784
Chromium	mg/kg dry	1,278	746	2,471
Mercury	mg/kg dry	2.6	100.5	-

ND = None Detected TR = Trace (<0.2 µg/l wet basis) solids are then not associated with waste activated sludge but are present in CSO sludges. In addition, CSO sludges have not been stabilized and therefore a comparison to undigested residues is valid.

A summary of generalized sludge characteristics including CSO sludges, raw primary and digested primary is included in Table 7. The data presented has been drawn from several sources, as indicated. Wide ranges have been presented because of the extreme variation in values obtained from the different references. However, it is understood that the large differences are due mainly to large variations in influent wastewater characteristics and treatment plant efficiencies throughout the country. There is also a large variation in values indicated for the CSO sludges due to the different treatment techniques utilized and the many other variables previously mentioned. Therefore, it is necessary to provide only broad comparisons between the dry-weather primary sludge and the CSO sludges.

The table indicates that the potential volume of CSO sludges exceeds the estimated primary sludge volume. However, the pounds of dry solids of the two residues is much more comparable due to the higher solids concentration in raw primary sludges. This difference in solids concentration is an important aspect when considering CSO sludges and is mainly due to the very dilute backwash residue produced from the screening processes which treat raw CSO. Additional thickening is required to reduce the volume of CSO sludge to be either further stabilized or transported. This is desirable since an increase in solids of 1% can halve the total volume being handled.

In addition to having a low solids content, the percent volatile solids in CSO sludges is significantly lower than that found in most raw primary sludges. The highest value obtained for CSO sludges was associated with the biological type of treatment, as expected. Even with this input, the volatile percentage was significantly lower for CSO sludge than for raw primary. Furthermore, the values were much more comparable to already digested primary solids. Therefore, lower effective removals of volatile solids are expected as the microbial mass is diminished due to a smaller feed source.

Comparison of other parameters indicate that there are some differences, but that the ranges of concentrations overlap in most categories. General observations indicate that the total nutrient concentrations are generally lower in CSO sludges than in raw and digested primary sludge. Fecal coliform numbers are also lower possibly due to dilution of influent from the rainfall. No comparable data regarding pesticide content was available for raw CSO sludges and raw primary, however, concentrations in digested primary were somewhat higher than those detected in raw CSO sludges. Metals concentrations in all of the sludge types showed extremely high variations. The concentration of metals in CSO sludges ranged close to the values obtained for raw primary residue. The concentration of nickel was somewhat higher for CSO sludges, however, lead concentrations did not reach the high levels reported for some raw primary sludges.

One significant difference between CSO sludges and raw primary which is not apparent from Table 7, is the high grit content of most CSO sludges. This

TABLE 7. CHARACTERISTICS OF CSO AND PRIMARY SLUDGES

Parameter	Units	CSO Sludges*	Raw primary sludge	Digested primary sludge
Volume	cu m/year	156×10^6	60.9×10^6	30.3×10^6
Dry solids	metric ton	1.67×10^6	2.88×10^6 [3]	2.88×10^6
Sludge production	m^3/Mm^3	2,000 - 200,000	2,440 - 3,530 [4]	500 [2]
TS	percent	0.3 - 6(1.04)	2 - 7(4) [1]	6 - 12(10) [1]
Volatile solids	% of TS	26.6 - 48.4	60 - 80 [1]	30 - 60 [1]
Phosphorus (as P)	mg/kg	2,875 - 7,450	3,500 - 12,200 [1]	4,700 - 13,900 [1]
TKN	mg/kg	1,100 - 13,000	15,000 - 40,000 [1]	6,700 - 54,000 [1]
Ammonia	mg/kg	80 - 750	--	3,000 - 13,000 [2]
Fecal coliform	#/100 mls	$1.4 \times 10^3 - 2.8 \times 10^6$	11×10^6 [3]	0.4×10^6 [3]
PCB's	µg/kg	ND - 6,570	--	ND - 10,500 [3]
pp'DDT	µg/kg	ND - 170	--	ND - 1,000 [3]
Dieldrin	µg/kg	ND - 192	--	100 - 2,000 [3]
Zinc	mg/kg	697 - 7,154	900 - 8,400 [5]	72 - 12,800 [5]
Lead	mg/kg	164 - 2,448	150 - 26,000 [5]	9,000 - 22,000 [5]
Copper	mg/kg	200 - 2,454	200 - 1,740 [5]	290 - 1,360 [5]
Nickel	mg/kg	83 - 995	44 - 740 [5]	20 - 1,500 [5]
Chromium	mg/kg	52 - 2,471	66 - 3,100 [5]	44 - 7,200 [5]
Mercury	mg/kg	0.01 - 100.5	1.2 - 3.4 [5]	1.4 - 7.0 [5]

* All CSO values referenced from Tables 3, 4 and 5.

[1] Superscript indicates reference number attached.

REFERENCES FOR TABLE 7

1. Metcalf & Eddy Inc., Wastewater Engineering: Collection, Treatment, Disposal, McGraw-Hill Book Company, 1972, p. 586, Table 13.2.

2. Reed, S., Wastewater Management by Disposal on the Land, Cold Regions Research and Engineering Laboratory, May 1972, Tables B-1 - B-4.

3. Farrell, J. B., Overview of Sludge Handling and Disposal Proceeding Pretreatment and Ultimate Disposal of Wastewater Solids, Rutgers University, May 21-22, 1974, p. 1-22.

4. U.S. EPA Process Design Manual for Sludge Treatment and Disposal., EPA 625/1-74-006, p. 3-1.

5. Blakelee, P.A., Monitoring Considerations for Municipal Wastewater Effluent and Sludge Application to the Land, Proceedings of the Joint Conference on Recycling Municipal Sludges and Effluents on Land, Champaign, IL, p. 183-198.

high concentration of heavy particulate matter is caused by the high velocity scouring of materials which accumulate in sanitary sewers and the lack of preseparation of grit before treatment. Primary sedimentation is generally preceded by grit removal which usually separates materials that settle faster than 5 fpm or have a specific gravity greater than 2.65. Without grit removal for CSO residues, the characteristics of the sludge are significantly affected by the presence of this grit. Special handling methods are necessary to stabilize and dewater these materials since most traditional techniques are not designed to take the heavy loading. This is especially true when transporting the sludges in a liquid form. The heavy particulates will tend to settle to the bottom of sewers or tanks and enhance putrefaction. This situation may be extremely difficult to remedy and should be considered before determining handling methods.

Another aspect of CSO sludge which is difficult to quantify is the intermittent nature of sludge production. This factor itself presents problems when compared to primary sludges which are produced daily with approximately the same volume and characteristics. The intermittent nature of the sludge production indicates that holding and pumpback of the material is necessary to equalize the flows, however, holding the sludge may cause significant changes in its characteristics, and create odor and septicity problems. If equalization is not possible, then the sludge handling method must be flexible enough to accept shock loadings from wet weather sludge or a separate facility capable of intermittent operation must be constructed and utilized. It is therefore evident that the problems associated with handling CSO sludges are unique and difficult to solve. The potential volumes of sludges and the accumulation of pollutants including solids, organics, heavy metals etc. generated by the treatment of combined sewer overflows are formidable. The relatively dilute nature and low volatile solids content of the sludges along with their intermittent generation create a situation significantly different from that encountered when dealing with raw primary sludges. These differences and proposed techniques for dealing with them will be considered in the following sections of the report. The evaluations of various alternatives for handling these residuals are developed to assist in arriving at an assessment of the impact, effort required, and resources needed, if full-scale treatment of CSO discharges on a national level is to be implemented.

SECTION V

EFFECT OF HANDLING CSO TREATMENT RESIDUALS BY BLEED/PUMP-BACK TO THE MUNICIPAL DRY-WEATHER PLANT

One of the possible methods for handling CSO treatment residuals is bleed/pump-back of these materials to the dry-weather treatment plant. These sludges may be either the dilute residuals themselves or the supernatant liquor which was generated by on-site dewatering. In addition, the return of residuals can affect either the total dry-weather treatment plant or the sludge handling facilities, or both, depending upon the nature of the return system. Full evaluation of the effect of residual bleed/pump-back can then be broken down into several sections:

1. Effect of bleed/pump-back of dilute residuals on the treatment plant.
2. Effect of bleed/pump-back of residuals from on-site dewatering on the treatment plant.
3. Effect of bleed/pump-back of dilute residuals on the sludge handling facilities.
4. Effect of bleed/pump-back of residuals from on-site dewatering on the sludge handling facilities.

To accomplish the evaluation, it is necessary to consider the effect of bleed/pump-back on the design characteristics of the dry-weather treatment plant. The following aspects are to be studied:

a) Hydraulic overload
b) Solids overload
c) Organic and inert solids overload
d) Toxicity to treatment
e) Treatment efficiency
f) Effluent quality (treatment system only)

These individual considerations have been studied with regard to the bleed/pump-back of residuals to the various parts of the treatment plant. The results of the evaluation are discussed individually in this section of the report.

TRANSPORT CONSIDERATIONS

It is apparent that bleed/pump-back of the sludges to the dry-weather treatment plant offers the simplest solution to handling CSO sludges. This alternative utilizes existing transport facilities, a centralized treatment location and trained dry-weather treatment plant staff to provide handling. However, there are inherent problems involved in bleed/pump-back, due to both the general design of combined sewers and the high grit content of CSO sludge. This section briefly presents some of the problems involved in bleed/pump-back. The sections which follow assume that the CSO sludge has been satisfactorily bled/pumped-back to the plant and the calculations establishing the effect of the CSO sludges continues from that point.

One of the main problems with bleed/pump-back is that combined sewers cannot be designed to provide needed velocity for scouring heavy particles during dry-weather conditions. The WPCF Manual of Practice No. 9 states that, "It is rarely possible to design combined sewers with adequate self-cleaning velocities at minimum dry-weather flow if the capacity of the sewer also must be adequate for stormwater runoff. Hence, combined sewers often are subject to deposition during dry weather and are dependent on frequent rainfall for flushing" (15).

Calculations of the possible velocity in an existing combined sewer verifies that statement. Using Camp's formula for calculation of the velocities required to transport sediments, the velocity in a 0.97 m x 1.27 m (38" x 50") interceptor required to transport a grit particle 0.2 mm in diameter with specific gravity of 2.65 was 0.87 m/s (2.87 fps). The interceptor was designed at a slope of 0.06 m/100 m (0.06 ft/100 ft) and velocity flowing full was calculated to be 0.7 m/s (2.31 fps) which would scour particles less than 0.13 mm. Typical grit chamber design can remove particles of 0.2 mm or more at velocities of 0.305 m/s (1 fps). So these calculations indicate that there would be significant accumulation of particulates greater than 0.13 mm in this sewer under dry-weather flow conditions.

It must then be recalled that there are high concentrations of grit within the CSO sludges. This is due in part to grit and associated stormwater infiltration through leaky joints in the sanitary sewers which is flushed to the CSO treatment site during storm flow. Replacing the gritty sludge in the downstream line will cause this accumulation to recur in the sewers under most conditions. The problem is augmented by the fact that it is desirable to equalize the flow to the treatment plant. Therefore, sludge bleed/pump-back would ideally occur at low flow, low velocity time periods, causing even greater solids deposition. Once the solid materials have collected on the sewer bottom, flow capacity usurpation and septicity and odor problems can occur. These nuisances can create premature flooding and pollution causing overflows, public relations problems and dry-weather treatment plant operations difficulties. The septic solids can exert a significant oxygen demand on the raw sewage flow and cause excessive oxygen requirements at the treatment plant.

In conclusion, problems of bleed/pump-back of the sludge are therefore difficult to overcome and should be considered prior to recommendation of this alternative for handling CSO sludges. If sufficient carrying velocity is not available, the excessive grit deposition can cause a myriad of secondary problems. Careful examination of the individual sewer interceptors to be used for bleed/pump-back and knowledge of the sieve analysis and density or particle settling velocities of the CSO sludge will be necessary in order to determine if bleed/pump-back will cause deposition of solids in the interceptors.

TREATMENT CONSIDERATIONS

General

In order to accurately assess the impact of bleed/pump-back of CSO residuals on any portion of the treatment plant, it is necessary to calculate the effects for each individual site. However, it is desirable to approximate the effects of bleed/pump-back of CSO sludges on a generalized basis to establish what aspect of bleed/pump-back is limiting and when this technique might be a viable handling method for CSO sludges. Therefore, it is necessary to make a series of assumptions in the approach to establishing the effect of bleed/pump-back of CSO sludges or their dilute residuals on the dry-weather treatment plant and the existing sludge handling facilities. Among the factors to be considered are the type and degree of treatment utilized, the effect of diurnal flow variation and contaminant strength, the CSO sludge characteristics, the percent of CSO area contributing sludge to treatment, etc.

Degree and Type of Treatment Used and Effluent Discharge Requirements

It is essential to know the type of treatment processes utilized at the dry-weather treatment plant in order to establish the effect of the bleed/pump-back of both sludges and residuals. It is also important to determine the type of sludge handling facilities used for dewatering and then consider the effect of CSO sludge bleed/pump-back on this portion of treatment individually.

U.S. Public Law 92-500 (1972) requires that by July 1, 1977, publicly owned (municipal) treatment works provide a minimum of secondary treatment. Moreover, effluent discharge limitations for suspended solids and BOD have been promulgated at 30 mg/l (monthly average) and 45 mg/l maximum (seven day average). Therefore, for purposes of this discussion, it may be assumed that the dry-weather treatment facilities to which CSO treatment residuals are to be bled/pumped back will provide a minimum of secondary treatment. Furthermore, for purposes of evaluating the effect of the CSO treatment residuals bleed/pump-back on dry-weather treatment efficiency, the effluent discharge limitations promulgated will be used. A schematic diagram of a typical activated sludge secondary treatment plant is shown in Figure 3. The end products of waste treatment, namely, treated effluent and residual sludge solids, must be disposed of efficiently and economically. Therefore, the dry-weather facility consists of two systems, the waste treatment system and the sludge handling system. The elements comprising the waste treatment system are shown in Figure 3.

Referring to Figure 3, the process elements making up the treatment portion of a municipal pollution control facility are grit removal, primary sedimentation, biological oxidation and final clarification. Various dry weather design and operational parameters associated with these process elements are summarized in Table 8 and were obtained from the literature (16, 17, 18, 19). These criteria are among those that will be used in the evaluation of the effect of the CSO treatment residuals bleed/pump-back to dry weather treatment facilities with regard to hydraulic, solids and organic overload as well as treatment efficiency.

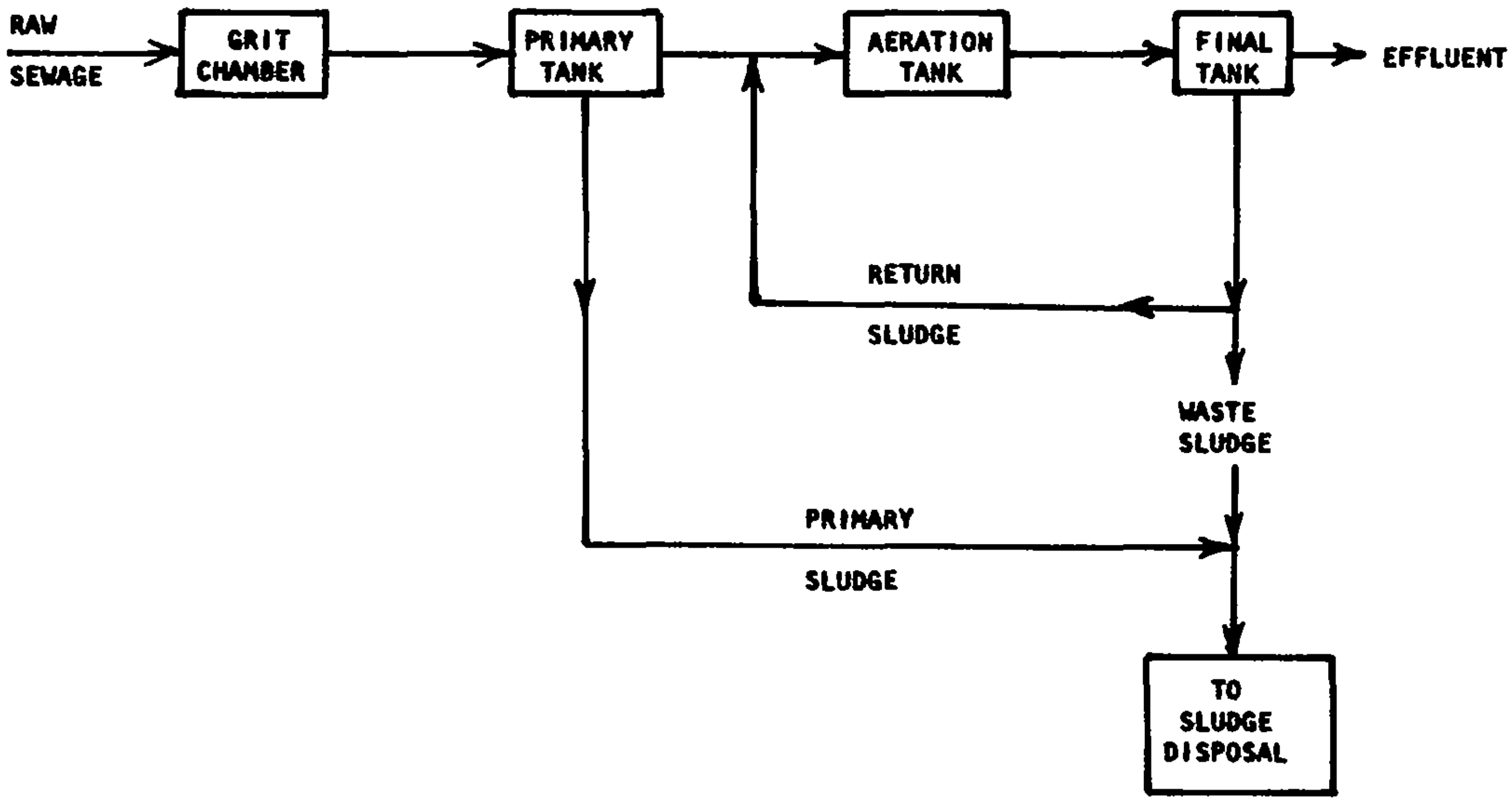


Figure 3. Conventional activated sludge plant.

TABLE 8. SUMMARY OF DESIGN AND OPERATIONAL PARAMETERS FOR VARIOUS DRY WEATHER TREATMENT PROCESSES (16)(17)(18)(19)

Treatment process	Hydraulic Overflow rate l/min/sq m (gpm/sq ft)	Suspended Solids loading kg/day/sq m (lb/day/sq ft)	Organic loading kg BOD/day kg MLSS	Detention time	Sludge produced cu m/1000 cu m (cu ft/MG)	% Sludge solids	Effluent SS mg/l
Grit removal (0.2 mm, SP. Gr. 2.65)	1258 (30.9)	- -	-	30-60 sec	0.01-0.09 (1-12)	-	-
Plain sedimentation	16-65 (0.4-1.6)	2.4-9.8 (0.5-2.0)	-	1.5.2-5 hr	2.43 (325)	5	80-120
Aeration	- -	- -	0.35-0.50	6-8 hr	-	-	-
Final sedimentation	10-31 (0.25-0.75)	98-146 (20-30)	-	2-3 hr	18.7	0.5-1.5	10-50

The treatment scheme shown in Figure 3 is the minimum required in the near future, and is one which is in common use today. It should be recognized that many existing treatment plants are not capable of meeting the more stringent performance levels required today [See Table 7 and compare final clarification effluent suspended solids content expected (10-50 mg/l) with that presently required (30 mg/l)]. Moreover, meeting additional regulatory agency stipulations, such as (1) more stringent disinfection requirements, (2) phosphorus removal and (3) partial or complete oxidation of ammonia nitrogen or high nitrogen removal, will require significant expansion and/or modification of existing facilities.

Sludge handling should be considered an integral part of the total waste treatment process. Although the volume of dry weather residual sludges obtained is relatively small, usually 2% to 3% of the wastewater volume treated, sludge handling and disposal is complex, troublesome, and represents up to 25% to 50% of the capital and operating costs of a waste treatment plant (20). Moreover, the problem is growing. With the expansion of the economy and the population and with the greater degree of treatment required, it is expected, within the next 5 to 10 years, that the volume of sludge requiring handling and disposal will increase by 60% to 70% (20). By far, the major portion of the increased sludge volume expected will be obtained from secondary treatment sludges, which are less concentrated than primary sludges, and which are most difficult and expensive to treat. For example, in 1980 it is anticipated that 530,000 cu m/day (140 MGD) of secondary sludge (2% solids) will be produced, whereas only about 37,850 cu m/day (10 MGD) of primary sludge (6% solids) are expected in that year (21).

The various steps leading to the ultimate disposal of the residual sludges are presented, schematically, in Figure 4. From Figure 4, sludge handling for ultimate disposal consists of a series of dewatering steps in which the volume of sludge is progressively reduced by removal of the water associated with the sludge solids.

Thickening is usually the first step in sludge handling and is responsible for removing the major portion of the water associated with the solids. Thickening may be carried out by gravity sedimentation or by dissolved-air flotation. Flotation thickening is more amenable than gravity thickening for dewatering biological sludges because flotation thickening is not adversely affected by the decomposition gases produced by the activity of the biological sludges.

As shown in Figure 4, further treatment and sludge volume reduction may be obtained by digestion. Digestion is a biological treatment process and may be carried out aerobically or anaerobically.

Further dewatering may also be performed using vacuum filtration or centrifugation, either with or without chemicals, or using sand drying beds or lagoons.

Ultimate disposal of sludges includes disposal on land (landfill, drying for soil conditioning, land application) discharge to sea, and use of incineration and related processes.

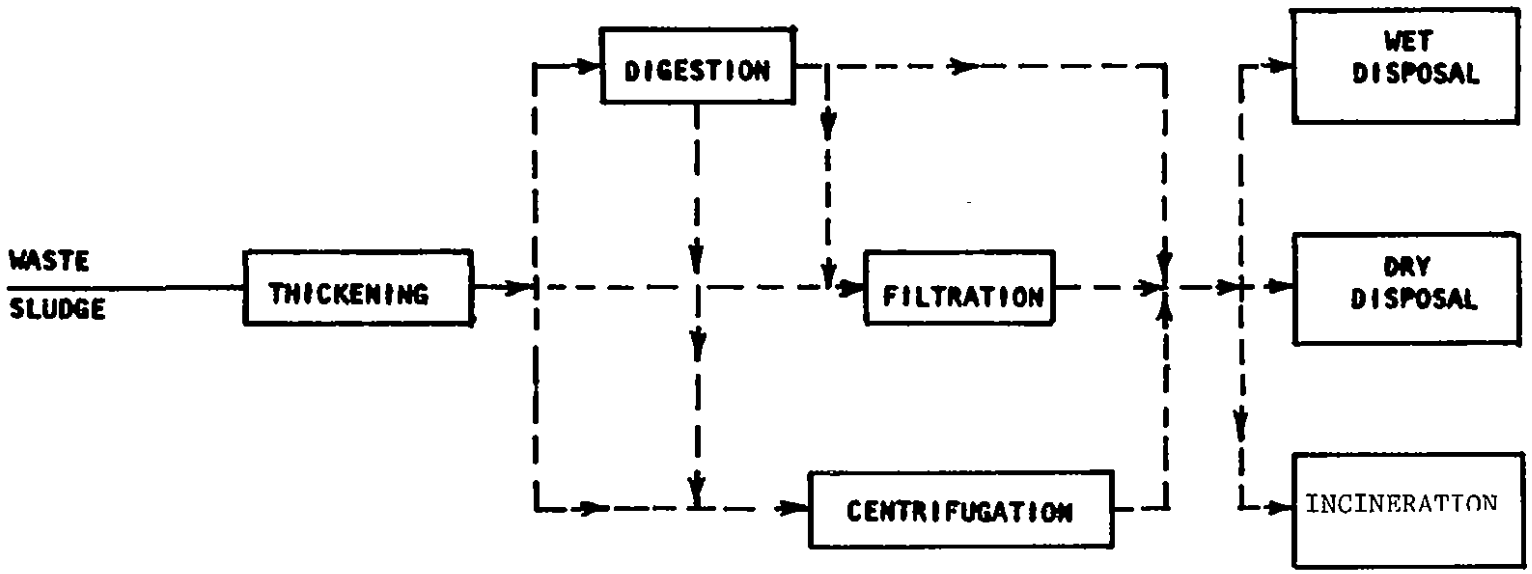


Figure 4. Schematic diagram of the various steps leading to ultimate sludge disposal.

For a particular location, the combination of the sludge handling and disposal steps to be used should be integrated in such a manner as to arrive at an optimum economical solution.

Various dry-weather design and operational parameters associated with several of the sludge handling and disposal methods were obtained from the literature (20)(22) and are summarized in Tables 9-13. Criteria for other sludge handling methods include:

1. Flotation Thickening
Solids loading of 49-59 kg/day/sq m (10-12 lb/day/sq ft) without chemicals to produce a thickened sludge concentration of 4-5% when thickening waste activated sludge.

2. Lagoons
Solids loading rates suggested for drying lagoons are 36 to 39 kg/year/cu m (2.2 to 2.4 lb/year/cu ft) of lagoon capacity.

3. Centrifugation
Pilot tests used to evaluate applications. Scale up procedures are considered proprietary and are generally not available.

These criteria, discussed above, are among those that will be used in the evaluation of the effect of CSO treatment residuals bled/pumped-back to the dry-weather sludge handling facilities.

Diurnal Dry Weather Flow and Contaminant Strengths

Another pertinent consideration to establishing the effect of bleed/pump-back is the diurnal dry-weather flow variation and contaminant concentration patterns. These patterns can have a significant effect upon the viable bleed/pump-back of CSO sludges. A typical diurnal flow and BOD pattern is shown in Figure 5. It is important to note that the diurnal pattern will vary from day to day, from week day to weekend and also from month to month.

It is apparent that the diurnal patterns developed for a dry-weather facility may be used to compare the actual loading parameters with those of the plant design values, to determine the degree of diurnal overload during dry-weather periods. It is also evident that bleed/pump-back of CSO treatment residuals will superimpose or increase the flow and contaminant loadings on the dry-weather diurnal patterns, and therefore, on the actual loadings to the dry-weather treatment facilities.

CSO Treatment Sludges Flow and Contaminant Strengths for Pump-Back

The magnitude and quality of the CSO treatment sludges to be pumped back to the dry-weather facilities is a function of the type and efficiency of CSO treatment, used. The CSO treatment methods presently being evaluated (12) may be broadly classified as physical, physical-chemical and biological. In general, it should be recognized that as treatment complexity and sophistication increase (say, from physical to biological treatment), treatment efficiency and sludge residue production also increase. The specific CSO

TABLE 9. GRAVITY THICKENER SURFACE LOADINGS AND OPERATIONAL RESULTS (22)

Type of sludge	Solids-surface loadings kg/day/sq m	($lb/day/ft^2$)	Thickened sludge solids concentration (%)
Separate sludges			
Primary	98-146	(20-30)	8-10
Modified activated	73-122	(15-25)	7-8.5
Activated	24-29	(5-6)	2.5-3
Trickling filter	39-49	(8-10)	7-9
Combined sludges			
Primary and modified activated	98-122	(20-25)	8-12
Primary and activated	29-49	(6-10)	5-8
Primary and trickling filter	49-59	(10-12)	7-9

TABLE 10. TYPICAL DESIGN CRITERIA FOR STANDARD RATE AND HIGH RATE DIGESTERS (22)

Parameter	Low rate	High rate
Solids retention time (SRT), days	30 to 60	10 to 20
Solids loading, kg VSS/cu m/day (lb VSS/cu ft/day)	0.64-1.60 (0.04 to 0.1)	2.40-6.40 (0.15 to 0.40)
Volume criteria cu m/capita (cu ft/cap.)		
Primary sludge	.056-.084 (2 to 3)	.037-.056 (1-1/3 to 2)
Primary sludge + thickening filter sludge	.112-.140 (4 to 5)	.065-.093 (1-2/3 to 3-1/3)
Primary sludge + waste activated sludge	.112-.168 (4 to 6)	.075-.112 (2-2/3 to 4)
Combined primary + waste biological		
Sludge feed concentration percent solids (dry basis)	2 to 4	4 to 6
Digester underflow concentration, percent solids (dry basis)	4 to 6	4 to 6

TABLE 11. AEROBIC DIGESTION DESIGN PARAMETERS

Parameter	Value
Solids retention time, days	10-15[a]
Solids retention time, days	15-20[b]
Volume allowance, cu m/capita	.084-.112
cu ft/capita	3-4
VSS loading, kg/cu m/day	.384-2.24
lb/cu ft/day	.024-0.14
Air requirements	
Diffuser system, cu m/min/1000 cu m	20-35[a]
cu ft/min/1000 cu ft	20-35
Diffuser system, cu m/min/1000 cu m	60[b]
cu ft/min/1000 cu ft	60
Mechanical system, kw/1000 cu m	26.6-33.3
hp/1000 cu ft	1.0-1.25
VSS, reduction, percent	35-50
Minimum DO, mg/l	1.0-2.0
Temperature, °C (°F)	>15 (>59)
Power requirement Bkw/10,000 pop. equiv.	6-7.5
BHP/10,000 pop. equiv.	8-10

[a] Excess activated sludge only.

[b] Primary and excess activated sludge, or primary sludge alone.

TABLE 12. VACUUM FILTRATION DESIGN PARAMETERS AND PERFORMANCE (20)

	Type of sludge	Chemical dose rate, (%) ferric chloride	lime	Yield kg/sq m/hr (lbs/sq ft/hr)	Cake moisture (%)
1.	Raw primary	2.1	8.8	33.7 (6.9)	69.0
2.	Digested primary	3.8	12.1	35.1 (7.2)	73.0
3.	Elutriated Digested primary	3.4	0	36.6 (7.5)	69.0
4.	Raw primary + filter humus	2.6	11.0	34.6 (7.1)	75.0
5.	Raw primary + activated sludge	2.6	10.1	22.0 (4.5)	77.5
6.	Raw activated sludge	7.5	0	--	84.0
7.	Digested primary + filter humus	5.3	15.0	22.5 (4.6)	77.5
8.	Digested primary + activated sludge	5.6	18.6	19.5 (4.0)	78.5
9.	Elutriated digested primary + activated sludge:				
	(a) average w/o lime	8.4	0	18.6 (3.8)	79.0
	(b) average w/lime	2.5	6.2	18.6 (3.8)	76.2

TABLE 13. CRITERIA FOR THE DESIGN OF SANDBEDS (22)

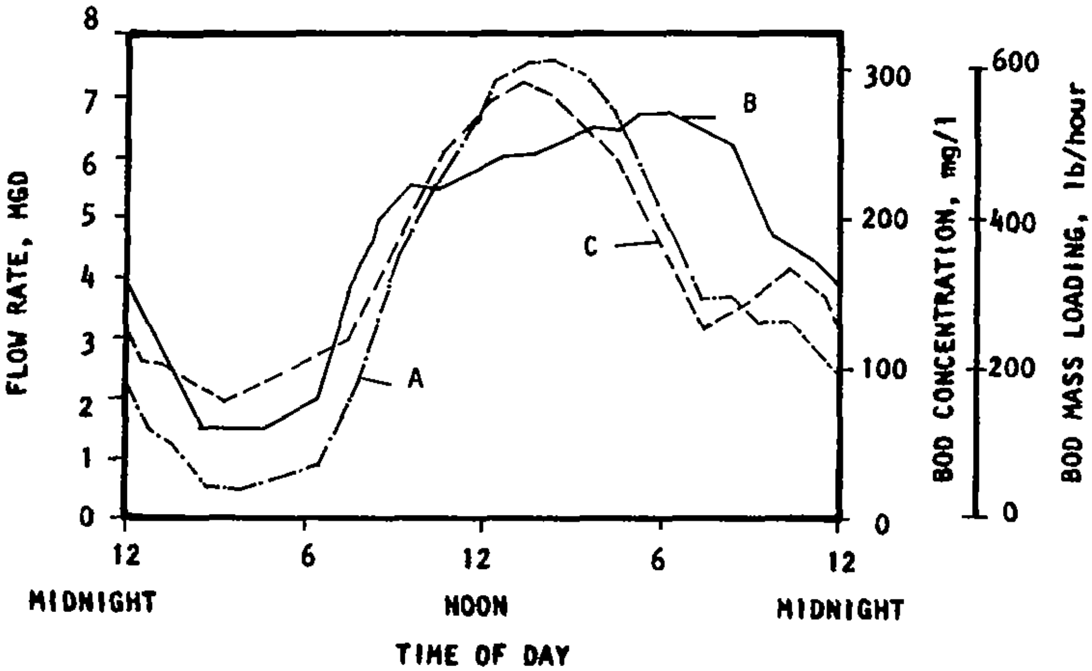
Type of digested sludge	Area sq m/capita	(sq ft/capita)	Sludge loading dry solids kg/sq m/yr	(lb/sq ft/yr)
Primary	0.09	(1.0)	134.4	(27.5)
Primary and standard trickling filter	0.15	(1.6)	107.4	(22.0)
Primary and activated	0.28	(3.0)	73.2	(15.0)
Chemically precipitated	0.19	(2.0)	107.4	(22.0)

LEGEND

A BOD LOADING, lb/hr

B FLOW RATE, MGD

C BOD CONCENTRATION, mg/l



NOTE: MGD x 3785 = cu m/day
lb/hr x .454 = kg/hr

Figure 5. Raw wastewater and BOD variation (19).

treatment methods being considered are listed in Table 14. Estimated sludge production solids concentrations and solids disposal methods for the various CSO treatment processes are shown in Table 15. Note from Table 9, that the CSO treatment sludge quantities are based upon the quantity and quality of the raw CSO treated.

TABLE 14. CSO TREATMENT METHODS UNDER EVALUATION

1. Physical Treatment
   a. Storage alone
   b. Storage-sedimentation
   c. Dissolved-air flotation
   d. Screening/dissolved-air flotation
   e. Screening

2. Physical-Chemical Treatment
   a. Screening/dissolved-air flotation
   b. Dissolved-air flotation

3. Biological Treatment
   a. Contact stabilization activated sludge
   b. Trickling filters
   c. Rotating biological contactors
   d. Treatment lagoons

Furthermore, from Table 15 the major sludge disposal method used was discharge to the interceptor with ultimate disposal along with dry-weather treatment facility sludge.

The quality of the CSO treatment sludges was observed in a recently completed EPA study (12) and, in general, the conclusions drawn with regard to raw sludge characteristics were as follows:

1. The sludge volumes produced from the treatment of combined sewer overflows varied from less than 1% to 3% of the raw flow volume treated. (This is generally in agreement with Table 15).

2. The solids concentration of the sludge residuals from CSO treatment varied widely, ranging from 0.12% to 11% total suspended solids. The wide range observed is attributed to the CSO treatment method used and treatment plant operation. (This is also in general agreement with Table 15).

3. The volatile content of the sludge solids varied between 25% and 63% for the sludges obtained from the treatment types investigated. Biological treatment sludges showed the highest volatile solids fraction (about 60%), whereas that for sludges from physical/chemical treatment showed only 25 to 40% volatile fraction.

TABLE 15. SLUDGE PRODUCTION AND SOLIDS DISPOSAL METHODS FOR VARIOUS CSO TREATMENT PROCESSES[a] (9)

Process	Sludge % Solids	SS Removal (%)	Wet Sludge Volume cu m/1000 cu m	Wet Sludge Volume (cu ft/MG)	Dry Solids Volume cu m/1000 cu m	Dry Solids Volume (cu ft/MG)	Sludge Disposal Method For Demonstration Project
Sedimentation	2.5-5.0	40-75	1.92-7.40	(260-1000)	0.07-0.15	(10-20)	Return to Interceptor
Dissolved-Air Flotation	1.0-2.0	40-70	4.96-17.0	(670-2300)	0.07-0.15	(10-20)	Return to Interceptor
Bar Screens	NA[b]	---	0.01-0.03	(1-4)[c]	---	---	Landfill
Rotary Fine Screens	---	27-34	---	---	0.04-0.07	(5-10)	Return to Interceptor
Ultrafine Screens and Microstrainers	---	25-90	---	---	0.04-0.18	(5-25)	Return to Interceptor
Filtration	0.4-1.5[d]	50-90	8.14-55.5	(1100-7500)	0.07-0.18	(10-25)	Return to Interceptor
Contact Stabilization	0.5-1.5	80-95	13.3-46.6	(1800-6300)[e]	0.15-0.18	(20-25)[e]	Return to Interceptor
Trickling Filters and Rotating Biological Contactors	3.0-10.0[f]	60-90	1.48-7.40	(200-1000)	0.11-0.18	(15-25)	Return to Interceptor
Physical-Chemical	2.0-5.0	80-100	3.92-12.6	(530-1700)[g]	0.15-0.18	(20-25)[g]	Incineration/Landfill

a. Assuming 250 mg/l SS in the CSO and dry solids sp. gr. = 1.30
b. NA = not available
c. Volumes shown for screenings only, not SS
d. Low value for unsettled backwash water; high value for settled backwash water
e. Does not include waste biological solids produced in aeration tanks
f. Assuming sludge recycle
g. Does not include added chemicals

4. As might be expected, fuel value of the sludges was correlated with volatile solids content, and the biological sludges were observed to have the highest fuel values among the sludge types investigated.

5. Pesticide and PCB concentrations in the residual sludges investigated were observed to be significant. Generally, the PCB concentrations were higher than those for pp'DDD, pp'DDT and Dieldrin.

   The range of PCB and pesticide values for the various sites investigated were presented in Section IV.

6. Heavy metal (Zn, Pb, Cr, Cu, Hg and Ni) concentrations in the residual sludges were also significant, and varied widely for the sludges investigated. The range of heavy metal concentrations for the various sites investigated were also presented in Section IV.

Using the above and previous information, an attempt can be made to determine the effect of pumping back CSO treatment residuals on the operation and performance of the dry-weather plant from the standpoint of hydraulic, organic and solids overloads, effluent quality, and treatment efficiency and toxicity to treatment.

<u>Capacity Available at Dry-Weather Plant and Percent of CSO Area Contributing Sludge</u>

Other considerations must include both the treatment and sludge handling capacity available at the dry-weather plant and the percent of the total CSO area which has treatment of runoff and therefore contributes sludge for bleed/pump-back. Basic design of a new sewage treatment facility includes a "built in" safety factor (which varies with the type of process equipment) from 1.5-3 times the average loading. If the total "safety capacity" is available for handling CSO sludge or residual bleed/pump-back, this will have a significant effect on the ability of the dry-weather plant to function properly when CSO sludges are bled/pumped-back. For the purpose of the following calculations, it is assumed that the total excess capacity is available for hydraulic, solids and organic loads to the dry-weather treatment plant and sludge handling facilities.

Another variable is the total amount of CSO area which is treated by one of the state-of-the-art CSO treatment methods. If 100% of the total CSO volume is treated, this impact on the dry-weather plant is significantly greater when considering bleed/pump-back. Also, the type of CSO treatment is crucial. The sludge characteristics and volume range widely, depending upon the CSO treatment method. It is not feasible to generalize, so, for most of the calculated effects, each process has been considered individually.

<u>Basis for Bleed/Pump-Back Calculations</u>

The sections which follow address the effects of CSO sludges and dilute residuals on a composite dry-weather treatment plant and sludge handling facilities. It must be reemphasized that actual determination of the feasibility of bleed/pump-back will require the complete analytical characterization of the CSO residuals and the dry-weather treatment plant influent and sludges, a knowledge of dry-weather flow characterization and actual design constraints for each of the unit processes in the treatment plant. However, for this generalized approach it has been assumed that a secondary treatment plant followed by thickening and dewatering will be the basic dry-weather plant which would be affected by bleed/pump-back. This plant is a composite of all dry-weather treatment plants which serve the population of 36,236,000 having combined sewer systems. Also, it is assumed that all CSO area and volume in the U.S. has been treated by one of the CSO treatment methods and that these sludges will affect the composite dry-weather plant. The specific aspects for each of the four general effects are discussed individually.

EFFECT OF CSO TREATMENT RESIDUALS BLEED/PUMP-BACK ON THE OPERATION AND PERFORMANCE OF THE DRY-WEATHER TREATMENT PLANT

The bleed/pump-back of CSO sludges can have an effect on any of the design aspects of the composite treatment plant. Hydraulic, solids loading, organic loading and toxicity limits are considered individually.

1. Hydraulic Loading Considerations

It was previously brought out (Section IV) that the sewered population served by combined sewers is estimated at 36,236,000. At 473 ℓ (125 gal.) per capita per day, the dry-weather treatment plants serving that population would have a dry-weather average design flow of 17.1×10^6 cu m/day (4.53×10^9 gal./day). Most water pollution control plants are designed to function properly at flows up to some low multiple of the average dry-weather flow. Typical multiples range from 1.5 to 3.0 (9). Using this criterion, our composite national dry-weather plant might be expected to function properly up to 25.7×10^6 cu m/day to 51.4×10^6 cu m/day (6.8 to 13.6×10^{12} gal./day). Therefore, the sum of the dry-weather average design flow (17.1×10^6 cu m/day) (4.53×10^9 gal./day) plus the estimated daily CSO residual flows to be pumped back may be compared to the above two figures to determine the effect of bleed/pump-back on hydraulic overload to the dry-weather plant.

Previous discussion has estimated the annual volume of combined sewer overflow in the United States as 5.6×10^9 cu m (1.5×10^{12} gal.). Assuming 60 storm days per year (based on a 20 year average of 63 storm days per year in the Milwaukee area), the average daily combined sewer overflow is 93.4×10^6 cu m/day (24.7×10^3 MGD).

CSO treatment methods currently under evaluation have been listed in Table 14 and the sludge volumes produced by various CSO treatment processes have also been given previously (Table 1 and in Table 9). Shown in Table 16 is the effect of CSO treatment sludges bleed/pump-back on the hydraulic overload of the composite dry-weather treatment plant for the various CSO treatment processes. It should be pointed out that the data in Table 16 were calculated on the basis that the entire CSO was treated by each of the selected treatment processes alone. From

TABLE 16. EFFECT OF BLEED-BACK OF CSO TREATMENT SLUDGES ON HYDRAULIC OVERLOAD OF DWF TREATMENT PLANT (12)

CSO Treatment Process	Sludge Volume % of CSO Treated	Sludge Volume million cu m/day	Sludge Volume MGD	Sludge Volume Plus Ave. DWF million cu m/day	Sludge Volume Plus Ave. DWF MGD	Hydraulic Overload
*Storage Alone	100	93.5	24700	110.6	29230	Yes
Storage-Sedimentation	0.9	0.83	220	18.0	4750	No
Dissolved-Air Flotation	0.6	0.57	150	17.7	4680	No
Screening/DAF	4.8	4.50	1190	21.7	5720	No
Microscreening	6.0	5.60	1480	22.7	6010	No
Contact Stabilization	3.5	3.26	860	20.4	5390	No
Trickling Filter	0.7	0.64	170	17.8	4700	No

DWF = Dry Weather Flow = 17,146,000 cu m/day (4530 MGD)(average)

Hydraulic overload determinations made by comparing sludge volume plus average DWF with design range of flows that DWF plants are expected to function properly: 26 to 51×10^6 cu m/day (6.8 to 13.6×10^3 MGD)

CSO Treated = 93.5×10^6 cu m/day (24.7×10^3 MGD) *Entire flow bled/pumped back

Table 16, it is evident that hydraulic overload would be expected only when storage alone was used to impound the entire CSO flow for bleed/pump-back. This becomes apparent when comparing the average daily CSO [90,840,000 cu m/day (24,000 MGD)] with the average daily DWF of [17,144,000 cu m/day (4,530 MGD)]. For the other CSO treatment processes investigated in Table 16, hydraulic overload would not be expected. However, the rate of residual sludge bleed/pump-back over a 24 hour period would have to be carefully controlled, with due regard to the diurnal dry-weather flow (DWF) fluctuations (See Figure 5).

The apparent hydraulic overload produced by pumping back impounded CSO from storage alone over a 24 hour period may be alleviated by spreading the bleed/pump-back period over three or more days. (Of course, any additional storms during the bleed/pump-back period may adversely affect bleed/pump-back operation). Again, the rate of bleed/pump-back would have to be carefully controlled, with due regard to the diurnal DWF flucutations.

2. Solids Loading Considerations

Untreated municipal sewage generally contains an average suspended solids content of 200 mg/l (9). For our hypothetical average DWF of 17.1×10^6 cu m/day (4,500 MGD), an average daily dry solids loading to the dry-weather plant of 3.4×10^6 kg (7.6×10^6 lbs) per day may be expected. Assuming that the range multiple of design solids that a dry-weather plant can properly handle is typically 1.5 to 3.0, the dry-weather plant may be expected to handle from 5.1×10^6 kg (11.3×10^6 lbs) per day to 10.3×10^6 kg (22.7×10^6 lbs) per day of dry solids. The above criterion will be used as one measure in evaluating the effect of solids overload resulting from pumping back CSO treatment residuals to the dry-weather plant.

Shown in Table 17 is the effect of bleed/pump-back of CSO treatment sludges on the solids overload of the composite dry-weather treatment plant for the various CSO treatment processes investigated. Again, it should be pointed out that the data in Table 17 were calculated on the basis that the entire CSO was treated by each of the selected treatment processes alone. The solids removal efficiencies in Table 17 for the CSO treatment processes investigated are reasonably in the range of those expected as indicated in the literature (9).

From Table 17, it is evident that a marked solids overload may be expected by pumping back CSO treatment sludges to the DWF treatment plant over a 24 hour period. In fact, the minimum solids overload varies from about 150% to about 400%. The magnitude of the solids overload varies directly with the solids removal efficiency of the CSO treatment processes in question. The appreciable solids overload exerted on the DWF treatment plant by pumping back CSO treatment residuals may be expected to additionally adversely affect organic loading, effluent quality and treatment plant efficiency,

TABLE 17. EFFECT OF BLEED/PUMP-BACK OF CSO TREATMENT SLUDGES ON SOLIDS OVERLOAD OF DWF TREATMENT PLANT (12)

CSO Treatment Process	Sludge Pumped Back: million cu m/day	MGD	Percent Solids	Dry Solids $kg/day \times 10^{-6}$	*Dry Solids $lb/day \times 10^{-6}$	CSO + DWF Solids: $kg/day \times 10^{-6}$	$lb/day \times 10^{-6}$	Solids Overload
Storage Alone	93.5	24700	0.041	38.4	84.5	41.8	92.1	Yes
Storage-Sedimentation	0.83	220	1.74	14.5	31.9	17.9	39.5	Yes
Dissolved-Air Flotation	0.57	150	2.75	15.6	34.4	19.1	42.0	Yes
Screening/DAF	4.50	1190	0.84	37.9	83.4	41.3	91.0	Yes
Microscreening	5.60	1480	0.70	39.2	86.4	42.7	94.0	Yes
Contact Stabilization	3.26	860	1.00	32.6	71.7	36.0	79.3	Yes
Trickling Filter	0.64	170	3.20	20.6	45.4	24.1	53.0	Yes

CSO Treated = 93.5×10^6 cu m/day (24,700 MGD)

Solids overload determination made by comparing sum of CSO + DWF solids with the design range of solids that DWF plants are expected to function properly:

5.1×10^6 to 10.3×10^6 kg/day (11.3×10^6 to 22.7×10^6 lb/day)

Available Capacity = 5.2 million kg/day

*Descrepancies in dry solids are due to inaccuracies in pilot plant experimental data

That substantial amounts of solids are transported to the dry-weather plants during wet weather conditions is substantiated by significant data available from the literature. For example, presented in Table 18 are data showing the quantities of grit collected during dry and wet weather periods for various United States installations. The data in Table 18 show that the grit volume ratio of wet to dry weather was appreciable, with the highest ratio at 1800 times the average dry-weather grit production.

The literature (9) also indicates that often the stormwater solids contribute a large increase in fine solids (silt) which is too fine to be removed in the grit chambers and results in overloading the primary sedimentation basins. The magnitude of the solids overload on the primary tanks may be estimated. For example, in Table 8 are shown the allowable range in hydraulic loading for primary tanks (16.3-65.1 ℓ/min/sq m) (0.4-1.6 gal./min/sq ft) and the allowable solids loading range for those basins (2.4-9.8 kg/day/sq m) (0.5-2.0 lb/day/sq ft). Assuming a dry weather influent solids concentration of 100 mg/l at the higher overflow rate (65.1 ℓ/min/sq m) (1.6 gpm/sq ft), the addition of CSO treatment residual solids may result in increasing the primary tank influent solids concentration to an estimated 150 mg/l to 400 mg/l. This would be expected to result in grossly overloading (14.2 to 37.6 kg/day/sq m) (2.9 to 7.7 lb/day/sq ft) the primary basins and detrimentally affecting primary effluent quality and treatment efficiency. Moreover, the high primary overflow rate (65.1 ℓ/min/sq m (1.6 gpm/sq ft) would result in grossly hydraulically overloading the activated sludge final tanks and to adversely affect final effluent quality and overall treatment efficiency.

Again, it may be apparent that the solids overloads to the dry-weather plant described above may be alleviated by storing the CSO treatment sludges and spreading the bleed/pump-back period over two to four days or more. Of course, any additional storms during the bleed/pump-back period may adversely affect the bleed/pump-back operation. Additionally, the rate of bleed/pump-back would have to be carefully controlled, with due regard to the diurnal DWF fluctuations.

3. Organic Loading Considerations

Untreated municipal sewage contains about 200 mg/l BOD (9) (19). Shown in Table 19 are the BOD characteristics observed for various CSO treatment residual sludges (12). The BOD concentrations of the sludges investigated varied widely, increasing with increasing sludge concentration. The BOD values shown in Table 19 were those associated with the solids contents of the corresponding sludge presented in Table 17.

One of the criteria to be used in evaluating organic overload is associated with the activated sludge portion of the treatment. Design organic loading DWF parameters for the aeration tank are shown in Table 8, and the organic loading range indicated is 0.35 to 0.5 kg (lb) BOD/day per kg (lb) MLSS. In addition, removals of BOD from DWF primary

TABLE 18. VARIATION IN QUANTITIES OF GRIT REMOVED DURING WET WEATHER AND PERIODS OF AVERAGE FLOW (17)

Municipality	Grit removed cu m/10^6 cu m (cu ft/MG) average day		maximum(wet) day		Ratio between maximum and average
Baltimore, MD	40	(5.4)	109	(14.8)	2.7
Battle Creek, MI	139	(18.8)	1258	(170.0)	9.0
Beacon, NY	23	(3.1)	138	(18.7)	6.0
Birmingham, AL	6	(0.8)	6	(0.8)	1.0
Cleveland, Ohio (East)	2	(0.3)	3995	(540.0)	1,800.0
Fort Dodge, IA	24	(3.2)	24	(3.2)	1.0
Green Bay, WI	52	(7.0)	56	(7.6)	1.1
Jeannette, PA	42	(5.7)	60	(8.1)	1.4
Kokomo, IN	10	(1.3)	74	(10.0)	7.7
La Crosse, WI	20	(2.7)	42	(5.7)	2.1
Muskegon, MI	10	(1.3)	60	(8.1)	6.2
Rockford, IL	50	(6.8)	119	(16.0)	2.3
Springfield, OH	16	(2.2)	48	(6.5)	2.9
Virginia Beach, VA	18	(2.4)	56	(7.5)	3.1

TABLE 19. ORGANIC CHARACTERISTICS (BOD) OF CSO TREATMENT RESIDUAL SLUDGES (9) (12)

CSO Treatment Process	BOD mg/l	Volume Pumped Back million cu m/day	Volume Pumped Back MGD	BOD Pumped Back kg/dayx10^{-6}	BOD Pumped Back lb/dayx10^{-6}	BOD Removed By Primary Treatment kg/dayx10^{-6}	BOD Removed By Primary Treatment lb/dayx10^{-6}	BOD To Activated Sludge kg/dayx10^{-6}	BOD To Activated Sludge lb/dayx10^{-6}	Number Of Days Required For Pump Back
Storage Alone	115	93.5	24700	10.8	23.7	3.8	8.3	7.0	15.4	11.9
Storage-Sedimentation	2200	0.83	220	1.8	4.0	0.6	1.4	1.2	2.6	2.0
Dissolved-Air Flotation	1000	0.57	150	0.6	1.3	0.2	0.5	0.4	0.9	0.6
Screening/DAF	1100	3.18	840	3.5	7.7	1.2	2.7	2.3	5.0	3.8
Contact Stabilization	1700	3.26	860	5.5	12.2	2.0	4.3	3.6	7.9	6.1
Trickling Filter	11200	0.64	170	7.2	15.9	2.5	5.6	4.7	10.3	7.9

Assumed 35% BOD removal by primary treatment at 40.8 cu m/day/sq m (1000 gpd/sq ft)

Number of days are based on DWF organic loading of 0.35 kg BOD/day/kg MLSS with possibility of increasing the organic loading to a maximum of 0.5 kg BOD/day/kg MLSS or an increase of 588,076 kg BOD/day (1,295,321 lb BOD/day) sedimentation is about 35% at an overflow rates of 40.8 cu m/day sq m (1000 gal./day/sq ft) (14)(15). Suspended solids and BOD removals drop drastically at primary tank overflow rates greater than 40.8 cu m/day/sq m (1000 gal./day/sq ft). For example, at an overflow rate of 19.8 cu m/day/sq m (2300 gal./day/sq ft), BOD removal decreases to about 20% (15) and suspended solids removal decreases to about 37% (14).

From previous discussion, it has been indicated that bleed/pump-back of CSO treatment sludges to the dry-weather plant over a 24 hour period will result in hydraulic and/or suspended solids overload. Furthermore, it was indicated that the overloads to the dry-weather plant may be alleviated by spreading the bleed/pump-back period over several days or more. Moreover, it is indicated that the bleed/pump-back period would be further extended because the primary tank operation is critical with regard to BOD and suspended solids removal and the resultant organic load to the secondary treatment system. Optimum operation of the primary tanks is an overflow rate of 40.8 cu m/day/sq m (1000 gal./day/sq ft) in order to maximize BOD and suspended solids removal. This overflow rate is appreciably less than the maximum normally allowed for DWF operation, [93.6 cu m/day/sq m (2300 gal./day/sq ft] (See Table 8).

Untreated municipal sewage generally contains an average BOD content of 200 mg/l and an average suspended solids content of 200 mg/l (9). For our hypothetical average DWF of 17.1×10^6 cu m/day (4,500 MGD), an average daily BOD and suspended solids loading to the dry-weather plant of 3.4×10^6 kg (7.6×10^6 lbs) per day each may be expected. Operating the primary treatment plant at a design overflow rate of 40.8 cu m/day/sq m (1000 gal./day/sq ft)(18), BOD removals of 35% (1.2×10^6 kg/day) (2.6×10^6 lb/day) may be expected and suspended solids removals of 60% 2.1×10^6 kg/day (4.5×10^6 lb/day) would be anticipated. Therefore, the organic (BOD) loading on the secondary activated sludge treatment system during dry-weather flow would be 2.2×10^6 kg/day (4.9×10^6 lb/day), and the corresponding solids loading to the secondary treatment plant would be 1.4×10^6 kb/day (3.0×10^6 lb/day) during dry-weather periods. From Table 8, the allowable organic loading range on the activated sludge system is 0.35-0.50 kg(lb) BOD/day/kg(lb) MLSS. Assuming our activated sludge plant is operating at the lowest end of the organic loading scale (0.35 kg(lb) BOD/day/kg(lb) MLSS) or 600,000 kg (1.3×10^6) lb) BOD/day may be added in the form of bled/pumped-back CSO treatment residuals. Of course, if the activated sludge plant is operating consistently at the upper end of the organic loading scale (0.5 kg(lb) BOD/day/kg(lb) MLSS), then no additional CSO treatment residuals can be bled/pumped-back to the DWF plant without organically overloading it. Also, if the DWF secondary plant is operating at somewhere in between the allowable organic range, then less additional BOD load than was previously indicated can be pumped back to the DWF plant.

Inasmuch as the rate of flow of CSO sludges bleed/pump-back is limited to the extent that the primary tank operation does not exceed an overflow rate of 40.8 cu m/day/sq m (1000 gal./day/sq ft), it becomes apparent from an examination of Figure 5 (DWF diurnal variations) that bleed/pump-back will be intermittent and restricted to low DWF periods during the day.

The above described constraints all tend to restrict the rate of bleed/pump-back flow downward to the extent that the total time period for pumping back the total CSO sludges volume is extended, which is an unfavorable trend from the standpoint of handling the effects of a succeeding series of storms. Shown in Table 19 are the number of days required for bleed/pump-back of the CSO treatment sludges from one average storm from an organic loading standpoint, when the DWF plant is operating at a low organic loading (0.35 kg(lb) BOD/day/kg(lb) MLSS). The number of days required to bleed/pump-back the CSO treatment residuals increases proportionately from those in Table 19, as the DWF organic loading increases from 0.35 to 0.5 kg(lb) BOD/day/kg(lb) MLSS. Also, as mentioned previously, DWF plants having organic loadings at the maximum of 0.5 kg(lb) BOD/day/kg(lb) MLSS may not be able to accept CSO treatment residuals if they are consistently heavily loaded.

From Table 19, it may be seen that four of the six CSO treatment methods investigated would require about four or more days for bleed/pump-back of a single storm's treatment sludges to the DWF plant when the dry-weather plant is operating at a low organic loading level. The time required for bleed/pump-back would be expected to increase as the dry-weather organic loading level increased.

From Table 19, it may also be seen that two of the six CSO treatment methods investigated would require two or less days for bleed/pump-back of a single storm's treatment sludges to the DWF plant when the dry-weather plant is operating at a low organic loading level. Again, the time required for bleed/pump-back would be expected to increase as the dry-weather organic loading level increased. Furthermore, it should be pointed out that the two CSO treatment methods involved here, sedimentation and dissolved-air flotation, were relatively low efficiency solids removal processes (about 40% suspended solids removal, (See Table 17)). Any increase in solids removal efficiency for these treatment processes would result in an increase in the bleed/pump-back period. Moreover, the CSO treatment processes in question are primary treatment methods and the treated effluents produced may require further treatment which would produce additional sludge for bleed/pump-back, thereby increasing the total bleed/pump-back time period.

Concurrent with the organic loading considerations, described above and under the operating conditions listed in Table 19, is the solids loading imposed on the secondary treatment plant and its concurrent effect on that operation. For our hypothetical DWF plant treating 17.1×10^6 cu m/day (4,530 MGD), it was previously calculated that the suspended solids loading to the dry-weather plant was 3.4×10^6 kg/day (7.6×10^6 lb/day). Operating the primary treatment plant at an overflow rate of 40.8 cu m/day/sq m (1000 gal./day-sq ft), suspended solids removals of 60% 2.1×10^6 kg/day (4.5×10^6 lb/day) may be expected, and the suspended solids loading to the secondary treatment plant would be 1.4×10^6 kg/day

3.0×10^6 lb/day) during dry-weather periods. From Table 7, the allowable solids loading on final clarifiers is 98 to 146 kg/day/sq m (20-30 lb/day/sq ft). Assuming our final clarifiers during dry-weather are operating at the lowest end of the solids loading scale 98 kg/day/sq m (20 lb/day/sq ft), then an additional solids load (up to 146 kg/day/sq m) (30 lb/day/sq ft) of 0.7×10^6 kg/day (1.5×10^6 lb/day) may be added in the form of pumped back CSO treatment residuals. Shown in Table 20 is the solids loading effect on the secondary treatment plant when pumping back CSO residuals at a rate which will prevent organic overload (See Table 13). From Table 20 it may be seen that under the operating conditions previously described, a gross solids overload is effected, and this indicates that solids overload is the limiting factor affecting the bleed/pump-back time period. It is indicated, therefore, that the bleed/pump-back time periods shown in Table 19 should be appreciably increased, which makes the concept of CSO residuals bleed/pump-back to the dry-weather plant more impractical from the standpoint of successfully handling the effects of succeeding storms in series.

4. Toxicity to Treatment

Some possible toxic substances in CSO treatment sludges for which data is available include heavy metals (zinc, lead, copper, nickel, chromium and mercury), PCB and pesticides (pp'DDD, pp'DDT and dieldrin). Heavy metal, PCB and pesticide concentrations in CSO treatment sludges were found to be significant, and the ranges of concentrations observed have been previously reported herein.

Heavy Metals - Domestic wastewater generally contains low concentrations of metals. The high concentrations of metals in wastewater are normally caused by the discharge of industrial wastes (such as metal finishing shops, plating wastes, etc.). Therefore, the metals content for municipal treatment plants may range from traces to 20 mg/l or more (23). During wet weather, street runoff may produce high concentrations of certain metals in combined sewers, on the order of 10 to 100 times and more than those normally present in domestic wastewater as shown in Table 21 (23,24).

Pertinent to this discussion is the determination of any toxic effect of heavy metals to treatment in the dry-weather plant operation caused by pumping back of CSO treatment sludges. The toxic effect, if any, would manifest itself in the secondary treatment portion of the dry-weather plant. Shown in Table 22 are criteria which are to be used in arriving at such a determination. Moreover, the literature indicates that mercury dosages of 5 mg/l or higher definitely inhibit aerobic biological processes (25). The inhibitory effect of lead on biological treatment was not uncovered in the literature, however, it was observed that primary sewage treatment removes "most" of the lead in sewage (21).

Presented in Table 23 are the heavy metal concentrations found in sanitary sewage (from Table 21) (24) and in the sludges from various CSO treatment processes (12). It may be recalled that previous discussion

TABLE 20. CONCURRENT SOLIDS LOADING ON SECONDARY TREATMENT PLANT UNDER THE OPERATING CONDITIONS DESCRIBED IN TABLE 13

CSO Treatment Process	Solids Pumped Back		Solids Removed By Primary Treatment		Bleed/Pump-Back Period (days)	Solids To Activated Sludge		Secondary Solids Overload
	$kg/day \times 10^{-6}$	$lb/day \times 10^{-6}$	$kg/day \times 10^{-6}$	$lb/day \times 10^{-6}$		$kg/day \times 10^{-6}$	$lb/day \times 10^{-6}$	
Storage Alone	38.4	84.5	22.7	50.1	11.9	1 3	2.9	Yes
Storage-Sedimentation	14.5	31.9	8.7	19.1	2.0	2.9	6.4	Yes
Dissolved-Air Flotation	15.6	34.4	9.4	20.6	0 6	10 4	23.0	Yes
Screening/DAF	37.9	83.4	22.7	50.0	3.8	4.0	8.8	Yes
Contact Stabilization	32.6	71.7	19.5	43.0	6.1	2.1	4.7	Yes
Trickling Filter	20.6	45.4	12.3	27.2	7.9	1.0	2 3	Yes

Bleed/Pump-Back solids were obtained from Table 11.

Assumed 60% SS removal by primary treatment at 40.8 cu m/day/sq m (1000 gpd/sq ft)

Solids overload was established when the CSO solids to the activated sludge system exceeded 686,088 kg/day (1,511,208 lb/day)

TABLE 21. METAL LOADING FROM ROAD SURFACE RUNOFF COMPARED TO NORMAL SANITARY SEWAGE FLOW (24)

Metal	Road runoff (mg/l)	Sanitary sewage (mg/l)	Runoff: sewage (ratio)
Pb	6.2	0.03	210
Cd	0.012	0.00075	16
Ni	0.10	0.01	10
Cu	0.37	0.04	9
Zn	1.4	0.20	7
Fe	83	13	6
Mn	1.6	2.3	0.7
Cr	0.80	2.8	0.3

Note: From a 0.25 cm rain (0.1 in.)

TABLE 22. EFFECTS OF HEAVY METALS ON BIOLOGICAL TREATMENT PROCESSES (26)

Metal	5-10% reduction in aerobic treatment efficiency	4-hr slug dose, causing reduction in COD removal	Highest allowable dose for satisfactory anaerobic sludge digestion
Cr	10 mg/l	>500 mg/l	>50 mg/l
Cu	1	75	5
Ni	1-2.5	50-200	>10
Zn	5-10	160	10

has indicated that bleed/pump-back of CSO treatment sludges over a 24 hour period would result in hydraulic, solids and organic overload of the dry-weather treatment plant facility. Moreover, it was further indicated that to prevent overload conditions, CSO treatment sludges would have to be stored and pumped back to the dry-weather plant over extended periods of time. For example, for efficient CSO treatment processes (storage alone, contact stabilization, screening/DAF, etc.) bleed/pump-back periods appreciably greater than 4 to 12 days have been indicated.

However, for purposes of this discussion in determining the toxic effect of CSO treatment sludges' heavy metals on dry-weather secondary treatment, a bleed/pump-back period of 24 hours will be assumed. If the combined heavy metal concentrations obtained under this condition are found not to be toxic to secondary treatment during dry weather conditions, then toxic conditions may not be expected over the more extended bleed-back periods.

Using our hypothetical average dry weather flow of 17.1×10^6 cu m/day (4,500 MGD), the daily CSO treatment sludge volumes expected (Table 5) and the appropriate heavy metal concentrations in the two flows (Table 23), the average heavy metal concentration of the blend of dry weather and CSO residual flows at the dry weather plant influent may be determined. The results of these calculations are shown in Table 24 on the basis that the entire CSO was treated by each of the selected CSO treatment processes alone. Also presented in Table 24 are the heavy metal concentrations contributing detrimentally to the efficiency of aerobic biological treatment. Noted in Table 24 are those values which significantly exceed the toxicity causing concentrations listed at the bottom of Table 24. It is indicated that copper and zinc in contact stabilization, storage alone and trickling filter treatment residuals warrant further discussion regarding toxicity to treatment. The values shown in Table 24 are the heavy metal concentrations at the influent to the dry weather plant. Assuming the heavy metals are predominantly of a particulate nature, a 60% reduction may be expected by primary treatment. Therefore, the primary effluent to secondary treatment will contain heavy metal concentrations of 40% of the values presented in Table 24. The primary effluent heavy metals contents so calculated will all be below the critical concentrations detrimental to secondary treatment efficiency. The general conclusion may be drawn from the above discussion that pumping back of CSO treatment sludges to the dry-weather plant will not result in heavy metal toxicity to secondary treatment. However, this is a preliminary and elementary study and the subject requires further attention.

PCB (12)(27) - This chemical, which has been contaminating fish, has been in common use since 1929. It is used in many products ranging from soaps to electrical transformers. In 1972, Monsanto Industrial Chemical Co., the only PCB manufacturer in the United States, stopped selling it except for use in closed electrical items such as transformers and capacitors. However, it still continues to get into waters from past usage and spills.

PCB is suspected of causing reproductive failure in fish, birds, and

TABLE 23. COMPARISON OF HEAVY METAL CONCENTRATION IN SANITARY SEWAGE AND VARIOUS CSO TREATMENT SLUDGES

	Zinc mg/l	Lead mg/l	Copper mg/l	Nickel mg/l	Chromium mg/l	Mercury mg/l
Sanitary Sewage	0.20	0.03	0.04	0.01	2.80	---
CSO Treatment Process						
Storage Alone	0.6	0.7	1.5	0.1	0.05	0.001
Storage-Sedimentation	15.2	29.0	8.4	2.5	4.4	0.05
Dissolved-Air Flotation	19.4	43.3	10.0	2.3	45.6	0.11
Screening/DAF	13.8	8.6	4.1	1.8	1.8	0.02
Microscreening	8.3	17.1	1.4	2.0	0.4	0.01
Contact Stabilization	71.5	5.3	14.5	5.3	17.3	0.03
Trickling Filter	41.7	11.4	32.8	25.2	79.5	---

TABLE 24. EVALUATION OF THE POSSIBLE TOXIC EFFECT OF HEAVY METALS ON DRY WEATHER TREATMENT DUE TO BLEED/PUMP-BACK OF CSO TREATMENT SLUDGES

CSO Treatment process	Concentration (mg/l after blending CSO sludge with dry weather flow)				
	Zinc	Copper	Nickel	Chromium	Mercury
Storage	0.5	1.3*	0.1	0.5	.001
Storage-sedimentation	0.9	0.4	0.1	2.9	.002
Dissolved-air flotation	0.8	0.4	0.1	4.2	.0001
Screening/DAF	3.0	0.9	0.4	2.6	.004
Microscreening	2.2	0.4	0.5	2.2	.002
Contact stabilization	11.5*	2.3*	0.9	5.1	.005
Trickling filter	1.7	1.2*	0.9	5.6	--

Concentrations of heavy metals causing a 5-10% reduction in aerobic treatment efficiency:

Zinc	5-10	mg/l
Copper	1	mg/l
Nickel	1-2.5	mg/l
Chromium	10	mg/l

* Values that are within or above given concentrations for causing a reduction in efficiency.

mammals. In human beings, it is suspected of causing cancer, skin discolorations and liver disorders. It is also suspected of affecting a person's recovery from other illnesses.

The literature (27) indicates that PCB is present in municipal sewage in amounts varying from 0.17 to 140 μg/l. Moreover, it is further indicated that municipal treatment plants are capable of removing more than 70% of the incoming PCB. However, over half the municipal treatment plants studied (27) had effluent concentrations ranging from 0.1 to 0.5 μg/l PCB, and about 20% of the plants studied had effluent concentrations greater than 1.0 μg/l PCB.

The mechanism of PCB removal in treatment plants appears to be adsorption on the solids with subsequent sedimentation clarification of the solids. This is evident from data collected (27) which show comparatively high concentrations of PCB in primary settling sludges (50 mg/l) and digester sludges (22 mg/l). In contrast, the CSO treatment sludges may be expected to contain PCB concentrations varying from 0.008 mg/l to 0.118 mg/l (27) which are several magnitudes lower than those concentrations reported from municipal dry weather sludges.

From the above discussion, it appears that the PCB content of the CSO treatment sludges will not cause toxicity to dry weather treatment if the CSO sludges are pumped back to the dry weather plant, all other things being equal. However, bleed/pump-back of CSO treatment sludges to the dry weather plant can increase the effluent PCB concentration and mass PCB transport to receiving waters if the dry weather facility becomes overtaxed.

Pesticides (28)(29) - Pesticides may be described as natural and synthetic materials used to control unwanted or noxious animals and plants. They may be conveniently classified according to their usage, such as fungicides, herbicides, insecticides, fumigants and rodenticides. The widespread presence of pesticides in the environment has caused much public and private concern because of their potential for upsetting ecological balances. Their dispersal in drainage systems and possible eventual accumulation in estuaries makes our coastal fisheries (for example, oysters, shrimp, crab and menhaden) especially vulnerable to their toxic effects. Laboratory tests show that these economically important animals are especially sensitive to the toxic effects of low levels of pesticides. For example, oysters will exist in the presence of DDT at levels as high as 0.1 mg/l in the environment, but at levels 1000 times less (0.1 μg/l), oyster growth or production would be only 20% of normal, shrimp populations would suffer a 20% mortality, and menhaden would suffer a disastrous mortality. Some insecticides are toxic enough to kill 50% or more of shrimp populations after 48 hours exposure to concentrations of only 30 to 50 nanograms per liter of the compounds.

Pesticides may be classified by their chemical affinities, their degree of toxicity and their degree of persistence. Pesticides which are acutely toxic to shrimp at low concentration levels (μg/l) include the organochlorine and organophosphorous insecticides. The organochlorines include the well-known DDT and aldrintoxaphene group, and typically, they are persistent compounds. The organophosphorous compounds include parathion, and typically, they hydrolyze or break down into less toxic products much more readily than the organochlorine compounds. Therefore, the organophosphorous compounds are usually preferable as control agents because of their relatively short life.

The pesticide content in municipal sewage was not uncovered in the literature. However, the concentrations of selected pesticides found in CSO treatment sludges are shown in Table 25. From Table 25, the pesticide content observed varied from non-detectable to significant. Note in Table 25, that the pesticides investigated were organochlorine insecticides.

Pumping back CSO treatment sludges to our hypothetical dry-weather plant over a 24 hour period will result in influent pesticide concentrations of the combined flow as shown in Table 26. The values shown in Table 26 were calculated using an average dry-weather flow of 17.1×10^6 cu m/day (4,500 MGD) (assuming no pesticide content), the daily CSO treatment residual volumes expected (Table 17) and the pesticide concentrations in the CSO treatment sludge volumes (Table 25). The results shown in Table 26 are on the basis that the entire CSO was treated by each of the selected CSO treatment processes alone.

The 48 hour TL_m (shrimp) for DDT and dieldrin are 0.6 µg/l and 0.3 µg/l, respectively (28). Comparing these values with those in Table 26 indicates that the corresponding values for the combined influent before treatment are well below the limit.

Also not covered in the literature was the extent of pesticide removal in municipal sewage treatment plants. However, it was indicated that pesticides are subject to a number of degrading actions, including volatilization, decomposition by ultraviolet light and other radiation, chemical degradation, microbial degradation and sorption by solids. Microbial degradation and sorption on solids appears to be the mechanism by which pesticides would be removed in a sewage treatment plant. The pesticide levels shown in Table 26 would not appear to be toxic to sewage treatment.

5. Effluent Quality and Treatment Efficiency

One of the most important criterion in evaluating the alternative of the bleed/pump-back of CSO treatment residuals to the dry weather plant is its effect upon treatment efficiency and effluent quality. Previous discussion has dwelled upon the effect of CSO residuals bleed/pump-back on the dry-weather treatment plant with regard to such criteria as hydraulic overload, solids overload, organic overload and toxicity to treatment. The effects on these criteria were found to be interrelated and to affect treatment efficiency and effluent quality for each treatment process element as well as for the overall treatment plant itself. It was observed that inasmuch as the treatment processes comprising the

TABLE 25. CONCENTRATION OF SELECTED PESTICIDES IN CSO TREATMENT SLUDGES (12)

CSO Treatment process	pp'DDD µg/l	pp'DDT µg/l	Dieldrin µg/l
Storage alone	ND	0.03	0.006
Storage-sedimentation	ND	3.00	0.67
Dissolved-air flotation	0.79	2.63	5.25
Screening/DAF	1.90	ND	0.14
Microscreening	ND	ND	ND
Contact stabilization	0.93	ND	0.88
Trickling filter	ND	ND	ND

ND = non-detectable

TABLE 26. EFFECT OF BLEED/PUMP-BACK OF CSO TREATMENT SLUDGES ON DRY WEATHER PLANT INFLUENT PESTICIDE CONCENTRATIONS

CSO Treatment process	Concentration (µg/l after blending CSO sludge with dry weather flow)		
	pp'DDD	pp'DDT	Dieldrin
Storage alone	ND	0.03	0.005
Storage-sedimentation	ND	0.14	0.04
Dissolved-air flotation	0.03	0.08	0.17
Screening/DAF	0.4	ND	0.03
Microscreening	ND	ND	ND
Contact stabilization	0.15	ND	0.14
Trickling filter	ND	ND	ND

ND = non-detectable

dry-weather plant are in series, any significant effect on any upstream treatment process will have significant effect on the performance of one or more of the downstream treatment processes. The discussion below summarizes the effect of CSO residuals bleed/pump-back on dry weather treatment plant treatment efficiency and effluent quality.

The effect of bleed/pump-back on various aspects of treatment plant loading have been discussed in detail. It is apparent that the rate of bleed/pump-back of CSO sludges to the dry-weather treatment plant is critical and appreciably affects the subsequent operation of the plant and the plant performance achieved.

Ideally, bleed/pump-back of the CSO treatment residuals over a 24 hour period would be most favorable from the standpoint of permitting the handling of subsequent CSO events in series. Previous discussion indicated, however, that discharge of the expected quantities of CSO treatment residuals to the dry weather plant over a 24 hour period would grossly overload the dry-weather treatment plant either hydraulically, solids-wise and/or organically, resulting in appreciably decreasing the treatment efficiency and intolerably (above allowable limits, see Table 8 and EPA regulations) deteriorating the plant effluent quality with regard to suspended solids, BOD, heavy metals, PCB and/or pesticides.

Inasmuch as a CSO residuals bleed/pump-back rate over a 24 hour period is impractical, the overload and unfavorable operating conditions caused thereby may be alleviated by storing the CSO treatment residuals and extending the bleed/pump-back period (reducing the bleed/pump-back rate) as required. Table 27 includes a summary of the limiting time periods for bleed/pump-back which can occur without overloading the capacity of the dry-weather treatment plant.

TABLE 27. LIMITING FACTORS IN DAYS FOR BLEED/PUMP-BACK

Treatment process	Days for bleed/pump-back				
	Hydraulic	Solids (Prim.)	Organic	Final Clarifier	Toxic
Storage	2.1	7.4	11.9	22.3	<1
Sedimentation	<1	2.8	2.0	9.5	<1
Dissolved Air Flotation	<1	3.0	0.6	9.1	<1
Screening/Dissolved Air Flotation	<1	7.3	3.8	22.1	<1
Microscreening	<1	7.5	-	-	-
Contact Stabilization	<1	6.3	6.1	19.0	<1
Trickling Filter	<1	4.0	7.9	12.0	<1

As can be seen, the most limiting aspect of bleed/pump-back of CSO sludges to the dry-weather treatment plant occurs with regard to the final clarifier solids loading. Storage and bleed/pump-back of sludge over periods of 8-22 days has several disadvantages. A major disadvantage of this alternative is that the capability of handling succeeding CSO treatment residual events is reduced. In fact, the longer the extended bleed/pump-back period, the more unfavorable this alternative becomes. Another disadvantage of any bleed/pump-back alternative is the necessity for carefully controlling bleed/pump-back (flow rate and constituent strength), with due regard for the diurnal DWF fluctuations (flow rate and constituent strength) to insure that peak treatment plant design operating conditions are not exceeded.

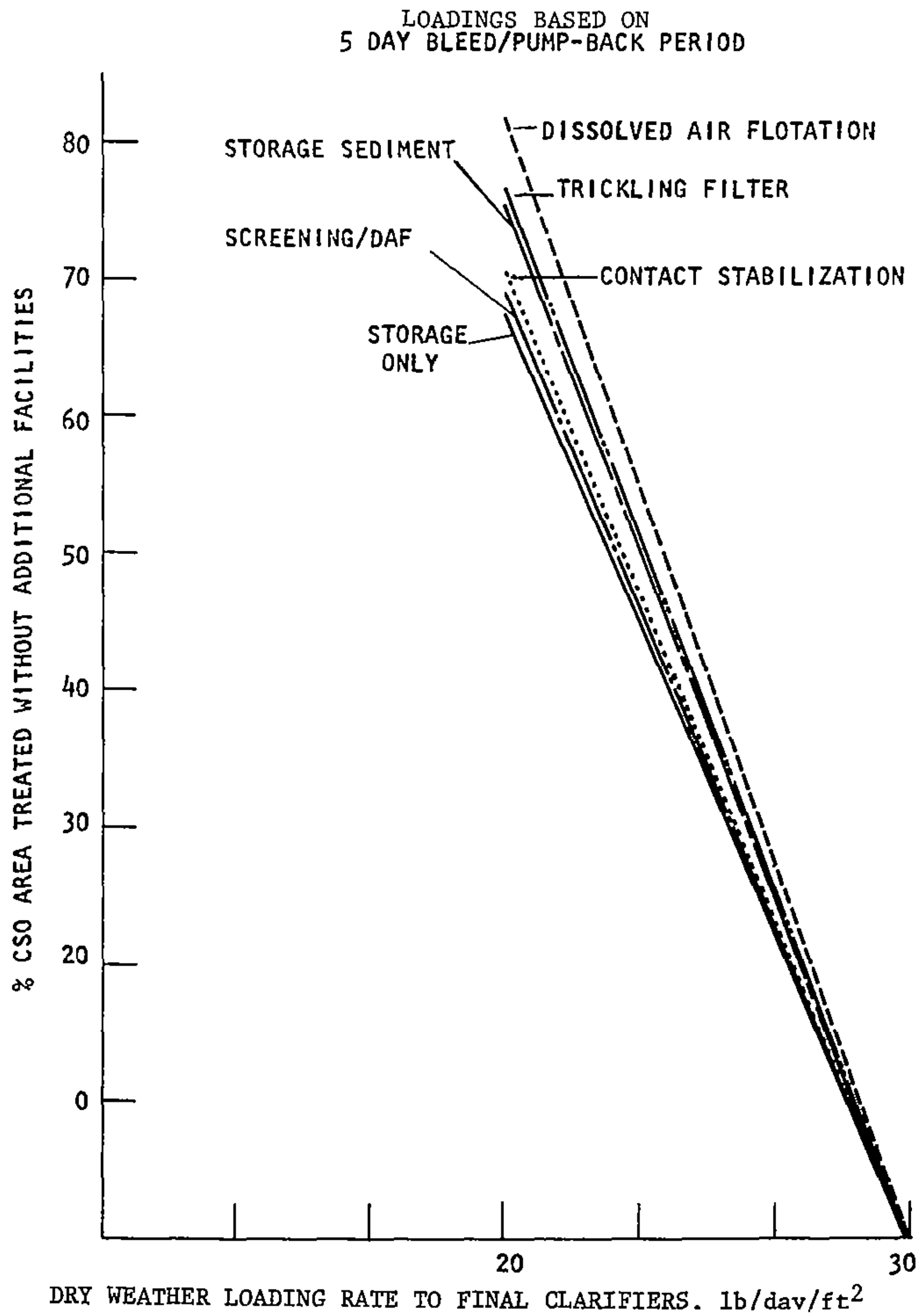
The final disadvantage is that the treatment efficiency and effluent quality would be lower than when CSO sludges are not bled/pumped-back. In order to minimize the bleed/pump-back period and the associated storage volumes required, it is assumed that the bleed/pump-back rate will be established so the dry-weather treatment plant will operate at the peak design operating conditions. It is felt that under this severe loading, the effluent discharge limitations (30 mg/l suspended solids and 30 mg/l BOD) would be exceeded. If the suspended solids loading is higher, then the effluent quality would range in the upper portion of the performance expectation and may reach concentrations of 50 mg/l (Table 14).

Using the assumptions that a 5 day bleed/pump-back period is feasible for storage and bleed/pump-back, and that the loading rate to the final clarifiers is the most limiting design parameter, the volume of CSO sludge which can be handled at the treatment plant can be calculated. This volume can then be related to the percent of CSO area and CSO volume which can be treated using the existing dry-weather treatment plant for sludge handling. A plot of this information is included in Figure 6. It is apparent that as the treatment plant tends to the higher design capacity, less CSO sludge can be adequately handled (disregarding the negative impact of constant maximum loading conditions).

It is therefore apparent that the problems associated with bleed/pump-back to the dry-weather treatment plant are complex. If the initial transport problems can be eliminated or overcome, the effect of the sludges on the operation and efficiency of the dry-weather treatment plant must be carefully evaluated. The built-in safety factors for design can provide a certain amount of additional capacity, however, operating a peak flow due to bleed/pump-back of CSO sludges at all times is difficult and will adversely affect effluent quality.

EFFECT OF BLEED/PUMP-BACK OF DILUTE RESIDUALS FROM THE ON-SITE DEWATERING OF CSO TREATMENT SLUDGES ON THE DRY-WEATHER TREATMENT PLANT

Previous discussion has indicated overwhelmingly that bleed/pump-back of raw CSO treatment sludges is not practicable in most situations. Another alternative is to separately dewater (on-site) the raw CSO treatment sludges, ultimately dispose of the dewatered sludge and bleed/pump-back the dilute effluents from the dewatering steps to the dry-weather plant. The purpose of this discussion is to evaluate the effect of pumping back the dilute effluents from the CSO sludge dewatering processes to the dry-weather treatment plant.



lb/day/ft^2 x 4.88 = kg/day/m^2

Figure 6. Limiting percent of CSO area based on available capacity.

The only pertinent information uncovered in the literature (12) was based upon bench scale dewatering studies performed on raw CSO treatment sludges obtained from various CSO treatment sites throughout the country. The conclusions drawn from the study indicated that centrifugation alone or in combination with thickening and thickening followed by vacuum filtration were found to be the optimum sludge dewatering processes based on such criteria as performance, costs and space requirements.

Based upon our hypothetical dry-weather plant handling a design flow of 17.1×10^6 cu m/day (4,500 MGD) sewage and design solids load of 3.4×10^6 kg/day (7.6×10^6 lb/day), shown in Table 28 are the combined flows and solids anticipated from the bleed/pump-back of the dilute effluent arising from the dewatering of the CSO treatment sludges.

Assuming the range multiple of design flow and solids that a dry weather plant can handle is 1.5 to 3.0, examination of Table 28 shows that a hydraulic or solids overload would not be expected when the dilute effluents from dewatering CSO sludges are pumped back over a 24 hour period.

BOD, heavy metal, PCB and pesticide data on the dilute effluents from dewatering CSO sludges were not discovered in the literature, and therefore, no comment is made at this time regarding organic overload and toxicity to treatment due to heavy metals, PCB and pesticides caused by the bleed/pump-back of dilute effluents from dewatering CSO sludge to the dry-weather plant.

EFFECT OF CSO TREATMENT RESIDUALS BLEED/PUMP-BACK ON THE OPERATION AND PERFORMANCE OF THE DRY WEATHER SLUDGE HANDLING FACILITIES

Previous discussion has dealt with the effect of pumping back CSO residuals on the operation and performance of the dry-weather treatment plant. One of the by-products of the dry-weather treatment plant is the residual sludges arising from treatment which have to be handled and disposed of. The discussion which follows is concerned with the effect of pumping back CSO treatment residuals on the operation and performance of the dry weather sludge handling facilities.

Previous discussion regarding the bleed/pump-back of CSO treatment sludges to the treatment portion of the dry weather plant has shown that bleed/pump-back over a 24 hour period results in a gross solids overload on the treatment plant. Moreover, depending upon the existing dry weather operating organic loading on the secondary treatment plant, bleed/pump-back of the CSO treatment sludges may not be permissible or would have to be extended over periods of one to two weeks or more, which does not appear practical from the standpoint of having the capability of handling the sludge residuals from successive combined sewer overflows.

However, assuming the dry weather treatment plant could handle the pumped back CSO treatment sludges, or assuming for the moment that the CSO treatment sludges are bled/pumped-back directly to the dry-weather sludge handling facilities, what would be the effect on those sludge handling facilities?

TABLE 28. EFFECT OF BLEED/PUMP-BACK OF DILUTE EFFLUENTS FROM DEWATERING OF CSO SLUDGES ON DRY WEATHER TREATMENT PLANT HYDRAULIC AND SOLIDS LOAD

CSO Treatment Process	Raw CSO Sludge volumes: million cu m/day	Raw CSO Sludge volumes: MGD	Dewatering Method Used	Dilute Effluents Bleed/Pump-Back: Flow million cu m/day	Dilute Effluents Bleed/Pump-Back: Flow MGD	Dilute Effluents Bleed/Pump-Back: Solids mg/l	Dilute Effluents Bleed/Pump-Back: Solids kg/dayx10^{-6}	Dilute Effluents Bleed/Pump-Back: Solids lb/dayx10^{-6}	Bleed/Pump-Back + DWF: Flow million cu m/day	Bleed/Pump-Back + DWF: Flow MGD	Bleed/Pump-Back + DWF: Solids kg/dayx10^{-6}	Bleed/Pump-Back + DWF: Solids lb/dayx10^{-6}
Storage-Sedimentation	0.83	220	C	0.76	200	347	0.26	0.59	17.90	4730	3.79	8.14
Dissolved-Air Flotation	0.57	150	C	0.49	130	34	0.04	0.09	17.64	4660	3.47	7.65
Screening/DAF	4.50	1190	T-C	4.39	1160	1321	5.80	12.78	21.57	5690	9.23	20.34
Contact Stabilization	3.26	860	T-F	3.07	810	331	1.02	2.24	20.21	5340	4.45	9.80
Trickling Filter	0.64	170	T-C	0.64	170	170	0.11	0.24	17.79	4700	3.54	7.80

NOTE C = centrifugation alone

T-C = combination of thickening followed by centrifugation of the thickened sludge

T-F = combination of thickening followed by vacuum filtration of the thickened sludge

Shown in Table 8 are typical sludge volumes produced in a dry-weather plant. Primary sedimentation [2,440 cu m(gal.) sludge (5% solids) per million cu m (gal.) sewage treated] and waste activated [18,700 cu m (gal.) sludge (1% solids) per million cu m (gal.) sewage treated] sludges are pertinent to this discussion.

Sludge handling facilities are usually based upon the estimated sludge produced at average design flow (17). For our hypothetical dry-weather plant treating an average daily flow of 17.1×10^6 cu m/day (4,500 MGD) a primary sludge volume of 42,000 cu m/day (11.1 MGD) and a waste activated sludge volume of 320,000 cu m/day (84.7 MGD) may be expected to be handled by the dry-weather sludge handling facilities.

1. Hydraulic Loading Considerations

The daily design volume (primary plus activated) of sludge to be handled by the dry-weather sludge handling facilities is 363,000 cu m/day (96 MGD). Shown in Table 16 are the daily CSO treatment sludge volumes expected if the entire CSO were treated by each of the various CSO treatment methods investigated. Table 17 shows that the daily volume of CSO treatment sludges from each of the CSO treatment methods investigated is of a higher order of magnitude than the design daily dry-weather sludge anticipated, varying from 5.8×10^5 cu m/day (150 MGD) to 5.6×10^6 cu m/day (1480 MGD). The above information indicates that the addition of CSO treatment sludges to the dry-weather sludge handling facilities would result in drastically reducing the detention time of the various process elements in the sludge handling facilities.

Since detention time is one of the important factors in the performance of sludge handling processes (thickening, digestion, vacuum filtration, centrifugation, sand bed drying, etc.), it may be concluded that the CSO treatment sludge volume would hydraulically overload the dry-weather facilities, thereby, appreciably adversely affecting their performance. Additionally, the hydraulic overload may be expected to result in deteriorated by-products (such as thickener effluents, digester supernatants, filtrates, centrates, etc.) which are normally returned to the head end of the treatment plant and will result in overloading the treatment plant with fine solids, organics, nutrients, etc., thereby detrimentally affecting treatment plant performance.

2. Solids Loading Considerations

For our hypothetical dry-weather plant, the design dry weather solids to be handled (primary plus activated) are 5.3×10^6 kg/day (11.69×10^6 lb/day). Presented in Table 17 are the daily dry weight of CSO treatment sludge solids expected if the entire CSO were treated by each of the various CSO treatment methods investigated. Table 17 shows that the daily dry weight of CSO treatment sludge solids from each of the CSO treatment methods investigated is several times greater than that of the design daily dry weather solids anticipated, varying from 14.5×10^6 kg/day (31.9×10^6 lb/day) to 39.2×10^6 kg/day (86.4×10^6 lb/day).

The above information indicates that the addition of CSO treatment sludges to the dry-weather sludge handling facilities will drastically overload the various process elements comprising the sludge handling facilities from a solids standpoint. For example, those process elements whose equipment capacities are based on solids loading (see Tables 9—13) (such as thickening, filtration, lagooning, sand drying beds, centrifugation, etc.) would require 3 to 8 times additional capacity to handle the excess load. Digestion processes are more affected by organic and inert solids and the effect of CSO treatment sludges on digestion will be covered separately below.

3. Organic and Inert Solids Considerations

The organic content (as measured by volatile solids) of municipal sludges (primary sludge and waste activated sludge) is 65% on a dry solids basis (30). For our hypothetical dry-weather plant, the design dry weather total solids to be handled (primary plus waste activated) has been previously established at 5.3×10^6 kg/day (11.7×10^6 lb/day). The corresponding volatile solids content is 3.5×10^6 kg/day (7.6×10^6 lb/day). Presented in Table 29 are the daily dry weight of CSO treatment sludge volatile solids expected if the entire CSO were treated by each of the various CSO treatment methods investigated. From Table 29 it may be seen that the volatile solids content of the CSO sludges was significantly to appreciably lower than that for dry-weather municipal sludges. For the CSO treatment methods shown in Table 29, the higher volatile solids contents are observed for the sludges derived from the biological treatment methods. This was expected because the biological treatment methods were preceded by treatment steps which removed the major portion of the grit and inert solids present in the raw CSO. The physical and physical-chemical treatment methods shown in Table 29 treated raw CSO with little or no preliminary treatment for inert solids removal.

Examination of Table 29 and comparison with the hypothetical dry-weather municipal volatile solids loading, shows that the daily volatile solids rate from the CSO treatment methods varied from about 1.5 to 5.5 times the design dry-weather rate of 3.5×10^6 kg/day (7.6×10^6 lb/day) previously determined. It is apparent from this comparison that additional digestion facilities (aerobic and anaerobic) will be required to handle the CSO sludges by these treatment methods. These additional digestion facilities (either on-site or parallel to the DWF facilities) for handling the CSO sludges should be preceded by a grit removal step to reduce the possibility of grit and other inert solids from settling in the digesters and occupying valuable space.

4. Toxicity to Treatment

Pertinent to this discussion is the determination of any toxic effect of heavy metals in the CSO sludges to treatment in the dry-weather sludge handling facilities. The toxic effect, if any, would manifest itself in the biological treatment portions of the sludge handling systems, such as in the aerobic or anaerobic sludge digestion processes.

TABLE 29. VOLATILE SOLIDS CONTENT OF SLUDGES FROM VARIOUS CSO TREATMENT PROCESSES

CSO Treatment Process	Sludge Characteristics						
	Total Solids		Percent Volatile Solids	Volatile Solids		Inert Solids	
	$kg/day \times 10^{-6}$	$lb/day \times 10^{-6}$		$kg/day \times 10^{-6}$	$lb/day \times 10^{-6}$	$kg/day \times 10^{-6}$	$lb/day \times 10^{-6}$
Storage-Sedimentation	14.5	31.9	46.9	6.8	15.0	7.7	16.9
Dissolved-Air Flotation	15.6	34.4	30.9	4.8	10.6	10.8	23.8
Screening/DAF	37.9	83.4	34.2	12.9	28.5	24.9	54.9
Microscreening	39.2	86.4	29.1	11.4	25.1	27.8	61.3
Contact Stabilization	32.6	71.7	58.7	19.1	42.1	13.4	29.6
Trickling Filter	20.6	45.4	60.8	12.5	27.6	8.1	17.8

Previous discussion has indicated that it is impractical to direct the CSO treatment sludges to the dry-weather sludge handling facilities because this would cause a gross hydraulic, organic and solids overload of those facilities. However, for purposes of this discussion, for those isolated cases where the dry-weather sludge handling facilities could handle the CSO sludges, what would be the effect with regard to toxicity of digestion sludge treatment?

Shown in Table 22 are the effects of various heavy metal concentrations on aerobic and anaerobic biological treatment processes. The data in Table 22 indicate, for example, that copper concentrations greater than 5 mg/l and zinc concentrations greater than 10 mg/l will detrimentally affect anaerobic sludge digestion. Another source (32) indicates that soluble heavy metal concentrations greater than 1 mg/l are toxic to anaerobic digestion. Still another source (31) indicated that raw sludge copper concentrations of 14.3, 27.7 and 60.6 mg/l for three sewage treatment plants in Ohio did not adversely affect anaerobic sludge digestion or gas production. The information presented above appears to be in conflict. It is indicated that the concentration at which a substance starts to exert a toxic effect is difficult to define because it can be modified by antagonism, synergism and acclimation. Moreover, in the case of intermittently treating CSO treatment sludges in dry weather sludge handling facilities, the digesters act as equalization basins to dilute any heavy metal concentration present in the CSO treatment sludges and thereby ameliorate any potential heavy metal toxic effect.

Presented in Table 23 are the heavy metal concentrations found in the sludges from various CSO treatment processes. It was observed that the heavy metal concentrations in the CSO treatment sludges were significant and in some cases, such as for zinc and copper, were generally excessive (based on the allowable values in Table 22). Moreover, the data showed that the heavy metal concentrations of the CSO sludges from biotreatment processes (contact stabilization and trickling filteration) were appreciably higher than those for the sludges from the physical and physical-chemical CSO treatment processes.

That CSO treatment sludges may be handled intermittently in dry-weather digesters (where applicable and all other things being equal) in spite of high heavy metal concentrations is exemplified by the Kenosha, Wisconsin sewage treatment plant which has a 75,700 cu m/day (20 MGD) dry-weather plant and a 75,700 cu m/day (20 MGD) wet weather contact stabilization plant. The relatively high heavy metal concentrations in the Kenosha CSO contact stabilization waste sludge are shown in Table 23 (zinc, 71.5 mg/l; copper 14.5 mg/l). The intermittent handling of this wet weather sludge by the Kenosha anaerobic digesters has been satisfactory with no apparent adverse effect on digestion or gas production.

Handling of CSO treatment sludges in parallel digester facilities at the dry-weather plant is another story because essentially no dilution or equalization is obtained with dry-weather sludge. It is questionable whether digestion should be used in the CSO sludge handling scheme when

CSO treatment sludges are to be treated on-site or in parallel digester facilities at the dry-weather plant.

In any event, if toxicity is suspected for a given application, potential solutions to toxicity problems should be evaluated in laboratory or pilot digesters.

Alternatively, a promising method for the rapid stabilization of difficult-to-handle sludges, such as CSO treatment sludges, is lime stabilization, and it is recommended that further investigation of this method be conducted.

5. Treatment Efficiency

It is readily evident from previous discussion that directing the CSO treatment sludges to the dry-weather sludge handling facilities will grossly overload those facilities from a hydraulic, organic and inert solids standpoint. These gross overloads will detrimentally affect the dewatering and stabilization performance and treatment efficiency of the dry-weather sludge handling facilities. The downgrading in treatment efficiency would be manifested in poorly stabilized sludge for disposal and grossly deteriorated thickener effluents, filtrates, supernatants, etc. for recirculation back to the dry-weather plant.

As previously recommended, alternative on-site treatment methods, such as lime stabilization, should be investigated for handling CSO treatment sludges.

EFFECT OF BLEED/PUMP-BACK OF THE DILUTE RESIDUALS FROM THE ON-SITE DEWATERING OF CSO TREATMENT SLUDGES ON THE DRY-WEATHER SLUDGE HANDLING FACILITIES

From previous discussion, it appeared that from a hydraulic and solids aspect the dry-weather treatment plant would be able to handle the bleed/pump-back of dilute residuals from the on-site dewatering of CSO treatment sludges. However, data was not available to evaluate the effect of dilute effluents bleed/pump-back on organic overload or toxicity to treatment in the dry-weather plant. This section allows evaluation of the separate effect of pump back of the dilute CSO sludge dewatering residuals on the dry-weather treatment plant sludge handling facilities.

Shown in Table 30 are the flows and characteristics of the dilute effluents from the dewatering of the CSO sludges pumped back to the hypothetical dry-weather plant. It may be noted in Table 28 that only solids data was available from the dilute effluents pumped back. It may also be seen from Table 28 that the strength (solids) of the dilute effluents varied widely with the CSO treatment process from which they were derived. Some of the dilute effluents were stronger than domestic sewage and some were weaker. The suspended solids content of sewage has previously been assumed at 200 mg/l (9). In order to estimate the quantity of sludge produced from the treatment of the dilute effluents bled/pumped-back, the dilute effluent flows shown in

TABLE 30. ESTIMATES OF DRY WEATHER PLANT SLUDGE VOLUMES PRODUCED FROM THE TREATMENT OF DILUTE EFFLUENTS PUMPED BACK AFTER DEWATERING CSO TREATMENT SLUDGES

CSO Treatment Process	Dilute Effluents Pumped Back			Equivalent Sewage			Sludge Flow Produced					
							Primary		Activated		Total	
	cu m/day	MGD	Solids mg/l	cu m/day	MGD	Solids mg/l	cu m/day	MGD	cu m/day	MGD	cu m/day	MGD
Storage-Sedimentation	757,000	200	347	1,325,000	350	200	3,217	0.85	24,640	6.51	27,858	7.36
Dissolved-Air Flotation	492,050	130	84	227,000	60	200	568	0.15	4,353	1.15	4,920	1.30
Screening/DAF	4,390,000	1160	1,321	28,993,000	7660	200	70,780	18.7	542,012	143.2	612,792	161.9
Contact Stabilization	3,066,000	810	331	6,245,000	1650	200	15,254	4.03	116,956	30.9	132,036	34.9
Trickling Filter	643,000	170	170	530,000	140	200	1,287	0.34	9,841	2.60	11,128	2.94

Table 28 were converted to equivalent domestic sewage by adjusting their suspended solids content to 200 mg/l. Then the sludges produced from treating the dilute effluents pumped back are estimated by assuming a primary sludge production of 2240 cu m (gal.) (5% solids) per million cu m (MG) of adjusted flow and 18,700 cu m (gal.) (1% solids) of waste activated per million cu m (MG) of adjusted flow. These calculations are summarized in Table 30.

1. Hydraulic Considerations

It may be seen from Table 30 that the estimated sludge volumes produced varied widely with the CSO treatment sludges dewatered, and this variation is attributable to the quality of the dilute effluents bled/pumped-back. That is, the poorer the dilute effluent quality, the greater the sludge volume produced by the dry-weather plant, which is to be expected. For example, the data in Table 30 show that the quality of the dilute effluent from screening-flotation is of appreciably poorer quality than those of the other dilute effluents investigated, and the sludge volumes produced as a result of treating the dilute effluents from screening-flotation are correspondingly appreciably greater than those from any of the other CSO treatment methods.

It was previously established that the daily design volume of sludge (primary plus activated) to be handled by the hypothetical dry-weather sludge handling facilities is 3.6×10^5 cu m/day (96 MGD). Comparing this value with the additional sludge volumes expected and shown in Table 30 indicates that three of the five sludge volumes shown (from storage - sedimentation, dissolved air flotation and trickling filtration) can be intermittently handled by the dry-weather sludge handling facilities, assuming that the dry-weather sludge handling facilities are below design conditions (which is a reasonable assumption).

On the other hand, it appears that two of the five sludge volumes in Table 30 (screening/DAF and contact stabilization) would hydraulically overload the dry-weather sludge handling facilities. Closer examination of Table 30 shows that the two sludge volumes in question were derived from dilute effluents comparatively higher in quantity and poorer in quality than the other dilute effluents. This lends emphasis to the importance of performing the CSO treatment methods and the CSO treatment sludge dewatering method as efficiently as possible so as to permit the bleed/pump-back of dilute effluents to the dry-weather treatment plant. For example, further investigation (12) into the dewatering tests performed on the sludges from screening/DAF of CSO yielding the dilute effluent qualities shown in Tables 21 and 30 indicate that the thickening-filtration dewatering was accomplished without the aid of chemicals. The use of chemical conditioning would probably improve the dilute effluent quality permitting bleed/pump-back to the dry-weather plant with an appreciable reduction in the amount of sludge produced for further treatment by the dry-weather sludge handling facilities.

2. Solids Loading Considerations

For our hypothetical dry-weather plant, the design dry-weather solids to be handled (primary plus activated) has been established at 5.3×10^6 kg/day (11.7×10^6 lb/day). The additional sludge solids produced by pumping back the dilute dewatering effluents (whose estimated sludge volumes are shown in Table 30) are estimated by assuming a primary sludge concentration of 5% and a waste activated sludge concentration of 1%. A summary of the additional sludge solids expected is shown in Table 31.

The conclusions drawn from the solids information contained in Table 31 are similar to those derived from Table 30 with regard to the hydraulic considerations evaluated, namely,

a. Comparison of the sludge handling facility design solids loading of 5.3×10^6 kg/day (11.7×10^6 lb/day) with the additional solids loadings shown in Table 29 indicates that three of the five solids loadings shown in Table 30 (from storage-sedimentation, dissolved-air flotation and trickling filtration) can be intermittently handled by the dry-weather sludge handling faicilities, assuming that the dry-weather sludge handling facilities are below design conditions (which is a reasonable assumption).

b. On the other hand, it appears that two of the five solids loadings in Table 30 (screening/DAF and contact stabilization) would create a solids overload problem for the dry-weather sludge handling facilities. However, as indicated previously, it is felt that this problem may be minimized by more efficient CSO treatment and CSO treatment sludge dewatering performance, thereby permitting the satisfactory bleed/pump-back of the dilute effluents to the dry-weather plant.

BOD, heavy metals, PCB and pesticide data on the dilute effluents from dewatering CSO sludges were not discovered in the literature, and therefore, no comment is made at this time regarding organic overload, toxicity to treatment, and sludge handling efficiency due to these pollutants.

In summary, it may be concluded that bleed/pump-back of CSO treatment sludges to the dry-weather plant does not appear to be a viable or practical solution on a generalized basis. If 100% of the CSO volume was treated and generated sludge, it would result in gross overloading of the dry-weather treatment plant and the dry-weather sludge handling facilities. The most limiting aspect of bleed/pump-back of sludge through the treatment plant and sludge handling facilities is the solids loading (to the final clarifiers and the digesters). On the other hand, bleed/pump-back of the dilute residuals from on-site dewatering of CSO treatment sludges to the dry-weather plant appears to be practical and warrants further considerations where applicable. However, it must be stressed that actual evaluation of the feasibility of bleed/pump-back of CSO sludges must be completely evaluated for each individual site. The potential problems associated with transport of a gritty sludge, solids overload to the treatment and sludge handling processes and lower

TABLE 31. ESTIMATED SOLIDS TO THE DRY WEATHER SLUDGE HANDLING FACILITIES FROM THE TREATMENT OF DILUTE EFFLUENTS OBTAINED FROM CSO SLUDGE DEWATERING

CSO Treatment Process	Primary Sludge		Activated Sludge		Total	
	$kg/day \times 10^{-6}$	$lb/day \times 10^{-6}$	$kg/day \times 10^{-6}$	$lb/day \times 10^{-6}$	$kg/day \times 10^{-6}$	$lb/day \times 10^{-6}$
Storage-Sedimentation	0.16	0.35	0.25	0.54	0.40	0.89
Dissolved-Air Flotation	0.03	0.06	0.05	0.10	0.07	0.16
Screening/DAF	3.54	7.79	5.42	11.94	8.96	19.73
Contact Stabilization	0.76	1.68	1.17	2.57	1.93	4.25
Trickling Filter	0.06	0.14	0.10	0.22	0.16	0.36

NOTE: Sludge volumes used for the calculations were obtained from Table 29.

treatment plant efficiency must be evaluated at each site and cost-effectiveness of bleed/pump-back determined.

SECTION VI

EFFECT OF HANDLING CSO TREATMENT RESIDUALS BY SEPARATE SLUDGE HANDLING FACILITIES

INTRODUCTION

The most feasible method for handling specific CSO treatment residuals must be evaluated on an individual basis. As indicated in the previous section, bleed/pump-back is not a viable solution in most situations due to problems of transport in pipelines and potential solids overload in the various dry-weather treatment processes. Once evaluation indicates that bleed/pump-back is not an acceptable alternative, then separate sludge handling facilities must be provided. The processes must be capable of handling the specific characteristics associated with CSO sludges. They also must be sufficiently flexible for anticipated intermittent operation. Once applicable processes for sludge handling are identified, treatment trains can be established to integrate all phases of sludge handling. It must be emphasized at this point that the systems proposed in this section are generally suited for CSO sludges, however design of a specific system must be considered on an individual basis where much different schemes may be appropriate. The last step in evaluation of separate sludge handling facilities is location. There are essentially three systems which can be considered: 1) transportation to parallel facilities at the dry-weather plant, 2) transportation to a centrally located CSO sludge handling site and 3) satellite sludge treatment. The advantages and disadvantages of each technique are presented.

This section has been divided to consider several aspects of sludge treatment for CSO residuals individually. The limitations imposed by the nature of CSO sludges are presented first. Then a brief discussion of various sludge handling processes is included, followed by development and technical evaluation of viable sludge handling alternatives. The final portion of the section discusses alternative locations available for treating the sludge.

SPECIAL HANDLING REQUIREMENTS FOR CSO TREATMENT RESIDUALS

The characteristics of CSO treatment residuals directly affect the number of processes which can be used for handling these sludges. Specific attention must be given to the high grit content and low volatile solids concentration of these materials. In addition, the wide variation in frequency and volume of each occurrence requires that the sludge handling process be flexible enough to handle intermittent operation.

The information indicating the effects of high grit and low volatile solids content has been presented previously throughout sections IV and V. The following is a summary of this information for convenience:

a. That substantial amounts of solids are transported to the dry weather plants under wet weather conditions is substantiated by significant data available from the literature (17). For example, presented in Table 18 were data showing the quantities of grit collected during dry and wet weather periods for various United States installations. The data in Table 18 showed that the grit volume ratio of wet to dry weather was appreciable, with the highest ratio at 1800 times the average dry weather grit production.

b. The literature (9) also indicates that often the stormwater solids contribute a large increase in fine solids (silt) which is too fine to be removed in the grit chambers and results in overloading the primary sedimentation basin to the extent that chain and flight collectors are sometimes buried and unable to function.

c. It was further shown that the volatile solids contents of the sludges from the various CSO treatment methods were significantly to appreciably lower than that for dry-weather municipal sludges. The higher volatile solids contents were observed for the sludges derived from the CSO biological treatment methods. This was expected because the biological treatment methods used were preceded by treatment steps which removed the major portion of the grit and inert solids present in the raw CSO, whereas the physical and physical-chemical treatment methods used treated raw CSO with little or no preliminary treatment for inert solids removal.

d. It was found that the net effect of the excess inert solids in the CSO sludges (when bled/pumped-back to the DWF plant) was to contribute to the solids overload on the dry weather treatment and sludge handling facilities. Moreover, it was indicated that alternative CSO sludge treatment, either on-site or in additional parallel facilities at the DWF plant, would require additional capacity to handle the excess inert solids load.

It can then be proposed that the high grit and low volatile solids content of the CSO treatment residuals will also have a direct bearing on the effectiveness of various sludge handling processes. The large amount of inert material will require compensation in the equipment designs which are based on solids loading such as thickening, filtration, lagooning, sand drying beds, centrifugation, etc. Also, grit and other inert solids would detrimentally affect digestion (aerobic or anaerobic) facilities because the possibility of settling of those solids in the digesters, thereby occupying valuable space. The heavy solids loading could also cause mechanical complications in some equipment.

The low volatile solids content will have the most effect on the processes which utilize the organic substrate. Of special concern are digestion processes, since the lower organic loadings will reduce the efficiencies of removal, and incineration, since many of the CSO residuals have significantly lower heat values (12).

The intermittent nature and wide variations in flows of CSO sludges could pose problems when many common sludge handling processes are considered. Most sludge systems are designed for operation on a continuous flow-through basis which is generally not possible when dealing with CSO sludges (unless extensive holding basins are provided). The volumes of CSO sludge generated will vary with the storm intensity and duration, time between storms, process efficiency, etc. Therefore, either additional holding (storage) capacity is needed or the unit processes must be designed to handle maximum anticipated flows and still effectively process lesser amounts. Several sludge handling processes, notably digestion, may be adversely affected by the intermittent operation. It is important to consider these factors when the sludge handling processes are evaluated.

From the foregoing discussion, several evaluation criteria can be established and they should be considered when choosing applicable sludge handling methods for CSO residuals. The following considerations are important:

1. Is the process design established by solids loading criteria?

   If so, the large volume of inert solids may adversely affect the system operation and additional capacity will be required.

2. Will the volume of inert solids affect the operation of the process?

   If so, then again additional capacity may be needed which may be detrimental to the process efficiency.

3. Is the process dependent on a specific amount of organic constituents for proper or efficient operation?

   If so, then the unusual ratio of volatile solids to inert material may cause severe problems in the overall design of the system.

4. Will intermittent use adversely affect the operation or efficiency of the process?

   If so, then the degree of lower efficiency must be established and the process evaluated from this criterion.

5. Will overdesign of the system (to handle maximum flow rates) adversely affect the process operation under lower loading rates?

   If so, then use of large storage basins preceding the sludge handling system or process are mandatory. If space for holding is not available, the given process may not be applicable.

Therefore the individual sludge handling processes must be reviewed with these criteria in mind when considering their use for CSO treatment residuals.

SLUDGE HANDLING PROCESSES

General Sludge Handling Systems

In general, sludge handling processes can be grouped according to the general phases shown in Figure 7. Various combinations of these processes can be utilized, to provide the overall sludge handling schematics. Basically the potential flow schematics are as follows:

1. (Conditioning)* → Thickening → Stabilization → (Dewatering) → Disposal
2. (Conditioning) → (Thickening) → Dewatering → Reduction → Disposal
3. (Conditioning) → Stabilization → Thickening → (Dewatering) → Disposal
4. (Conditioning) → Stabilization → Disposal

* parentheses indicate optional process

Individual processes can now be evaluated and the appropriate systems developed for CSO treatment residual handling.

Conditioning

Conditioning is used to pretreat the sludge to allow more effective thickening or dewatering. The processes used can include chemical addition of polymer, lime, ferric chloride or alum, among others, or heat treatment. Effective conditioning can increase the efficiency of the processes when applied properly. However, choice of proper chemicals for this type of conditioning is dependent upon individual sludge characteristics. If there are significant variations in sludge quality, as are common with CSO treatment residuals, then the needed chemical dosages will change.

If provision cannot be made to correct the dosages utilized in the field, which is difficult with intermittent CSO generation, then the effectiveness of chemical conditioning can be severely reduced. Heat treatment can also be utilized with temperatures from 149-260 ^{o}C (300-500 ^{o}F) and pressures of 10.2-27.2 atm. (150-400 psig)(22). The treatment breaks up cell masses and improves dewatering characteristics. However, the resulting supernatant is highly polluted with various organics and requires that additional capacity be available at wastewater treatment facilities. In addition, the process is extremely energy intensive which may cause future problems.

Thickening

Thickening removes the major portion of the liquid in sludge and is often the initial step in sludge dewatering. Thickening is applicable to the dewatering of CSO sludges, and in particular, gravity thickening equipment is usually employed for sludges derived from physical and physical-chemical CSO treatment methods, whereas flotation thickening is normally more amenable to thickening sludges emanating from biological treatment methods.

Centrifugal thickening may also be applicable to some CSO sludges, however prior grit removal is necessary to prevent excessive wear on the centrifuge

GENERAL TREATMENT PROCESS

Conditioning	Thickening	Stabilization	Dewatering	Reduction	Disposal
Chemical	Gravity	Anaerobic digestion	Vacuum filtration	Incineration	Sanitary landfill
Heat	Dissolved-air Flotation	Aerobic digestion	Centrifugation	Flash drying	Ocean
	Centrifuge	Chlorine oxidation	Drying beds	Wet air oxidation	Land application
		Lime treatment	Drying lagoons	Pyrolysis	Land reclamation
		Heat treatment	Filter press	Cyclonic furnace	
		Composting	Moving screen	Electric furnace	
			Capillary belt		
			** DCG/MRP		

GENERAL TREATMENT TRAINS

1. (Conditioning)* → Thickening → Stabilization → (Dewatering) → Disposal

2. (Conditioning) → (Thickening) → Dewatering → Reduction → Disposal

* Parentheses indicate optional process.

** Rotating Gravity Concentrators

Figure 7. Sludge handling systems.

mechanism.

Stabilization

In most cases, stabilization of the sludges is required before ultimate disposal in order to minimize organic solids mass, health hazards and nuisance conditions. In fact, where final disposal is on land [50% of U.S. installations (22)], such as by sanitary landfill, cropland application and land reclamation, it is essentail that sludges be stabilized prior to spreading on land.

Stabilization, therefore, minimizes nuisance conditions by decomposing organic solids to a more acceptable stable form and minimizes health hazards by reducing or eliminating pathogenic organisms. Stabilization processes and equipment available include anaerobic and aerobic digestion, heat treatment, composting and chemical treatment (chlorine oxidation and lime treatment). Some of these stabilization processes are established and some are experimental. Further discussion regarding them and their applicability for handling CSO sludges is included.

Anaerobic and Aerobic Digestion - Both anaerobic and aerobic digestion are established processes and because of the current energy shortage are increasing in popularity; the former because of the potential benefits of methane production and the latter because it can produce exothermic conditions. These processes are applicable for handling CSO sludges derived from biological treatment methods and the associated equipment required should be located at the dry weather treatment plant along with the CSO biological treatment equipment so as to be able to keep the "CSO digesters" viable with dry-weather sludge between storms. It may be evident that these processes are not applicable at remote on-site CSO physical and physical-chemical facilities where the means for keeping the processes viable between storms is not existent.

Heat Treatment - Heat treatment of sludges has seen rapid growth in recent years and includes the following: pasteurization, low pressure oxidation (Sterling Drug) and the Porteous heat treatment process. At this time, the heat treatment of sludges has many vigorous advocates and equally vigorous opponents. Usual complaints include failure of equipment, excessive cost and high supernatant BOD and color. Because of the impact of this process on cost and the unknown effect of high supernatant BOD on organically overloading the dry-weather plant, this process will not be further considered as a CSO sludge stabilization alternative.

Composting - Composting of sludge has not been widely applied in North America. Of the 18 composting plants constructed in the U.S. between 1951 and 1969, few are currently operated and many of these are operated intermittently. The primary problem has been the lack of a market for the stable product to offset the cost of the process and make it economical. Composting will not be further considered for handling CSO sludges.

Chemical Stabilization - Chemical stabilization processes include chlorine oxidation and lime stabilization. The Purifax process oxidizes sludge with heavy doses of chlorine (about 2000 mg/l) and produces a stable and sterile sludge which is low in pH (about 2). The treated sludge dewaters well on sandbeds and is amenable to vacuum filtration after conditioning. Chlorine cost only is about \$5.50/metric ton dry solids (\$5/ton). Other operating and capital costs would increase this figure. The primary concern with this process is that the drainings from the treated sludge contain high concentrations of chlorinated compounds which may be toxic. Because of this concern and the possibility of ultimate disposal on land, further consideration of this process for handling CSO sludges will not be made.

The lime stabilization process is also a chemical stabilization process designed to reduce many of the harmful properties of sludges. The process involves addition of slurried calcium hydroxide to a pH greater than 11-12 and continued mixing of the solution for thirty minutes. This time period allows the slower reacting lime to hydrolyze and provides contact for pathogen destruction. A schematic of the typical process is shown in Figure 8. Previous studies (32, 33) on the subject have indicated that this procedure effectively reduces the indicator organisms for bacterial pollution up to 99 percent and significantly reduces nuisance odors (34). In addition, the dewatering characteristics of the sludge are markedly improved. Investigators (34) concluded that lime stabilized sludge is as safe to handle as that produced from conventional anaerobic digesters. However, there can be problems with lime stabilized sludge if proper disposal methods are not utilized. The high pH of the sludge is not permanent and as the pH decreases during the degradation process, odor and bacteria problems may reoccur. Excess lime dosages and proper disposal can retard or eliminate the problem.

Lime stabilization seems to be quite adaptable to CSO sludge treatment for several reasons. First, the process is flexible. It can be used intermittently with sludges of a wide variety of characteristics. The process control is commonly performed utilizing pH measurements so that operator intervention is minimal. The anticipated total capital investment is lower due to simple operation and shorter detention times than other stabilization techniques. If necessary, a portable treatment unit could be developed for use. This type of system may be used to augment dry-weather sludge handling facilities when not required for CSO sludge treatment. However, the lime dosages required are high and this cost must be considered. Previous studies (35) have indicated that lime dosages range from 102-208 g $Ca(OH)_2$ per kg of dry solids and operating and maintenance costs are estimated to be \$9-\$19 per metric ton (\$8-17 per ton) of dry solids. In addition, direct land application of lime stabilized sludges requires hauling large volumes of liquid sludge which may not be practical in some situations. In these situations, further dewatering using centrifugation or vacuum filtration is a necessary subject for further study. However, it is anticipated that with lime stabilization, further chemical conditioning requirements would be minimal since the lime addition significantly improves sludge dewatering capabilities. Another advantage of using lime stabilization is the reduction of potential odor prior to further handling. This aspect may be important if storage for any length of time is required.

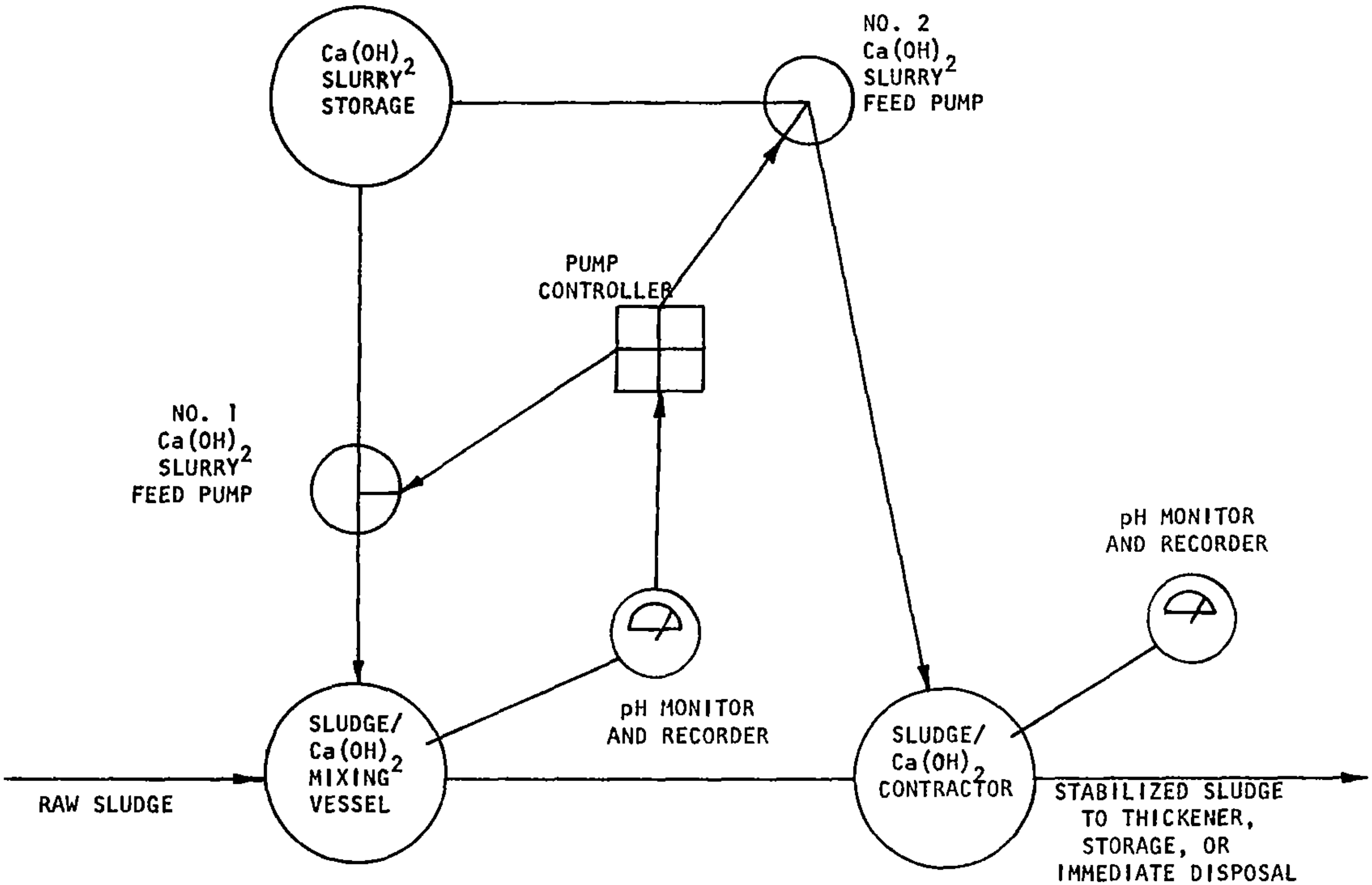


Figure 8. Lime stabilization process conceptual flowsheet (35).

Dewatering

Dewatering is used to remove additional moisture from the sludge (50-90%) to produce a damp cake (22, 36). The devices utilize several methods including natural evaporation and percolation plus mechanical techniques such as filtration, squeezing, vacuum withdrawal, centrifugation and compaction. Referral to Figure 7 indicates that there are many potential techniques available for dewatering. When considering these processes with respect to CSO sludges, some can be eliminated due to apparent operational problems. Space restrictions will eliminate use of both drying beds and drying lagoons, in most cases. Devices such as moving screens, capillary systems and rotating gravity concentrators (DCG/MRP) are new systems which have not been defined with respect to their applicability to the high grit content of CSO sludges. The techniques may be appropriate, however, further investigation would be needed prior to their use.

More conventional techniques include filter press, vacuum filtration and centrifugation. Use of a filter press is desirable if incineration or other combustion technique is being utilized, otherwise it may be too expensive for CSO sludge dewatering. In addition, conditioning requirements and operator control needs may be greater. It may be more desirable to use vacuum filtration, which will provide a workable cake (approximately 20% solids) for landfill or land application. Preliminary studies (12) have indicated that dewatering thickened sludges by vacuum filtration was amenable to CSO sludges derived from contact stabilization. Centrifugation may also be an appropriate dewatering technique if the grit concentration will not cause extensive mechanical wear. It was indicated that the use of thickening and centrifugation was applicable to the CSO sludges emanating from treatment by screening/DAF and trickling filtration. In some instances it was indicated that some CSO sludges may be most effectively dewatered by centrifugation alone (without pre-thickening). These included sludge from storage-sedimentation and from dissolved-air flotation alone (25) (see Table 28).

Reduction

In some cases reduction can be utilized as a stabilization and/or disposal process. Several types of processes can be utilized as outlined in Figure 7 and these can be further divided into new or established types. Pyrolysis and the use of cyclonic and electric furnaces are new techniques which have been used mainly on a small scale basis. The effects of the high grit and low volatile solids content is not readily predictable. However, it is speculated that the same features which affect the use of incineration for CSO sludge handling are applicable in these systems.

Incineration can be used to reduce the sludge to ash after thickening and dewatering. Incineration although costly, is receiving increased attention as an alternative with decreasing land availability and the possibility of more stringent standards for land disposal. However, wastewater treatment sludges have low heat values in comparison to common fuels to the extent that combustion is not self-sustaining unless extremely high solids contents are reached in feed cakes. Often an auxiliary fuel is required, if wastewater sludges are incinerated alone. The heat value for typical dry-weather activated sludge solids is 3563 cal/gm (6413 BTU/lb) as compared to gasoline with a value of 11,100 cal/gm (19,980 BTU/lb). Furthermore, it was observed (12) that the heat value of most other CSO treatment sludges was even less. The average heat value for CSO sludges from physical and physical-chemical treatment was 2032 cal/gm (3657 BTU/lb), whereas that for similar dry-weather sludges is estimated at 4581 cal/gm (8246 BTU/lb) (27). This difference in heat value is attributed to the higher inert and low volatile solids content of the CSO treatment sludges in question. On the other hand, the heat value of the biological sludges from CSO biological treatment was comparable to that for the dry-weather biological sludges, and that was expected because of the similar solids characteristics.

Because the heat value for CSO sludges is relatively low, the cake solids in the feed must be proportionately higher to avoid the use of auxilliary fuel. The energy and capital costs of obtaining a sufficient solids concentration in the feed cake may be prohibitive. If auxilliary fuel is utilized, in the light of the increase in energy cost and the current energy shortage, incineration would not be a viable method for handling CSO sludges at this time. However, interest in using incineration may be revived if the combined incineration of solid waste residues and wastewater sludges are incorporated with energy recovery as a prime feature.

Wet air oxidation is the final technique which may be used for sludge reduction. It is used at higher temperatures and pressures than heat treatment and theoretically oxidizes any materials capable of burning in water at temperatures of 121-371 ^{o}C (250-700 ^{o}F). Preliminary thickening and dewatering are not necessary, however it is necessary to provide disposal for the oxidized material. The main disadvantages associated with this technique are the high energy cost and the associated problems due to intermittent operation. High pressure and temperature operations should be run as continuously as possible to alleviate start-up problems and energy loss.

Disposal Techniques

Disposal techniques involve either the land or oceans. However, recent regulations have restricted ocean dumping, so that only land disposal remains. Three techniques are applicable; land reclamation, land application and landfill. Land reclamation is most restrictive since it requires that land needing to be reclaimed (such as abandoned strip mines) be located near the sludge generation site. This criterion will not generally be met with regard to CSO sludges. Land application does pose a viable solution for disposal and has been considered in depth in Section VIII. Further discussion is not included here.

Landfilling of sludges and other residual by-products of municipal and industrial waste treatment is a major ultimate disposal alternative. A sanitary landfill accepting sludge must be designed in accordance with EPA "Guidelines for Land Disposal of Solid Wastes" (37) even if sludges are disposed of separately or along with municipal solid wastes. These guidelines are a result of increasing concerns for public health and environmental quality (38). The guidelines state that prior to landfilling, (a) sludges must be stabilized (ie. digestion, lime, heat etc.) to prevent odor problems and reduce health hazards and (b) sludges must be dewatered to eliminate leachate migration.

A sanitary landfill must be managed so that wastes are systematically deposited and covered with soil to control environmental impacts within defined limits. Proper management consists of four basic operations (39): 1) wastes are added in a controlled manner in a prepared portion of the site; 2) the wastes are spread and compacted in thin layers; 3) the wastes are covered daily or more frequently, if necessary with a layer of soil; and 4) the cover material is compacted daily.

Proper site selection is an important step toward establishing an acceptable sanitary landfill operation. Some of the major factors which should be considered in site selection are (40): a) land requirements, b) waste haul distances, c) cover material, d) geology, and e) climate.

Important public health and nuisance aspects which must be considered in landfill operation are 1) vector control, 2) water pollution, 3) odors, and 4) gas production (40).

EPA guidelines require that a program must be developed and implemented to provide for adequate monitoring of landfills accepting sludges (38). This plan would include groundwater observation wells, and surface runoff collection basins to measure pollutant migration from leachates or surface water.

DEVELOPMENT OF VIABLE TREATMENT SCHEMATICS

General

The first step in the development of viable treatment schematics is to identify those processes which are applicable to possible use for CSO sludge handling. Once this has been accomplished, then various treatment trains can be identified and further evaluated from a space and preliminary economic standpoint.

Generally, the process elements comprising a CSO sludge handling system might include grit and low volatile solids removal, sludge dewatering, stabilization and ultimate disposal. The specific treatment train used will vary with the CSO treatment method employed and location and the ultimate disposal method used. For example, it has been shown that the grit and low volatile solids contents of CSO sludges are greater than those for dry-weather municipal sludges. Moreover, for the CSO treatment methods investigated, greater concentrations of grit and low volatile solids contents were associated with sludges from physical and physical-chemical treatment than from sludges derived from biological treatment. This was expected because the biological treatment methods (contact stabilization and trickling filtration) were preceded by treatment steps which removed the major portion of the grit and inert solids present in the raw CSO, whereas the physical and physical-chemical treatment methods (storage-sedimentation, DAF, screening/DAF and microscreening) treated raw CSO with little or no preliminary treatment for inert solids removal. Therefore, it would be expected that the sludges from physical and physical-chemical treatment might require provision for grit and low volatile solids removal whereas those sludges from biological treatment might not. Suitable equipment for grit removal includes: chain and flight grit removal devices, hydroclones, and the swirl concentrator (41). Hydroclones are commercially available for grit removal from sludges. The swirl degritter is a newly developed device (77) (78) (79).

Specific Processes for Use In CSO Sludge Handling

The previous discussion briefly identified various processes which could be used for handling CSO treatment residuals. Due to the discussion presented therein and evaluation of the question criteria outlined previously in this section, the following processes are considered to be potentially applicable to CSO sludge handling:

Conditioning:	Chemical treatment
Thickening:	Gravity thickening
Stabilization:	Lime stabilization Anaerobic digestion (in some cases)
Dewatering:	Vacuum filtration Centrifugation
Reduction:	None
Disposal:	Land application (LA) Landfill

Potential Treatment Schemes

As indicated, the individual treatment scheme chosen is determined by the specific characteristics of the CSO sludge to be treated. However, for generalization, the biological sludges can be grouped into one type and the physical or physical/chemical sludges into another. Another important consideration is the location of the sludge handling system, especially when biological treatment techniques are being considered. Usually, if biological systems are applicable, the treatment system and sludge handling facilities are located at or near the dry-weather treatment plant. When this is the case, a different flow schematic than that generally proposed may be desirable.

Combination of the processes chosen which may be applicable to CSO sludge handling yields the following ten alternatives:

1. Lime Stabilization → Gravity Thickening → Vacuum Filtration → Landfill
2. Lime Stabilization → Gravity Thickening → Vacuum Filtration → Land Application

3. Lime Stabilization → Gravity Thickening → Land Application
4. Lime Stabilization → Land Application
5. Anaerobic Digestion → Gravity Thickening → Vacuum Filtration → Landfill
6. Anaerobic Digestion → Gravity Thickening → Centrifugation → Landfill
7. Anaerobic Digestion → Gravity Thickening → Vacuum Filtration → Land Application
8. Anaerobic Digestion → Gravity Thickening → Centrifugation → Land Application
9. Anaerobic Digestion → Gravity Thickening → Land Application
10. Anaerobic Digestion → Land Application

It is observed that centrifugation was not included as a thickening method when lime stabilization was utilized. This is mainly due to the fact that the large doses of lime used for stabilization should allow vacuum filtration to proceed easily, with a minimum of additional chemicals. Also these schematics do not presently include provision for grit removal, so the potential wear on a centrifuge might be a problem. Therefore, centrifugal dewatering was not considered at this time. However, both vacuum filtration and centrifugation were considered if anaerobic digestion was utilized as the stabilization technique, since prior grit removal is generally included. Chemical conditioning is anticipated to be needed and the chemical type can be tailored to meet the optimum dosage for the given dewatering method.

Both landfill and land application have been considered as viable disposal techniques, although land application can accept much more dilute sludges, if transportation costs are not prohibitive.

Preliminary Evaluation of Schematics

Evaluation of the flow schematics given involves an initial comparison of lime stabilization and anaerobic digestion. Considering operational variables plus cost and space requirements, the advisability of using lime stabilization over digestion is indicated even when biological treatment of CSO is utilized. For example, lime stabilization is less complex in operation, less subject to upsets, can be more easily automated and is more adaptable to intermittent operation (digestion process would have to be kept viable between storms). Moreover, lime stabilization appears to require less space. A lime sludge contact time of about 30 minutes is needed for lime stabilization (42), whereas 10-15 days solids retention time is required for digestion (See Tables 22 and 23). From the standpoint of costs, it appears that the cost of digestion is appreciably greater than that for lime stabilization. For example, for a 37,850 cu m/day (10 MGD) sewage treatment plant which produces a total sludge flow of approximately 254 cu m/day (0.067 MGD), the capital cost of a lime stabilization process is estimated at $28,000, and this cost includes tankage, piping, chemical feed system and automatic control instrumentation. On the other hand, the construction cost for an anaerobic digestion system to handle the same quantity of sludge is estimated at $800,000 and this cost includes sludge heating, circulating and control equipment and control building (43). The operating costs for digestion are also appreciably greater than those for lime stabilization. For example, the total annual costs for anaerobic digestion (including amortization) are estimated at \$31 per metric ton dry solids (\$28/ton) whereas those for lime stabilization are about \$10 per metric ton dry solids (\$9/ton) (44). From the above discussion, it is evident that lime stabilization is a promising method for handling the unique CSO treatment sludges. It should be recognized that lime stabilization is not an established sludge handling method and demonstration of its application for treating CSO treatment sludges should be pursued to obtain basic design and operating criteria and further investigation is recommended.

Sludge dewatering by thickening, where economically feasible, should be performed after lime stabilization because it has been found that lime treatment enhances the sludge settling characteristics (44). Further dewatering may be achieved by vacuum filtration. Ultimate disposal of the sludge, depending on land availability and other factors, would be by landfill or land application. Therefore preliminary screening indicates that four treatment systems may be applicable for handling CSO residuals. All involve lime stabilization but the degree of intermediate treatment, prior to disposal cannot be estimated at this point. Individual transportation and storage costs must be considered to establish which of these general alternatives is most cost-effective.

IMPACT OF HANDLING CSO SLUDGES AT VARIOUS SITES IN THE CITY

General

When considering separate treatment of CSO sludges by any of the chosen handling schemes, it is necessary to establish the location at which the sludge will be treated. There are three potential locales: treatment at parallel facilities at the dry-weather treatment plant; treatment at a central location and treatment at remote satellite locations.

A natural basis for selection of the location for CSO sludge treatment is the CSO treatment method used for treatment of the raw CSO. The physical, physical-chemical, and biological processes used on storm flows each have limitations as to where they can be used (9). Biological treatment facilities should be located at sewage treatment plants to provide a continuous active biomass. Physical and physical-chemical treatment facilities lend themselves more easily to remote satellite locations. Inasmuch as the CSO sludges from biological treatment will be treated both "on-site" and "at parallel facilities at the DWF plant", the question arises as to which alternative to use for treatment of the CSO sludges from physical and physical-chemical treatment.

Treatment of CSO Residuals at Parallel Facilities at the Dry-Weather Plant

Handling these CSO sludges in additional parallel facilities at the dry-weather plant does not appear to be generally feasible because of the problems involved in transporting the sludges from the CSO treatment site to the dry weather treatment plant. Alternative means for transporting the sludges to the parallel facilities at the dry-weather plant include bleed/

pump-back to the combined sewers, transport by separate pipeline and hauling. It is apparent from previous discussion that sludge bleed/pump-back to existing combined sewers would not be feasible in most cases because it would require storage, the sludge would be admixed with the sewage contributing to an overload on the dry-weather plant and grit in the sludge may settle out quickly in the interceptor causing blockage and premature overflow via backwater effect.

Separate pipeline transportation of sludges, say from remote overflow treatment points, would not appear to be feasible since it would require separate pipelines from many treatment points to the dry-weather plant which would appear to be costly. Moreover, because the flows through these lines are intermittent, grit and other solids deposits can accumulate between storms increasing pluggage problems. It may be possible to partially alleviate these accumulations by flushing the lines, however, this procedure may cause hydraulic overload problems at the treatment plant due to large volumes of water needed. In addition, the characteristics of the wastewater is extremely different from typical influent, and may adversely affect plant operation. However, where the CSO treatment facilities are centrally located near the dry-weather plant, pipeline transportation of CSO treatment sludges to parallel sludge treatment facilities at the dry-weather plant may be a viable alternative in spite of potential problems.

Similarly, hauling of CSO treatment sludges to parallel treatment facilities at the dry-weather plant may be feasible in isolated instances, but would not appear to be generally feasible because of the cost involved and the logistics for a trucking operation from many remote overflow points.

Utilization of pipeline transportation and hauling for bringing CSO sludges to the dry-weather plant may be enhanced if the major portion of the grit and inorganic solids were removed on-site at the overflow treatment facility and if subsequently the sludges were treated by digestion (aerobic or anaerobic) in parallel facilities which were kept viable between storms with dry weather sludge. If transportation of CSO sludges by bleed/pump-back, pipeline or hauling to the parallel sludge handling facilities at the dry-weather plant is not feasible, as is indicated from previous discussion, then the other alternatives must be considered.

Treatment of CSO Residuals at Centrally Located Sludge Handling Facilities

This alternative involves transportation of the CSO treatment residuals to a central location for stabilization, storage and further dewatering. All of the disadvantages associated with transport of the sludge to parallel dry-weather facilities are applicable with the exception of bleed/pump-back, which may not be possible. There may be some additional difficulty associated with obtaining sufficient property for locating the treatment plant, since in most areas of the country the combined sewers are located in the center of the city. This may possibly be a prohibitive factor in utilizing the central location alternative. If property is scarce and if transportation using separate pipelines, or hauling is not feasible, as was indicated in the previous section, then on-site treatment of CSO sludge is the only remaining alternative. This choice is not without problems, such as the operation and maintenance of several solids handling plants at different remote locations in a city, but does have the advantage in that it eliminates the operational problems and cost associated with transporting the sludges from the remote CSO treatment sites to the dry weather plant.

Treatment of CSO Residuals at Satellite Treatment Sites

The remaining alternative to consider is therefore treatment of the CSO residuals at separate sites throughout a city. It is necessary to evaluate the effect of this handling with respect to performance, operation, maintenance and cost (9). The disadvantage of maintaining and operating several treatment systems is obvious with respect to both manpower and utilities costs. In addition, capital equipment costs are anticipated to be greater since the typical economics of scale can not be fully utilized. However, overall evaluation is necessary before this alternative can be implemented or disregarded.

The following discussion is pertinent to and limited to CSO treatment facilities at remote satellite locations. In this regard, and as previously noted, physical, physical-chemical and biological treatment processes used on storm flows each have limitations as to where they can be applied. Biological treatment systems should be located at sewage treatment plants which can supply a continuous active biomass. On the other hand, physical and physical-chemical treatment processes lend themselves more easily to remote locations at overflow points, and it is these locations which are the subject of this discussion.

The question has been raised that if on-site treatment of residual sludges is performed as recommended, what effects on operation, performance and maintenance would occur due to the logistics of operating and maintaining several sludge handling facilities at different locations, say 5 to 10 or perhaps 100, by one municipality? It is evident that sludge handling and disposal is an integral part of a CSO treatment system and the effectiveness with which sludge handling is carried out influences the efficiency of treatment, operation and maintenance, and overall costs. Moreover, the effective operation of a total CSO treatment system requires not only the physical operation of the components (overflow treatment and sludge handling) but also their operation in unison and on-call. Therefore, the aspects of operation and maintenance for CSO treatment and residual sludge handling should be equally emphasized. These aspects include operating controls and options, sustaining (dry-weather) maintenance, support facilities and supply, and safety.

Storm events occur at random intervals, and for this reason it is essential that multiple remote treatment sites be capable of automatic startup and shutdown. Furthermore, the instrument and equipment reliability requirements may be much more demanding than for dry-weather treatment facilities.

The lime stabilization process, for example, lends itself well to automation because two of the most important variables in the process are pH and contact time. Contact time may be adequately controlled by system design, and pH is relatively simple to control and automate.

It is indicated that a sustaining or preventative maintenance program is the one key to a successful combined sewer overflow pollution abatement and control system. The program begins with the careful planning and design of the combined sewer overflow treatment and solids handling facilities. For example, whenever several systems are needed, which is the primary thrust of this discussion, it is usually economical to use the same type device, equipment, and design to reduce operation and maintenance costs. Also, designing in increased automation permits minimization of cleanup and maintenance.

The performance of remote site facilities are greatly enhanced by strict adherence to a well-planned sustaining maintenance program. Generally, the sustaining maintenance required increases as the degree and complexity of treatment sophistication increases. Effective control and operation of such facilities are usually dependent upon varying degrees of instrumentation. For example, to ensure reliable startup and shutdown, all instrumentation must be checked and calibrated on a regular basis.

Satisfactory operation of combined sewer overflow abatement and treatment facilities depends, to a large extent, on adequate regular inspection and maintenance. The purpose of this is twofold: first, to locate and correct any operational problems or failures and second, to prevent or reduce the probability of such problems or failures.

Inspection should be as frequent as necessary to keep such facilities in good operating condition. Generally, this means inspections both on a weekly schedule and following each major storm. All equipment must be exercised regularly to check and insure readiness, and facility cleanup, lubrication and dewatering must be done following each storm.

Complete records should be kept of all inspection and maintenance. The time and date of each inspection should be recorded, together with a description of the condition of the equipment and the work performed. The number of man-hours spent on each piece of equipment should be noted. These data should be tabulated for each piece of equipment requiring excessive maintenance or that is out of service with unusual frequency. These records can provide the data needed to compare the cost and efficiency of different types of equipment for guidance in the design and purchase of new equipment or the remodeling of existing equipment. Such records also aid in the scheduling of preventive maintenance. Required maintenance common to most off-line facilities may include lubricating of equipment; inspecting and cleaning of chemical pumps, electrical and pneumatic sensing probes, flow measuring and recording devices, and automatic samplers; checking and calibrating instruments; checking emergency power generators and starting batteries; and inspecting all pumps, valves, and piping.

The importance of maintenance support in the operation of treatment facilities increases as the number and/or size of such facilities increases. In view of the wide variety of control and treatment processes, no attempt will be made to cover the specific requirements of each individual process; only the common general requirements will be listed. The four major requirements are (1) access to equipment, (2) adequate tools and equipment, (3) a specialized work area, and (4) spare parts stock.

Finally, storm flow management applications expose personnel to very real and very dangerous environmental conditions. The hazards are a function of the working environment, operating procedures and practice, and condition and design of facilities. The chemicals used or stored present another problem because of their toxicity, corrosiveness, etc. Plant features, such as railings, kickboards, safety treads, multiple access/egress points, ventilation, lighting, auxiliary power sources, and detection and observation points, must be fully incorporated into design and practice.

In summary, the logistics of operating and maintaining several solids handling plants at different locations throughout a city is formidable but not insurmountable.

SECTION VII

CONSIDERATIONS FOR LAND APPLICATION OF CSO WASTES

Land application of wastes, in general, entails the use of plants, the soil surface, and the soil matrix for removal of certain pollutional constituents. Land application systems can be considered as viable alternatives for waste treatment and disposal.

However, the consideration of land for the treatment and disposal of any type of waste is a very complex matter that encompasses a wide range of design possibilities which are available to suit specific site characteristics, treatment requirements and project objectives. To date, no generalized design procedure is in use or available which would assist in evaluating the major variables that influence the design of a land application system. Therefore, the information in this section is intended to summarize the present state-of-the-art technology and, from this knowledge, provide information and criteria for evaluating the feasibility of applying CSO constituents to the land. The storm generated discharge residuals that will be considered for study include:

1. Raw CSO
2. CSO sludges, liquid and dewatered

The following discussions are primarily based on the following EPA Technical Bulletins and Information Transfers: "Wastewater Treatment and Reuse by Land Application" (45); "Land Treatment of Municipal Wastewater Effluents" (46); "Evaluation of Land Application Systems" (47); "Costs of Wastewater Treatment by Land Application" (48); and "Municipal Sludge Management: Environmental Factors" (38).

LAND APPLICATION TECHNOLOGY

The inclusion of this technology section is to establish a general procedure, based on an understanding of the pollutant management capabilities of soils, for evaluating the feasibility of land application of CSO wastes under various conditions. This development will provide a rational screening method which should lead to 1) the identification of specific factors, 2) an indication of the public health and legal constraints in using land application, and 3) site locations that combine the required characteristics for safe pollutant management. Essentially, the information presented in this section includes state-of-the-art discussions of the following areas: land application methods, public health considerations, imposed government regulations, site selection and factors, and design considerations.

Land Application Methods

The three basic methods of land application are irrigation, infiltration - percolation, and overland flow. Each method, shown schematically in Figure 9, can produce renovated waters of different quality, can be adapted to different site conditions, and can satisfy different overall objectives. Tables 32 and 33 compare major design and operational characteristics employed for these application systems. Relevant characteristics, including factors involved in selection and design of land application systems, will be briefly reviewed in this text.

Irrigation - Irrigation is the most widely used method of land application in practice today. The controlling factors in implementing this type of land application system are site selection and design, methods of irrigation, loading constraints, management and cropping practices, and the expected treatment or removal of pollutional constituents.

Important factors involved in site selection are: type, drainability and depth of soil; the nature, variation of depth and type of underground formation; topography; and considerations of present and future land use trends. Climate is equally as important as the land in the design and operation of irrigation systems. However, climate is not a design variable since it is specific to regions under consideration.

Table 34 lists major factors and generalized criteria for site selection. Soil drainability is considered the primary factor because, coupled with the type of crop or vegetation selected, it directly affects the hydraulic loading rate. The ideal geological formation is a moderately permeable soil capable of infiltrating approximately 5 cm per day (2 in/day) or more on an intermittent basis. In general, soils ranging from clay loams to sandy loams are suitable for irrigation. Soil depth should be a minimum of 0.6 meters (2 ft) of homogenous material and preferably 1.5 to 1.8 m (5-6 ft) throughout the site. This depth is necessary to promote extensive root development of some plants, as well as for wastewater treatment.

The minimum depth to groundwater should be 1.5 m (5 ft) to ensure aerobic conditions. Control procedures, such as underdrains or wells, may be required if the groundwater is within 3 to 6 meters (10-20 ft) of the surface and site drainage is poor.

For crop irrigation, slopes should be limited to about 10 percent or less, depending upon the type of harvesting equipment to be used. Densely foliated hillsides, up to 30 percent in slope, have been spray irrigated successfully.

Spray, ridge and furrow, and flood are three of the most common methods of irrigating. Spray irrigation is accomplished using a variety of systems from portable to solid-set sprinklers. Ridge and furrow irrigation consists

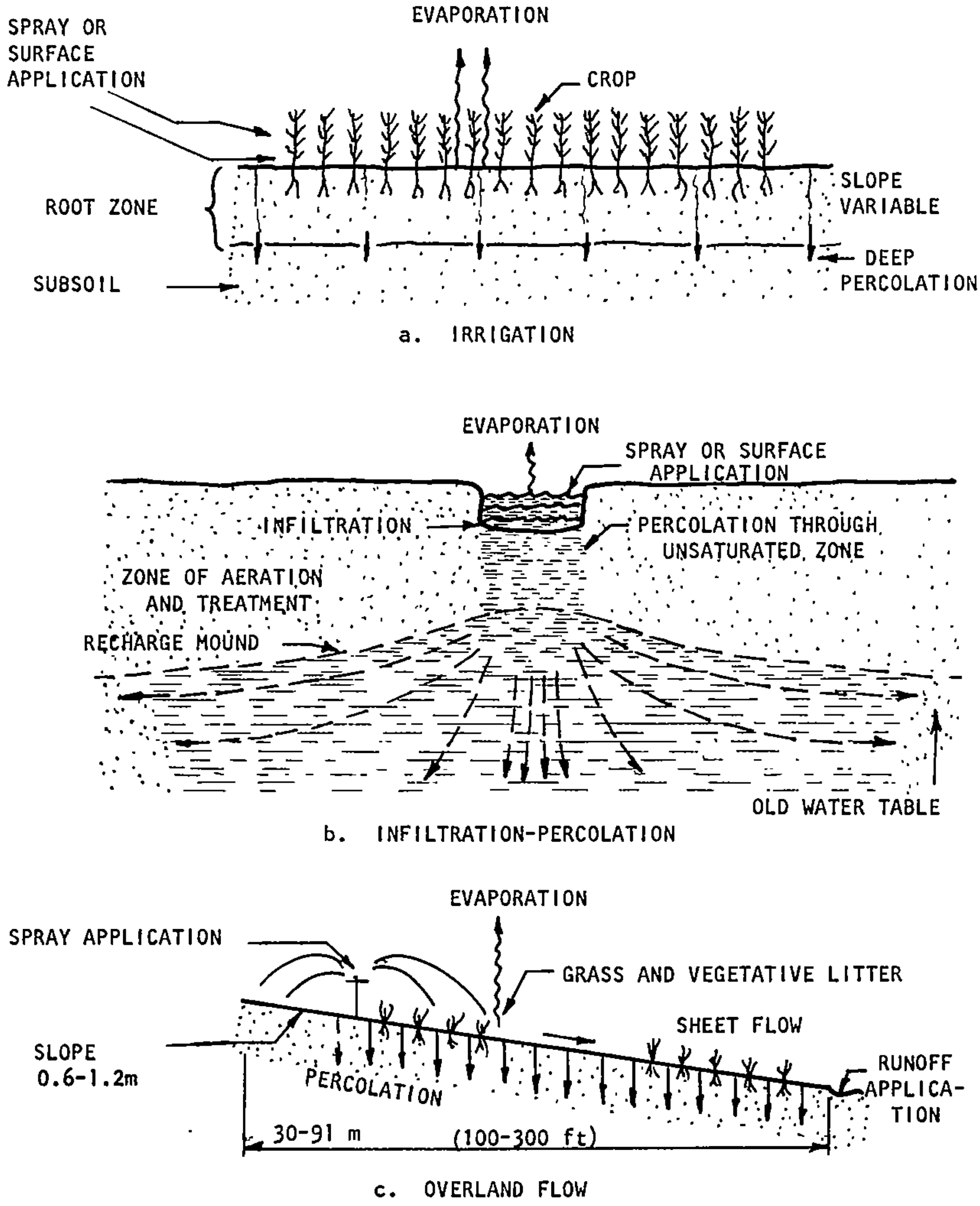


Figure 9. Methods of land application (47).

TABLE 32. COMPARATIVE CHARACTERISTICS OF IRRIGATION, INFILTRATION-PERCOLATION, AND OVERLAND FLOW SYSTEMS (48)

Factor	Irrigation: Low-rate	Irrigation: High-rate	Infiltration-percolation	Overland flow
Liquid loading rate, in./wk	0.5 to 1.5	1.5 to 4.0	4 to 120	2 to 9
Annual application, ft/yr	2 to 4	4 to 18	18 to 500	8 to 40
Land required for 1-mgd flowrate, acres[a]	280 to 560	62 to 280	2 to 62	28 to 140
Application techniques	Spray or surface		Usually surface	Usually spray
Vegetation required	Yes	Yes	No	Yes
Crop production	Excellent	Good/fair	Poor/none	Fair/poor
Soils	Moderately permeable soils with good productivity when irrigated		Rapidly permeable soils, such as sands, loamy sands, and sandy loams	Slowly permeable soils, such as clay loams and clays
Climatic constraints	Storage often needed		Reduce loadings in freezing weather	Storage often needed
Wastewater lost to:	Evaporation and percolation		Percolation	Surface runoff and evaporation with some percolation

(continued)

TABLE 32. (continued)

Factor	Irrigation: Low-rate	Irrigation: High-rate	Infiltration-percolation	Overland flow
Wastewater lost to:	Evaporation and percolation		Percolation	Surface runoff and evaporation with some percolation
Needed depth to groundwater	About 5 ft		About 15 ft	Undetermined
Probability of influencing groundwater quality	Moderate		Certain	Slight

[a] Dependent on crop uptake

Metric conversion: in. x 2.54 = cm
ft x 0.305 = m
acre x 0.405 = ha

TABLE 33. COMPARISON OF IRRIGATION, OVERLAND FLOW, AND INFILTRATION-PERCOLATION SYSTEMS (47)

Objective	Type of approach: Irrigation	Overland flow	Infiltration-percolation
Use as a treatment process with a recovery of renovated water[a]	0-70% recovery	50 to 80% recovery	Up to 97% recovery
Expected Treatment Performance:			
1. For BOD_5 and suspended solids removal	98+%	92+%	85-99%
2. For nitrogen removal	85+%[b]	70-90%	0-50%
3. For phosphorus removal	80-99%	40-80%	60-95%
Use to grow crops for sale	Excellent	Fair	Poor
Use as direct recycle to the land	Complete	Partial	Complete
Use to recharge groundwater	0-70%	0-10%	Up to 97%
Use in cold climates	Fair[c]	--[d]	Excellent

[a] Percentage of applied water recovered depends upon recovery technique and the climate.

[b] Dependent upon crop uptake.

[c] Conflicting data--woods irrigation acceptable, cropland irrigation marginal.

[d] Insufficient data.

TABLE 34. SITE SELECTION FACTORS AND CRITERIA FOR EFFLUENT IRRIGATION (45)

Factor	Criterion
Soil type	Loamy soils preferable but most soils from sands to clays are acceptable.
Soil drainability	Well drained soil is preferable; consult experienced agricultural advisors.
Soil depth	Uniformly 5 to 6 ft or more throughout sites is preferred.
Depth to groundwater	Minimum of 5 ft is preferred. Drainage to obtain this minimum may be required.
Groundwater control	May be necessary to ensure renovation if water table is less than 10 ft from surface.
Groundwater movement	Velocity and direction must be determined.
Slopes	Up to 15 percent are acceptable with or without terracing.
Underground formations	Should be mapped and analyzed with respect to interference with groundwater or percolating water movemeht.
Isolation	Moderate isolation from public preferable, degree dependent on wastewater characteristics, method of application, and crop.
Distance from source of wastewater	A matter of economics.

m = 0.305 x ft

of grooming relatively flat land into alternating ridges and furrows and applying water by gravity to these furrows. Flood irrigation is the inundation of land with several inches of wastewater.

The type of irrigation system to be used to maintain specified ground and surface water criteria depends on soil drainability, crop, topography, climate and economics. Preapplication treatment is provided for most irrigation systems, and a wide range of treatment requirements are encountered. The bacteriological quality of wastewater is usually limiting where food crops or landscape areas are to be irrigated, or where aerosol generation by sprinkling is of concern. In other cases, reductions in BOD and suspended solids may be necessary to prevent clogging of the distribution system, or to eliminate odor problems.

The important loading rates are hydraulic loading in terms of cm(inches) per week, and nitrogen loading in terms of kilograms per hectare per year (lbs/acre/yr). Organic loading rates are not considered important if an intermittent application schedule is followed. Hydraulic loadings should not exceed the infiltration capacity of the soil and may range from 1.3 to 10.7 cm per week (0.5-4.2 in./wk) depending on soil, crop, climate and wastewater characteristics. Typical hydraulic loadings are from 3.8 to 10.2 cm/wk (1.5-4.0 in./wk). Although irrigation rates have ranged up to 20.3 cm/wk (8 in./wk), a generalized division between irrigation and infiltration-percolation systems is 10.2 cm/wk (4 in./wk).

Nitrogen-loading rates have been considered because of nitrate occurrences in groundwaters and aquifers. To minimize such occurrences, application rates should be such that the total amount of plant available nitrogen added is no greater than twice the nitrogen requirement of the crop grown (38). In most cases, the permissible nitrogen loading rate will be the controlling factor.

Crop selection can be based on several factors: high water and nutrient uptake, salt or boron tolerance, market value, or management requirements. Popular crop choices are grasses with high year-round uptakes of water and nitrogen and low maintenance requirements. A drying period ranging from several hours each day to several weeks is required to maintain aerobic soil conditions. The length of time depends upon the crop, the wastewater characteristics, the length of the application period, and the texture and drainage characteristics of the soil. A ratio of drying time to wetting or application time of about 3 or 4 to 1 should be considered as a minimum.

Treatment of the wastewater often occurs after passage through the first 0.6 to 1.2 m (2-4 ft) of soil. Treatment efficiencies or removals are found to be on the order of 85 to 99 percent for BOD, suspended solids and bacteria (Table 35). Loamy soils with considerable organic matter have been found to almost completely remove heavy metals, phosphorus and viruses by adsorption and fixation. Nitrogen is taken up by plant growth, and if the crop is harvested, removals can be in the order of 90 percent.

<u>Infiltration-Percolation</u> - In this method, wastewater is applied to the soil by flooding or spraying onto basins and is treated as it percolates through

TABLE 35. REPORTED REMOVAL EFFICIENCIES OF LAND DISPOSAL AFTER BIOLOGICAL TREATMENT (47)

Constitutent	Removal efficiency, %		
	Irrigation	Infiltration-percolation	Overland flow
BOD	98+	85-99	92+
COD	80+	50+	80+
Suspended solids	98+	98+	92+
Nitrogen (total as N)	85+[a]	0-50[b]	70-90[a,b]
Phosphorus (total as P)	90-99	60-95	40-80[c]
Metals	95+	50-95[d]	50+
Microorganisms	98+	98+	98+[e]
TDS	+30-0[f]	+10-0[f]	+30-0[f]

a. Depends on crop uptake

b. Depends on denitrification

c. May be limiting

d. Ion exchange capacities may be limited

e. Chlorination of runoff may be needed

f. May increase

the soil matrix. Infiltration-percolation has been used with moderate loading rates [10 to 30 cm/wk (4-12 in./wk)] as an alternative to discharging effluent to surface waters. High-rate systems [1.53 to 2.44 m/wk (5-8 ft/wk)] have been designed to recharge groundwater.

Soil drainability on the order of 10 to 30 cm/day (4-12 in./day) or more is necessary for successful use of the infiltration-percolation approach. Acceptable soil types include sand, sandy loams, loamy sand, and gravel. Very coarse sand and gravel are less desirable because they allow wastewater to pass too rapidly through the first few feet where the major biological and chemical action takes place.

Important criteria for site selection include high percolation rates; depth, movement, and quality of groundwater; topography; and underlying geologic formations. To control the wastewater after it infiltrates the surface and percolates through the soil matrix, the hydrogeologic characteristics must be known. Recharge should not be attempted without specific knowledge of the movement of the water in the soil system.

Preapplication treatment is generally provided to reduce the suspended solids content and thereby allow the continuation of high application rates. Disinfection is often provided prior to spreading or ponding to control bacteriological quality.

Depending on wastewater characteristics and water quality objectives, loadings of nitrogen, phosphorus, organic, or trace elements may be critical. Although hydraulic or nitrogen loading is most often limiting, loadings of salts and heavy metals may be critical in some cases. Loading schedules that include alternating loading and resting periods are required to maintain the infiltration capability of the soil surface and to promote optimum BOD and nitrogen removals by aerobic-anaerobic conditions.

In most cases, the filtering and straining action of the soil is extremely effective, so suspended solids, bacteria, and BOD are almost completely removed (Table 35). Nitrogen removals are generally poor unless specific operating procedures are established to maximize denitrification. Phosphorus removals range from 70 to 90 percent, depending on the percentage of clay or organic matter in the soil matrix which will adsorb phosphate ions.

The useful life of an infiltration-percolation system will be less than that of irrigation or overland flow. This is a result of unacceptably high loadings of inorganic constituents, such as phosphorus and heavy metals which are fixed in the soil matrix and not positively removed. Once the fixation capacity for phosphorus and heavy metals have been exhausted, removal efficiencies will deteriorate.

Management practices important to infiltration-percolation systems include maintenance of hydraulic loading cycles, basin surface management, and system monitoring. Intermittent application of wastewater is required to maintain high infiltration rates, and the optimum cycle between inundation periods and resting periods must be determined for each individual case.

Basin surfaces may be bare or covered with gravel or vegetation. Each type of surface requires some maintenance and inspection for satisfactory operation. Monitoring of groundwater levels and quality is essential to system management.

Overland Flow - In this method, wastewater is applied on the upper reaches of sloped terraces of relatively impermeable soils and allowed to flow across the vegetated surface to runoff collection ditches. Renovation is accomplished by physical, chemical and biological means as the wastewater flows in a sheet through the vegetation. A high percentage of the applied water is collected as runoff at the bottom of the slope, with the remainder being lost to evapotranspiration and percolation.

Important factors in overland flow are site selection, application rates and design loadings, management practices, and expected removal efficiencies. If the collected runoff is to be discharged into a navigable water, it will have to meet the stream discharge criteria.

Criteria important for site selection include: soil conditions, topography and climate. Soil conditions is perhaps the most important. Soils with minimal infiltration capacity, such as clays, clay loams and soils underlain by impermeable lenses are best suited for this method. However, a mantel of 15 to 20 cm (6-8 in.) of good topsoil is desirable. The land should have a slope of between 2 and 6 percent, so that the wastewater will flow as a sheet over the ground surface. Grass is planted to reduce soil erosion and to provide a habitat for the microbial flora which help purify the wastewater.

Since groundwater will not likely be affected by overland flow, it is of minor concern in selection. However, the groundwater table should be deeper than 0.6 m (2 ft) to insure aerobic conditions for plant growth.

When overland flow is used as a secondary treatment process, the minimum preapplication treatment is screening and possibly grit and grease removal to avoid clogging of the distribution system. Disinfection prior to application may avoid post-disinfection and allow spraying at higher pressures.

Overland flow systems are generally designed on the basis of hydraulic loading rates, although an organic loading rate or detention time might be the limiting criteria. The treatment process is essentially biological, requiring a minimum contact time between soil microorganisms and applied wastewater for adequate removals. Liquid application rates used in design have ranged from 6 to 14 cm/wk (2.4-5.5 in./wk), with a typical loading being 10 cm/wk (4 in./wk).

Treatment of wastewater by overland flow is only slightly less efficient than that by irrigation (Table 35). Results from field demonstration projects have suggested BOD and suspended solids removals of 95 to 99 percent, nitrogen removals of 70 to 90 percent, and phosphorus removals of 50 to 60 percent. Solids and organics are removed by biological oxidation of the solids as they pass through the vegetative mat. Nutrients are removed mainly by crop uptake. Removal mechanisms for other waste constituents include biological uptake and transformations and adsorption and fixation in the soil. Management practices important in overland flow are: maintaining the proper liquid application and resting cycles; maintaining an active biota and a growing grass; and monitoring the performance of the system. Hydraulic loading cycles have been found to range from 6 to 8 hours of spraying followed by 6 to 18 hours of drying. Cropping practices are necessary to stimulate growth and subsequent nutrient uptake. Monitoring of loading cycles is needed to achieve maximum removal efficiencies.

Public Health Considerations

The passing of the Federal Water Pollution Control Act Amendments of 1972 has focused attention on the public health aspects of land application of wastes. Consequently, the impact of land application on the environment, including public health, social and legal aspects, will be regulated by state and federal agencies.

Potential public health problems are attributed to (a) transmission of pathogens, (b) groundwater quality, (c) crop contamination, and (d) insect propagation. Generally, state health regulations and guidelines serve to protect against many of these potential public health problems.

The concern for pathogen survival and transmission involves aerosols, runoff and leachates from waste application. The danger of spray aerosols lies in their potential for transmitting pathogens which could conceivably be inhaled or contaminate adjacent lands. Aerosol travel and pathogen survival and transmission are dependent on several factors, including wind, temperature, humidity, and vegetative screens. In order to reduce pathogen transmission from spray-irrigated aerosols, some safeguards can be employed. Among these are disinfection, sprinklers that spray horizontally or downward with a low nozzle pressure, and adequate buffer or vegetative screening zones.

Survival times of various organisms in soil, water and vegetation have been extensively reported in the literature (46). The survival of pathogenic organisms in the soil can vary from days to months, depending on the soil moisture, temperature, and type of organisms. In relation to survival of coliform organisms, some bacteria do survive for a longer time in soil. The survival of viruses in soil is essentially unexplored.

Contamination of groundwater is another public health aspect that must be considered. In most cases, a sufficient degree of renovation will be required to meet the best practicable treatment requirements for groundwater protection. EPA regulations on National Primary Drinking Water Standards, listed in Table 36, impose groundwater quality guidelines upon land application systems. Nitrates are the most common concern, but other constituents, including stable organics, dissolved salts, trace elements, and pathogens should be considered. Thus, proper management practices and extensive monitoring programs are necessary to comply with regulatory restrictions.

TABLE 36. NATIONAL PRIMARY DRINKING WATER STANDARDS (49)

Constituent or characteristic	Value	Reason for standard
Physical:		
Turbidity, units	1[a]	Aesthetic
Chemical, mg/l:		
Arsenic	0.05	Toxic
Barium	1.0	Toxic
Cadmium	0.01	Toxic
Carbon chloroform extract	0.7	Toxic
Chromium, hexavalent	0.05	Toxic
Cyanide	0.2	Toxic
Fluoride	1.4-2.4[b]	Toxic
Lead	0.05	Toxic
Mercury	0.002	Toxic
Nitrates as N	10	Toxic
Selenium	0.01	Toxic
Silver	0.05	Cosmetic
Bacteriological:		
Total coliform, per 100 ml	1	Disease
Pesticides, mg/l:		
Chlordane	0.003	Toxic
Endrin	0.0002	Toxic
Heptachlor	0.0001	Toxic
Heptachlor Epoxide	0.0001	Toxic
Lindane	0.004	Toxic
Methoxychlor	0.1	Toxic
Toxaphene	0.005	Toxic
2,4-D	0.1	Toxic
2,4,5-TP	0.01	Toxic

[a] 5 mg/l may be substituted if it can be demonstrated that it does not interfere with disinfection.

[b] Dependent upon temperature, higher limits for lower temperatures

Another public health consideration for the land disposal site is maintaining crop quality with regards to safety for consumption. Many states have regulations dealing with the types of crops that may be irrigated with wastewater, degrees of preapplication treatment required for various crops, and purposes for which the crops may be used.

Propagation of mosquitoes and flies, poses a health hazard as well as a nuisance condition. Mosquitoes are known vectors of several diseases. Mosquitoes may increase in population because of the wetter environment and the availability of standing puddles for breeding (50). For these reasons a mosquito control program may be required as part of the land disposal site operation.

Government Regulations

On a nationwide basis, the Federal Water Pollution Control Act Amendments of 1972, PL92-500, has been responsible for the renewed interest in land application of wastes. PL92-500 places emphasis on waste management alternatives which are cost-effective; utilize the best practicable treatment technology; and consider reuse and recycling of water and nutrient resources. Land application can comply with these recommendations. A preliminary bulletin (38) released by the EPA, addressed several factors which are important to the environmental assessment of a particular land application option, including considerations and guidelines for design.

Other laws which are pertinent to the practice of land application are the National Environmental Policy Act of 1969 (NEPA) and The Safe Drinking Water Act. NEPA requires the preparation of an environmental impact statement for all projects involving Federal funds. The Safe Drinking Water Act sets forth National Primary Drinking Water Standards which apply primarily to groundwater sources used for drinking water. Therefore, land application systems discharging to groundwater will be forced to meet these standards.

In general, the national requirement for land application of sludges to lands on which crops will or may be grown must be examined closely in terms of protecting public health and future land productivity. Sludges must be stabilized to reduce public health hazards and to prevent nuisance odor conditions. For some wastes, it may be necessary to achieve increased pathogen reduction beyond that attained by stabilization. Additionally, groundwater should be protected from pollution. Consideration should be given to the duration of the project, the quality of the groundwater, and if the groundwater is typically used for drinking water supplies with little or no additional treatment. Specific groundwater criteria for land application application systems are contained in the EPA publication, "Alternative Waste Management Techniques for Best Practicable Waste Treatment" (51).

State regulatory agencies have recognized the increasing interest in the land application alternative and thus, are developing regulations and guidelines concerning land application for use within their own boundaries. Twenty-six states have issued regulations or guidelines for this practice whereas five states are currently preparing guidelines. Of the remaining states, design plans are approved on a case by case basis. At present, these regulations and guidelines vary according to local geography, climatology and economy of the states (52). However, similar restrictions can be observed for state land application guidelines because many of the states have used similar reference materials: "Great Lakes-Upper Mississippi River Board of State Sanitary Engineers - Recommended Standards for Sewage Wastes - Addendum #2" (53) and EPA's "Evaluation of Land Application Systems" (47).

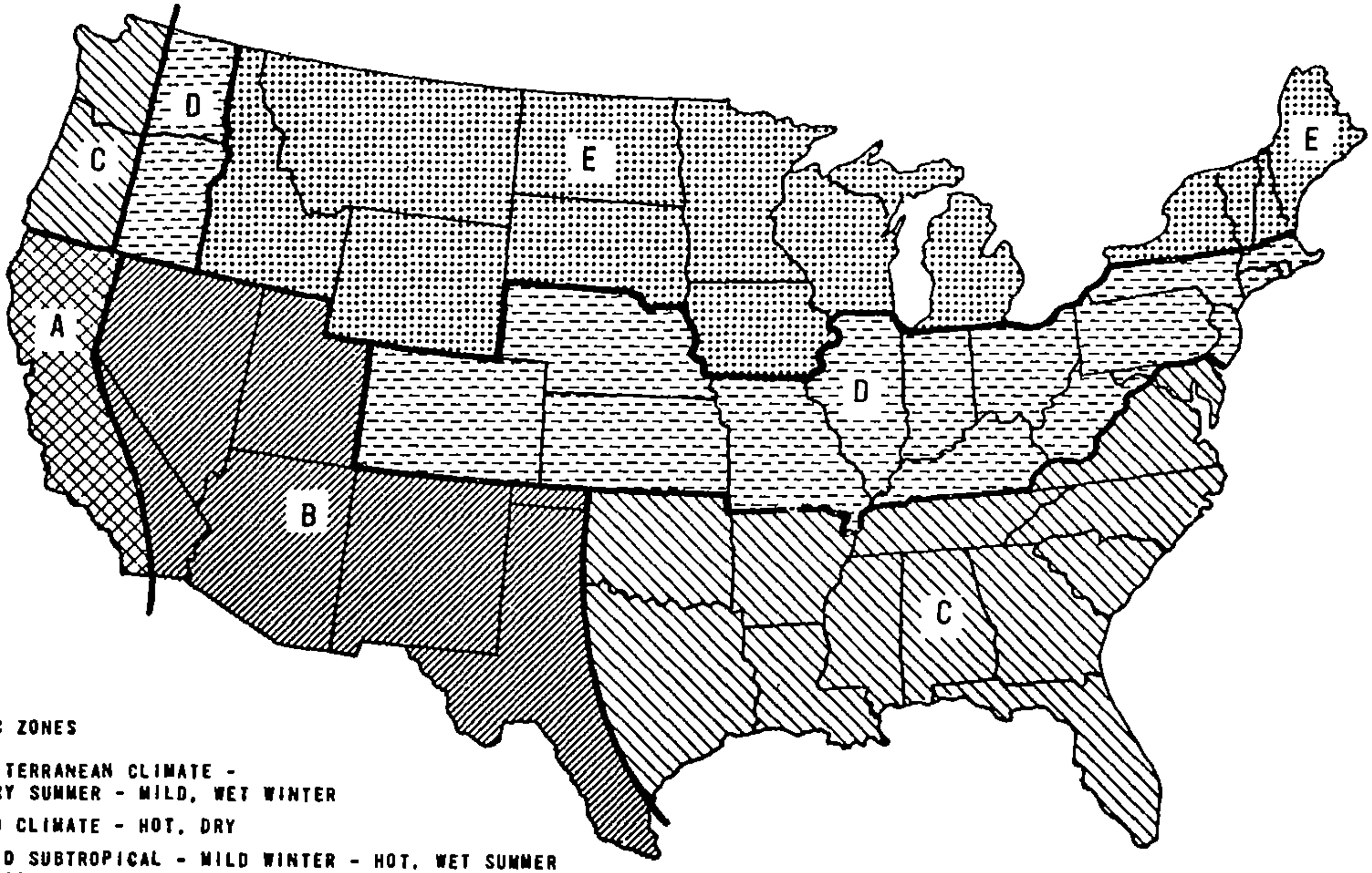
Site Selection and Evaluation

The wide range of potential site characteristics greatly complicates any attempt to develop standardized evaluation criteria. Even so, initial planning concerns have some degree of commonality which include considerations for land use, climate, topography, groundwater, and soils and geology. The selection of a site location should include both the distance and elevation difference from the wastewater collection area. These factors will affect the feasibility and economics of the transmission of the waste to the site. Also, of significant importance in site selection is the compatibility of the intended use with regional land-use plans. Knowledge of current land-use in an area provides an indication of the quantity of land potentially available or suitable for waste application. A review of land use maps can avoid consideration of areas with conflicting features.

Prevailing climatic conditions will affect a large number of design decisions including; the method of land application, storage requirements, total land requirements, and loading rates. Relationships between climate and land application systems are shown in a generalized climatic map (Figure 10). The depicted zones are only useful in preliminary planning stages, since detailed analysis of local climatic data is essential for design purposes.

Zone A has a seasonal pattern of precipitation of about 38 to 64 cm (15-25 in.) during the months from November to April. Temperatures are mild in winter and hot in summer. Plant growth can continue through the year assuming irrigation is provided. Storage of effluent is not required for climatic reasons. Zone B covers the areas that are very hot and arid year round. Winter storage is not a major concern. Zone C includes the areas where precipitation is distributed throughout the year, with hot, humid summers and fairly mild winters. Year round operation of land application systems is possible in these areas. Zone D has moderately cold winters and hot summers. Precipitation is distributed throughout the year. Winter conditions are such that storage will often be required for periods up to 3 months. Zone E has precipitation occurring in all months of the year, averaging from 50 to 100 cm (20-40 in.) annually. Winter operations are severely limited due to low temperatures, ice and snow, thus requiring storage for periods up to six months.

The National Weather Service, local airports, and universities are potential sources of climatological data. Climatic factors of concern include precipitation, storm intensity, duration and frequencies, temperature, evapotranspiration, and wind velocity and direction. The data base should consider sufficient durations of time so that long-term averages and frequencies of extreme conditions can be established.



CLIMATIC ZONES

A MEDITERRANEAN CLIMATE - DRY SUMMER - MILD, WET WINTER

B ARID CLIMATE - HOT, DRY

C HUMID SUBTROPICAL - MILD WINTER - HOT, WET SUMMER (WASHINGTON, OREGON AREA MILD, MOIST SUMMER)

D HUMID CONTINENTAL - SHORT WINTER, HOT SUMMER

E HUMID CONTINENTAL - LONG WINTER, WARM SUMMER

Source: EPA publication 660/2-73-006b (1973)

Figure 10. Generalized climatic zones for land application (45).

Topography affects both the water handling capability of a site and the extent of contact between waste constituents and soil particles. Examination of local and surrounding topography is useful in determining drainage patterns and flow rates of surface and subsurface water. Topographic maps, available from the USGS, are necessary for site selection and subsequent system design. Topographic information of concern includes ground slope, proximity of surface water, erosion and flood potential, and existing vegetative cover.

Soil properties determine the suitable waste application or loading rate, thereby affecting the amount of land required and the method of application. Thus, soil properties are often considered the most important factors in selecting both the site and the land application method. Properties that are important in describing and evaluating soils include soil texture, structure and profile, permeability, available water capacity, and chemical characteristics such as pH, salinity, nutrient levels and adsorption and fixation capabilities. Information on soil properties can be obtained from the National Cooperative Soil Survey, the Agricultural Extension Service and some state universities.

Groundwater characteristics are important considerations in selecting a particular site. The effect of groundwater levels on renovation capabilities and the effects of the applied waste on groundwater movement and quality should be extensively evaluated. Additionally, the depth to groundwater should be determined, along with an evaluation of the groundwater rate of flow and direction and the permeability of the aquifer. Information on these sources can be obtained from the U.S. Geological Survey or State Divisions of Water Resources.

Design Considerations

For most land application systems, vast numbers of design possibilities are available to suit specific site characteristics, treatment requirements and overall project objectives. The scope of factors that are commonly considered in the design process include: a) preapplication treatment requirements; b) storage requirements; c) climatic factors; d) pollutional loading constraints; e) land area requirements; f) crop selection and management; g) system components; h) site monitoring program; and i) cost-effectiveness. It should be recognized that since land application system designs are site specific, design criteria must be based on the actual conditions of the site and therefore cannot be generalized.

Preapplication Treatment Requirements - Treatment of wastes prior to land application may be necessary for a variety of reasons, including: 1) public health regulations, 2) loading constraints with respect to critical wastewater characteristics, and 3) the desired effectiveness and dependability of the system components. In areas where long-term winter storage is required, some degree of treatment may be necessary to prevent nuisance conditions during storage.

Public health considerations, pathogen transmission and groundwater quality are usually the most important factors in determining the required degree of preapplication treatment. Wastewater constituents that may tend to limit the application rate or hinder the quality of renovated water may also necessitate pretreatment. High concentrations of grit, suspended solids and grease and oil can deteriorate the effectiveness and dependability of the pumping and distribution systems, thus requiring some degree of pretreatment prior to application.

Storage Requirements - In most land application systems, considerations in determining storage capacity include the local climate, the design period of operation, flow equalization, and system back-up if breakdown occurs. Required storage capacities may range from one day's storage to several months'.

Storage requirements will most often be based on the period of operation and the local climate. Three different conditions that may necessitate storage include: 1) winter weather requiring cessation of operation; 2) precipitation requiring the temporary reduction or cessation of application; or 3) winter weather requiring reduction of winter application rates. When cessation of operation is expected, storage requirements should be based on the maximum expected period of nonoperation. The number of consecutive nonapplication days due to climatic constraints (i.e. precipitation, temperature and snow) may be determined through the use of a computer program developed by the National Weather Service (54). Figure 11 presents a nationwide estimation of storage days as calculated from this computer program.

Climatic Factors - Design assumptions must be evaluated with regard to climatic factors. Climatic conditions most often considered are precipitation, temperature and wind.

Precipitation, such as rainfall, snow and hail, will affect a number of design factors, such as: 1) hydraulic loading rates; 2) storage requirements, and 3) system drainage requirements. Precipitation data that will be necessary for design purposes include: total annual precipitation; maximum and minimum annual precipitation; monthly distribution of precipitation; storm intensities; and snowfall characteristics.

Temperature, because of its influence on plant growth and freezing conditions, will affect liquid loading rates and the period of operation. Temperature data that may be incorporated into system design include: monthly or seasonal averages and variations; length of growing season; and periods of freezing conditions.

For spray application systems, wind conditions may require a reduction or temporary cessation of waste application in order to prevent disease transmission. Wind velocity and direction should be determined with respect to frequencies and durations.

Another climatological factor that should be considered is the potential amount of evapotranspiration for the area. Figure 12 presents a nationwide comparison of potential evapotranspiration rates versus the mean annual precipitation. The effect of the evapotranspiration, if the yearly evapotranspiration, is greater than the mean annual precipitation, is that it will reduce the liquid volume of waste to the applied on the land.

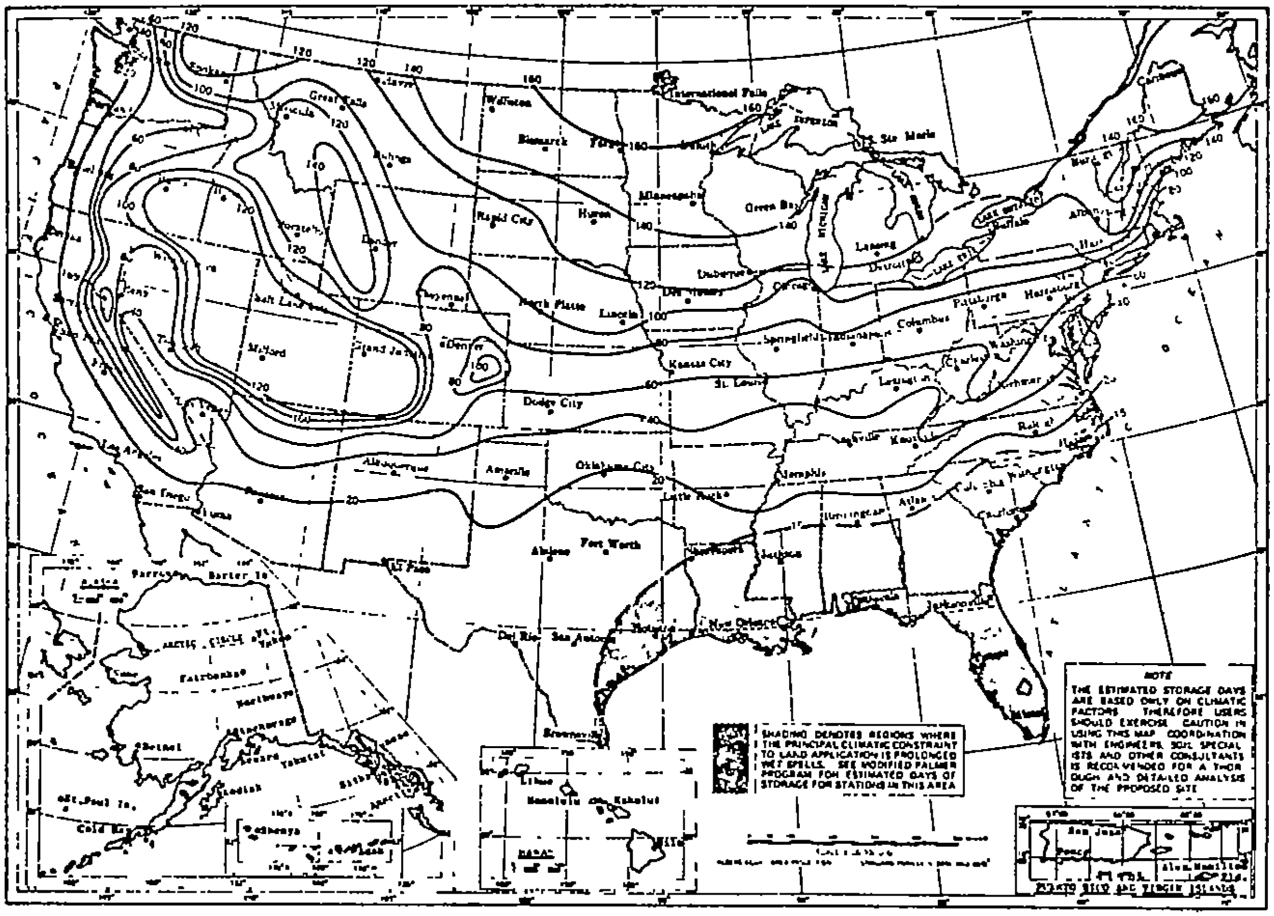


Figure 11. Storage days required as estimated from the use of the computer program as described (54).

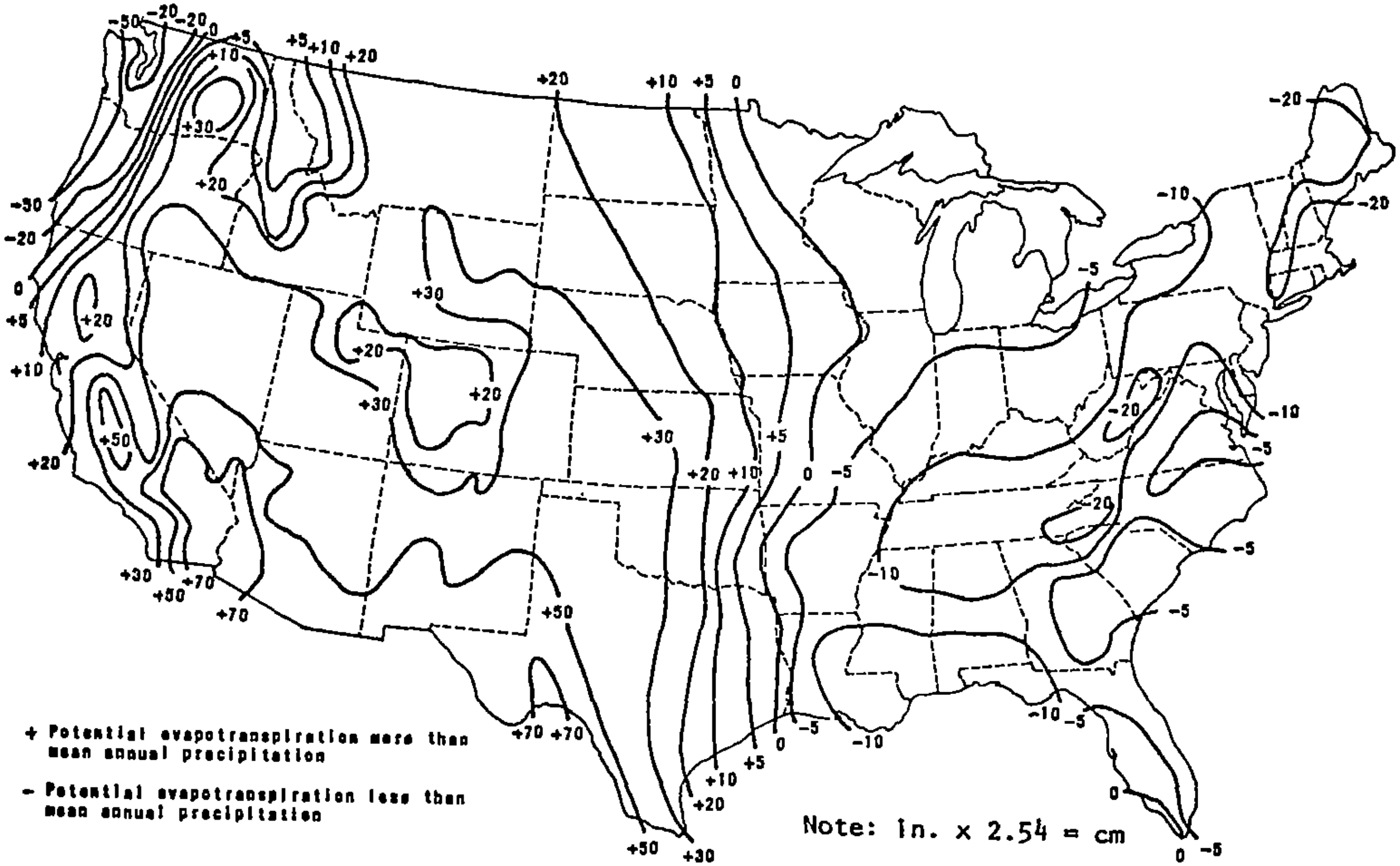


Figure 12. Potential evapotranspiration vs. mean annual precipitation (inches) (46).

Pollutional Loading Constraints - Loading rates for the liquid applied and the pollutional constituents of the waste will form the basis in determining design criteria for land requirements, application rates, and crop selection. To determine what characteristics of the applied waste will be limiting, balances should be conducted for water, nitrogen, phosphorus, organic matter, and other constituents that appear high in concentration. On the basis of these balances, a loading rate can be established for each parameter which then can be used in calculating the required land area. The critical loading rate will be the one requiring the largest field area.

The hydraulic loading rate can be determined by conducting a water balance on the effluent applied, precipitation, evapotranspiration, percolation, and runoff. In other words, the amount of effluent applied plus precipitation should equal the evapotranspiration plus a limited amount of percolation. In all cases except overland flow, surface runoff from irrigated fields should not be permitted. The water balance can be expressed as:

$$\text{Precipitation} + \begin{matrix}\text{Applied}\\\text{Effluent}\end{matrix} = \text{Evapotranspiration} + \text{Percolation}\ [+\ \text{Runoff}]$$

Seasonal variations should be taken into account when encountering these values. This can be done by means of evaluating the water balance for each month as well as the annual balance.

Nitrogen loadings must be balanced against acceptable nitrogen losses and removals because nitrate ions are mobile in the soil and can affect groundwater quality. On an annual basis, the applied nitrogen must be accounted for in crop uptake, denitrification, volatilization, leachate, or storage in the soil. A nitrogen mass balance equation for a terrestrial system can be developed as:

$$\begin{matrix}\text{Applied}\\\text{N in}\\\text{waste}\end{matrix} + \begin{matrix}\text{N in}\\\text{precipi-}\\\text{tation}\end{matrix} = \begin{matrix}\text{N Removal}\\\text{in crops}\end{matrix} + \begin{matrix}\text{Leaching}\\\text{Loss}\end{matrix} + \begin{matrix}\text{Denitri-}\\\text{fication}\end{matrix} + \begin{matrix}NH_3\\\text{Volatili-}\\\text{zation}\end{matrix}$$

This balance equation can be used to calculate nitrogen loading rates for waste applications.

For most land application systems, the phosphorus loading will usually be well below the capacity of the soil to fix and precipitate the phosphorus. Typically, 95 percent of the phosphorus applied can be removed from the percolating wastewater. The removal mechanisms for phosphorus are crop uptake, microbial uptake, chemical precipitation, and fixation by the soil.

The average daily organic loading rate should be calculated from the hydraulic loading rate and the BOD concentration of the applied waste. Thomas (55) has estimated that organic loading rates between 11 to 28 kg/ha/day (10 to 25 lb/acre/day) are needed to maintain a static organic-matter content in the soil. Additions of organic matter at these rates help to maintain the tilth of the soil, replenish the carbon oxidized by microorganisms, and would not be expected to pose problems of soil clogging. Higher loadings rates of 56 to 112 kg/ha/day (50 to 100 lb/acre/day) can be employed successfully, depending upon the type of system and the resting period. Resting periods, which are standard with most application systems, give soil bacteria time to break down organic matter and allow the water to drain from the top few inches, thus restoring aerobic conditions.

Loading rates for suspended and dissolved solids are the two major types of remaining constituents that are of interest for land application systems. The organic and inorganic fractions of the suspended solids are usually filtered out and become incorporated into the soil, which can reduce the infiltration rate into the soil. As a result, preapplication treatment for suspended solids reduction may be necessary.

Dissolved solids are affected differently in the soils depending on their movement through the soil matrix. Chlorides, sulfates, nitrates, and bicarbonates move relatively easy through most soils without being tied up in the soil profile. These compounds can, therefore, be readily leached into the groundwater. Other dissolved solids, such as sodium, potassium, calcium, and magnesium, are exchangeable and react with the soil so that their concentrations will change with depth. Other constituents, such as heavy metals, pesticides and other trace elements may or may not be removed by the soil matrix, depending upon such factors as clay content, soil pH and soil chemical balance. On the basis of the analyses of waste characteristics, any constituent suspected of having a limiting loading rate should be calculated. Table 37 gives recommended concentration limits for specific elements based on common application rates for land application systems. If the limiting criteria is met, there should be little concern about toxic effects on plants or excessive accumulation in soils.

Land Area Requirements - The total land area required includes provisions for treatment; buffer zones; storage; sites for buildings, roads and ditches; and land for emergencies or future expansion. If any on-site preapplication treatment is required, provisions must also be provided for land furnishing these facilities.

The field area is that portion of the disposal site in which the waste is applied to the land. It is determined by calculating acceptable loading rates for each different loading parameter (liquid, nitrogen, phosphorus, organic, or others) and then selecting the largest area. The loading parameter that corresponds to the largest field area requirement would then be the critical loading parameter.

Regulatory agency requirements may specify buffer zones around application sites because of concern about the effects of aerosol-borne pathogens. Buffer zones ranging from 15 to 61 meters (50 to 200 ft) wide have been reported (45), although requirements for even larger buffer zones may exist depending on a number of factors.

Land application systems will generally require land for off-season or

TABLE 37. RECOMMENDED AND ESTIMATED MAXIMUM CONCENTRATIONS OF SPECIFIC IONS IN IRRIGATION WATERS [1], mg/l (46)

Element	Removal Mechanism [2]	For Waters Used Continuously on All Soil: 0.9 m/yr Application Recommended Limit [3]	For Waters Used Up to 20 Years on Fine-Textured Soils of pH 6.0 to 8.5: 0.9 m/yr Application Recommended Limit [3]	For Waters Used Up to 20 Years on Fine-Textured Soils of pH 6.0 to 8.5: 2.4 m/yr Application Estimated Limit	For Waters Used Up to 20 Years on Fine-Textured Soils of pH 6.0 to 8.5: 24 m/yr Application Estimated Limit
Aluminum	PR, S	5.0	20.0	8.0	0.8
Arsenic	AD, S	0.10	2.0	0.8	0.08
Beryllium	PR	0.10	0.50	0.2	0.02
Boron	AD, W	0.75	2.0-10.0	2.0	2.0
Cadmium	AD, CE, S	0.010	0.050	0.02	0.002
Chromium	AD, CE, S	0.10	1.0	0.4	0.04
Cobalt	AD, CE, S	0.050	5.0	2.0	0.2
Copper	AD, CE, S	0.20	5.0	2.0	0.2
Fluoride	AD, S	1.0	15.0	6.0	0.6
Iron	PR, CE, S	5.0	20.0	8.0	0.8
Lead	AD, CE, S	5.0	10.0	4.0	0.4
Lithium	CE, W	2.5[4]	2.5[4]	2.5	2.5
Manganese	PR, CE, S	0.20	10.0	4.0	0.4
Mercury	AD, CE, S	---	---	---	---
Molybdenum	AD, S	0.010	0.050[5]	0.02[5]	0.002[5]
Nickel	AD, CE, S	0.20	2.0	0.8	0.08
Selenium	AE, W	0.020	0.020	0.02	0.02
Silver	AD, CE, S	---	---	---	---
Zinc	AD, CE, S	2.0	10.0	4.0	0.4

(1) These levels will normally not adversely affect plants or soils. No data are available for mercury, silver, tin, titanium, or tungsten.

(2) AD = adsorption with iron or aluminum hydroxide, pH dependent; AD = anion exchange; CE = cation exchange; PR = precipitate, pH dependent--iron and manganese are also subject to changes by oxidation reduction reaction; S = strong strength of removal; W = weak strength of removal

(3) EPA Water Quality Criteria, 1972.

(4) Recommended maximum concentration for irrigating citrus is 0.075 mg/l.

(5) For only acid fine-textured soils or acid soils with relatively high iron oxide contents.

winter storage, especially in the northern states. Storage capacities may also be necessary to equalize flow rates or to provide backup services.

Crop Selection and Management - Crops grown at the land application site can have a significant effect on treatment efficiencies and loading rates, especially the removal of nutrients from the applied waste. Factors that should be considered in crop selection include: 1) relationship to critical loading, 2) public health regulations, 3) ease of cultivation and harvesting, and 4) the length of the growing season. Also, if the crop is to be harvested, the local market for the crop must be considered. The four general classes of crops that may be considered are perennials, annuals, landscape vegetation, and forest vegetation.

Compatibility of the loading rates with the selected crop is important to ensure both the survival of the crop and the efficiency of wastewater renovation. Loading rates should have allowances with respect to the tolerances and uptake capacities of the intended crops. Therefore, crop selection will be dependent on a combination of loading parameters, including 1) water requirement and tolerance, 2) nutrient requirement, tolerance, and removal capability, and 3) sensitivity to various inorganic ions.

As of 1972, at least 17 states had public health regulations that exist with regard to: the types of crops that may be irrigated with wastewater; the degree of preapplication treatment required for certain types of crops; and the methods of application that may be employed (56).

System Components - Typically, land application systems are composed of a number of different system components, such as: preapplication treatment facilities, transmission facilities, storage facilities, distribution system, recovery system and monitoring system. The design of each component of a land application system is highly variable and is dependent on many factors relating to site characteristics and project objectives.

The design of preapplication treatment facilities will be controlled by factors such as the loading rate of various constituents, the method of application employed, and the type of crop grown. In most cases, regulations concerning required levels of preapplication treatment have been set forth by local agencies.

Design of the transmission facilities to the site from the collection area may become a very important aspect to consider if land application is to be cost-effective. Selection of a conveyance method will usually depend on the production rate, distance to application site, seasonability of application, and planned lifetime of the site. Three potential methods of wastewater conveyance include gravity piping, open channels and force mains. For each of these methods, standard design criteria should be used since these transmission facilities will rarely differ from that designed for conventional treatment systems. In conveying sludges, additional methods have included tank trucking for liquid sludges and open bed trucking for dewatered sludges.

In almost all cases, some sort of storage facility will be necessary. If storage is to be provided for winter flows and storage requirements are high, winter storage, especially in the northern states. Storage capacities may also be necessary to equalize flow rates or to provide backup services.

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TABLE 38. IMPORTANT MONITORING SEGMENTS OF LAND APPLICATION PROCESS (59)

I. Influent Quality (Treatment Quality)

   a. Nutrient levels (N, P, K)
   b. Sodium absorption ratio (SAR)
   c. Heavy metal concentration, having potential toxicity to plant and animal life (Zn, Cu, Ni, Cd, Pb, Hg)
   d. Other physical and chemical determinations (pH, BOD, COD, TS, TOC)
   e. Pathogens, viruses, salmonella and protozoa

II. Soil Condition and Quality (Preservation of Soil's Physical & Chemical Characteristics)

   a. Nutrient profile - N, P, K distribution
   b. Cation exchange capacity
   c. Hazardous heavy metal distribution
   d. Organic content
   e. Soil kind - physical
      - infiltration rate
      - size distribution
      - soil horizons
      - redox profile, pH

III. Drained or Leachate Water Quality and Groundwater (Prevention of Contamination of Surface and Groundwater)

   1. Groundwater
      a. Nutrients (NO_3/NO_2, P)
      b. Heavy metals
      c. Pesticides, herbicides, etc.
      d. Microbiological
         - fecal coliform
         - fecal strep
         - salmonella
         - viruses
      e. Other physical, chemical determinations
         - pH, specific conductivity, detergents

   2. Receiving Surface Waters
      a. Nutrients
      b. Heavy metals
      c. Microbiological
         - fecal coliform
      d. Other physical and chemical determinations

   3. Crop Quality and Yield (Safe for Animal/Human Consumption)
      a. Heavy metals content
      b. Nutrient content
      c. Pathogens

gradient groundwater quality, as well as influent to the system, should be monitored for the parameters commonly measured to ensure environmental quality and any additional parameters that are of concern to the land application system, such as heavy metals. In the case of overland flow application, the effluent discharging from the site will have to be monitored for the parameters required by state and federal discharge requirements.

In addition to quality, changes in groundwater levels should also be monitored. The effect of increased levels should be assessed with respect to changes in the hydrogeologic conditions of the area. Changes in the groundwater movement and the appearance of seeps and perched water tables should be noted and system modifications, such as underdraining or reducing application rates in the area should be undertaken (46).

When vegetation is grown as a part of the treatment system, monitoring may be required for the purpose of optimizing growth and yield and preventing buildup of toxic materials. Measurements should include: heavy metal content; nutrient content; and pathogens.

Cost-Effectiveness - In selecting the best wastewater treatment alternative, a cost-effectiveness analysis should be properly performed. To conduct such an analysis, detailed cost estimates must be prepared and evaluated for each alternative on an equivalent basis in terms of total present worth or annual cost. Generally, cost estimates for an alternative would include costs for operation, maintenance and supervision and the amortized capital cost. Capital and operating cost considerations of importance for land application systems have been documented in current reports entitled "Costs of Wastewater Treatment by Land Application" (48) and "Water Pollution Abatement Technology: Capabilities and Cost" (43).

LAND APPLICATION OF RAW CSO

An alternative to the treatment of CSO and the resultant problems of sludge handling and disposal is direct application of the raw CSO to the land. This method would eliminate the need for extensive CSO treatment facilities and the further problem of sludge handling and disposal facilities.

The waste management alternative of applying raw CSO to the land will be discussed with respect to many of the design factors presented in the previous section.

Preapplication Treatment

If the land is used for treatment and disposal of raw CSO, it is apparent that some form of preapplication treatment will be required. First, since high densities of coliform have been reported for CSO (9), disinfection will most likely be required as a preapplication treatment process. Second, since CSO's are intermittent events, storage will have to be provided to equalize the flow to the land site and thus, some type of stabilization to prevent nuisance conditions from developing will be required. If spray irrigation is employed, grit, oil and grease removal combined with a reduction in suspended solids may be necessary to prevent potential clogging of the distribution system. Since the raw flow will be held in a storage facility, grit and organic solids could be removed there and some provision would have to be made for disinfection prior to land application.

Collection and Transportation of Raw CSO

A very important aspect to consider, if land disposal of raw CSO is to be used, is how the CSO will be collected and transported to the land disposal site. The cost of such a collection and transportation system could be more than the land disposal facility itself. In most cities, a collection system will be necessary to intercept all CSO discharge points and deliver the flows to a transport system. The collection system must function year round and must be sized to carry peak flows. The transport system would have to convey the CSO out of the urban and suburban areas to a selected land site. The transport system normally would be a pipeline but under some circumstances, could be an open channel.

Several problems will become apparent when implementing conceptual plans for transmission facilities. First, combined sewers are usually located in the older, central sections of metropolitan areas. Therefore, the collection system may require sewer construction in densely populated commercial areas, which could prove to be very costly. Second, in order to convey the CSO out of the urban area to a selected treatment site, the transportation distance could easily be 32 to 64 km (20 to 40 miles). These distances may prove to be impractical because of the high costs for transportation systems. Third, and probably most important, the transmission facilities must be capable of handling peak storm flows. To illustrate this better, a typical city in the Great Lakes region with a combined sewer area of 972 ha (2400 acres), would require transport pipelines in the order of 5.3 m (17.5 ft) in diameter to provide for peak flow design rates based on one hour storm intensities at one year return frequencies. If longer return periods or shorter time intervals are used in order to achieve complete CSO abatement, the sizes of the collection and transport systems would increase significantly. To avoid the design capacities needed for peak flow rates, it would be necessary to provide for equalization basins and temporary storage basins to maintain a constant transportation program. The cost for these facilities alone may be prohibitive.

Storage

Design considerations for storage facilities are usually based upon incoming flow rates and the number of consecutive unfavorable application days over the year. The nonapplication period is determined by the number of days during which the following exist: temperature below freezing $0^{\circ}C$ ($32^{\circ}F$), total daily rainfall greater than 1.3 cm (0.5 inches), and greater than 2.5 cm (1 inch) of snow cover (54). For the Great Lakes and Northeastern regions of the U.S., the average number of nonapplication days for which storage would normally be required is around 100 days (Figure 10). However, in determining the storage requirement, it is necessary to conduct a monthly water balance considering intermittent CSO flow rates, precipitation, evaporation and soil percolation rates.

Therefore, it appears that storage facilities will be required to handle CSO flows for periods up to four months. In addition to providing storage facilities, because of the large amounts of solids that can be expected in raw CSO, precautions will have to be taken to prevent nuisance problems from occurring. These precautions could be stabilization and/or disinfection of the CSO during storage and a mosquito control program. The storage area could also support extensive algal growths which could become a significant problem.

Climatological Effects

The general climate of the area can have a significant effect on the operation of a CSO land disposal site. As seen from the previous discussion, the winter season will greatly reduce the time that a land disposal operation can be used. On the average, the operation of a site in the Great Lakes region would have to be shut down for 3 1/2 months.

The yearly precipitation over the area will also affect the operation since the irrigation or overland flow methods of application can not be used during periods of rainfall because the highly polluted CSO could be carried away from the site with the surface runoff. Wet ground that results from the rainfall events will also reduce the capacity of the soil to hydraulically assimilate the added loadings of the raw CSO. These factors will increase the amount of land required for the disposal site. The days of operation were approximated as 205 days for an average year in the Great Lakes region of the country. This value was arrived at by subtracting 100 days for winter conditions and 60 days for non-operative conditions due to periods of rainfall-runoff.

Another climatological factor that should be considered is the potential amount of evapotranspiration for the area. The effect of the evapotranspiration rates can be shown by using the Great Lakes region of the country as an example. From Figure 11, it is estimated that the potential yearly evapotranspiration is less than the mean annual precipitation rate. The impact of evapotranspiration is that it must be considered as part of the hydraulic loading. Therefore, it will not significantly reduce the added precipitation that will necessitate disposal.

It can be seen that for the Great Lakes and the Northeastern regions of the USA, the precipitation and evapotranspiration rates can be significant factors affecting the liquid volume of the waste to be handled.

Pollutant Loading Constraints

Since CSO represents large quantities of urban runoff, it can contain large concentrations of heavy metals which may be in excess of those that can be removed by the soil. The leaching of these metals into the receiving water could pose a serious health problem. This fact, and the fact that high concentrations of some pollutants in CSO may cause operational problems for the land disposal site, may lead to constraints on the loading rates allowed and thus, on the overall feasibility of land disposal of raw CSO. As the first consideration in design, the factors which may limit land disposal of wastes and the risks involved with this practice will be estimated. This will be accomplished by identifying the parameter that limits loading rates.

For preliminary calculation purposes, the following CSO values, based on average characteristics obtained from the literature, have been assigned for use in this section. The raw CSO volume is an arbitrary value to serve as a basis for design calculations.

Raw CSO volume: 1382×10^6 ℓ/yr (365×10^6 gal./yr)
Yearly CSO solids volume: 552 metric tons (609 tons-dry weight basis)

Pollutional Characteristics:

SS	400 mg/l	
BOD	120 mg/l	
N	16 mg/l	
P	5 mg/l	
Zn	1000 mg/kg	SS
Cu	400 mg/kg	SS
Ni	200 mg/kg	SS

Toxic Elements - The most common concern with land application of pollutants is the question of the effect of toxic elements on the soil-crop system. In order to protect the land from toxic elements accumulation from waste applications, Wisconsin (60) has adopted guidelines, based on an interim guide recommended by the EPA, which takes into account the combined effect of the metals by using a measurement entitled the zinc equivalent (ZE). The ZE can be determiend as follows:

$$ZE = (1 \times [Zn]) + (2 \times [Cu]) + (4 \times [Ni])$$

where all concentration values are expressed in mg/kg dry weight. The total dry solids loading is calculated from the formula (60):

$$\text{Total Solids } \left(\frac{\text{dry tons}}{\text{acre}}\right) = \frac{32{,}500 \times CEC}{ZE}$$

To determine area requirements, the following assumptions were made: 1) the cation exchange capacity (CEC) of the soil is 15 meq/100 g; and 2) the life span for the soil is 20 years. As a result, the area requirements for land application of CSO would be about 1.9×10^{-2} ha/10^6 ℓ CSO/yr (17.8×10^{-2} ac/10^6 gal. CSO/yr).

Organic Solids Application Rates - The organic assimilation capacity of soils is highly variable depending on detailed soil characteristics. In general, organics are continuously added to soils as plant residues, dead animals, etc. and are continuously oxidized by soil organisms. As organic additions increase, soil respiration also increases until a maximum rate of oxidation is reached. Although few guides are available, regulations have been proposed to limit BOD_5 and SS application rates to around 672.6 kg/ha-day (600 lbs/acre-day). If this limitation is used, the safe application areas for raw CSO wastes would be 0.4×10^{-2} ha/10^6 ℓ CSO/yr (3.7×10^{-2} ac/10^6 gal. CSO/yr) for BOD and 1.6×10^{-2} ha/10^6 ℓ CSO/yr (15.0×10^{-2} ac/10^6 gal. CSO/yr) for SS.

Nitrogen and Phosphorus Control - The nitrogen and phosphorus constituents in CSO wastewater are likely to appear as major limiting factors for land application designs. Current knowledge indicates that phosphorus removal to levels of 0.05 mg/l can be achieved over site lifetimes of 20 years or more at annual loading rates within the 168 to 336 kg P/ha-yr (150-300 lb P/acre - yr) range (6). Using this assumption, the total land area required for safe application of phosphorus would be 1.9×10^{-2} ha/10^6 ℓ CSO/yr (17.8×10^{-2} ac/10^6 gal. CSO/yr).

Conversion of nitrogen forms to nitrates may result in contamination of the groundwater. Thus, nitrogen must be considered as a nutrient which must be applied at a controlled rate. To calculate nitrogen loading rates for wastewater applications, the following equation can be used (6):

$$N^* = \frac{y}{4.43} \left(\frac{4.43\ C + a(P-ET) - cP}{y-a}\right)$$

where:

- N = total nitrogen in applied waste (lb/ac-yr)
- C = removal of N in crop (lb/ac-yr)
- P = precipitation (ac-in./ac-yr)
- c = concentration of N in precipitation (mg/l)
- a = allowable N in leachate (mg/l)
- ET = potential evapotranspiration (ac-in./ac-yr)
- y = total nitrogen concentration in waste (mg/l)

* conversion factor = N x 1.122 = kg N/ha-yr

The following assumptions are made to determine nitrogen loading rates for an area in the Great Lakes region: 1) average annual precipitation is 89 ha-cm/ha-yr (35 ac-in./ac-yr); 2) evapotranspiration is 51 ha-cm/ha-yr (20 ac-in./ac-yr); 3) allowable N concentration in leachate is 10 mg/l; and 4) crop nitrogen removal rate is 280 kg/ha-yr (250 lb/ac-yr).

Using these assumptions, the wastewater application rate would be approximately 834 kg N/ha-yr (743 lb N/ac-yr), thus resulting in a land area requirement of 1.9×10^{-2} ha/10^6 ℓ CSO/yr (17.8×10^{-2} ac/10^6 gal. CSO/yr).

Hydraulic Loading - The maximum hydraulic loading rate for the CSO must also be taken into consideration. This rate will be dependent on the application method employed and the type of soil characteristics given for the area. First, it will be assumed that a loam type soil is characteristic of a possible land disposal site in the northern states. This soil type suggests the use of the irrigation method of land application. Secondly, it is assumed that an allowable liquid loading rate for the selected application method and the predominant soil type would be 12.7 cm per wk (5 in./wk). Finally, if the operational period is assumed as 30 weeks a year, the annual application rate becomes 381 cm (150 in.). This results in a land area requirement of 2.6×10^{-2} ha/10^6 ℓ CSO/yr (24.7×10^{-2} ac/ 10^6 gal. CSO/yr).

Land Area Requirements

After a suitable land site has been selected, the next consideration for a city using land disposal of raw CSO will be the amount of land required for actual application. For field area requirements, a summary of the application rates estimated to be acceptable and the resulting land requirements are shown in Table 39. It is perhaps surprising to note that the limiting factor is the hydraulic loading of the CSO. Hydraulics often is the limiting factor for application of wastewaters, usually in cases where the application rate is controlled by surface runoff and groundwater protection. Hence, if the liquid loading is assumed to determine the required land area, it can be seen that the application rates of the other pollutants are one-third to two-thirds that which is considered to be an environmentally safe rate of application. Therefore, recommendation of the use of a 2.9×10^{-2} ha/10^6 ℓ CSO/yr (27.1×10^{-2} ac/10^6 gal. CSO/yr) land area requirement should incorporate a safety factor large enough to account for unpredictable events. The above land area requirement can also be expressed in terms of a design application rate: 34.4×10^6 ℓ/ha/yr (3.6×10^6 gal./ac/yr).

This "first cut" land estimate can increase significantly as more criteria are considered because additional land may be required for storage and possible pretreatment facilities, necessary non-application buffer zones, runoff control structures, etc.

For example, the inclusion of a 122m (400 ft) buffer zone around the site increases the required area significantly; if 61 m (200 ft) is acceptable with a line of trees and shrubs, the area requirement still is significant. Other buffer areas may also be required within the site around roads, streams, buildings, and storage areas. This, of course, would further increase the area required for the total operation.

Employing an application rate of 34.4×10^6 ℓ/ha/yr (3.6×10^6 gal./ac/yr) and if the nationwide annual volume of CSO totals 5.60×10^9 cu m (1.48×10^{12} gal.), field area requirements for raw CSO disposal would approximate 166,500 ha (411,110 acres) of land. However, this is land required for actual disposal only. Assuming that, on the average, the land required for actual disposal is 70 percent of a disposal site, the nationwide disposal of raw CSO would require a total land area of 237,857 ha (587,300 acres).

Crops

As discussed in the previous section, the crops grown at the land application site can have a significant effect on treatment efficiencies and loading rates, especially for the removal of nutrients from the CSO. Since

TABLE 39. SUMMARY OF RECOMMENDED APPLICATION RATES FOR VARIOUS RAW CSO POLLUTANTS AND THE RELATED LAND AREA REQUIREMENT

Pollutant	Acceptable application rate		Land area requirement	
	kg/ha/yr	(lbs/ac/yr)	10^{-2} ha/10^{6} ℓ/yr	(10^{-2} ac/10^{6} gal./yr)
Toxic metals	21.0	(9.4)[a]	1.9	(15.8)
Nitrogen	834	(744)	1.9	(15.8)
Phosphorus	252	(225)	1.9	(15.8)
BOD	672	(600)[b]	0.4	(4.1)
SS	672	(600)[b]	1.6	(13.3)

[a] expressed as metric tons/ha/yr (tons/ac/yr) - dry weight basis

[b] expressed as kg/ha/day (lb/ac/day)

removal of nitrogen is a primary objective, a perennial forage grass appears to be the best selection because it can remove nitrogen to low concentrations (62). Reed canary grass has been shown to be effective in removing nitrogen; however, other grasses may be just as good and may respond better under some circumstances.

Monitoring

Contamination of groundwater is a public health aspect that must be considered. The proposed EPA regulations on National Primary Drinking Water Standards (49) must be maintained for the groundwater. The land disposal of large volumes of CSO has the potential to significantly increase the nitrate and total dissolved solids of the groundwater. Therefore, these parameters should be monitored closely. Since CSO represents large quantities of surface runoff, it could contain high concentrations of heavy metals and pesticides; concentrations in excess of what can be removed by the soil. Any leaching of these pollutants could pose a serious health problem. Due to the lack of information on the passage of the large concentrations of pollutants expected in CSO through the soil, extensive monitoring programs would have to be established to guard against contamination of groundwater and nearby surface waters that may be used as water supplies.

Another public health consideration for the land disposal site is maintaining crop quality. When vegetation is grown as a part of the land disposal system, a detailed vegetation monitoring program may be required in which the uptake of certain elements must be analyzed. The analysis is usually required because of the potentially toxic constituents that may be present in CSO in abnormally high concentrations.

Summary

Hence, it can be concluded that land application of CSO wastewaters to the soil may be a viable treatment alternative. However, land application has two major limitations in allowing the process to become cost-effective. First, regulations require the CSO to be disinfected and in some cases stabilized before application. This might prove to be a very costly expenditure. Secondly and most importantly, the cost of the collection-transport and/or equalization system may be the crucial factor in disallowing land disposal of CSO as an alternative to other CSO treatment methods. It may be feasible to use land disposal of the raw CSO in cities which have relatively small CSO areas and have land available in close proximity to the city, but cities with large CSO areas, even if the land is available, may find that the cost of the collection-transport system might be prohibitive.

LAND APPLICATION OF CSO SLUDGES

If CSO treatment is employed by a city, the residual sludges that are produced will require some method of treatment and disposal. One alternative that can be considered is land disposal. It could be land disposal of the liquid sludge which can range from 0.7 to about 4.0 percent solids depending on the CSO treatment process employed; or it could be land disposal of the sludge after it has undergone thickening and/or dewatering. The disposal of liquid sludge on land is popular because it can meet two basic objectives: simplicity and cost-effectiveness. The objectives of land disposing a dewatered sludge are similar to those for a liquid sludge, although in the latter case solids-liquid separation must be achieved prior to disposal. In both cases, the sludge may be useful as a soil conditioner or as fertilizer for crop growth.

The sludges that are produced by CSO treatment can vary greatly from the sludges that are produced at conventional municipal wastewater treatment plants. Therefore, any criteria developed for land disposal of municipal dry-weather sludges may not be applicable for land disposal of CSO sludges.

As with the land disposal of the raw CSO, this section will attempt to present the design considerations necessary for the land disposal of sludges, either liquid or dewatered, and then relate these considerations to the unique characteristics of CSO produced sludges and to the problems that may be caused by these characteristics.

Preapplication Treatment

Variable characteristics, presented earlier in Tables 4, 5 and 6 have been observed for various CSO sludges around the country (12). The very high values of BOD's, volatile solids and coliforms indicate that direct disposal of raw sludges may present problems for public health (through possible disease transmission) and development of odor problems. For these reasons, it appears that CSO sludges must be stabilized before land application.

The stabilization method most frequently used is anaerobic digestion. However, there are numerous other acceptable methods, such as aerobic digestion, chemical treatment, heat stabilization or heat drying, and composting, which may be used. A promising method of stabilization for CSO sludges is lime treatment. The use of this method would allow for the stabilization of the CSO sludges either at the site of the CSO treatment facility or at the land disposal site. If dewatering of the CSO sludge is employed in order to reduce transportation and handling costs, lime stabilization can be accomplished prior to dewatering.

A procedure for the lime stabilization of municipal sludges has been developed and operated successfully on a pilot scale (35). Significant reductions in pathogenic bacteria and obnoxious odors resulted from lime treatment. Growth studies indicated that disposal of lime stabilized sludge on cropland produced no detrimental effects.

For high rate application either by entrenchment or sanitary landfill, it has been reported that the sludges should first be limed and dewatered (63). The pH of the sludge at the time of dewatering should exceed 11.5 to reduce pathogen survival and potential nuisance conditions.

Because of the success of stabilization of municipal sludges by lime treatment and the ability to achieve the stabilization at the site of the CSO treatment facility instead of transporting the sludge to a central stabilization facility and also, the ability to treat intermittent flows; lime stabilization should be considered as a feasible preapplication treatment process for a land application system.

Transportation of the Sludge

The solids characteristics of the sludge will be a primary factor influencing the type of transportation selected. If the sludge has a solids content less than 8%, it may be transported by pipelines, tank trucks or tank wagons. When the sludge is dewatered to a solids content of 15% or higher, it must be transported by either dump trucks or manure spreaders. Selection of the desired transportation mode will usually depend on production rate, distance to application site, and planned lifetime of the site.

Many large cities may optimize sludge handling and disposal costs by pumping their liquid sludges relatively long distances through pipelines. However, pipelines are probably uneconomical for small communities due to economics of scale. In addition, convenience and accessability of satellite CSO treatment sites, may make pumping very difficult to implement. As has been previously discussed, the combined sewer areas of most cities are centrally located thus creating two problems: 1) construction in heavily built up areas; and 2) vast pumping distances to avoid urban-suburban areas. These considerations along with other factors such as intermittent peak quantities of sludge to be handled and settling of grit in pipelines would probably make transportation of CSO sludges by pipeline impractical and uneconomical.

The land disposal of liquid CSO sludge can become very expensive if truck hauling is employed over long distances. The costs will be extensively dependent on the hauling distance (which can be great from the CSO treatment sites to the disposal site), the size of the truck, and the quantity of solids being hauled. However, tank trucks provide considerable flexibility with regard to site selection and hauling schedule and have the additional advantage that liquid sludge can be applied directly from the truck. These considerations seem to indicate that tank truck transportation of CSO sludges may be a viable approach.

Thickening and dewatering of the sludge could significantly reduce the operating cost of transporting CSO sludges to a land disposal site. For example, a sludge volume requiring disposal can be reduced fifteenfold if a sludge of one percent solids is thickened and dewatered to 15 percent solids. This in turn, would significantly reduce the city's annual sludge transportation costs.

From the discussion of the transportation aspects of land disposal of CSO sludges, it appears that truck transportation of either liquid or dewatered sludge is the most desirable alternative in CSO areas with significant volumes of sludge to be handled. Truck transportation of dewatered sludges might prove to be the more desirable alternative because it represents a significant reduction in operational costs from trucking the liquid sludges. However, a detailed economic analysis should be required for each individual case to determine if these savings would cover the added costs of thickening-dewatering facilities.

Storage Requirements

Since CSO events are intermittent and thus sludge volumes will not be a continuous flow, storage facilities will be required to maintain a constant application program. Storage will also be required if land disposal is prohibited due to inclement weather, frozen soil and snow cover as well as the possibility of equipment breakdown. As was previously discussed for land application of raw CSO, the average number of nonapplication days for which storage would normally be required in colder climates is about 100 days. Dewatering the sludge would significantly reduce the volumes required for storage even though the solid weights remain the same. For example, if dewatering to 15% solids is used, the volume to be stored is reduced to 1/15 of the original liquid volume. For a dewatered sludge, temporary storage pits have been used into which the sludge is dumped and from which front-end loaders obtained the sludge for application. The pits can then be closed as they become impassable and/or too far from the application area (63).

Liquid sludges are usually stored in tanks or lagoons located at the disposal site. If liquid sludge is stored, settling of the sludge solids will occur in the basin. Therefore, provisions should be made for resuspending these solids before the sludge is applied to the land. The storage facility could also become a source of odor problems and a breeding ground for mosquitoes and other insects, therefore precautions will have to be taken to prevent these problems from occurring. These precautions could be stabilization with lime before storage and a possible insect control program.

A dewatered sludge storage area would not be as troublesome as a storage basin for liquid sludge. However, the dewatered sludge could become a source of odor problems and then some remedial action would be required.

Climatological Effects

The general climate of the area will have some effects on the operation of the disposal site, although the effects will not be as pronounced as that for raw CSO.

The main climatological concern will be the restrictions that inclement weather will impose on the application operation. For the disposal of liquid CSO sludges, rainfall periods will prevent application to the land and therefore, lagoons are usually designed for the site so that they can be used for storage until the weather permits application. During winter weather, the application of both liquid and dewatered sludge may be prohibited because of frozen ground. Any CSO sludges generated during this period must be stored until application is allowed. On the average, the operation of facilities in the Great Lakes region will have to be shut down for about 3 1/2 months.

If the liquid sludge is to be applied by a truck, all-weather roads that would allow for discharge to either side of the road should be constructed at the site. This would help to offset wet periods and compaction problems. For inclement weather operation, flexibility could be established by use of fixed piping or movable irrigation equipment (64). For a dewatered sludge disposal operation, all-weather roads should be provided so that disposal can be utilized during periods of rainfall and wet grounds.

Pollutional Loading Constraints

In applying CSO sludges to the land, the control of loading rates will be based mainly on concerns for the migration of pollutants to the groundwater and the accumulation of heavy metals in the soil and vegetation. As was illustrated using raw CSO, some of the pollutants that may lead to restrictions on the loading rates of sludges to the land will be investigated using similar constraints as that presented earlier. The following CSO values, based on average characteristics, have been assigned for use in this section.

Raw CSO Volume: 1382×10^6 ℓ/yr (365×10^6 gal./yr)
Volume of Sludge as Percent of Volume Treated: 2.8%
Yearly CSO Sludge Volume: 38.6×10^6 ℓ(10.2×10^6 gal.)
CSO Sludge Concentration: 1 percent solids
Yearly CSO Sludge Solids Volume: 386 metric tons (425 tons)-dry weight basis*
Pollutional Characteristics:

SS	10,000	mg/l	
BOD	100	mg/gm	SS
N	12.5	mg/gm	SS
P	10	mg/gm	SS
Zn	1000	mg/kg	
Cu	400	mg/kg	
Ni	200	mg/kg	

Yearly CSO Sludge Volume after Thickening to 4% Solids: 9.8×10^6 ℓ(2.6×10^6 gal.)
Yearly CSO Sludge Volume after Dewatering to 15% Solids: 2.6×10^6 ℓ (0.7×10^6 gal.)

Toxic Elements - Restrictions have been placed on the practice of land disposal in order to limit the maximum loading of the metals on the land (16). Wisconsin has developed an approach which takes into account the combined effect of the metals by using a measurement entitled the zinc equivalent. This was presented and discussed in the previous section. From this approach it is possible for a standard to be developed which would maintain heavy metal concentrations below toxic levels.

Since calculation of the ZE of the CSO sludge material requires knowledge of zinc, nickel and copper concentrations, it was assumed that the concentrations (mg/kg) will be similar to raw CSO. Using the Wisconsin approach, the acceptable total zinc equivalent loading would approximate 21 metric tons/ha/yr (9.4 tons solids/ac/yr) for soils having cation exchange capacities of 15 meq/100 gm and 20 year designed life. Thus, the area requirements

*All metric tons throughout this section are expressed on a dry weight basis for safe control of toxic metals would be about 4.7×10^{-2} ha/metric ton/yr (10.6×10^{-2} ac/ton/yr).

In addition to the metal equivalents' limitations, cadmium additions may become a serious limiting parameter because of its toxicity effects to both humans and plants. Cadmium loadings must be limited to a maximum of 2.2 kg/ha/yr (2 lb/ac/yr) and the total site lifetime maximum of 22 kg/ha (20 lb/ac) (65). To determine loading constraints, a cadmium value of 40 mg/kg was assumed. The calculation of loading rates indicate that cadmium loadings limit annual application to 56 metric tons/ha (25 tons/ac) and overall cadmium loading to 560 metric tons/ha (250 tons/ac), assuming a 20 year site life. Therefore, the area requirements necessary for safe applications of cadmium would be about 1.8×10^{-2} ha/metric ton/yr (4.0×10^{-2} ac/ton/yr). It is apparent that from the differences in land area requirements the metal equivalents are the limiting loading constraints in the application of toxic materials to the land.

Nitrogen and Phosphorus Control - In determining the allowable loading of nitrogen to the land, the objective shall be to match as closely as possible the quantity of nitrogen removed from the soil by the harvesting of the crop. The allowable loading rate will thus be determined by the nutrient content of the sludge and the nutrient uptake capabilities of the particular crop under consideration. The rate of application for CSO sludges can be calculated using the same equation as that used for the application of raw CSO. Additional assumptions that had to be made included: 1) crop nitrogen removal rate for corn is 201 kgN/ha-yr (180 lb N/ac-yr) and 2) the nitrogen concentration in CSO sludges is 12.5 mg TKN/gm SS or 125 mg/l.

Using these assumptions, the sludge application rate would be approximately 255.4 kg N/ha-yr (228 lb N/ac-yr) thus resulting in a land area requirement of 4.9×10^{-2} ha/metric ton sludge/yr (11.1×10^{-2} ac/ton sludge/yr). If grass is grown instead of corn, the land area requirements could be reduced to 3.7×10^{-2} ha/metric ton sludge/yr (8.2×10^{-2} ac/ton sludge/yr).

Besides nitrogen, phosphorus has also been a nutrient of concern. Current restrictions limit phosphorus annual loading rates within the 68 to 136 kg P/ha-yr (150-300 lb P/ac-yr) range. On this basis, the total land area required for safe application of phosphorus should not exceed 4.0×10^{-2} ha/metric ton sludge/yr (8.9×10^{-2} ac/ton sludge/yr) for CSO sludges containing P concentrations of 10 mg P/gm SS.

Organic Application Rates - Although the rate of organic carbon oxidation in soils is known to be high, limitations for waste additions are not adequately established. A few regulations have been proposed to limit BOD_5 application rates to around 672.6 kg/ha-day (600 lbs/ac-day). However, Jewell (66) recently reported that a soil system could degrade organics at a rate exceeding 4480 kg/ha-day (4000 lb/ac-day). If this latter limitation is used, the safe application areas for CSO organics would be 2.3×10^{-2} ha/metric ton sludge/yr (5.2×10^{-2} ac/ton sludge/yr).

Hydraulic Loading - Since the permeability of much of the area in the northern states exceeds 5 cm per hr (2 in./hr), it can be inferred that the transmission of water from the sludge would be a minimal problem. However, the application of the more dilute sludges (i.e. 1% solids) may be restricted to several application periods per year to prevent surface flooding and runoff.

Land Area Requirements - The actual land area required for the disposal of the CSO sludges, either liquid or dewatered, will be dependent on the allowable application rates which, in turn, will be dependent on the soil type, the nutrient and heavy metals content of the particular sludge, and the nutrient uptake characteristics of any vegetation crops on the site.

For field area requirements, a summary of the application rates estimated to be acceptable and the resulting land requirements are shown in Table 40. Similar to raw CSO, the limiting pollutant loading factor is the nitrogen content of the sludges. Nitrogen is most often the limiting factor for application of municipal sludges. If nitrogen limitations determine the required land area, it can be seen that the application rates of the other pollutants are one-third to two-thirds that which is assumed to be an environmentally safe rate of application. Recommendation of the use of a 5.3×10^{-2} ha/metric ton sludge/yr (11.8×10^{-2} ac/ton sludge/yr) land area requirement should provide a safety factor large enough to account for any unpredictable events. This application is equivalent to adding a CSO sludge (4% solids) once at a depth of 4.8 cm (1.9 in.); or an application rate equal to 19.0 metric tons/ha/yr (8.5 tons/ac/yr).

These land requirements are for the actual application only and, as shown in the discussion of land disposal of the raw CSO, additional land may be required for roads, buffer zones, possible storage and pretreatment facilities, etc. In studies of land application of municipal wastewater plant effluents, it has been found that only 70 percent of the total site area is available for actual application (67).

Employing the above application rate of 19.0 metric tons/ha/yr (8.5 tons/ac/yr), and if the nationwide annual generation of CSO solids totals 1.57×10^6 metric tons (1.73×10^6 tons), field area requirements for CSO sludges, either liquid or dewatered, would approximate 82×10^3 ha (203×10^3 acres) of land. Assuming that, on the average, the land required for actual disposal is 70 percent of the entire disposal site, the nationwide disposal of CSO sludges would require a total land area of 118×10^3 ha (290×10^3 acres).

Application Techniques

The application technique that is employed at a specific land disposal site will be dependent to a large extent on the characteristics of the site, physical properties and quantity of sludge, and the objectives of the land disposal program. The techniques presented here are those that have been reported in the literature for municipal treatment plant sludges.

Systems are available for surface and subsurface application of liquid sludges. Surface application of liquid sludge is generally accomplished by ridge and furrow irrigation or by tank truck land spreading. The most common technique is direct application to the land by spraying from tank wagons. Most communities employing this technique use city-owned tank trucks with capacities ranging from 3.8 to 18.9 cu m (1,000 to 5,000 gal.) and equipped with various spreading devices operated by gravity or pumping (64). The tank truck has the advantage that it can also be used for sludge transport. Liquid manure spreaders, pulled by farm tractors, have been found to be very effective and accurate in the application of the sludge to the soil. It may be desirable to incorporate the sludge into the soil as soon as possible following application in order to prevent possible odor and runoff problems.

TABLE 40. SUMMARY OF RECOMMENDED DRY SLUDGE SOLIDS APPLICATION RATES FOR VARIOUS CSO SLUDGE POLLUTANTS AND THE RELATED LAND AREA REQUIREMENT

	Acceptable application rate		Land area requirement	
Pollutant	kg/hr/yr	(lb/ac/yr)	10^{-2} ha/metric ton/yr	(10^{-2} ac/ton/yr)
Toxic	21.0[a]	(9.4)[a]	4.7	(10.6)
Nitrogen	255.6	(288)	4.9	(11.1)
Phosphorus	252	(225)	4.0	(8.9)
Organics	4,484[b]	(4000)[b]	2.3	(5.2)

[a] Expressed as metric tons/ha/yr (ton/ac/yr) - dry weight basis

[b] Expressed as kg/ha/day (lb/ac/day)

Flooding and ridge and furrow irrigation methods have also been used as sludge application techniques. Ridge and furrow has the advantage that it is suitable for row crops during the growing season.

Soil incorporation of liquid sludge can be accomplished in a number of ways. The most common methods are plow-furrow cover and subsurface injection. The plow-furrow-cover method involves the spreading of sludge in a narrow swath from a wagon and immediately covering the waste using a plow. Subsurface injection involves the discharging of liquid sludge into subsurface channels caused by chisel-like plows.

Another disposal technique has been used at non-agricultural land sites. Disposal by small treatment plants may incorporate digging of shallow trenches, filling them with liquid sludge and covering the sludge with soil to prevent nuisance conditions (69). The literature shows that, with the use of ridge and furrow irrigation, trench disposal, and flooding techniques on non-agricultural land, it is possible to use greatly increased loading rates. However, groundwater and other public health consideration may place significant constraints on these loading rates.

When dewatered sludge is applied to the land, the usual method of application is to spread the sludge on the land and then disc it into the soil using earth moving equipment and farm machinery. The one disadvantage of this method is that it may be difficult to break up the sludge cake in such a manner that it can be easily spread.

Entrenchment is another application method that has been employed. Entrenchment has been found to be a feasible method for simultaneously disposing of sewage sludges and improving marginal agricultural land, particularly for dewatered (20% solids) raw, lime treated sludge (63).

In devising an application system for land disposal of CSO sludges, minimizing costs and maximizing the application season should be the major considerations. The preceeding discussion shows that there is a very wide range of application techniques that have been used with varying application systems. It appears that many considerations may dictate the possible application technique at the site, however, the most economical application technique should be selected.

Growth Of Crops On The Site

For the disposal of CSO sludges on agricultural land, the growth of crops or vegetation on the disposal site can be a very important aspect of the site operation. The basic reason for cultivating crops or a vegetative cover is to achieve nitrogen uptake so that the nitrogen is removed from the soil and ultimately removed from the site when the crops or vegetation are harvested (64).

It is generally agreed that alfalfa is a most desirable crop, particularly if sufficient nitrogen is available in the sludge to eliminate nodule formation on the root structure (64). This ensures that the maximum uptake of nitrogen occurs and that the movement of nitrates into either ground or surface water will be minimized. By cutting alfalfa three or four times during the growing seasons increased quantities of nutrients may be removed. In addition, each cutting allows for additional sludge application. This would be advantageous for the more dilute sludges requiring several application periods.

Corn is perhaps the next best and most widely used cover crop, having the advantages of high nitrogen uptake and good saleability. It has limited flexibility for sludge application during the growing season unless the ridge and furrow method of liquid sludge application can be used.

The other general purpose group of crops is the forage grasses. The greatest advantage of these crops, in addition to nitrogen uptake, is their accessibility in inclement weather, during early spring planting, in late fall before the soil cools down, and during the active growing season when other crops restrict tank truck operation (64).

Monitoring Program

The application of sludge to land disposal sites must be managed to minimize the risks of nitrogen and pathogen contamination of surface and groundwaters; to minimize the risks of soil degradation by metal overloading and of toxic metal uptake by crops; to minimize the risks of pathogen transmission by insects and animals; and to minimize offensive odors. Thus, the monitoring program employed at the disposal site will be extremely important. A comprehensive monitoring program, as that suggested earlier, will be essential to ensure that proper renovation of the CSO is proceeding without degradation of environmental quality.

Application rates should be subject to good record keeping and monitoring because overloading of a particular soil can be a major reason for failure of a land site. Caution should be used in dealing with acid soils because of the possible release of heavy metals. Here the general rule is to maintain a pH above 6.5 to control heavy metal solubility (64).

Summary

In discussing the logistics of treatment and disposal of CSO sludges, it is apparent that land application in general may be extremely feasible, both practically and economically. Therefore, the municipality or sanitary district should regard land application as a viable alternative. However, its implementation should be based upon this alternative being the least-cost acceptable means of sludge handling and disposal.

Three management options are available: 1) land spreading a dilute sludge (1% solids); 2) land spreading a thickened sludge (4-8% solids); and 3) land spreading a dewatered sludge (>12% solids). It should be noted that land area requirements are the same for all three options, however, the solids handling and disposal costs will differ greatly. The high costs associated with transporting, storage and intermittent application of dilute sludges will probably cause option one to be least cost-effective. In most cases, options two and three will be economically feasible. The difference will depend on transporting and storing costs versus additional dewatering costs.

Land application of CSO sludges has one major limitation which must be considered when evaluating the cost-effectiveness of this alternative to that of another management technique. Before sludge can be disposed, it must first be treated (stabilized) to reduce adverse impact on receiving land. From some stabilization processes, this can be a very costly expenditure. The most promising and possibly the most cost-effective method of stabilization of CSO sludges may be lime treatment.

SECTION VIII

ECONOMIC IMPACT OF HANDLING CSO TREATMENT RESIDUALS

INTRODUCTION

The economic impact of handling CSO residuals is difficult to estimate on a generalized basis. This section presents basic economic data to approximate the costs associated with handling generated volumes of CSO sludges using various CSO treatment systems. It is emphasized at this point that the costs presented herein are guidelines and are included only as a first approximation of the actual costs involved. If a detailed economic evaluation is necessary or desired, the individual site must be evaluated separately with respect to locale, rainfall patterns, type and location of treatment system, etc. Then the equipment costs should be established by estimates of manufacturers, not by generalized cost curves. However, the information presented will allow an approximation of the ranges of costs for handling CSO treatment residuals throughout the country and is valuable when properly applied.

BASES OF COST ESTIMATES

In providing cost estimates, it was desirable to utilize similar bases for all of the treatment trains evaluated. This was done, as much as possible, by utilizing published cost curves or other data and then adjusting them to reflect June, 1976 prices. Whenever a similar unit process was applied in different schemes, the same cost estimating structure was used.

When satellite treatment systems were evaluated, the same four systems were considered for each site. These included the following:

1. Lime Stabilization → Storage → Gravity Thickening → Vacuum Filtration → Landfill
2. Lime Stabilization → Storage → Gravity Thickening → Vacuum Filtration → Land Application
3. Lime Stabilization → Storage → Gravity Thickening → Land Application
4. Lime Stabilization → Storage → Land Application

An average of the annual CSO sludge volume was used to establish system design flow rates and the following assumptions were made to size equipment:

1. Storage - store 48 hours of CSO sludge.
2. Lime Stabilization - treat within 24 hours.
3. Gravity Thickening - treat within 48 hours.
4. Vacuum Filtration - treat within 48 hours.

It was assumed for all cities, that half of the rainfall results in combined sewer overflow and of this volume, a fixed percentage is CSO sludge, depending upon the CSO treatment system used. Also it was assumed that addition of lime for stabilization increased the solids to be handled by 15%. (35). Figures 13 - 17 were used to estimate capital costs for pumping, gravity thickening, lime stabilization, vacuum filtration and landfill (43). Storage tank costs were estimated using unit costs per volume as listed below (69).

Tanks:

m^3	Gallons	$ Installed
936	(250,000)	98,000
1872	(500,000)	150,000
3744	(1,000,000)	230,000
7488	(2,000,000)	355,000
14976	(4,000,000)	560,000
22464	(6,000,000)	760,000

Operation and maintenance costs were estimated from several sources. Figures 18 - 23 included manpower and utilities costs for pumping, gravity thickening and vacuum filtration. These costs were adjusted to dollars using a daily rate of $32 per man-day and utilities cost of $0.001/KWhr. Lime stabilization operating and maintenance costs were estimated based on published data regarding lime stabilization (35):

Sludges from physical treatment = $9-10/metric ton ($8-9/ton)
Sludges from physical/chemical treatment = $14-19/metric ton ($13-17/ton)
Sluges from biological treatment = $13-17/metric ton ($12-15/ton)

Landfill operation and maintenance costs were based on those presented in Figure 24 and then adjusted to June, 1976 values (70).

Transportation costs utilized depended upon the type of sludge, percent solids, and distance to landfill or land application site. The solids concentrations utilized were: Lime Stabilized only - 1%
Gravity Thickened - 5%
Vacuum Filtered - 20%

Distances used were dependent upon the size of the CSO area in the city. The approximate distances were estimated from the following:

CSO Area	Distance
0-202ha (0-500 acres)	32.2km (20mi)
203-2307ha (501-5700 acres)	32.2km (20mi)
2308-10118ha (5701-25000 acres)	64.4km (40mi)
10119-24282ha (25001-60000 acres)	64.4km (40mi)

Once these assumptions were established, then annual transportation costs were estimated using Figures 25 and 26. Land application cost estimates consisted of several individual components including storage requirements, distribution costs, land requirements and costs and land preparation costs. It was assumed that liquid sludge would be applied periodically throughout the growing

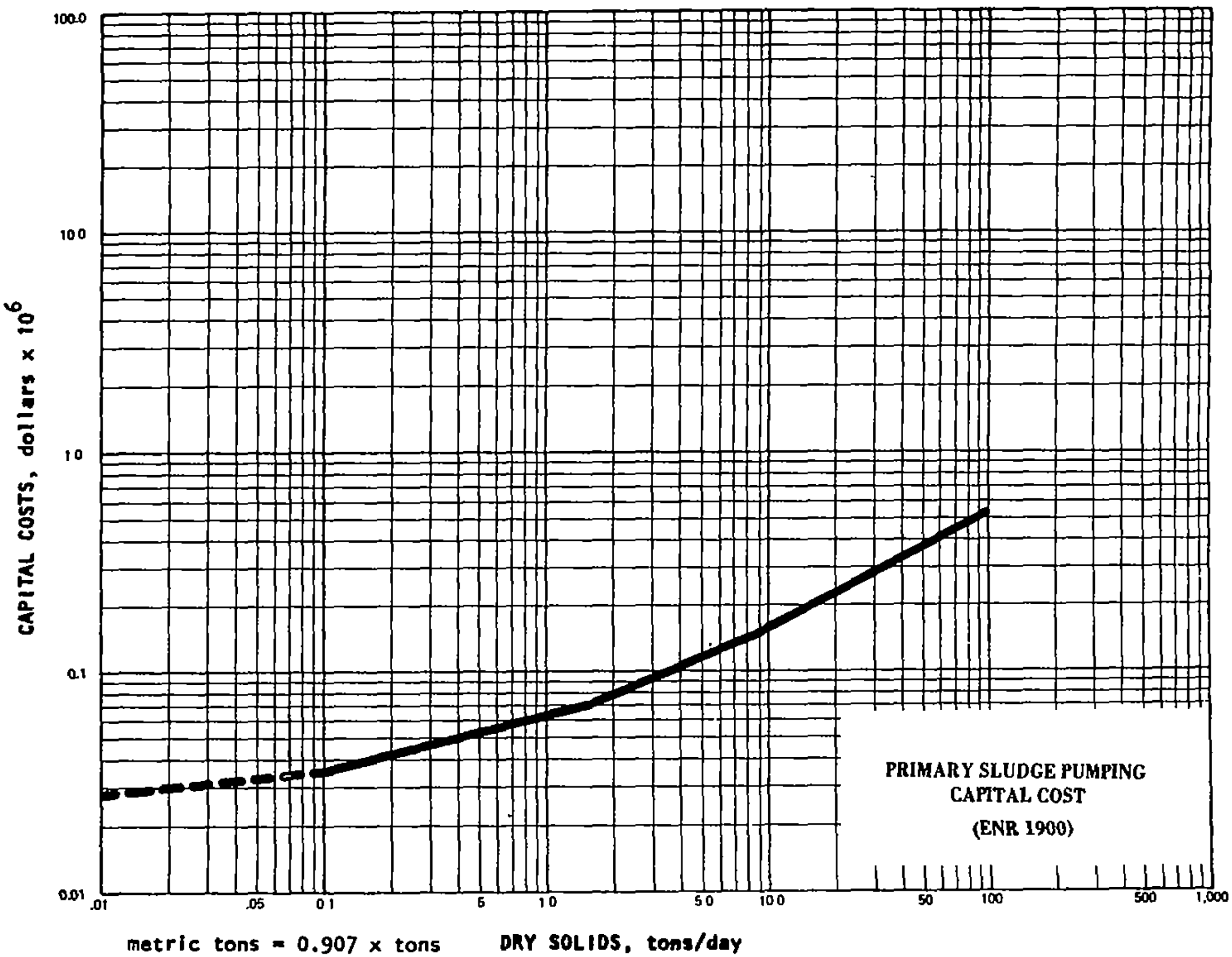
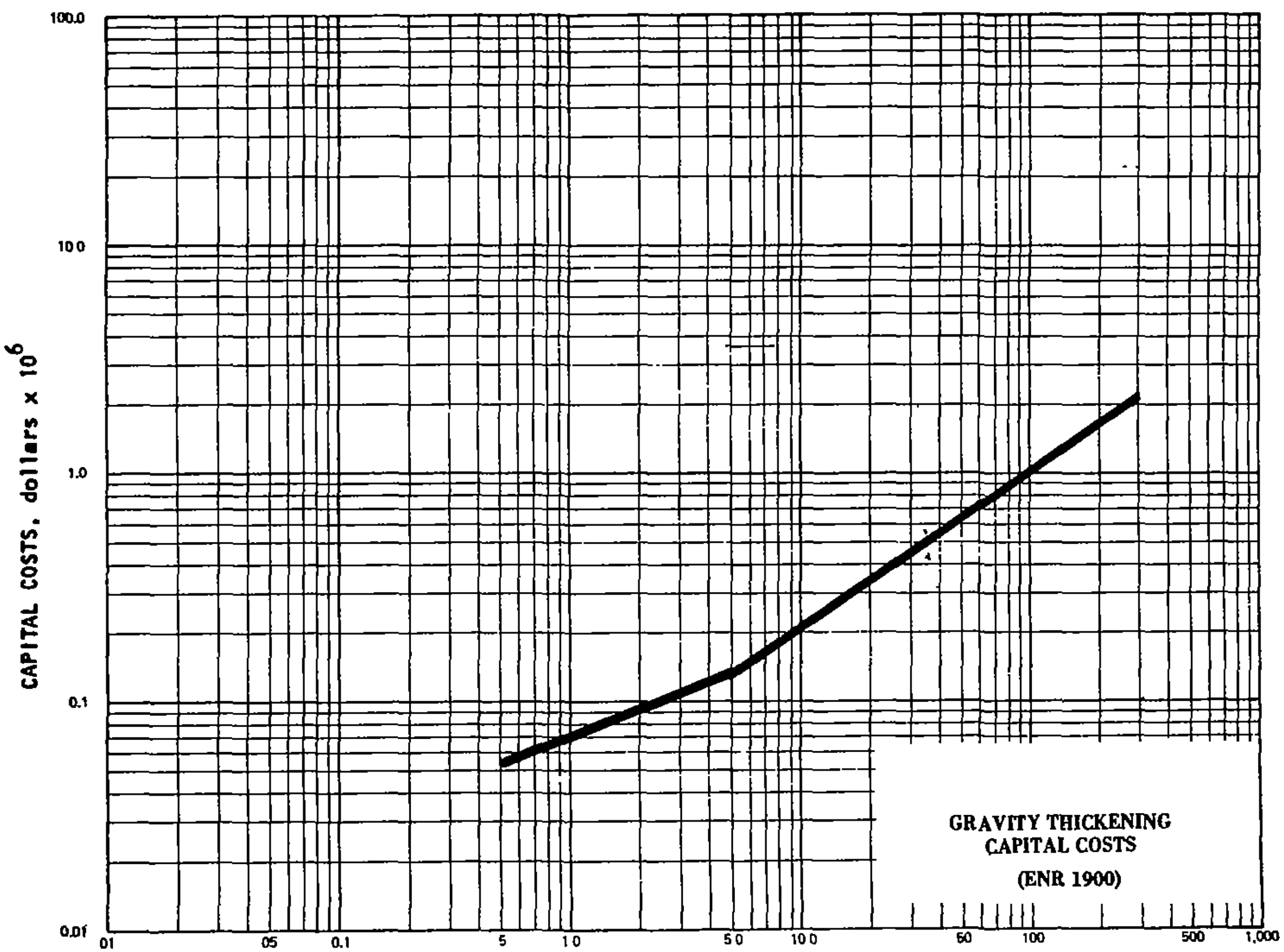


Figure 13. Capital cost estimate basis-primary sludge pumping (43).



metric tons = 0.907 x tons DRY SOLIDS, tons/day

Figure 14. Capital cost estimate basis-gravity thickening (43).

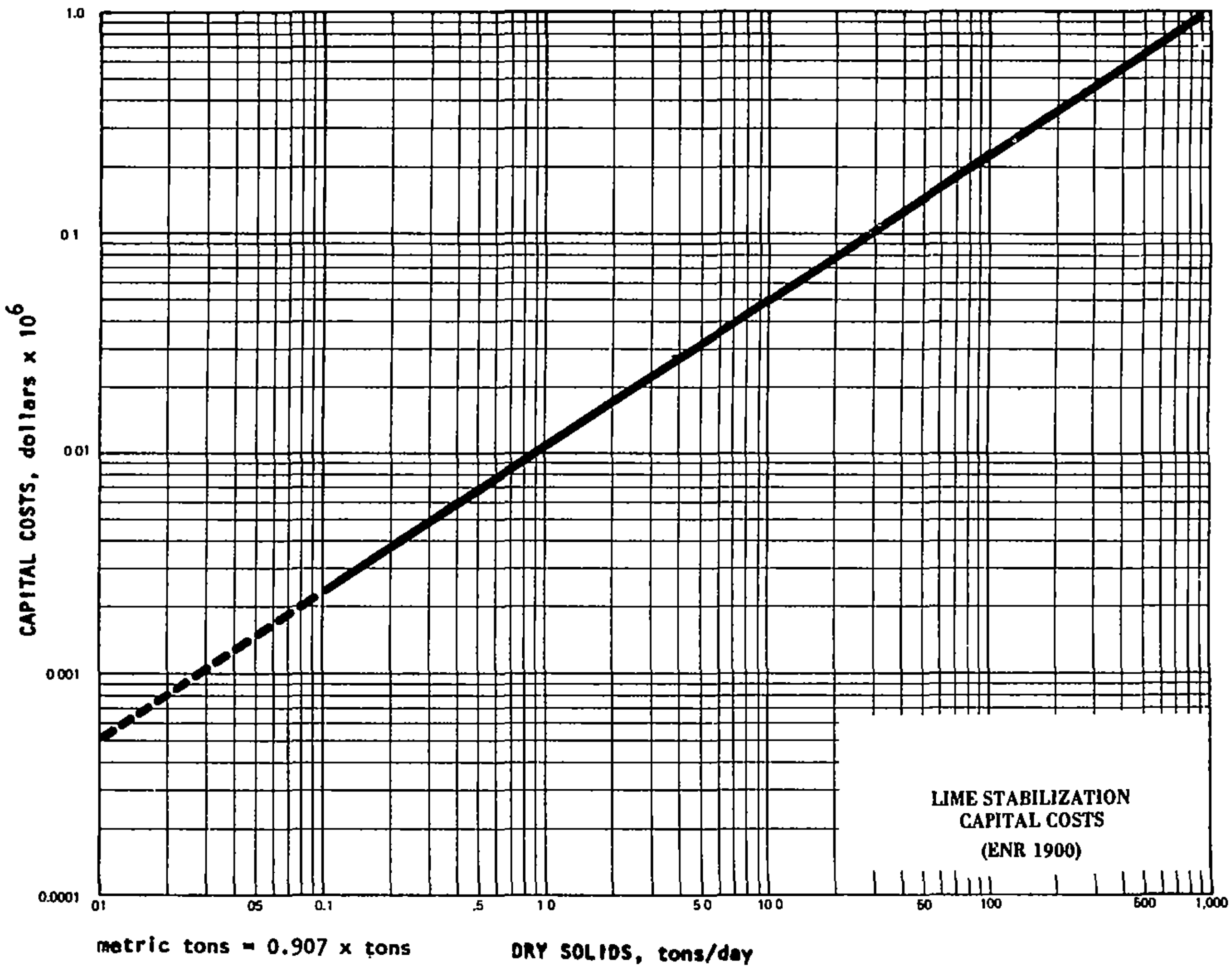


Figure 15. Capital cost estimate basis-lime stabilization (43).

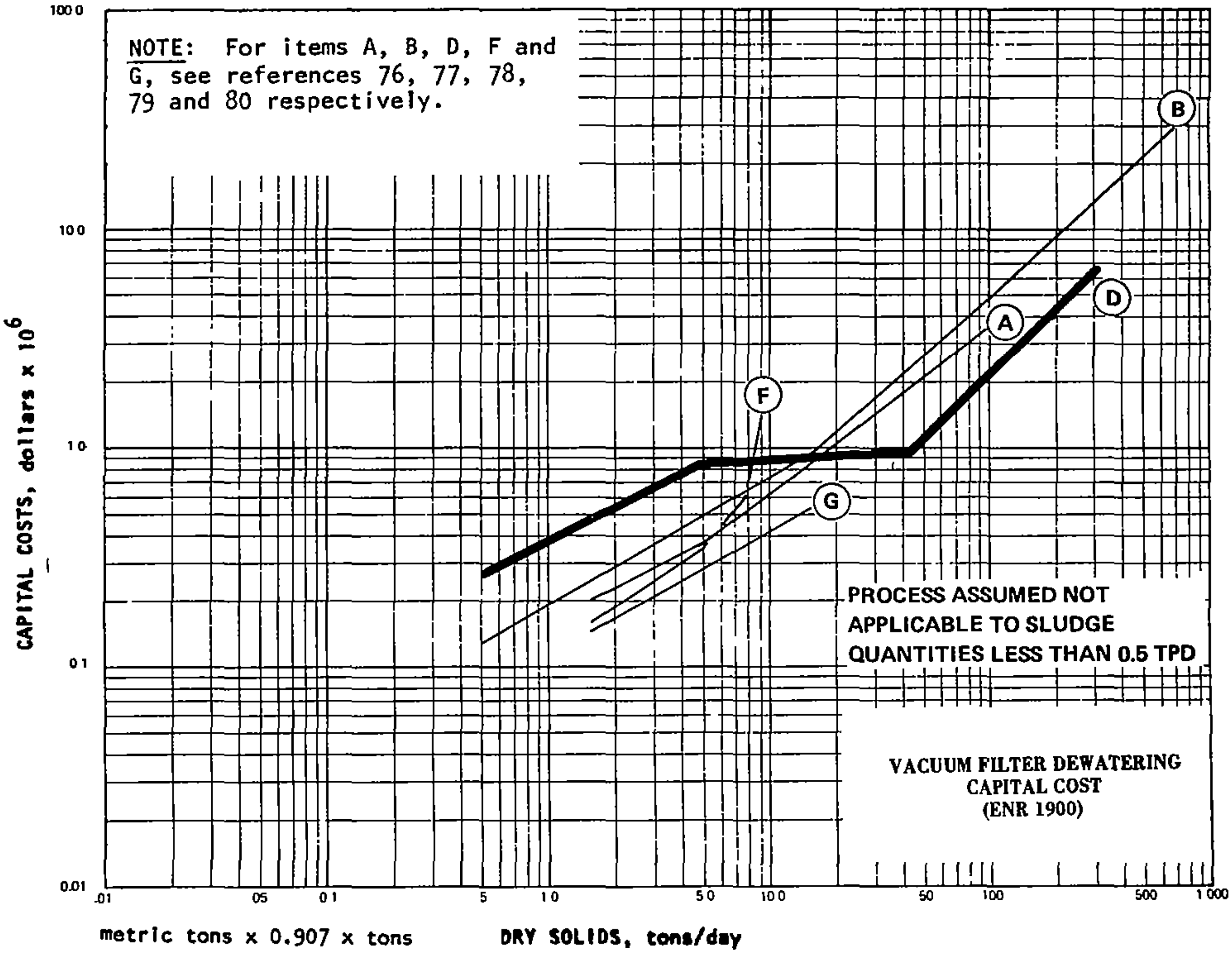


Figure 16. Capital cost estimate basis-vacuum filter dewatering (43).

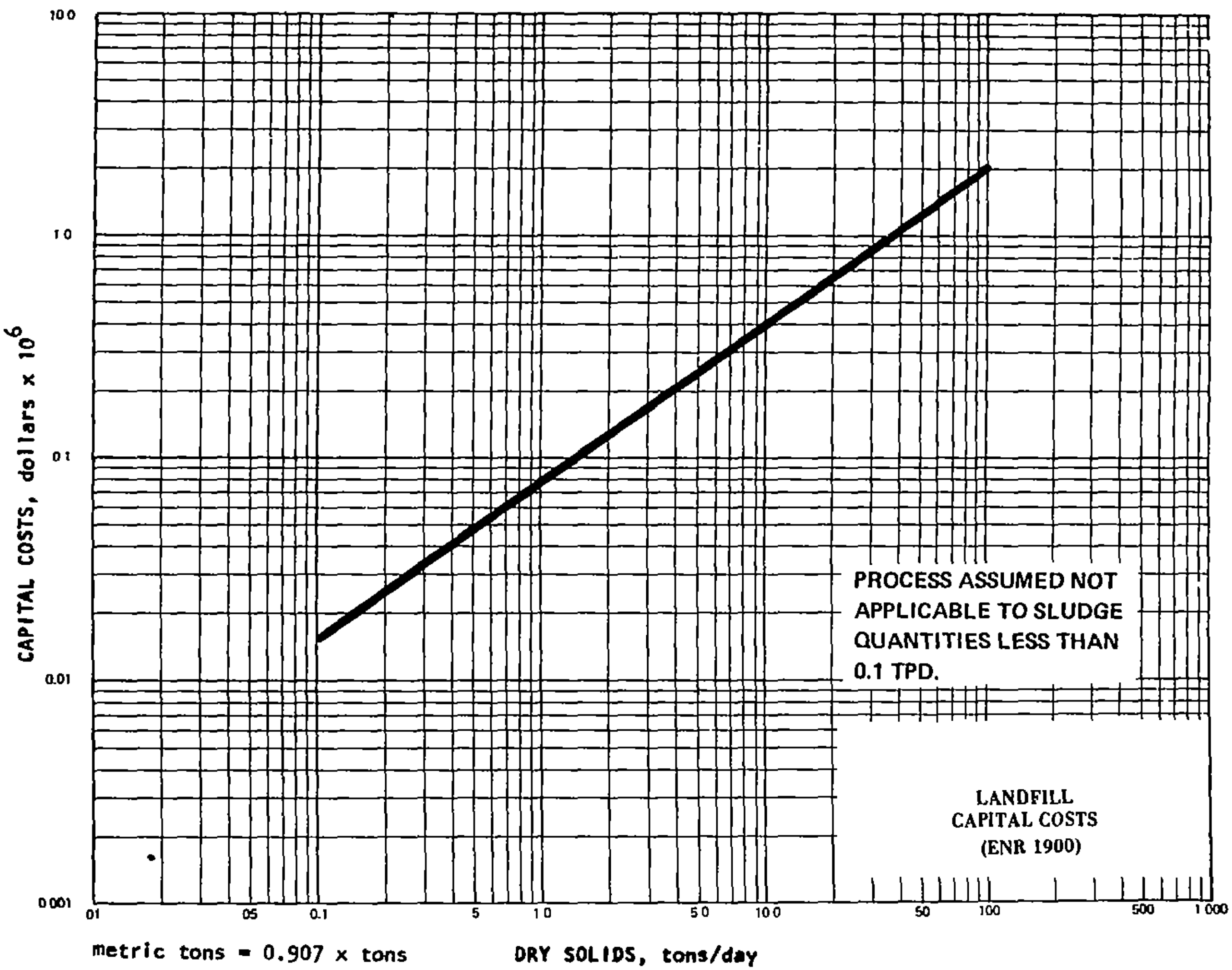


Figure 17. Capital cost estimate basis-landfill (43).

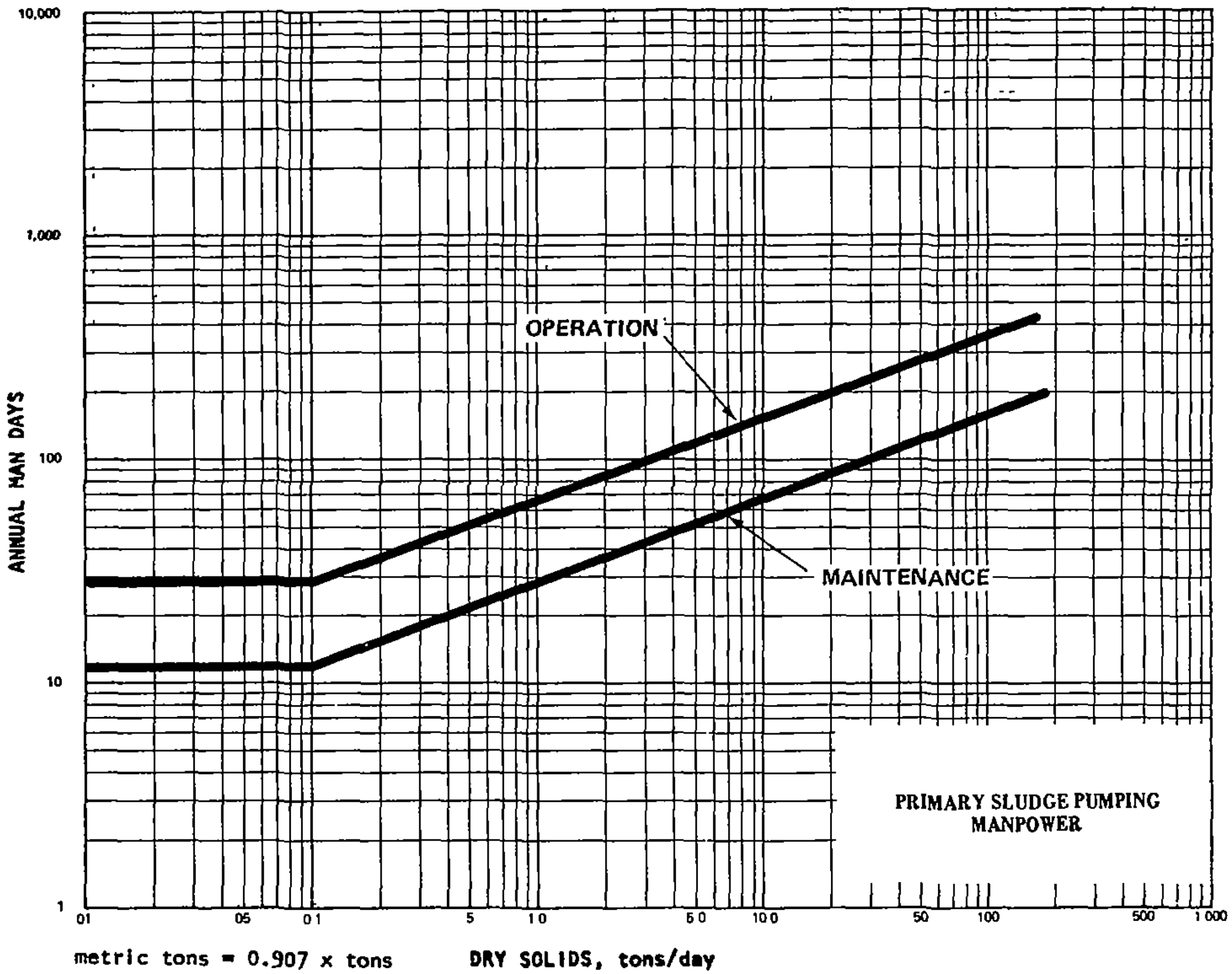
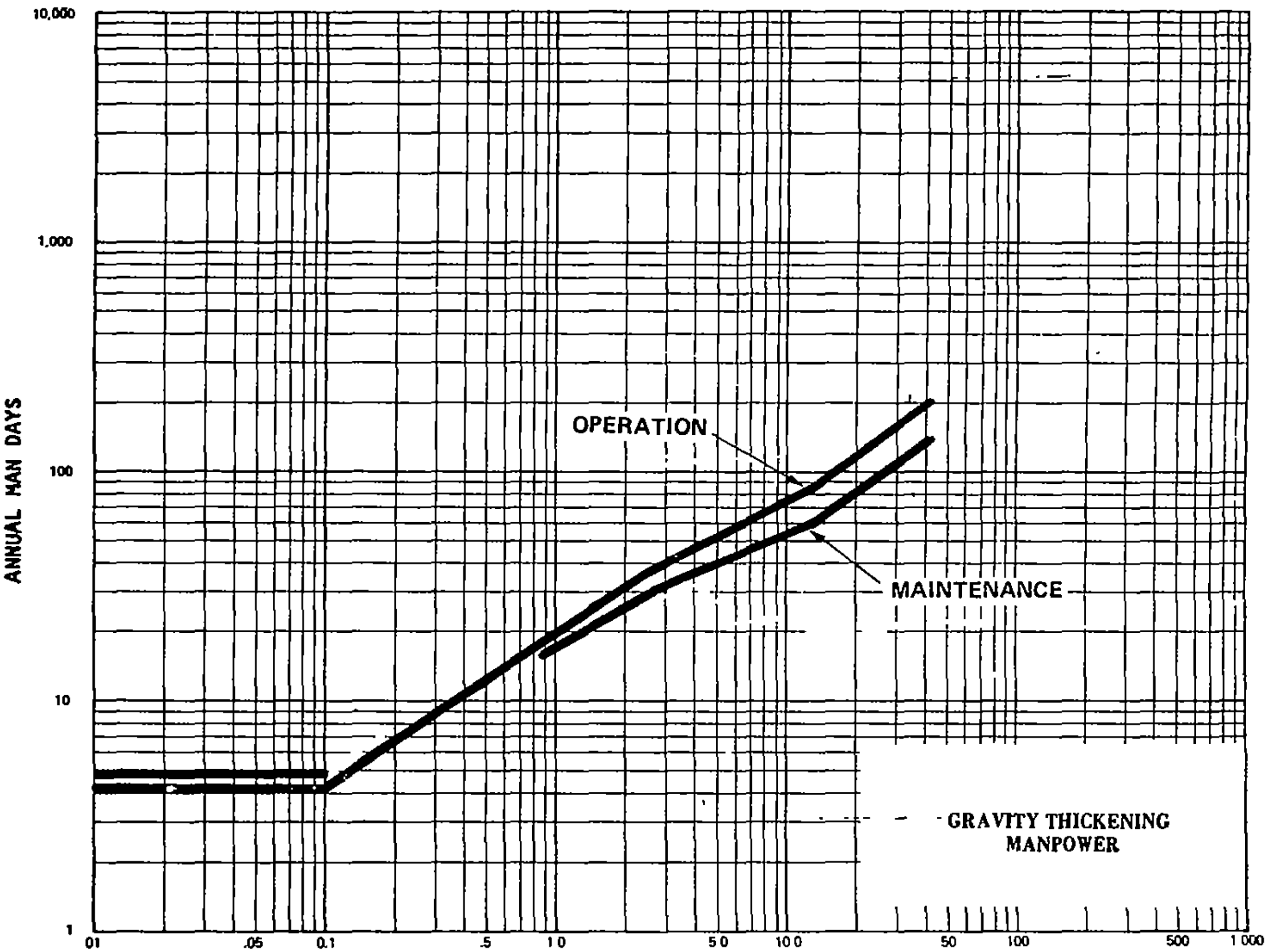


Figure 18. Manpower cost estimate basis-primary sludge pumping (43).



metric tons = 0.907 x tons DRY SOLIDS, tons/day

Figure 19. Manpower cost estimate basis-gravity thickening (43).

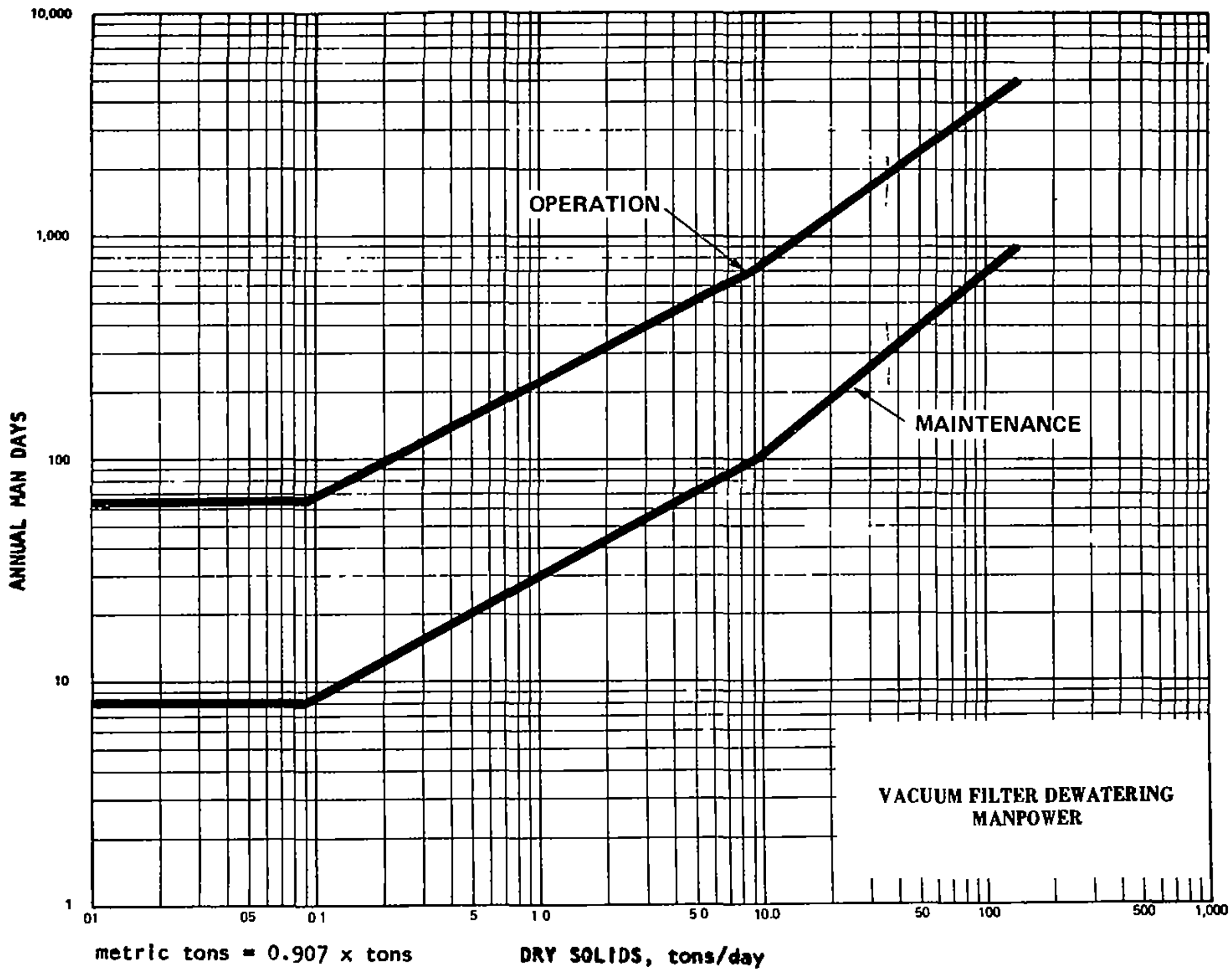
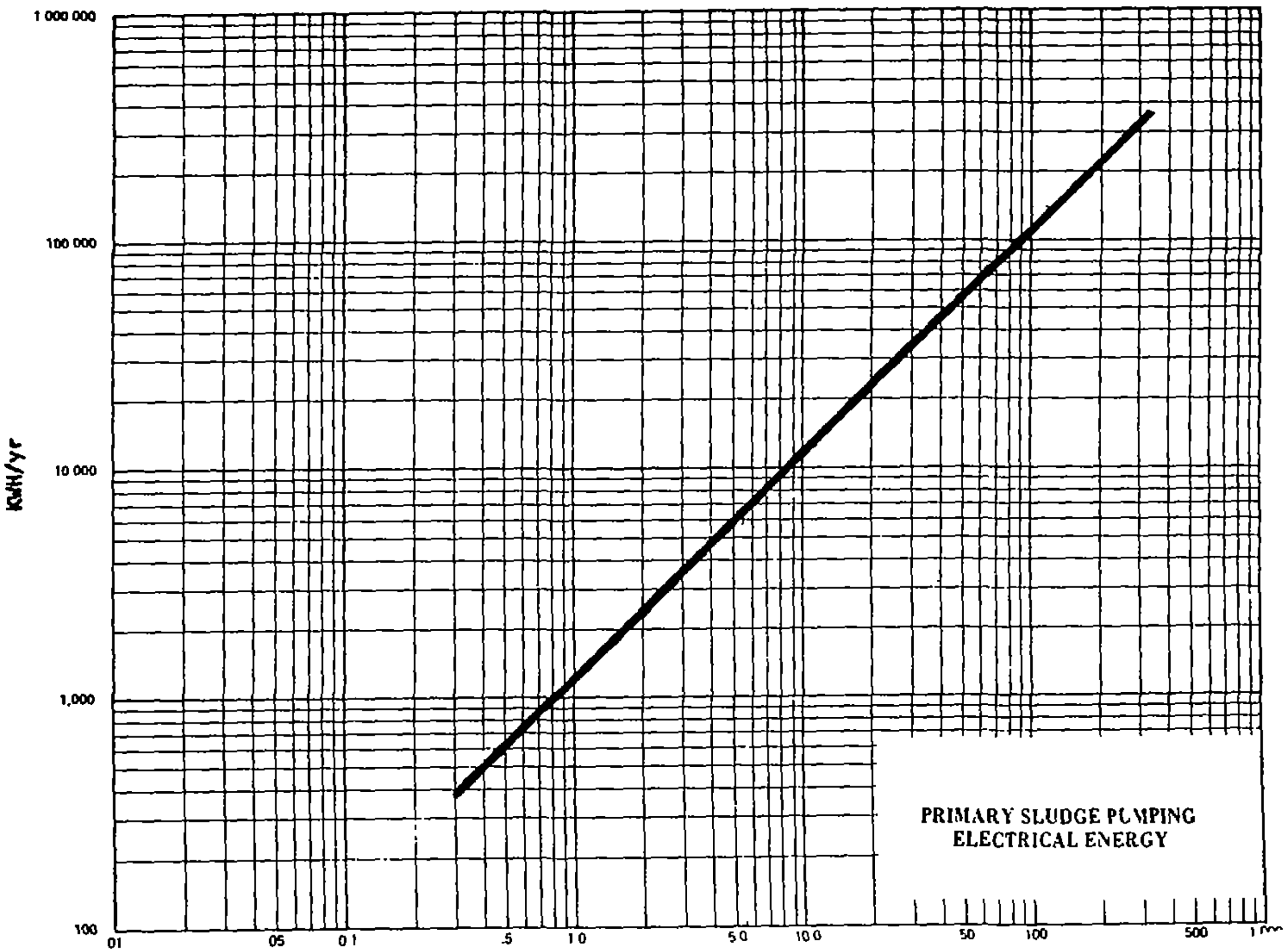


Figure 20. Manpower cost estimate basis-vacuum filter dewatering (43).



metric tons = 0.907 x tons DRY SOLIDS, tons/day

Figure 21. Electrical energy cost estimate basis-primary sludge pumping (43).

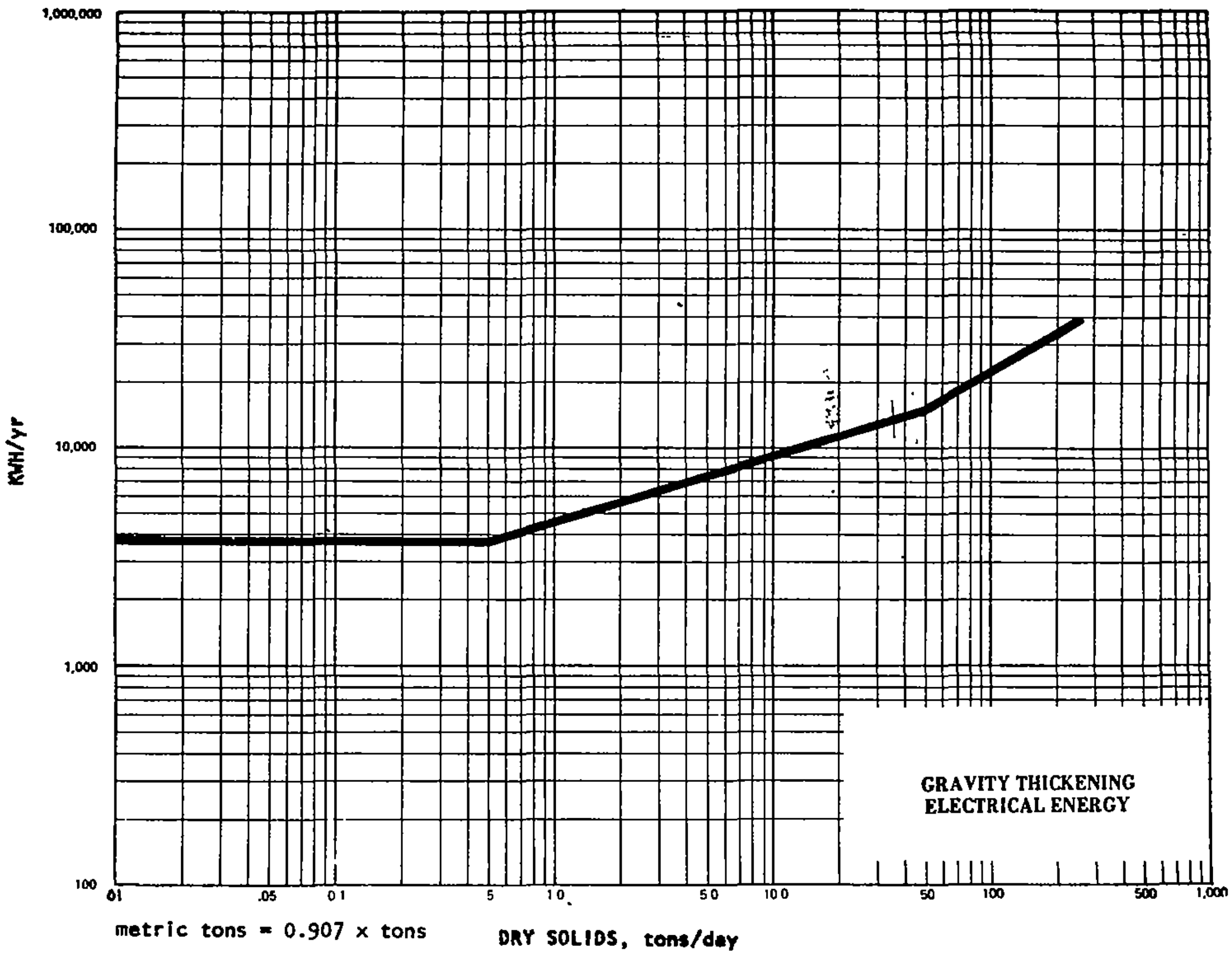


Figure 22. Electrical energy cost estimate basis-gravity thickening (43).

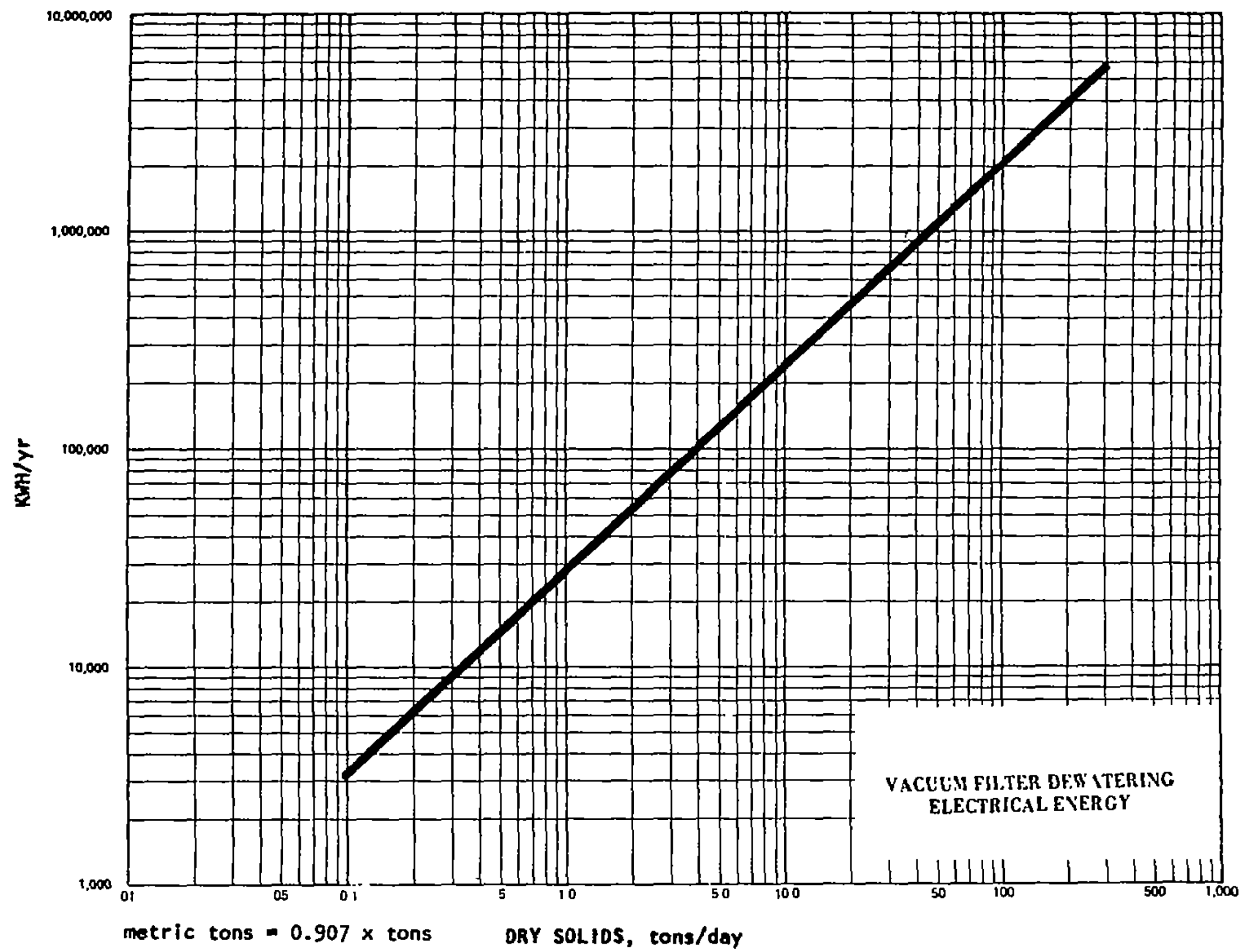
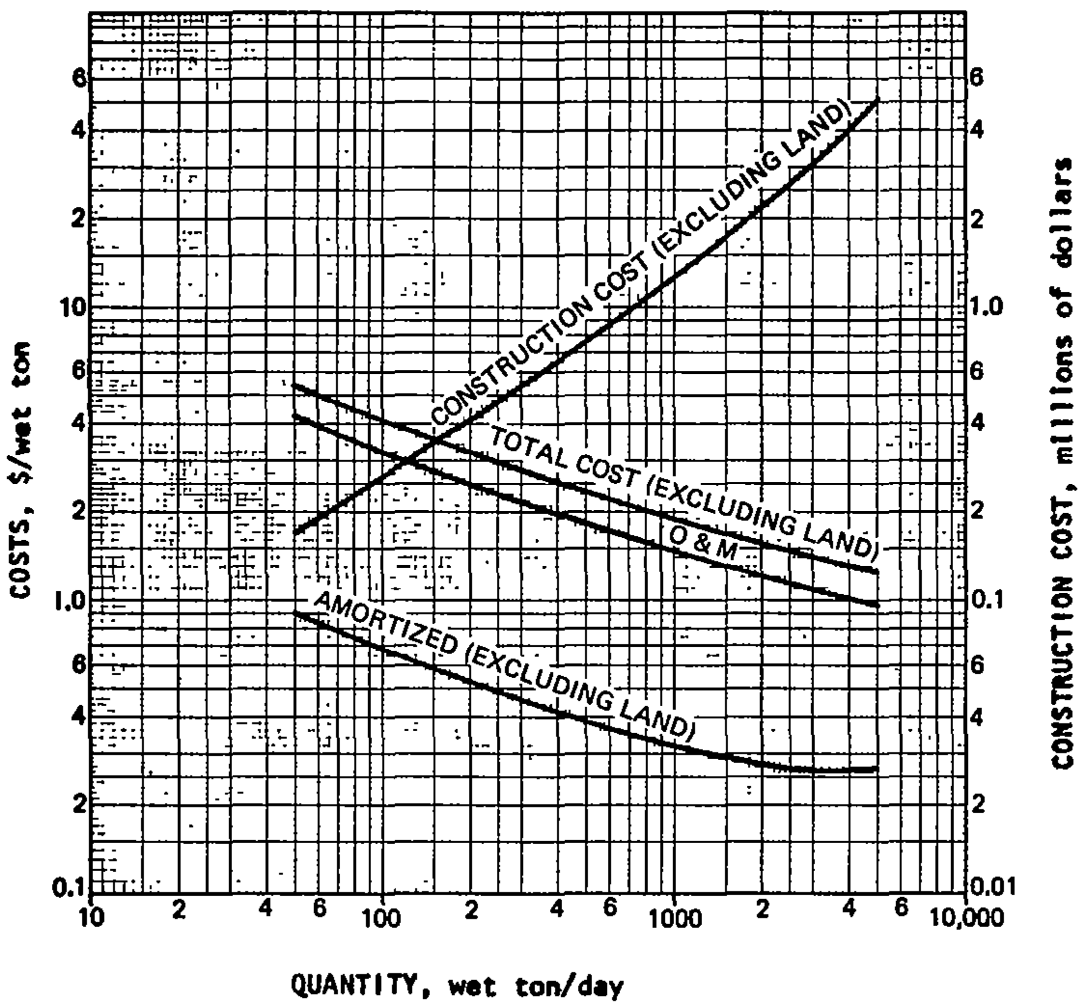


Figure 23. Electrical energy cost estimate basis - vacuum filter dewatering (43).

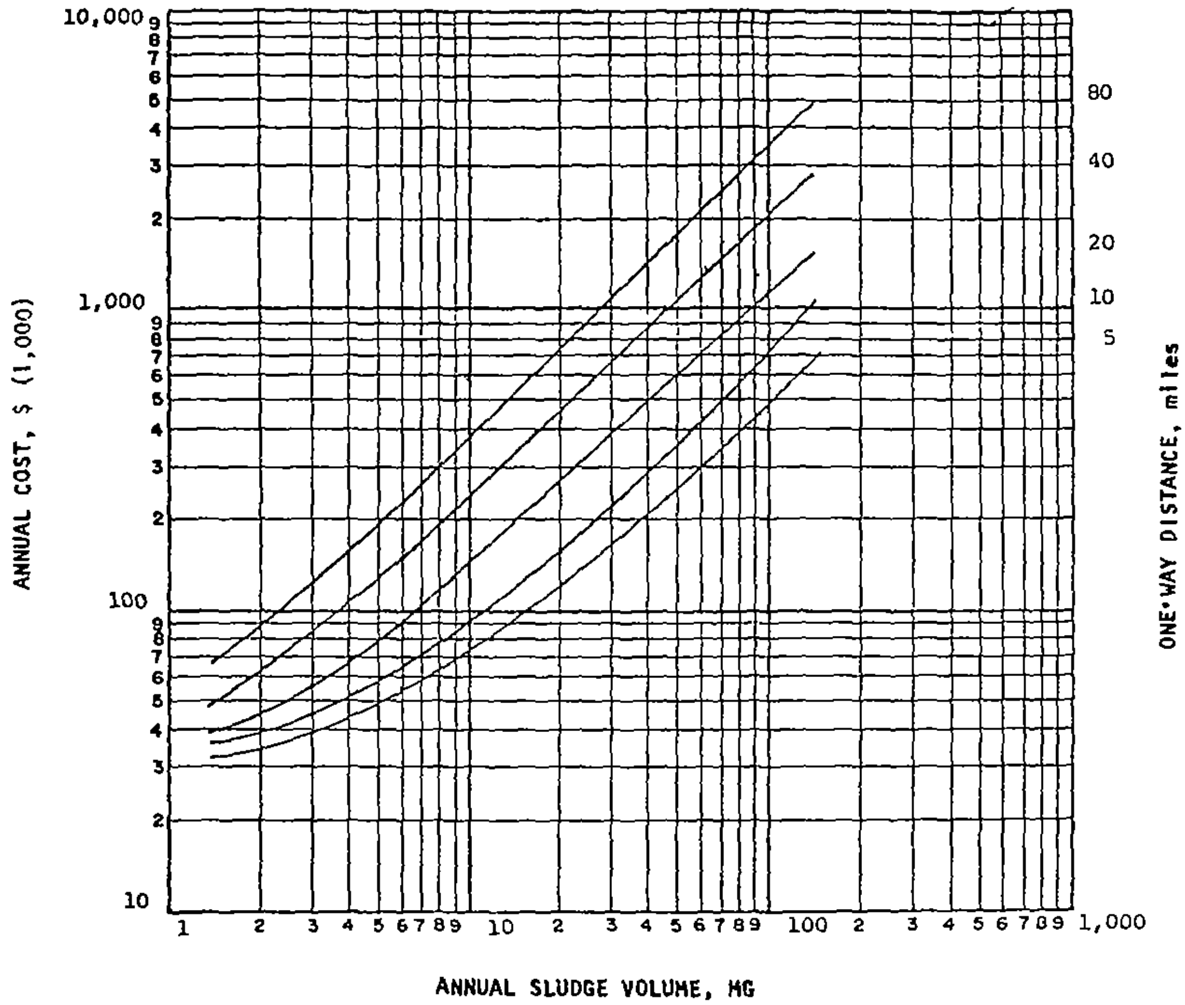


NOTES:

1. Minneapolis, Mar., 1972, ENR Construction Cost Index of 1827.
2. Amortization of 7% for 20 years.
3. Labor rate of $6.25 per hour.
4. Quantity assumes 6-day work week.
5. Wet sludge must be considered for cost per ton.
6. Source: U. S. P. H. S. and Stanley Consultants.

NOTE: $/ton ÷ .907 = $/metric ton
ton/day X .907 = metric ton/day

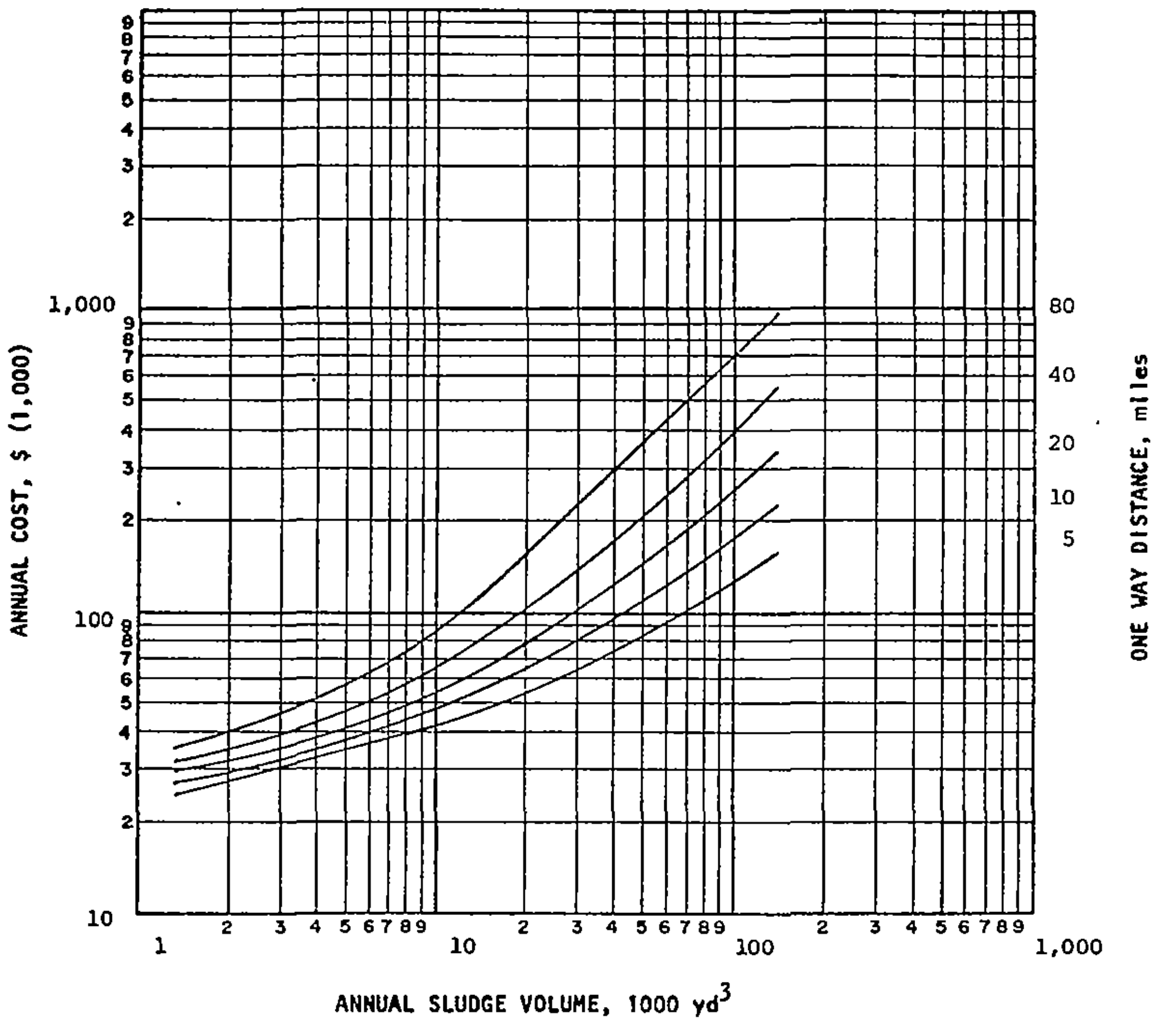
Figure 24. Capital and O/M costs for sanitary landfills (22).



NOTES:

1. Most economical type truck from selection of standard frame or semi trailer mounted bodies; tanks for liquid and dump or ram type for dewatered.
2. Eight hours of trucking operation per day.
3. Full cost at $.60 per gallon.
4. Operating and maintenance labor at $8.00 per hour including fringes.
5. Electric energy at $.02 per kwh.
6. Amortization of truck capital cost over six years at seven percent.
7. Truck O&M cost, excluding fuel and operator, $0.20 to $0.30 per mile depending on type of truck.
8. Truck loading time 30 minutes and unloading time 15 minutes.
9. Truck average speed 25 mph for first 20 miles one way and 35 mph for rest.
10. General and administrative costs 25 percent of total O&M cost.

Figure 25. Truck transport total annual cost with loading & unloading facilities 8 hour operation per day liquid sludge 1976 (71).



cubic meters = 0.765 x yd^3
km = 1.61 x miles

NOTES:

1. Most economical type truck from selection of standard frame or semi trailer mounted bodies; tanks for liquid and dump or ram type for dewatered.
2. Eight hours of trucking operation per day.
3. Full cost at \$.060 per gallon.
4. Operating and maintenance labor at \$8.00 per hour including fringes.
5. Electric energy at \$.02 per kwh.
6. Amortization of truck capital cost over six years at seven percent.
7. Truck O&M cost, excluding fuel and operator, \$0.20 to \$0.30 per mile depending on type of truck.
8. Truck loading time 30 minutes and unloading time 15 minutes.
9. Truck average speed 25 mph for first 20 miles one way and 35 mph for rest.
10. General and administrative costs 25 percent of total O&M cost.

Figure 26. Truck transport total annual cost with loading & unloading facilities 8 hour operation per day dewatered sludge 1976 (71).

season and that lagoon storage would be required for only 10% of the generated sludge volume. Thickened or vacuum filtered sludge would be stored for longer time periods and applied approximately two times per year, in spring and fall. Storage of 40% of the volume was then required. The basis for these costs are given in Figures 27 and 28. Distribution costs were assumed to be a percentage of the transportation costs associated with a site. For haul distances of 32.2km (20mi) or less, distribution costs were estimated to be 25% of the transportation costs and for haul distances of 33-64 km (21-40mi) the distribution costs were estimated to be 12.5% of the transportation costs.

Land requirements were calculated based on 18.9 metric ton/ha/yr (8.5 ton/acre/year) as established in Section VII. These were adjusted to include borders, buffer zones, roads, etc. using a multiplier of 1.4 for acreage less than or equal to 405ha (1000 acres) or 1.1 for larger land requirements. The land costs were based on the assumption that the purchase value of the land is equivalent to its salvage value and the anual cost was equal to the annual interest on the purchase price (5 7/8%). The purchase price of land was estimated to be $3706/ha ($1500/acre) (40). The land preparation costs included clearing, leveling and site preparation. These costs were estimated from Figure 29.

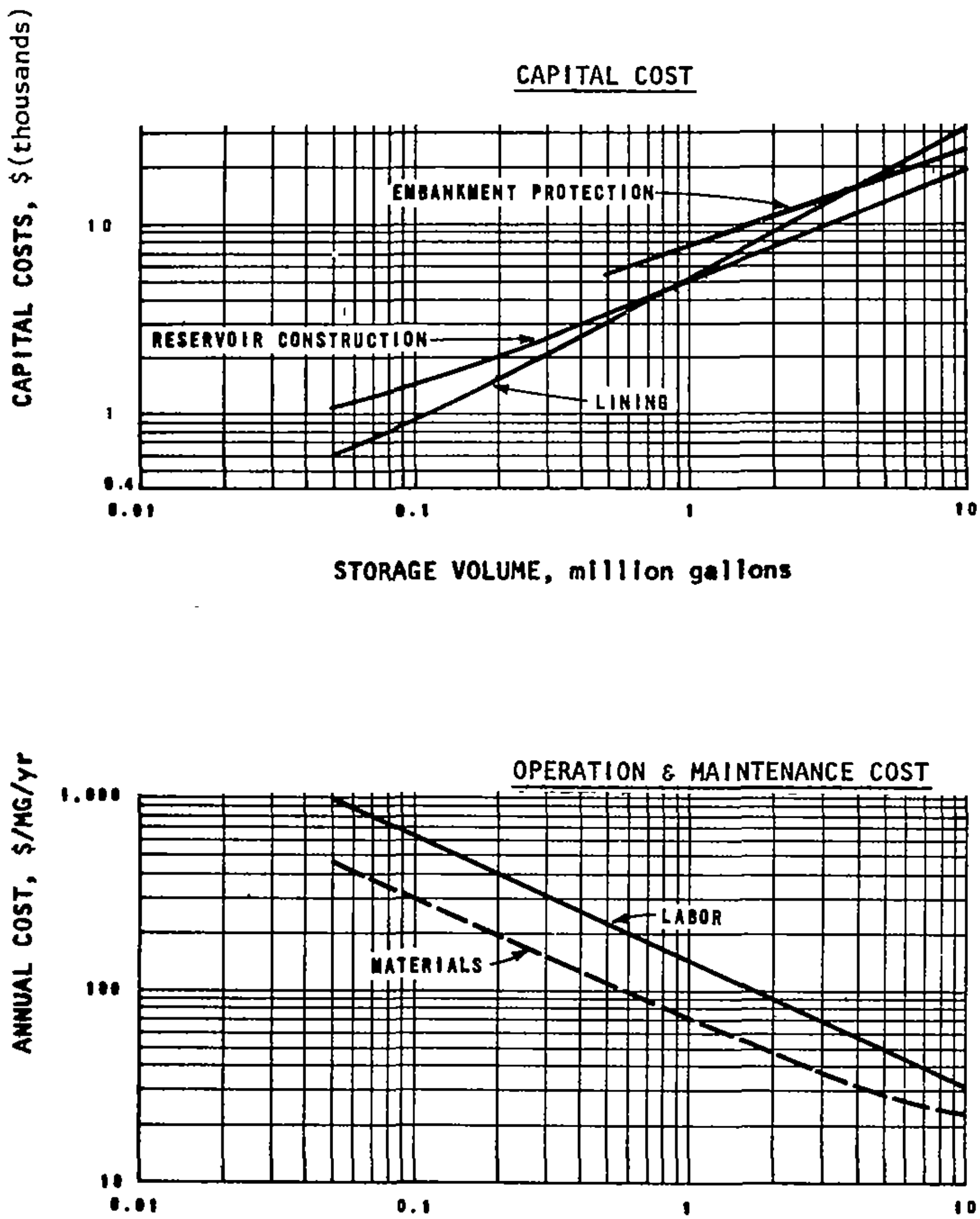
Once all capital and operating costs were estimated based on the various cost curves etc., then these were amortized to establish a total annual cost for the system. The amortization was based on 5 7/8% interest and a 20 year life for all systems.

IMPACT OF SLUDGES PRODUCED BY CSO TREATMENT ON FOUR EXAMPLE CITIES

The potential economic impact of treatment and handling of CSO treatment residuals is considered in this subsection with respect to four example cities. Four actual cities have been chosen to illustrate different CSO treatment sludges and different size systems. The cities which have been evaluated are Milwaukee, Wisconsin; San Francisco, California; Kenosha, Wisconsin; and New Providence, New Jersey.

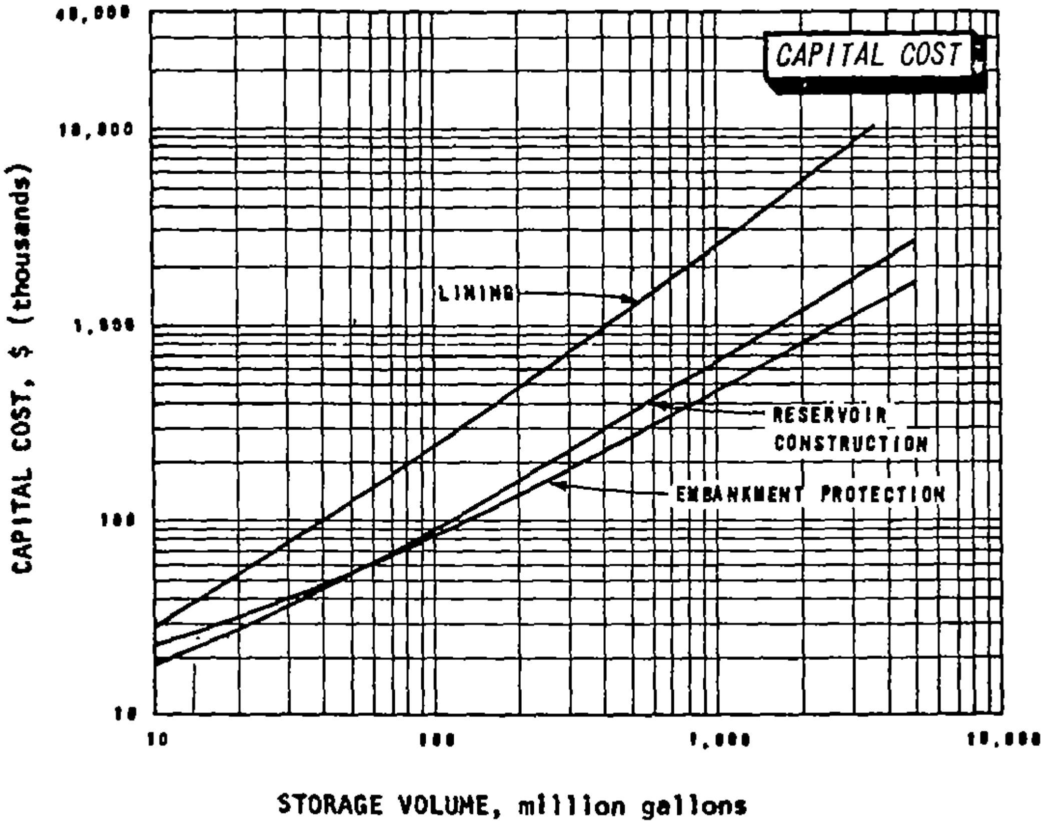
Extensive analysis involving the various CSO sludge handling alternatives has been performed for the Milwaukee site. The evaluation includes potential costs for bleed/pump-back, treatment at parallel sludge handling facilities, and satellite treatment using several different treatment trains. It is apparent from these analyses and previous discussion, that although bleed/pump-back may be most inexpensive, it is likely to be most impractical. Treatment at parallel facilities at the dry-weather plant is expensive if handled in 120 days and may be impossible due to space limitations. Therefore further evaluation of the potential impact of CSO sludges in other cities was limited to satellite treatment considerations.

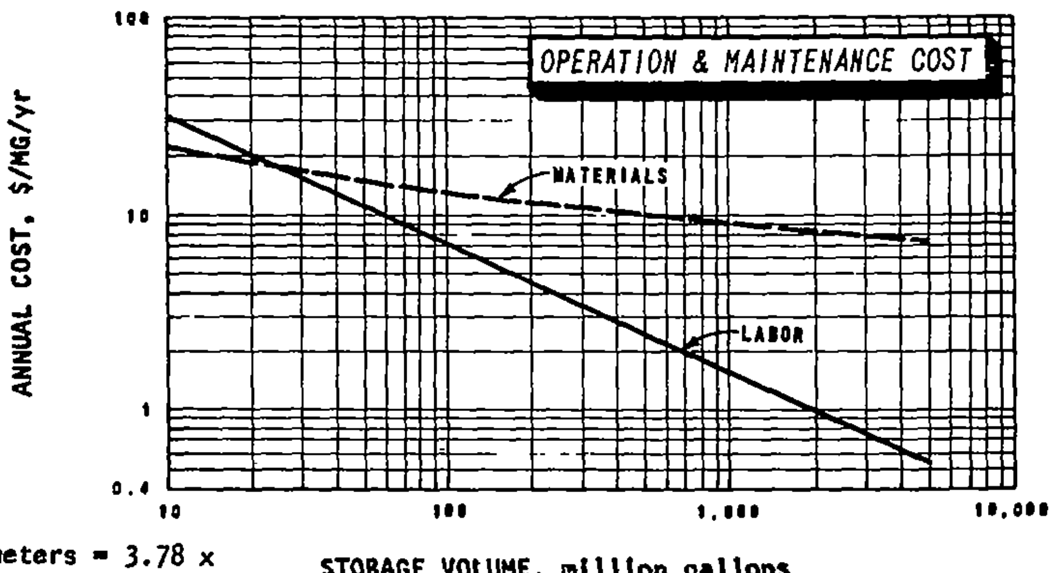
The individual evaluation was then divided into several steps. The first step involved estimation of the extent of the CSO problem based on precipitation data, area of the city served by combined sewers, the potential pro-



cubic meters = 3.784 x 10^3 million gallons

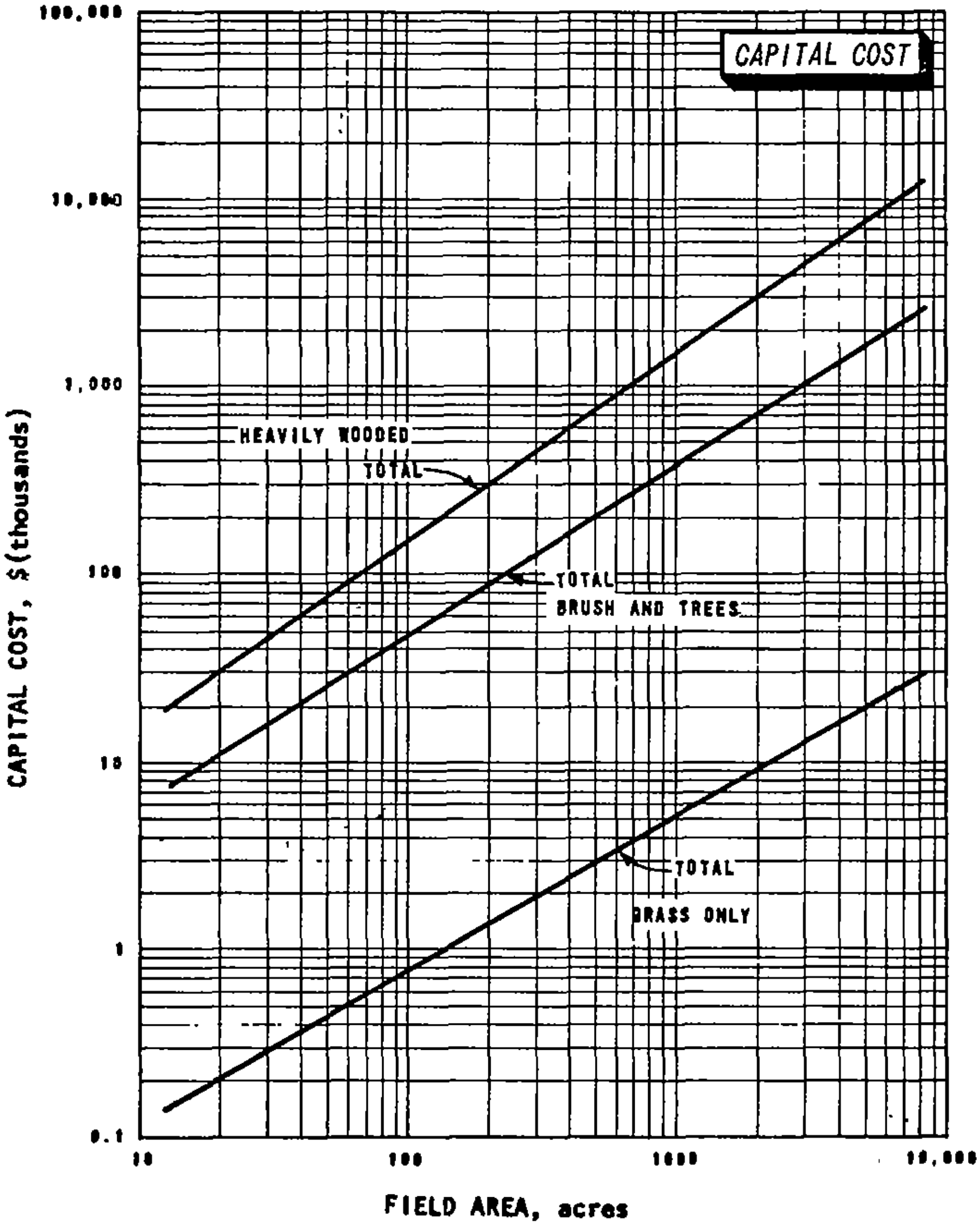
Figure 27. Storage (0.05-10 million gallons)(48).





cubic meters = 3.78 x 10^3 x million gallons

Figure 28. Storage (10-5,000 millions gallons)(48).



hectares = 0.405 x acres

Figure 29. Field preparation - site clearing (48).

cess used for CSO treatment and the characteristics of the sludges produced by the CSO treatment process.

The second step will be to present information on each city's dry-weather sludge handling facilities, including capacities, amount of solids presently being handled, and any excess handling capacity presently available.

Once the necessary information has been developed, the final step will be to assess the impact of the CSO generated solids on the city's present sludge handling and disposal system. The impact will be evaluated on both a physical and economic basis. Rough estimates of what the capital costs will be for constructing new sludge handling facilities at the site of CSO treatment have been developed and are presented in the following discussion.

CSO SLUDGE HANDLING IN MILWAUKEE, WISCONSIN

Evaluation of the various methods of handling CSO sludges in Milwaukee, Wisconsin was completed in depth to illustrate the effect of bleed/pump-back of CSO sludge and sludge handling at parallel sludge facilities and on-site satellite treatment. In Milwaukee, the dry-weather treatment plant is presently at capacity with respect to its sludge handling facilities. This is a common situation for plants serving combined sewer areas since often the treatment plant has reached design capacity and sometimes exceeded it, due to age. Therefore the example provided by Milwaukee is somewhat typical of conditions at treatment plants serving combined sewered areas.

In Milwaukee, the entire drainage area is 25,110 ha (62,000 acres). Of this total, 7,006 ha (17,300 acres) or 28 percent are served by combined sewers. The average annual precipitation for the city is 74.7 cm (29.4 in). If it is assumed that 50 percent of this rainfall accounts for combined sewer overflow, the annual volume of CSO for the city of Milwaukee is 26 million cu m (6,910 MG).

Presently in Milwaukee there is a CSO storage tank demonstration facility. This storage tank is equipped with mixers so that when the contents are bled/pumped-back to the dry-weather treatment plant, it is similar to the raw CSO. However, when the storage tank has its capacity exceeded, the mixers are not operated and the tank functions similar to a sedimentation basin. The impact of CSO sludges on the city of Milwaukee will be based on the assumption that complete CSO treatment is achieved by storing the 26 million cu m (6,910 MG) in storage tanks located in four parts of the city. The supernatant from the tanks will be continuously bled/pumped-back to the dry-weather treatment plant. After bleed/pump-back of the supernatant, a residual settled sludge will remain to be handled and disposed of.

Based on bench scale settling tests (12), it has been found that the sedimentation process will produce a sludge volume equal to 0.9 percent of the CSO volume stored. The resultant sludge will have an average total solids concentration of about 1.7 percent. The sludge characteristics were given in Table 4.

Based on the reported data, Milwaukee can expect an annual CSO volume of 26 million cu m (6,910 MG). Of this total 25.9×10^6 cu m (6.8×10^6 MG) would be bled back to the dry-weather plant as supernatant and 2.3×10^5 cu m (62 MG) would remain as residual sludge at a concentration of 1.7 percent.

The average raw CSO concentration of suspended solids at the Milwaukee CSO storage facility is 192 mg/l. Storage of all the CSO would mean storage of 5.0×10^6 kg (11.0×10^6 lbs) of CSO solids. The residual sludge volume of 2.3×10^5 cu m (62 MG) would represent 4.0×10^6 kg (8.8×10^6 lbs) of the solids. The remaining 1.0×10^6 kg (2.2×10^6 lbs) of solids would be bled back to the dry-weather treatment plant with the 25.9×10^6 cu m (6.8×10^3 MG) of supernatant. This means a supernatant suspended solids concentration of 40 mg/l.

The metropolitan Milwaukee area is served by two sewage treatment plants, the Jones Island Plant and the South Shore Plant. The Jones Island Plant is the major plant and serves almost all of the city's combined sewer areas and, therefore, will be the subject of analysis. The treatment consists of primary screening followed by the conventional activated sludge process, and chlorination. Plant data indicates that the facility has an average daily flow of 6.5×10^5 cu m/day (1.7×10^2 MGD) with an average suspended solids concentration of 236 mg/l. This results in 1.5×10^5 kg/day (3.4×10^5 lb/day of solids.

The primary sludge is incinerated. The waste activated sludge is gravity thickened, vacuum filtered, and then processed into a commercial fertilizer. The sludge handling capacity at the plant is 199 metric tons/day (220 tons/day), and the facilities run near capacity at all times.

The use of storage/settling facilities for complete CSO abatement will have two impacts on the dry-weather plant. First, there may be an impact due to bleed/pump-back of the supernatant and, second, there may be a much greater impact from the residual sludges if they are bled/pumped-back.

For complete CSO abatement, the supernatant represents 25.9×10^6 cu m (6.8×10^3 MG) and 1.0×10^6 kg (2.2×10^6 lbs) of wet weather solids. On an annual basis, the supernatant volume represents a hydraulic loading increase of 11 percent to the dry-weather plant. The additional solids loading to the dry-weather plant represents an increase of only 2 percent. The design capacity of the Jones Island Plant is 757,000 cu m/day (200 MGD) and it is presently operating at 6.5×10^5 cu m/day (1.7×10^2 MGD) or 86 percent of capacity. Therefore it should be able to handle the increased flows due to bleed/pump-back of the supernatants from the storage facilities. This assumes a constant yearly bleed/pump-back of 7.1×10^4 cu m/day (19 MGD) from the facilities.

Although the solids handling facilities at the dry-weather plant are operating near capacity, the slight solids loading increase of 2 percent due to the supernatants should be manageable without the need for expansion of the facilities. Therefore, the impact of the supernatants on the dry-weather treatment plant will probably be minimal.

The bleed/pump-back of the settled sludge, on the other hand, does not appear to be feasible. The 4.0×10^6 kg (8.8×10^6 lbs) of sludge solids represent a 7 percent increase in solids loading to the dry-weather plant. Since these solids would be fed along with the supernatant, the total solids loading will be increased by 9 percent. Since the solids handling facilities are now operating near capacity, a 9 percent solids increase would probably require construction of new facilities.

In addition to the 9 percent solids loading increase, other considerations seem to rule out bleed/pump-back as a means of handling the CSO generated solids. One factor to be considered is that Milwaukee's waste activated sludge is converted to a commercial fertilizer. Thus, even if the solids handling facilities are adequate for the increased solids loading, the effect of these solids on the fertilizer being produced may be a significant problem. The volatile solids percentage of the CSO sludge is 48.4 percent which is very low when compared to waste activated sludges. This casts doubt on the quality of the CSO solids as a fertilizer material.

The second consideration also relates to the low volatile content of the CSO sludge. As stated previously, the primary sludge at the Jones Island Plant is incinerated. The inclusion of the low volatile CSO solids in the dry weather sludge could greatly reduce the efficiency of the incineration process and a significant amount of auxiliary heat may be required for combustion due to the presence of CSO solids.

A final consideration is the logistics of bleed/pump-back itself which may be difficult to effectively accomplish. The potential accumulation of grit and organics in the sewers could be a problem without sufficient carrying velocity from dry-weather flow.

However, if it is assumed that the CSO sludge can be bled/pumped-back to the treatment plant without problems and that the plant operation will not be adversely affected by the sludge, then a preliminary cost estimate for this approach can be made. There are two potential techniques to consider. One involves holding the sludge and pumping it back over the entire year (365 days) and the other involves approximately 48 hour storage or a 120 day bleed/pump-back period. The difference has a significant effect upon the size of the additional facilities required at the plant.

With the addition of the South Shore Treatment Plant in Milwaukee, the hydraulic loading on the Jones Island facility has been decreased. However, the sludge handling facilities are operating at maximum capacity. Therefore bleed/pump-back of the sludge will require that the sludge handling system including thickeners, incinerators, vacuum filters, sludge dryers and Milorganite bagging be increased in size to handle the excess loading. The operating costs at the plant will also be greater.

Assuming that the sludge is handled through the treatment plant, the solids will increase from 3.6 to 11.4 metric tons/day (4 to 12.6 tons/day). This additional loading will require a significant increase in sludge handling facilities. According to cost estimates prepared from various sources (72, 73), the capital and O & M costs for bleed/pump-back are included in Table 41 for either a 365 or 120 day bleed/pump-back period. As can be seen, costs will range from approximately \$1.26 million-\$1.56 million annually for CSO sludge treatment using bleed/pump-back.

Table 41 COSTS FOR BLEED/PUMP-BACK-MILWAUKEE

Pump-back Time	120 day	365 day
Capital Costs:		
Storage Tanks	\$ 520,000	\$1,692,000
Incinerator	117,000	30,000
Pumps	1,360,000	1,360,000
Sludge Handling Equip.	7,082,000	3,376,000
15% Contingency	1,362,000	968,000
Total Capital Cost	10,441,000	7,427,000
Amortized Capital Cost	885,000	629,000
Annual Operation & Maintenance Cost	677,000	635,000
Total Annual Cost	1,562,000	1,264,000

Another approach, given that bleed/pump-back is not feasible due to the difficulty in transport through pipelines, is to haul the sludge to parallel facilities at the dry-weather treatment plant itself. This procedure would involve trucking of the dilute sludge to the treatment plant and placing it directly into the sludge handling facilities. It is assumed, at this plant, that the additional load will not adversely affect the Milorganite operation but it will require additional solids handling equipment. Two approaches are utilized as before. One involves storage and hauling over the complete 365 days and the second involves hauling over a 120 day period. The costs for these procedures are presented in Table 42. It is apparent that due to the transportation costs, that this option is more costly for both time periods than bleed/pump-back.

The third system which can be evaluated involves handling the CSO sludges at the sites of the CSO storage/settling facilities. The CSO facilities will generate 234,670 cu m (62 MG) of sludge at 1.7 percent solids annually. The first step in handling the sludge on site should be lime addition to raise the pH above 12. This should destroy any pathogens present in the sludge and prevent odor problems from developing at the sites. After this the sludge can be gravity thickened and then possibly dewatered. Vacuum filtration should be used because of the large amounts of lime in the sludge. For a number of CSO storage/settling facilities located throughout the city, it may be more economically advantageous to have a mobile unit that could move from site to site rather than vacuum filtration facilities located at each individual site. However, for this evaluation it has been assumed that the sludge has been handled at four sites within the city with each site processing an equal volume of sludge.

Table 42 COSTS OF TREATMENT
AT PARALLEL DRY-WEATHER FACILITIES-MILWAUKEE

Hauling Period	120 day	365 day
Capital Costs:		
Storage	$ 520,000	$1,692,000
Pumping	1,360,000	1,360,000
Sludge Handling Equip.	7,082,000	3,376,000
15% Contingency	1,344,000	964,000
Total Capital Cost	10,306,000	7,392,000
Amortized Capital Cost	873,000	626,000
Annual Operation & Maintenance Cost	977,000	935,000
Total Annual Cost	$1,850,000	$1,561,000

Based on the information available on CSO sludge generated in Milwaukee and the four treatment schemes developed previously, cost estimates for satellite treatment in Milwaukee were developed. The basis of costs and figures presented earlier in this chapter were utilized and the results are presented in Table 43. It can be seen that hauling the stabilized only sludge to a land application site (Alternate 4, Table 43) is extremely expensive due to the transportation costs. These costs indicate that Alternative 3 or lime stabilization followed by gravity thickening and land application may be the most cost effective approach in Milwaukee. High costs of vacuum filtration at several sites indicate that use of this dewatering technique is not cost effective.

A comparison of the annual costs for all three approaches to handling CSO sludge is presented below:

Method 1 - Bleed/Pump-back

120 days - $1,561,000

365 days - $1,264,000

Method 2 - Treatment at Parallel Dry-Weather Facilities

120 days - $1,850,000

365 days - $1,561,000

TABLE 43. COST ESTIMATES FOR CSO SLUDGE HANDLING BY SATELLITE TREATMENT - MILWAUKEE

Alternative Number	Element	Capital Cost $	Operation & maintenance cost	Annual cost
1	Pumping	$1.36x10^6$	$ 55,000	$ 170,000
	Storage	$1.42x10^6$	--	120,000
	Lime Stabilization	$0.426x10^6$	223,000	259,000
	Gravity thickening	$1.193x10^6$	24,000	125,000
	Vacuum filtration	$5.112x10^6$	185,000	617,000
	Transportation	--	--	130,000
	Landfill	$2.272x10^6$	60,000	252,000
	Subtotal			$1,673,000
	15% Contingency			251,000
	TOTAL			$1,924,000
2	Pumping	$1.36x10^6$	$ 55,000	$ 170,000
	Storage	$1.42x10^6$	--	120,000
	Lime Stabilization	$0.426x10^6$	223,000	259,000
	Gravity Thickening	$1.193x10^6$	24,000	125,000
	Vacuum Filtration	$5.112x10^6$	185,000	617,000
	Transportation	--	--	130,000
	Land Application	--	--	86,000
	Subtotal			$1,507,000
	15% Contingency			226,000
	TOTAL			$1,733,000

TABLE 43 (continued).

Alternative Number	Element	Capital Cost $	Operation & Maintenance Cost	Annual Cost
3	Pumping	$1.36x10^6$	$ 55,000	$ 170,000
	Storage	$1.42x10^6$	--	120,000
	Lime Stabilization	$0.426x10^6$	223,000	259,000
	Gravity Thickening	$1.193x10^6$	24,000	125,000
	Transportation	--	--	490,000
	Land Application	--	--	137,000
	Sub Total			$1,301,000
	15% Contingency			195,000
	TOTAL			$1,496,000
4	Pumping	$1.36x10^6$	$ 55,000	$ 170,000
	Storage	$1.42x10^6$	--	120,000
	Lime Stabilization	$0.42x10^6$	223,000	259,000
	Transportation	--	--	1,400,000
	Land Application	--	--	249,000
	Sub Total			$2,198,000
	15% Contingency			330,000
	TOTAL			$2,528,000

Method 3 - Satellite Treatment (120 days)

Alternative 1 - 1,924,000

Alternative 2 - 1,733,000

Alternative 3 - 1,496,000

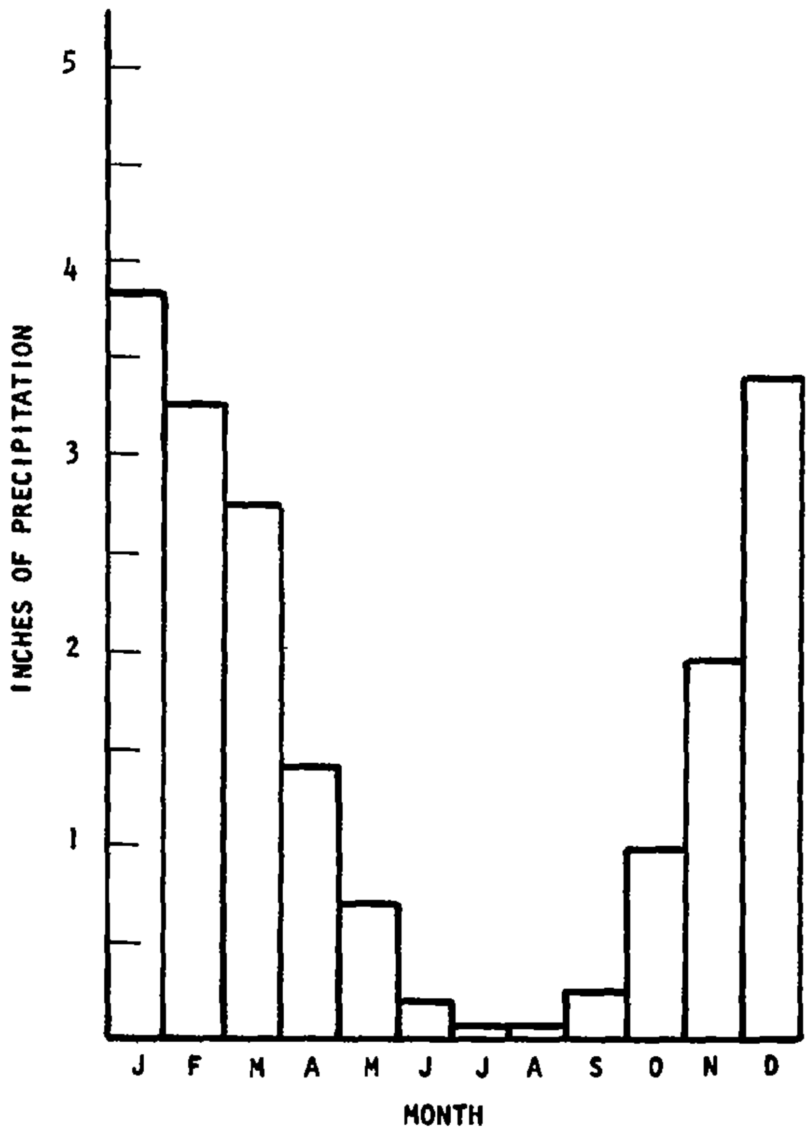
Alternative 4 - 2,528,000

It can be seen that the cost of bleed/pump-back is less than other alternatives when considered over 365 days, but it begins to exceed other alternatives when a shorter bleed/pump-back period is established. Treatment at parallel dry-weather facilities does not offer significant advantages over satellite treatment and when coupled with potential interference in plant operation and space limitations at Jones Island, this method becomes less viable. Finally, the various alternatives chosen for satellite treatment could be utilized without operating problems associated with bleed/pump-back or parallel facilities. The costs are similar to other alternatives presented. Therefore the most cost effective and least problematic approach at this time seems to be satellite treatment using lime stabilization, storage, gravity thickening and land application.

CSO SLUDGE HANDLING IN SAN FRANCISCO, CALIFORNIA

In San Francisco, the entire drainage area of 12,150 ha (30,000 aeres) is served by a combined sewer system. The average annual precipitation for the area is 47.5 cm (18.7 in) and typically occurs on a monthly basis as shown in Figure 30. It can be seen that very little precipitation occurs during the summer months while the majority of the precipitation occurs from November through April. If it is assumed that 50 percent of this rainfall produces combined sewer overflow, the annual volume of CSO for the city of San Francisco is 28.8 million cu m (7,620 MG).

Presently, a dissolved air flotation CSO treatment demonstration unit is located in San Francisco. It has been reported that this unit will produce a sludge volume equal to 0.6 percent of the CSO volume treated. The resultant sludge will have an average total solids content of approximately 2.2 percent. Other pertinent sludge characteristics are presented in Table 5. Since this unit is working in San Francisco and data is available, it will be assumed for this evaluation that all CSO is treated using the dissolved-air flotation process. The sludge data indicates that San Francisco can expect an annual CSO sludge volume of 1.7×10^5 cu m (46 MG) at 2.2 percent solids or 3.9×10^6 kg (8.6×10^6 lbs) of wet weather produced solids that must be handled and disposed of. The metropolitan San Francisco area is served by three separate primary sewage treatment plants with a total design capacity of 1,135,500 cu m/day (300 MGD). The three treatment sites produce approximately 5.0×10^3 cu m/day (1.3 MGD) of sludge at 1.1 percent solids. This results in 54,480 kg/day (120,000 lbs/day) of solids to be handled. The sludge is gravity thickened, anaerobically digested, and vacuum filtered to a solids concentration of about 28 percent before being disposed of in a landfill or used as a soil conditioner. The present solids handling facilities in San Francisco are operating at capacity (12).



NOTE: In. x 2.54 = cm

Figure 30. Typical monthly distribution of precipitation in San Francisco, California (74).

If complete CSO treatment is achieved in the city, the yearly volume of CSO sludge will represent a hydraulic increase of 9.6 percent over the dry-weather sludge volume presently being handled and an 18.8 percent increase on a dry solids basis. The percentages calculated, however, are based on a constant yearly flow of CSO sludge to the sludge handling facilities. Since CSO events are intermittant in nature and will occur with greater frequency during certain times of the year, it would be impossible to space the flow of CSO sludge to the handling facilities over the entire year unless storage facilities are employed. Therefore, the impact of the CSO sludges has also been calculated based on the following assumptions: no storage in the system, a 72 hour period of CSO sludge bleed-back to the handling facilities, and rainfalls of 1.3 and 0.5 cm (0.5 and 0.2 in) over the CSO area.

The 1.3 cm (0.5 in) rainfall over the CSO area will produce 4.6×10^3 cu m (1.2×10^6 gal) of CSO sludge and 1.0×10^5 kg (2.3×10^5 lbs) of CSO solids. Bleeding the residue into the sludge handling facilities over three days results in additional flows of 1.5×10^3 cu m/day (4.1×10^2 MG) and 3.5×10^4 kg/day (7.6×10^4 lbs/day). These flows represent a 31 percent increase in the hydraulic loading and a 61 percent increase in the solids loading. Thus, the impact of the CSO sludges has increased significantly. The 0.5 cm (0.2 in) rainfall over the CSO area will result in a 12 percent increase in the hydraulic loading, and a 24 percent increase in the solids loading over the three day bleed-back period.

Based on the preceeding calculations, it appears that the first consideration in developing a method of handling the CSO sludge problem will be to reduce the impacts caused by the sporadic flows of the CSO itself. This could be achieved by storage of the CSO in conjunction with the CSO treatment facility. Based on the yearly rainfall of 47.5 cm (18.7 in), San Francisco can expect a yearly CSO volume of 28,840,000 cu m (7,620 MG). Year round operation of a CSO treatment facility would require a treatment plant capacity of 79,485 cu m/day (21 MGD).

The storage facility capacity based on the monthly rainfall variations (Figure 30) is calculated on the next page. These calculations indicate a maximum storage capacity of 11.4×10^6 cu m (3.0×10^3 MG) required for the system at the end of March. This value should then be increased to protect against the yearly fluctuations in rainfall amounts.

This volume, of course, would be for one storage facility serving the entire city. Numerous storage facilities could be located throughout the city and they could then feed a number of small CSO treatment facilities or one 79×10^3 cu m/day (21 MGD) central CSO treatment plant.

The treatment of 79×10^3 cu m/day (21 MGD) of CSO using the dissolved-air flotation process would result in the generation of 480 cu m (126,000 gal) per day of sludge at about 2.2 percent solids. Some of the data reported from the San Francisco demonstration system has indicated floated sludge concentrations of only 1000 to 2000 mg/l. The value of 2.2 percent solids for the floated sludge being used is based on samples taken at the demonstration site and the reported values for floated sludge at other sites using the dissolved-air flotation process (12). Based on the 2.2 percent solids, 10,600 kg/day (23,400 lbs/day) of CSO solids will have to be handled and disposed of from the CSO treatment site.

	CSO Volumes 10^6 cu m (MG)	Volume Treated 10^6 cu m (MG)	Difference 10^6 cu m (MG)	Cumulative Storage 10^6 cu m (MG)
November	2.91 (770)	2.38 (630)	+0.53 (+140)	0.53 (140)
December	5.31 (1402)	2.46 (651)	+2.84 (+751)	3.37 (891)
January	5.95 (1573)	2.46 (651)	+3.49 (+922)	6.86 (1813)
February	5.03 (1328)	2.23 (588)	+2.80 (+740)	9.66 (2553)
March	4.23 (1117)	2.46 (651)	+1.76 (+466)	11.43 (3019)
April	2.11 (558)	2.38 (630)	-0.27 (-72)	11.15 (2947)
May	1.06 (281)	2.46 (651)	-1.40 (-370)	9.75 (2577)
June	0.26 (69)	2.38 (630)	-2.12 (-561)	7.63 (2016)
July	0.06 (16)	2.46 (651)	-2.40 (-635)	5.23 (1381)
August	0.06 (16)	2.46 (651)	-2.40 (-635)	2.82 (746)
September	0.40 (106)	2.38 (630)	-1.98 (-524)	0.84 (222)
October	1.45 (383)	2.46 (651)	-1.01 (268)	0

The two available alternatives for handling the CSO sludge are handling at the CSO treatment site or transporting it to the dry-weather plant and handling it with the existing or expanded dry-weather plant facilities. As mentioned previously, the dry-weather sludge handling facilities are operating at capacity and the addition of the CSO sludges would increase the hydraulic loadings by 10 percent and the solids loadings by 19 percent.

The first consideration would be to transport the sludge to the dry-weather treatment plant by bleeding it back to the sewer system after the CSO event is over. However, due to the characteristics of the CSO sludge, the sludge should not be handled with the processes used for the dry-weather plant. The low volatile content of the sludge, 39.2 percent, indicates that digestion would be ineffective. Therefore, if the solids are introduced into the anaerobic digesters, they would increase the solids and hydraulic loadings and may not digest. This would result in reductions in volatile solids destruction and gas production. There is also the possibility that the heavy metals present in the CSO sludge could pose a toxic hazard to the biological life in the digesters.

The dry-weather sludges are usually gravity thickened before they are pumped to the digesters. The CSO sludge produced by the dissolved-air flotation process can be expected to be over 2 percent solids, and, therefore, may not require further thickening. If the CSO sludge is bled back to the dry-weather plant, it will be diluted in the sewer system and, then, would have to be re-thickened at the dry-weather plant. The sludge volumes would also increase the hydraulic loading on the gravity thickeners by 10 percent.

Based on the preceeding discussion, bleed-back of the sludge to the dry-weather plant should not be attempted for the following reasons:

1. necessity to dilute and then re-thicken the solids,
2. introduction of the low volatile solids into the anaerobic digesters will require valuable space and reduce digester efficiency, and
3. the solids may pose toxic hazards to the anaerobic digesters.

By eliminating bleed-back of the CSO solids to the dry-weather plant, the CSO sludge will have to be transported by tank truck if sludge handling is to be achieved at the dry-weather plant. This would require trucking 477 cu m (126,000 gal) of sludge per day. Since the sludge is already thickened it could go directly to the vacuum filtration process. The vacuum filter facilities, of course, would have to be expanded to handle a solids loading increase of 19 percent. After vacuum filtration the CSO sludge cake could be disposed of at the landfill along with the dry weather sludge. The dry-weather plant now trucks approximately 203 cu m (7260 cu ft) of sludge cake per day to the landfill. The CSO sludge, dewatered to 20 percent solids, will increase this amount by 26 percent to 256 cu m/day (9143 cu ft/day).

Because the CSO sludge has not undergone anaerobic digestion, the sludge should be limed to a pH of greater than 12 in order to stabilize it. This could be accomplished just before vacuum filtration. The liming should insure pathogen destruction before the sludge is landfilled (35).

As the previous discussion indicates, however, the applicability of bleed/pump-back or treatment at additional facilities is a questionable procedure, at best. Considering the results of the total cost evaluation presented for Milwaukee, it can be seen that only a small cost benefit can be achieved by implementing these two questionable processes. Therefore, detailed costs have been prepared only for the alternatives with potential for handling CSO sludge generated in San Francisco at six individual sites throughout the city. These costs are included in Table 44 for the four sludge handling schematics previously chosen applicable for CSO sludge treatment. It can be seen from Table 44 that the handling alternative involving lime stabilization, additional thickening and land application of the resultant sludge is anticipated to be most cost effective of those investigated. Further dewatering does not appear to be feasible.

TREATMENT OF CSO SLUDGES IN KENOSHA, WISCONSIN

The entire drainage area for the city of Kenosha is 3850 ha (9507 acres). Of this total, 539 ha (1331 acres) or 14 percent are served by combined sewers. The average annual precipitation for the area is 77.5 cm (30.5 in). If it

TABLE 44. COST ESTIMATES FOR CSO SLUDGE HANDLING BY SATELLITE OPERATION - SAN FRANCISCO

Alternative Number	Element	Capital Cost $	Operation & Maintenance Cost	Annual Cost
1	Pumping	1.53×10^6	$ 68,000	$ 197,000
	Storage	0.588×10^6	--	50,000
	Lime Stabilization	0.50×10^6	92,000	134,000
	Gravity Thickening	1.45×10^6	31,000	154,000
	Vacuum Filtration	7.67×10^6	212,000	860,000
	Transportation	--	--	120,000
	Landfill	2.68×10^6	89,000	316,000
	Sub Total			$1,831,000
	15% Contingency			275,000
	TOTAL			$2,106,000
2	Pumping	1.53×10^6	$ 68,000	$ 197,000
	Storage	0.588×10^6	--	50,000
	Lime Stabilization	0.50×10^6	92,000	134,000
	Gravity Thickening	1.45×10^6	31,000	154,000
	Vacuum Filtration	7.67×10^6	212,000	860,000
	Transportation	--	--	120,000
	Land Application	--	--	82,000
	Sub Total			$1,596,000
	15% Contingency			239,000
	TOTAL			$1,835,000

TABLE 44 (continued).

Alternative Number	Element	Capital Cost $	Operation & Maintenance Cost	Annual Cost
3	Pumping	1.53×10^6	$ 68,000	$ 197,000
	Storage	0.588×10^6	--	50,000
	Lime Stabilization	0.50×10^6	92,000	134,000
	Gravity Thickening	1.45×10^6	31,000	154,000
	Transportation	--	--	380,000
	Land Application	--	--	118,000
	Sub Total			$1,033,000
	15% Contingency			155,000
	TOTAL			$1,188,000
4	Pumping	1.53×10^6	$ 68,000	$ 197,000
	Storage	0.58×10^6	--	50,000
	Lime Stabilization	0.50×10^6	92,000	134,000
	Transportation	--	--	1,000,000
	Land Application	--	--	194,000
	Sub Total			$1,575,000
	15% Contingency			236,000
	TOTAL			$1,811,000

is assumed that 50 percent of this rainfall accounts for combined sewer overflow, the annual volume of CSO for Kenosha is 2.1×10^6 cu m (550 MG).

In Kenosha, CSO treatment is being achieved at a demonstration project by the use of the contact stabilization process and data is available concerning the treatment of CSO using this process. For this reason, the impact of CSO sludges on the city of Kenosha will be based on complete CSO treatment using contact stabilization.

The combined sewer overflow treatment system in Kenosha is significantly different from those discussed previously because it is located on the same grounds as the existing conventional dry weather treatment plant. In fact, since the system utilizes biological treatment it depends on the dry-weather plant as a source of active biomass. Waste activated sludge from the dry-weather treatment plant is continuously fed through the CSO treatment system stabilization tank, where it has a hydraulic retention time of approximately five days before going on to flotation thickening. When the CSO treatment system is in operation, the contents of the stabilization tank are pumped to a contact tank instead of to thickening.

It has been reported (12) that the Kenosha contact stabilization process will produce a sludge volume equal to 3.5 percent of the CSO volume treated. The resultant sludge will have an average total solids concentration of 0.85 percent. Other characteristics of the sludge were previously presented in Table 6. The sludge data indicates that Kenosha can expect an annual CSO sludge volume of 73.0×10^3 cu m (19 MG) at 0.85 percent solids or 6.2×10^5 kg (1.4×10^6 lbs) of wet weather produced solids that must be handled and disposed of.

The conventional dry weather treatment plant at Kenosha is a 8.7×10^4 cu m/day (23 MGD) activated sludge process. Waste activated sludge, approximately 300 cu m/day (83,000 gpd) at a solids concentration of 1.47 percent or 4.5×10^3 kg/day (10,000 lbs/day) of solids, is flotation thickened to about 5 percent solids concentration before going on to anaerobic digestion. The digested solids are then further dewatered by means of a filter press. The total daily loading on the digesters, primary and waste activated sludge combined, is 190 cu m/day (50,000 gpd) resulting in a dry solids weight of 1.1×10^4 kg/day (2.4×10^4 lbs/day). The filter press is operated at less than capacity and would be able to handle an additional solids load. The digesters, on the other hand, are already at capacity and additional solids loadings would require construction of additional digestion facilities.

The CSO treatment system presently located on the grounds of the Kenosha dry-weather treatment plant has a capacity of 75,700 cu m/day (20 MGD). The average flow rate during system operation has been found to be 6.1×10^4 cu m (16 MGD)(54). Assuming complete CSO treatment is achieved, this means that in an average year the treatment process will be operated 34 1/2 days. Of course, some form of storage will have to be provided in conjunction with the CSO treatment system in order to detain flows in excess of the 75,700 cu m/day (20 MGD) plant capacity.

In the Kenosha area, rainfall usually occurs from mid-March to mid-December, a total of nine months, with snow being the form of precipitation during the other three months. During the period of rain there occurs about 50 CSO events. Based on these assumptions, then, a CSO event can be expected to occur every fifth day. On the average, each event will generate 42×10^3 cu m (11 MG) of CSO and require 0.7 days of treatment process operation. This, then, allows for 4.3 days of wet weather sludge bleed/pump-back to the dry-weather plant solids handling facilities.

The 42×10^3 cu m (11 MG) of CSO per storm event will generate 1460 cu m (385,000 gal) of sludge and 12×10^3 kg (27×10^3 lbs) of solids. Feeding this sludge to the dry-weather plant flotation thickening unit over the next 4.3 days results in additional loadings of 340 cu m/day (90×10^3 gpd), an increase of 108 percent, and 2.8×10^3 kg/day (6.3×10^3 lb/day), an increase of 63 percent. Apparently a very significant impact can be expected.

The increased solids due to the CSO sludge will also mean an increased solids loading to the anaerobic digesters of 26 percent and a hydraulic increase of 30 percent. This could result in decreased digester efficiency.

Since the CSO treatment process is located at the dry-weather plant, CSO sludge handling can be accomplished on-site. The two available alternatives are to either handle the CSO sludge with separate parallel facilities or with the existing and/or expanded dry-weather plant facilities.

The handling of the Kenosha CSO sludge will require a treatment scheme similar to the dry-weather plant's process: thickening, stabilization, and dewatering. The primary consideration here is that the dry-weather plant's anaerobic digesters are presently operating at capacity, therefore, the use of anaerobic digestion for the CSO sludge would require digester expansion to handle a 30 percent increase in hydraulic loading and a 26 percent increase in solids loading. This construction would be very costly.

It is possible that excess sludge produced by CSO treatment could be stabilized by lime and this process is therefore a viable alternative to anaerobic digestion. The use of lime stabilization also indicates that gravity thickening is most appropriate, rather than flotation thickening, because the lime treatment will greatly enhance the settling characteristics of the sludge.

It is therefore indicated that the CSO sludges should be handled by parallel processes at the dry-weather plant due to the present location of the CSO treatment unit at this point. Final disposal of dry-weather sludge is presently accomplished using land application, which may be most feasible. However, landfill will also be investigated. The same four CSO sludge handling alternatives have been evaluated for the biological sludge from Kenosha and the results are presented in Table 45. The annual costs range from \$205,000-\$462,000 for the various alternatives. As indicated previously, the most feasible approach appears to be lime stabilization and gravity thickening followed by land application at an annual cost of approximately \$205,000.

However, when further consideration is given to the specific circumstances at

TABLE 45. COST ESTIMATES FOR CSO SLUDGE HANDLING BY SATELLITE TREATMENT-KENOSHA

Alternative Number	Element	Capital Cost $	Operation & Maintenance Cost	Annual Cost
1	Pumping	0.28×10^6	$12,000	$ 36,000
	Storage	0.139×10^6	--	12,000
	Lime Stabilization	0.085×10^6	14,000	15,000
	Gravity Thickening	0.256×10^6	5,000	27,000
	Vacuum Filtration	1.28×10^6	38,000	146,000
	Transportation	--	--	16,000
	Landfill	0.50×10^6	29,000	71,000
	Sub Total			$323,000
	15% Contingency			48,000
	TOTAL			$371,000
2	Pumping	0.284×10^6	$12,000	$ 36,000
	Storage	0.139×10^6	--	12,000
	Lime Stabilization	0.085×10^6	14,000	15,000
	Gravity Thickening	0.256×10^6	5,000	27,000
	Vacuum Filtration	1.28×10^6	38,000	146,000
	Transportation	--	--	16,000
	Land Application	--	--	16,000
	Sub Total			$268,000
	15% Contingency			40,000
	TOTAL			$308,000

TABLE 45 (continued).

Alternative Number	Element	Capital Cost $	Operation & Maintenance Cost	Annual Cost
3	Pumping	0.284×10^6	$12,000	$ 36,000
	Storage	0.139×10^6	--	12,000
	Lime Stabilization	0.085×10^6	14,000	15,000
	Gravity Thickening	0.256×10^6	5,000	27,000
	Transportation	--	--	60,000
	Land Application	--	--	28,000
	Sub Total			$178,000
	15% Contingency			27,000
	TOTAL			$205,000
4	Pumping	0.284×10^6	$12,000	$ 36,000
	Storage	0.139×10^6	--	12,000
	Lime Stabilization	0.085×10^6	14,000	15,000
	Transportation	--	--	260,000
	Land Application	--	--	79,000
	Sub Total			$402,000
	15% Contingency			60,000
	TOTAL			$462,000

Kenosha, other variables must be discussed. One aspect is that the land application costs could be reduced since the city of Kenosha is presently disposing of their dry-weather treatment plant sludge on private farms and if this arrangement could be continued for the additional CSO sludge, there would be no capital expense for land disposal in alternatives 2-4. The second factor is that, as discussed previously, the dry-weather plant's pressure filter has available, enough additional capacity to handle the CSO sludge. For the estimates in Table 45, a complete handling and disposal system was set up to handle all the CSO sludge flows assuming no additional capacities being available in the dry-weather plant. Vacuum filtration was selected as the dewatering method because it was felt that this method would be most amenable for dewatering the heavily limed sludge resulting from the lime stabilization process. For the specific case of Kenosha, investigations should be conducted to determine the ability to pressure filter the lime sludge. If these tests show that pressure filtration will produce satisfactory results, then, for Kenosha, the capital costs of vacuum filtration could be eliminated from alternatives No. 1 and 2.

With these factors considered, the annual costs for alternatives 1 through 4 become:

	Old	New
Alt. 1	$371,000	$247,000
Alt. 2	308,000	171,000
Alt. 3	205,000	193,000
Alt. 4	462,000	456,900

Therefore, since additional dewatering capacity is available, this process, with land application using the existing dry-weather sludge disposal procedure, seems to be very economically attractive for Kenosha.

WET WEATHER SLUDGE HANDLING FOR NEW PROVIDENCE, NEW JERSEY

In New Providence, the entire drainage area for the sewage system is 985 ha (2432 acres). There are no areas serviced by combined sewers but during periods of wet weather, high flows are experienced because of infiltration into the sanitary sewers. If these high flows are treated, New Providence will experience increased solids production due to wet weather conditions even though there are actually no combined sewer overflows.

The average annual precipitation for the area is 109.0 cm (42.9 in). It has been reported in the literature (9) that about 10 percent of this rainfall can be expected to appear as increased flow in infiltrated sanitary sewers. Using these values, then, the annual volume of increased flow due to wet weather for the city of New Providence is 1.1×10^6 cu m (280 MG).

There is a demonstration treatment system employing the trickling filter process in New Providence. The trickling filters are used to treat both the dry-weather flows and wet weather flows. The trickling filters are operated in series during dry weather and switched to parallel operation for high flow rates generated by wet weather. The trickling filter removal efficiency data is available but the necessary sludge production data is not. Therefore the sludge production data required will be estimated based on the pollutant removal efficiencies. The sludge estimates will then be used to assess the impact of wet weather sludges on the city of New Providence.

The following values have been reported (9) for the trickling filter process:

Dry Weather		
Average Flow	2,044 $\frac{\text{cu m}}{\text{day}}$	(0.54 MGD)
SS (influent)		154 mg/l
SS (primary effluent)		86 mg/l
SS (final effluent)		20 mg/l
BOD (primary effluent)		104 mg/l
BOD (final effluent)		23 mg/l
Wet Weather		
Average Flow	14,989 $\frac{\text{cu m}}{\text{day}}$	(3.96 MGD)
SS (influent)		109 mg/l
SS (primary effluent)		64 mg/l
SS (final effluent)		36 mg/l
BOD (primary effluent)		86 mg/l
BOD (final effluent)		39 mg/l

Based on the suspended solids removals achieved by primary sedimentation, 140 kg/day (300 lbs/day) of sludge solids can be expected during dry weather and 680 kg/day (1500 lbs/day) during wet weather. Using a primary sludge concentration of 5.5 percent solids, this results in a rate of (2.5 cu m/day) (670 gal/day) during dry weather and 12 cu m/day (3000 gal/day) during wet weather.

The production of secondary sludge is based on suspended solids removal and the production of 0.5 kg(lb) of solids per kg(lb) of BOD removed. During dry weather, the sludge solids production by secondary treatment will be 220 kg/day (480 lb/day) and 770 kg/day (1700 lbs/day) during wet weather. It has been reported that trickling filter sludges will vary from 5 to 10 percent solids depending on the time they are held in the filter (25). For this reason, it is estimated that the secondary sludge will be 7 percent solids during dry weather (low flow) and 5 percent solids during wet weather (high flow). These values result in the production of 3 cu m/day (800 gal/day) of secondary sludge during dry weather and 15 cu m/day (4000 gal/day) of secondary sludge during wet weather. Combining the primary and secondary sludges means the trickling filter will produce 6 cu m/day

(1600 gal/day) of sludge at 6.3 percent solids during dry weather and 28 cu m/day (6200 gal/day) of sludge at 5.2 percent solids during wet weather. The wet weather value represents 0.2 percent of the wet weather flow volume treated. Some of the other sludge characteristics based on samples taken at the trickling filter site were given in Table 6 (12).

For the annual wet weather volume of 1.1×10^6 cu m (280 MG), New Providence can expect an excess sludge volume of 2.1×10^3 cu m (5.6×10^5 gal.) at 5.2 percent solids or 1.1×10^5 kg (2.5×10^5 lb) of wet weather produced solids that must be disposed of.

As mentioned previously, the trickling filter operation also serves the city of New Providence during dry weather. During dry weather the plant treats an average flow of 2×10^3 cu m/day (0.5 MGD) and produces a 6.0 cu m/day (1600 gal/day) of sludge, primary and secondary, at 6.3 percent solids or 350 kg/day (770 lbs/day) of solids. There are no sludge handling facilities at the trickling filter plant. The solids settling in the secondary clarifier are pumped to the primary sedimentation tank where they settle out with the primary solids. This combined sludge is then drained to a sewer which flows to a larger sewage treatment plant downstream. Apparently the downstream treatment plant has the capacity to remove and handle the solids produced at the New Providence facility; and since the New Providence plant handles the entire wet weather flow, no appreciable increase in flow will occur in the future. Therefore, the bleed/pump-back of both dry weather and wet weather sludges from the New Providence facility to the downstream plant appears to be functioning as planned and will continue to be used in the future. In this case, then, there is no impact due to wet weather conditions in the sanitary sewers.

The impact of the wet weather generated solids would be great, however, if the plant were to construct sludge handling facilities. As presented previously, during dry weather the trickling filter plant can be expected to generate 2.5 cu m/day (550 gal./day) of primary sludge at 5.5 percent solids and 3 cu m/day (660 gal./day) of secondary sludge at 7 percent solids. Combining the two sludges gives 6 cu m/day (1600 gal./day) at 6.3 percent solids or 350 kg/day (770 lbs/day) of dry solids.

Any new sludge handling facilities must take into consideration the volumes of sludge generated by wet weather. On an annual basis, wet weather flows will generate a sludge volume of 2.1×10^3 cu m (5.6×10^5 gal.) (primary plus secondary) at approximately 5.2 percent solids or 1.1×10^5 kg (2.5×10^5 lbs) of solids. If these sludge volumes can be bled/pumped-back to the sludge handling facilities over an entire year, the additional loadings would be 6 cu m/day (1600 gal./day), a 100 percent increase over the dry weather flow, and 300 kg/day (660 lb/day), an 86 percent increase over dry weather.

If bleed/pump-back of the wet weather sludge is not achieved over the entire year, the impacts of the sludge will be much greater. The reported daily dry weather flow is 2×10^3 cu m/day (0.5 MGD) while during wet weather conditions the average flow is 15×10^3 cu m/day (4 MGD). This wet weather flow will generate a sludge flow of 28 cu m/day (7.3×10^3 gal./day) and 1.4×10^3 kg/day (3.1×10^3 lb/day). These flow rates are 492 and 406 percent, respectively, above the daily dry weather flow rates.

Thus, even though the city of New Providence does not have a combined sewer system, the impact of wet weather generated solids in the sanitary sewer could be significant. If sludge handling facilities were to be constructed, the wet weather flows would dictate capabilities 2 to 4 times greater than those that would be required based on the dry weather flow rates.

Since there are no available sludge handling facilities at the New Providence site, the same sludge handling schemes were evaluated with respect to the generated volume of wet weather sludge. The costs were developed as before and based on a sludge volume of 36 cu m/day (9.4×10^3 gpd) at solids concentration of 5.2 percent. Therefore the only applicable alternatives involved hauling the stabilized sludge directly to a land application site or dewatering followed by landfill or land application. The cost estimates are included in Table 46. It is indicated that stabilization followed by direct land application of the sludge is the most cost effective approach for the New Providence sludge handling. This alternative provides a significant cost advantage over the other methods, although it is readily apparent that any attempt at on-site sludge handling is costly.

ECONOMIC IMPACT OF NATIONWIDE HANDLING AND DISPOSAL OF CSO TREATMENT SLUDGES

General

This evaluation involved developing an approximation of the economic impact of handling CSO treatment residuals across the country. In order to accomplish this task, the cities containing CSO areas were statistically evaluated. Four specific areas were evaluated for two types of CSO treatment methods (dissolved air flotation and contact stabilization). The same four sludge handling schematics as previously indicated were developed for both types of sludges. All economic data was based on the same cost criteria as presented previously.

Basis of Evaluation

There were several aspects involved in developing the necessary information for hypothetical cities across the United States. The first involved choice of CSO areas for evaluation. The next involved establishing both the sludge volume and characteristics so that the process equipment could be properly sized.

To select the city size, the area served by combined sewerage systems in urban United States was obtained (75) and analyzed. The available data consisted of combined sewerage areas serving the fifty states and Washington, D.C. and more specifically included a tabulation of the combined sewerage areas serving the urbanized areas (cities) of the country. A total of 248 urbanized areas were covered with the combined sewerage areas ranging from none to about 205,000 acres. Of the 248 urbanized areas for which data was available 128 of them were not served by combined sewerage systems. The remaining 120 urbanized areas had areas served by combined sewers ranging from 40.5 - 83,025

TABLE 46. COST ESTIMATES FOR CSO SLUDGE HANDLING BY SATELLITE TREATMENT-NEW PROVIDENCE

Alternative Number	Element	Capital Cost $	Operation & Maintenance Cost	Annual Cost
1	Pumping	$0.12x10^6$	$ 4,000	$ 14,000
	Storage	$0.019x10^6$	--	2,000
	Lime Stabilization	$0.028x10^6$	2,000	4,000
	Gravity Thickening	N/A	N/A	--
	Vacuum Filtration	$0.618x10^6$	12,000	64,000
	Transportation	--	--	27,000
	Landfill	$0.128x10^6$	11,000	22,000
	Sub Total			$133,000
	15% Contingency			20,000
	TOTAL			$153,000
2	Pumping	$0.12x10^6$	$ 4,000	$ 14,000
	Storage	$0.019x10^6$	--	2,000
	Lime Stabilization	$0.028x10^6$	2,000	4,000
	Gravity Thickening	N/A	N/A	--
	Vacuum Filtration	$0.610x10^6$	12,000	64,000
	Transportation	--	--	27,000
	Land Application	--	--	9,000
	Sub Total			$120,000
	15% Contingency			18,000
	TOTAL			$138,000

TABLE 46 (continued)

Alternative Number	Element	Capital Cost $	Operation & Maintenance Cost	Annual Cost
3	Pumping	--	--	--
N/A	Storage	--	--	--
	Lime Stabilization	--	--	--
	Gravity Thickening	--	--	--
	Transportation	--	--	--
	Land Application	--	--	--
	Sub Total			
	15% Contingency			
	TOTAL			N/A
4	Pumping	$0.12x10^6$	$ 4,000	$14,000
	Storage	$0.019x10^6$	--	2,000
	Lime Stabilization	$0.028x10^6$	2,000	4,000
	Transportation	--	--	35,000
	Land Application	--	--	27,000
	Sub Total			$82,000
	15% Contingency			12,000
	TOTAL			$94,000

ha (100-205,000 acres). The combined sewer area data for the 120 urbanized areas noted above were examined and the following conclusions drawn:

1. The mean combined sewer acreage served was 2309 ha (5700 acres).
2. As mentioned previously, the areas served by combined sewers ranged from 40.5 - 82,025 ha (100-205,000 acres). The following further breakdowns were observed:
   a. Fifteen cities (about 12.5%) had combined sewer areas serving less than 40.5 ha (1000 acres) each.
   b. Fifty-seven cities (about 47.5%) had combined sewer areas serving between 405-4050 ha (1000-10,000 acres) each.
   c. Forty-two cities (about 35%) had combined sewer areas serving between 4050 and 16,200 ha (10,000 and 40,000 acres) each.
   d. Only six cities (about 5%) had combined sewer areas greater than 20,250 ha (50,000 acres) each (San Francisco, CA; Cincinnati, OH; New York, NY; St. Louis, MO; Detroit, MI; and Chicago, IL).

From this information it was established that four example areas could be chosen and representative costs established. An area in each range was used as follows:

a. 12.5% - 0-405 ha (0-1000 acres) CSO area choice: 203 ha (500 acres)
b. 47.5% - 405-4050 ha (1001-10,000 acres) CSO area choice: 2307 ha (5700 acres)
c. 35% - 4050-16,200 ha (10,001-40,000 acres) CSO area choice: 10,118 ha (25,000 acres)
d. 5% - >16,200 ha (>40,000 acres) CSO area choice: 24,300 (60,000 acres)

Once the size of the affected area was established, further assumptions were made regarding the volume of CSO sludge generated. Two types of CSO treatment sludges were considered to allow a range of costs due to varying residue characteristics. One type was biological and contact stabilization sludge was considered and the second type was physical/chemical so dissolved air flotation sludge was evaluated. The criteria listed in Table 47 were then applied to establish CSO sludge flow rates and characteristics.

<u>Economic Results</u>

Each of the CSO areas and resultant sludges were then evaluated with regard to the costs for utilizing one of the four sludge handling alternatives:

Alternative 1. Lime Stabilization → Gravity Thickening → Vacuum Filtration → Landfill
2. Lime Stabilization → Gravity Thickening → Vacuum Filtration → Land Application
3. Lime Stabilization → Gravity Thickening → Land Application
4. Lime Stabilization → Land Application

Table 47 ASSUMPTIONS FOR COST CALCULATIONS

CSO Volume

1. 50% of rainfall is CSO
2. Average rainfall is 0.914m/year (36"/year)
3. 60 storm events occur per year

CSO Sludge - Biological

1. 3.5% of CSO volume = sludge volume
2. Solids concentration is 10,000 mg/l

CSO Sludge - Physical/Chemical

1. 0.6% of CSO volume - sludge volume
2. Solids concentration is 27,500 mg/l

The results are presented in detail for each of the chosen CSO areas in Tables 48-51. A comparison of the cost ranges for the city size is summarized in Tables 52 and 53. It can be seen that the cost for treatment of CSO residuals can vary significantly depending upon the type of CSO treatment used, the sludge handling schematic and the total volume of CSO to be treated. The overall annual cost ranges from \$139/ha-\$1403/ha (\$56-\$660/acre) of CSO served area. When it is recalled that there are 1.2×10^6 ha (3.0×10^6 acres) of area served by combined sewers throughout the country, the economic impact of treating CSO sludges nationwide could range from \$169,000,000 - \$1,720,000,000 annually.

If initial capital costs are evaluated, as indicated in Table 53, this first expense ranges from \$447-\$10,173/ha (\$181-4120/acre). These capital costs assume an initial expenditure for the land which will be recovered when the land is sold. When considering the nationwide impact with respect to initial capital costs, this could range from \$548 $\times 10^6$ - \$12.5 $\times 10^9$ to provide sludge handling and disposal for all treatment residues.

TABLE 48. COST ESTIMATES FOR 500 ACRE CSO AREA

Alternative Number	Element	Annual cost: Biological Treatment	Annual cost: Dissolved-Air Flotation Treatment
1	Pumping	$ 25,000	$ 19,000
	Storage	8,000	13,000
	Lime Stabilization	12,000	6,000
	Gravity Thickening	18,000	13,000
	Vacuum Filtration	108,000	74,000
	Transportation	31,000	25,000
	Landfill	44,000	27,000
	Sub Total	$246,000	$177,000
	15% Contingency	37,000	27,000
	TOTAL	$283,000	$204,000
2	Pumping	$ 25,000	$ 19,000
	Storage	8,000	13,000
	Lime Stabilization	12,000	6,000
	Gravity Thickening	18,000	13,000
	Vacuum Filtration	108,000	74,000
	Transportation	31,000	25,000
	Land Application	19,000	9,000
	Sub Total	$221,000	$159,000
	15% Contingency	33,000	24,000
	TOTAL	$254,000	$183,000

acres x 0.405 = ha

TABLE 48 (continued).

Alternative Number	Element	Annual Cost: Biological Treatment	Annual Cost: Dissolved-Air Flotation Treatment
3	Pumping	$ 25,000	$ 19,000
	Storage	8,000	13,000
	Lime Stabilization	12,000	6,000
	Gravity Thickening	18,000	13,000
	Transportation	42,000	30,000
	Land Application	182,000	11,000
	Sub Total	$287,000	$ 92,000
	15% Contingency	43,000	14,000
	TOTAL	$330,000	$106,000
4	Pumping	$ 25,000	$ 19,000
	Storage	8,000	13,000
	Lime Stabilization	12,000	6,000
	Transportation	140,000	40,000
	Land Application	43,000	13,000
	Sub Total	$231,000	$ 91,000
	15% Contingency	35,000	14,000
	TOTAL	$266,000	$105,000

acres x 0.405 = ha

TABLE 49. COST ESTIMATES FOR 5700 ACRE CSO AREA

Alternative Number	Element	Annual cost: Biological Treatment	Annual cost: Dissolved-Air Flotation Treatment
1	Pumping	$ 104,000	$ 78,000
	Storage	51,000	17,000
	Lime Stabilization	108,000	58,000
	Gravity Thickening	102,000	54,000
	Vacuum Filtration	375,000	229,000
	Transportation	90,000	38,000
	Landfill	247,000	100,000
	Sub Total	$1,077,000	$574,000
	15% Contingency	162,000	86,000
	TOTAL	$1,239,000	$660,000
2	Pumping	$ 104,000	$ 78,000
	Storage	51,000	17,000
	Lime Stabilization	108,000	58,000
	Gravity Thickening	102,000	54,000
	Vacuum Filtration	375,000	229,000
	Transportation	90,000	38,000
	Land Application	87,000	39,000
	Sub Total	$ 917,000	$513,000
	15% Contingency	138,000	77,000
	TOTAL	$1,055,000	$590,000

acres x 0.405 = ha

TABLE 49 (continued).

Alternative Number	Element	Annual cost: Biological Treatment	Annual cost: Dissolved-Air Flotation Treatment
3	Pumping	$ 104,000	$ 78,000
	Storage	51,000	17,000
	Lime Stabilization	108,000	58,000
	Gravity Thickening	102,000	54,000
	Transportation	375,000	60,000
	Land Application	140,000	46,000
	Sub Total	$ 880,000	$313,000
	15% Contingency	132,000	47,000
	TOTAL	$1,012,000	$360,000
4	Pumping	$ 104,000	$ 78,000
	Storage	51,000	17,000
	Lime Stabilization	108,000	58,000
	Transportation	1,100,000	240,000
	Land Application	346,000	346,000
	Sub Total	$1,709,000	$739,000
	15% Contingency	256,000	110,000
	TOTAL	$1,965,000	$849,000

acres x 0.405 = ha

TABLE 50. COST ESTIMATE FOR 25000 ACRE CSO AREA

Alternative Number	Element	Annual cost: Biological Treatment	Annual cost: Dissolved-Air Flotation Treatment
1	Pumping	$ 322,000	$ 186,000
	Storage	141,000	56,000
	Lime Stabilization	451,000	244,000
	Gravity Thickening	354,000	209,000
	Vacuum Filtration	1,025,000	731,000
	Transportation	450,000	100,000
	Landfill	432,000	474,000
	Sub Total	$3,175,000	$2,000,000
	15% Contingency	476,000	300,000
	TOTAL	$3,651,000	$2,300,000
2	Pumping	$ 322,000	$ 186,000
	Storage	141,000	56,000
	Lime Stabilization	451,000	244,000
	Gravity Thickening	354,000	209,000
	Vacuum Filtration	1,025,000	731,000
	Transportation	450,000	100,000
	Land Application	276,000	141,000
	Sub Total	$3,019,000	$1,667,000
	15% Contingency	453,000	250,000
	TOTAL	$3,472,000	$1,917,000

acres x 0.405 = ha

TABLE 50 (continued)

Alternative Number	Element	Annual cost: Biological Treatment	Annual cost: Dissolved-Air Flotation Treatment
3	Pumping	$ 322,000	$ 186,000
	Storage	141,000	56,000
	Lime Stabilization	451,000	244,000
	Gravity Thickening	354,000	209,000
	Transportation	1,800,000	1,000,000
	Land Application	456,000	258,000
	Sub Total	$3,524,000	$1,953,000
	15% Contingency	529,000	293,000
	TOTAL	$4,053,000	$2,246,000
4	Pumping	$ 322,000	$ 186,000
	Storage	141,000	56,000
	Lime Stabilization	451,000	244,000
	Transportation	7,000,000	1,700,000
	Land Application	1,111,000	346,000
	Sub Total	$ 9,025,000	$2,532,000
	15% Contingency	1,354,000	380,000
	TOTAL	$10,379,000	$2,912,000

acres x 0.405 = ha

TABLE 51. COST ESTIMATES FOR 60,000 ACRE CSO AREA

Alternative Number	Element	Annual cost: Biological Treatment	Annual cost: Dissolved-Air Flotation Treatment
1	Pumping	$ 287,000	$ 600,000
	Storage	328,000	126,000
	Lime Stabilization	1,056,000	209,000
	Gravity Thickening	630,000	832,000
	Vacuum Filtration	2,199,000	941,000
	Transportation	900,000	190,000
	Landfill	1,572,000	1,015,000
	Sub Total	$6,972,000	$3,913,000
	15% Contingency	1,046,000	587,000
	TOTAL	$8,018,000	$4,500,000
2	Pumping	$ 287,000	$ 600,000
	Storage	328,000	126,000
	Lime Stabilization	1,056,000	209,000
	Gravity Thickening	630,000	832,000
	Vacuum Filtration	2,199,000	941,000
	Transportation	900,000	190,000
	Land Application	626,000	265,000
	Sub Total	$6,026,000	$3,163,000
	15% Contingency	904,000	474,000
	TOTAL	$6,930,000	$3,637,000

acres x 0.405 = ha

TABLE 51 (continued)

Alternative Number	Element	Annual cost: Biological Treatment	Annual cost: Dissolved-Air Flotation Treatment
3	Pumping	$ 287,000	$ 600,000
	Storage	328,000	126,000
	Lime Stabilization	1,056,000	209,000
	Gravity Thickening	630,000	832,000
	Transportation	4,000,000	780,000
	Land Application	1,043,000	347,000
	Sub Total	$7,344,000	$2,894,000
	15% Contingency	1,102,000	434,000
	TOTAL	$8,446,000	$3,328,000
4	Pumping	$ 287,000	$ 600,000
	Storage	328,000	126,000
	Lime Stabilization	1,056,000	209,000
	Transportation	20,000,000	3,400,000
	Land Application	1,043,000	677,000
	Sub Total	$22,714,000	$5,012,000
	15% Contingency	3,407,000	752,000
	TOTAL	$26,121,000	$5,764,000

acres x 0.405 = ha

TABLE 52. ANNUAL COST FOR CSO SLUDGE HANDLING

	Size of CSO area			
	500 acres	5700 acres	25,000 acres	60,000 acres
Treatment alternative	Cost in dollars			
Alternative 1:				
Biological sludge	$283,000	$1,239,000	$ 3,651,000	$ 8,018,000
DAF sludge	204,000	660,000	2,300,000	4,500,000
Alternative 2:				
Biological sludge	254,000	1,055,000	3,472,000	$ 6,930,000
DAF sludge	183,000	590,000	1,917,000	3,637,000
Alternative 3:				
Biological sludge	330,000	1,012,000	4,053,000	$ 8,446,000
DAF sludge	106,000	360,000	2,246,000	3,328,000
Alternative 4:				
Biological sludge	266,000	1,965,000	10,379,000	26,121,000
DAF sludge	105,000	849,000	2,912,000	5,764,000
$/acre	$210-$660	$64-$345	$77-$415	$56-$435
$/ton of dry solids	$347-$1140	$188-$483	$193-$581	$162-$610

Acres x 0.405 = ha
Tons x 0.907 = metric tons

TABLE 53. CAPITAL COST INFORMATION* FOR CSO SLUDGE HANDLING

	Size of CSO area			
	500 acres	5700 acres	25,000 acres	60,000 acres
Treatment alternative	Cost in dollars			
Alternative 1:				
Biological sludge	$\$2.06 \times 10^6$	$\$8.43 \times 10^6$	$\$22.54 \times 10^6$	$\$52.54 \times 10^6$
DAF sludge	1.49×10^6	5.37×10^6	16.94×10^6	38.17×10^6
Alternative 2:				
Biological sludge	1.86×10^6	7.48×10^6	20.86×10^6	46.76×10^6
DAF sludge	1.39×10^6	5.29×10^6	14.85×10^6	32.37×10^6
Alternative 3:				
Biological sludge	0.74×10^6	4.56×10^6	14.48×10^6	34.07×10^6
DAF sludge	0.53×10^6	2.37×10^6	8.69×10^6	14.68×10^6
Alternative 4:				
Biological sludge	0.54×10^6	2.36×10^6	10.68×10^6	26.36×10^6
DAF sludge	0.42×10^6	1.03×10^6	6.36×10^6	14.49×10^6
$/acre	$840-$4120	$181-$1479	$254-$902	$242-$876
$/ton of dry solids	$1310-$8660	$538-$2804	$598-$2018	$616-$1892

* All handling and distribution costs for land application were considered operating only.

Acres x 0.405 = ha
Tons x 0.907 = metric tons

SECTION IX

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TECHNICAL REPORT DATA
(Please read Instructions on the reverse before completing)

1. REPORT NO. EPA-600/2-77-053b	2.	3. RECIPIENT'S ACCESSION NO.
4. TITLE AND SUBTITLE HANDLING AND DISPOSAL OF SLUDGES FROM COMBINED SEWER OVERFLOW TREATMENT Phase II - Impact Assessment		5. REPORT DATE December 1977 (Issuing Date)
		6. PERFORMING ORGANIZATION CODE
7. AUTHOR(S) Kathryn R. Huibregtse, Gary R. Morris, Anthony Geinopolos and Michael J. Clark		8. PERFORMING ORGANIZATION REPORT NO.
9. PERFORMING ORGANIZATION NAME AND ADDRESS Environmental Sciences Division Envirex Inc. (A Rexnord Company) 5103 West Beloit Road Milwaukee, Wisconsin 53214		10. PROGRAM ELEMENT NO. 1BC611
		11. CONTRACT/~~GRANT~~ NO. 68-03-0242
12. SPONSORING AGENCY NAME AND ADDRESS Municipal Environmental Research Laboratory--Cin.,OH Office of Research and Development U.S. Environmental Protection Agency Cincinnati, Ohio 45268		13. TYPE OF REPORT AND PERIOD COVERED Final, 2/74-2/76
		14. SPONSORING AGENCY CODE EPA/600/14

15. SUPPLEMENTARY NOTES
See also Phase I, EPA-600/2-77-053a, NTIS PB-270 212
Project Officer: Anthony N. Tafuri, Phone: (201)321-6679, Ext. 6679 (8-340-6679)

16. ABSTRACT

This report documents the results of an assessment of the effort that the United States will have to exert in the area of sludge handling and disposal if, in fact, full-scale treatment of combined sewer overflows is to become a reality. The results indicate that nationwide an average yearly sludge volume of 156×10^6 cu m (41.5×10^9 gal.) could be expected from CSO if complete CSO treatment were achieved.

Evaluation of the effect of bleed/pump-back of CSO sludge on the hydraulic, solids and/or organic loadings to the dry-weather plant indicated that overloading would occur in most instances. The most promising treatment trains were found to include possible grit removal, lime stabilization, optional gravity thickening, optional dewatering and land application or landfill. Land application systems can be considered as viable alternatives for CSO treatment and disposal.

Costs for overall CSO sludge handling depend on the type of CSO treatment process, volume and characteristics of the sludge and the size of the CSO area, among other considerations. Estimates indicate that first investment capital costs range from \$447-10,173/ha (\$181-4129/ac) with annual costs of \$139-1630/ha (\$56-660/ac).

17. KEY WORDS AND DOCUMENT ANALYSIS

a. DESCRIPTORS	b. IDENTIFIERS/OPEN ENDED TERMS	c. COSATI Field/Group
Combined sewers Sludge Sludge disposal Thickening Dewatering	Lime stabilization Land application Bleed/pump/back Sludge characterization Sludge treatment	13B

18. DISTRIBUTION STATEMENT RELEASE TO PUBLIC	19. SECURITY CLASS (This Report) UNCLASSIFIED	21. NO. OF PAGES 209
	20. SECURITY CLASS (This page) UNCLASSIFIED	22. PRICE

EPA Form 2220-1 (9-73)

☆ U.S. GOVERNMENT PRINTING OFFICE: 1978— 757-110/6677