DRAFT

DEVELOPMENT DOCUMENT FOR EFFLUENT LIMITATIONS GUIDELINES AND STANDARDS OF PERFORMANCE

WATER SUPPLY INDUSTRY

ENVIRONMENTAL PROTECTION AGENCY
MARCH 1975

DRAFT

NOTICE

The attached document is a DRAFT CONTRACTOR'S REPORT. It includes technical information and recommendations submitted by the Contractor to the United States Environmental Protection Agency ("EPA") regarding the subject industry. It is being distributed for review and comment only. The report is not an official EPA publication and it has not been reviewed by the Agency.

The report, including the recommendations, will be undergoing extensive review by EPA, Federal and States agencies, public interest organizations, and other interested groups and persons during the coming weeks. The report and in particular the contractor's recommended effluent limitations guidelines and standards of performance is subject to change in any and all respects.

The regulations to be published by EPA under Section 304 (b) and 306 of the Federal Water Pollution Control Act, as amended, will be based to a large extent on the report and the comments received on it. However, pursuant to Sections 304 (b) and 306 of the Act, EPA will also consider additional pertinent technical and economic information which is developed in the course of review of this report by the public and within EPA. EPA is currently performing an economic impact analysis regarding the subject industry, which will be taken into account as part of the review of the report. Upon completion of the review process, and prior to final promulgation of regulations, an EPA report will be issued setting forth EPA's conclusions concerning the subject industry, effluent limitation guidelines and standards of performance applicable to such industry. Judgments necessary to promulgation of regulations under Sections 304 (b) and 306 of the Act, of course, remain the responsibility of EPA. Subject to these limitations, EPA is making this draft contractor's report available in order to encourage the widest possible participation of interested persons in the decision making process at the earliest possible time.

The report shall have standing in any EPA proceeding or court proceeding only to the extent that it represents the views of the Contractor who studied the subject industry and prepared the information and recommendations. It cannot be cited, referenced, or represented in any respect in any such proceedings as a statement of EPA's views regarding the subject industry.

U. S. Environmental Protection Agency
Office of Water and Hazardous Materials
Effluent Guidelines Division
Washington, D.C. 20460

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SECTION I

CONCLUSIONS

In this study of the water-supply industry (SIC 4941), the nature and the amounts of the raw wastewater loadings were found to depend on the types of processes and the combinations of processes in the treatment of the raw water used as feed. The size of water-treatment plants and the hardness of the raw water had significant effects on raw wastewater loads. Therefore the types of processes and the combinations of processes were used as the basis of subcategorization, and an equation was developed from multiple linear regressions of the collected data to provide allowances for the effects of plant size and raw-water hardness. The subcategories developed for the water-supply industry are:

Subcategory I - Plants that use one of the following processes: coagulation, oxidative iron-and-manganese removal, direct filtration, or diatomaceous earth filtration. In plants grouped in Category I only one of the above solids-removal processes is used. Combinations of two or more solids removal processes are included in other categories.

Subcategory II - Plants that use only the chemical* (i.e., lime or lime-soda) softening processes. No combinations of solids-removal processes are included.

Subcategory III - Plants that use combinations of coagulation and chemical softening, or oxidative-iron-manganese removal and chemical softening.

Plants in these categories generate wastewaters with sludges of suspended solids, but differ in treatability of sludges, the amounts of wastewater, the pH of the wastewater, and the concentrations and loadings of suspended solids in the wastewaters. The concentration or loading of suspended solids in

*Chemical softening is used in this report as a collective term to cover either lime or lime-soda softening so that repetitions of the two terms (lime and lime-soda) can be avoided.

wastewaters before any waste treatment is termed the "raw waste load."

There are plants in the three subcategories that use zeolite iron removal or zeolite softening processes in combination with the solids-removal processes identified in the subcategories. These plants were not treated as a subcategory; but separate provisions, described below, were made for the wastewaters from the zeolite processes.

Pollutants are defined to be constituents in wastewaters in concentrations posing potential detriment to the environment. For the three subcategories of plants that generate wastewaters, pollutants were found to be pH and total suspended solids (TSS).

If a zeolite process is used in combination with any of the subcategorized solids-removal processes, the following constituents are pollutants: total dissolved solids (TDS), dissolved iron, dissolved manganese, and the fluoride ion. However, none of these pollutants found in waste zeolite brines was the subject of the effluent limitations guidelines to be met by 1977 because there is no adequately demonstrated control and treatment technology. For the effluent limitations guidelines to be met by July 1, 1983, the pollutants in waste zeolite brines will not be subject to limitations because the brines will be segregated from other wastes, reclaimed, and reused, and only a solid waste will be generated.

Water-treatment plants that use the processes of dissolved-solids removal or defluoridation generate wastewaters that may contain potentially detrimental concentrations of TDS or fluoride. However, for these wastes, no adequate control or treatment technology has been demonstrated. Therefore, the means for disposal of the wastewaters from these processes will be judged individually with the following possibilities for disposal in mind: discharge to a sewer, controlled dilution prior to discharge to a water-course, discharge to the ocean, or deep-well injection.

A few water-treatment plants use presedimentation basins. In these much of the suspended solids in the raw water settles, and the sludge generated is discharged continuously into the source from which the raw water came. Studies of the costs and energy requirements needed to dewater such sludges and transport the dewatered sludges to landfill sites indicate unfavorable cost-benefit ratios for this treatment in a number of cases. Since the total number of plants with presedimentation basins is small compared with the total number of waste-producing plants, no across-the-board limitations are recommended for the wastes from presedimentation basins. Instead, each case should be judged individually.

Few of the verified data sheets used as a data base for this study were from plants that treat water for use by industry (24 out of 782 total). From statistical analysis of these 24 plants, there appears to be no significant differences between the wastes from industrial water-treatment plants and the wastes from other plants. Therefore, the industrial plants we included with the total number of plants for the statistical studies to develop effluent limitation guidelines. However, additional data from industrial water-treatment plants may be desirable.

SECTION II

RECOMMENDATIONS

The effluent limitations commensurate with the best practicable control technology currrently available (BPCTCA) recommended for each of the three subcategories identified in Section I were established by applying the "statistical variability factor," which describes the day-to-day variations in wasteloads, to the annual average waste loads.

The annual average loadings of TSS are given in terms of kilograms of TSS per 1000 cubic meters of product water (kg/1000 cu m), and in English units of pounds per million gallons (lb/MG), and are defined by the following equation.

Eq. II - 1 $$L = 0.6 + S + H$$

where: L = annual average loading of TSS, kg/1000 cu m

S = allowance for plant size taken from Table II-1, kg/1000 cu m

H = allowance for hardness of raw water taken from Table II-1, kg/1000 cu m

For all categories an annual average waste load of 0.6 kg/1000 cu m (5 lb/MG) of product is recommended for what is termed the "base-load" plant. The basis for this 0.6 kg/1000 cu m (5 lb/MG) waste load stems from multiple-regression analyses of the data. The base-load plant is a large plant [>1,893,000 cu m/day (>500 MGD)] that does not use chemical or softening processes. For smaller plants an additional allowance for plant size, S, is recommended. The magnitude of the allowance depends on the plant size as shown in Table II-1.

For plants in Category I, chemical softening is not performed. Therefore, no allowance is given for the hardness of the raw water, and only the size allowance, S, in Table II-1 is applicable. For plants in Categories II and III, in which chemical softening is performed, the hardness allowance, H, in Table II-1 is used.

The allowable waste load of TSS calculated by equation II-1 will be the annual average waste load, whereas the daily maximum waste load should be used to express the effluent limitations. As explained in Section IX daily maximum values of waste loads, which are short-term limitations that must not be exceeded, can be obtained by the use of the statistical "variability factor". The statistical variability factor for TSS loadings was found to 6.6, when the available data on TSS loadings in effluents from solids-separation devices in the water supply industry was analyzed statistically. The daily maximum loading limitation will be 6.6 x L, when L is calculated from equation II-1 and Table II-1.

At present, this limitation should be viewed as tentative because few data were available to establish the statistical variability factor, V. More data are being sought and a more definitive value of V may be established, when additional data are obtained.

The pH ranges recommended as limitations for three categories are the following:

Subcategory I - pH from 6.0 to 9.0
Subcategory II - pH from 6.0 to 10.5
Subcategory III - pH from 6.0 to 10.5

Effluent limitations are recommended that are based on the best available technology economically achievable (BATEA). For all three categories it is recommended that the supernatants from solids-separation devices be recycled for use as feed water to the plant. It is also recommended that in any plants that use either the zeolite softening or zeolite-iron-and-manganese-removal processes the waste brines will be segregated from other wastewaters, reclaimed, and reused for regeneration.

The recommended technology and effluent limitations for new sources are the same as those described above as BPCTCA, except that for new sources filter backwash water will be recycled to the feed end of the plant. It is recommended that the technology and effluent limitations identified above as BATEA be reconsidered after the necessary developmental work is performed to demonstrate the reliability and acceptability of recycling the water-borne discharges from solids-separations systems used to treat sludges, and of segregating spent zeolite brines, reclaiming and reusing them for regeneration.

Table II-1

Allowances to Adjust the Annual Average Waste Load for Plant Size and Raw Water Hardness

Plant size,[a] 1000 cu m/day	<3.8	3.8-11.4	11.4-38	38-114	114-379	379-1136	1136-1893	>1893
MGD	(<1)	(1-3)	(3-10)	(10-30)	(30-100)	(100-300)	(300-500)	(>500)
S(allowance), kg/1000 cu m	0.70	0.50	0.40	0.30	0.20	0.10	0.05	(0)
lb/MG	(5.8)	(4.2)	(3.3)	(2.5)	(1.7)	(0.8)	(0.4)	(0)
Hardness,[a] mg/l	0-100	100-200	200-300	300-400	400-500	500-600	600-700	
H(allowance), kg/1000 cu m	0.13	0.24	0.35	0.46	0.56	0.67	0.78	
lb/MG	(1.1)	(2.0)	(2.9)	(3.8)	(4.7)	(5.6)	(6.5)	

a) Annual average total hardness expressed as mg/l of $CaCO_3$

SECTION III

INTRODUCTION

A. Purpose and Authority

Section 301(b) of the Act requires the achievement by not later than July 1, 1977, of effluent limitations for point sources, other than publicly owned treatment works, which are based on the application of the best practicable control technology currently available as defined by the Administrator pursuant to Section 304(b) of the Act. Section 301(b) also requires the achievement by not later than July 1, 1983, of effluent limitations for point sources, other than publicly owned treatment works, which are based on the application of the best available technology economically achievable which will result in reasonable further progress toward the national goal of eliminating the discharge of all pollutants, as determined in accordance with regulations issued by the Administrator pursuant to Section 304(b) of the Act. Section 307 of the Act requires the achievement by new sources of a Federal standard of performance providing for the control of the discharge of pollutants which reflects the greatest degree of effluent reduction which the Administrator determines to be achievable through the application of the best available demonstrated control technology, processes, operating methods, or other alternatives, including, where practicable, a standard permitting no discharge of pollutants.

Section 304(b) of the Act requires the Administrator to publish, within one year of enactment, regulations providing guidelines for effluent limitations setting forth the degree of effluent reduction attainable through the application of the best practicable control technology currently available and the degree of effluent reduction attainable through the application of the best control measures and practices achievable including treatment techniques, process and procedure innovations, operation methods and other alternatives. The regulations proposed herein set forth effluent limitations guidelines pursuant to Section 304(b) of the Act for the water supply source category.

Section 306 of the Act requires the Administrator, within one year after a category of sources is included in a list published pursuant to Section 306(b) (1) (A) of the Act, to propose regulations establishing Federal standards of performances for new sources within such categories.

B. Basis for Guidelines Development

The effluent limitations guidelines and performance standards recommended in this report were developed from analysis of information in the literature, reports from the American Water Works Association and from individual companies, Refuse Act Permit Program (RAPP) applications, state-agency files, and information gathered by personal visits to water-treatment plants to identify potential subcategories and exemplary plants and to obtain information on water use and wastewater characteristics. On-site studies of potential exemplary plants were subsequently conducted to verify this information and observe the control and treatment technology employed to achieve exemplary performance. Discussions were also held with consultants and others with knowledge of the manufacturing and waste-treatment practices in the industry.

Some information was obtained about more than 2500 waste-producing water-treatment plants, and detailed information was collected for 1467 of the more than 9000 waste-producing water-treatment plants identified as currently in operation. The sources and types of information consisted of

- 656 applications to the Corps of Engineers for Permits to Discharge under the Refuse Act Permit Program (RAPP). However, less than 50 of the RAPP applications contained enough information to characterize such factors as wastewaters, control and waste treatment practices employed, amounts of chemicals used, and the processes used in treating raw water.

- Many reports from the files of state agencies with responsibility for environmental protection. These reports contained valuable information about the compositions of raw water and product water, the treatment processes, and the amounts of chemicals used.

- On-site inspections of water-treatment plants that provided flow diagrams and detailed information on the practices used in water-treatment and waste management, and on the control and treatment methods, equipment, and costs.

- Other sources of information including EPA technical reports, trade literature, personal and telephone interviews and meetings with regional EPA personnel, industry personnel, and consultants, and information from the American Water Works Association.

The reliability of the data was verified by sending data sheets with the information obtained from the above sources to each of 2500 water treatment plants for correction of any incorrect or out-of-date data and for addition of any missing data. Of the 2500 data sheets sent to the water-treatment plants, 782 were verified (or corrected and verified) and returned. In addition, personal visits were made to 151 plants, and samples were taken and analyzed at 128 of these. The data base used in development of charts, tables, and figures includes only the 782 plants for which data have been verified. The 782 plants represent approximately 8% of the total waste-producing plants, including both municipal and industrial plants.

The information obtained in this way was compiled by data processing techniques and used to prepare data sheets, such as that illustrated for a hypothetical plant in Figure III-1, and analyzed for the following:

- Identification of distinguishing features that could potentially provide a basis for subcategorization of the industry. These features included composition of raw water, in-plant processes used for treatment of wastes, plant size and age, and other features which are discussed in detail in Section IV.

- Determination of the waste characteristics for each subcategory as discussed in Section V including the volume of water used, the sources of the waste streams in the plant, and the type and quantity of constituents in the wastewaters.

- Identification of those constituents, discussed in Section VI, which are characteristic of the industry and present in measurable quantities, thus being pollutants subject to effluent limitations guidelines and standards.

The control and treatment technologies employed at exemplary plants were identified during the on-site studies, and are discussed in Section VII.

SUMMARY OF DATA FOR PLANT NUMBER 9999 CATEGORY 21 EPA REGION 11

SLUDGEBANK WATER BOARD LOWER MUDDY FILTER PLANT SLUDGEBANK ST

AVERAGE DAILY FLOWS (MGD)	INTAKE	PRODUCT	BCKWASH	CSR*	ISR**	TOT WASTE
	30.0000	29.0000	0.6500	0.3350	0.0120	0.9970

TREATMENTS PERFORMED ON RAW WATER

PRESED
AERATION
COAGULATION
SED BASIN
ZEOL SOFT
IR-OXDN
FRS
ACT CARBON

CHEMICALS ADDED (PPM)

LIME	20.000
CHLORINE	1.200
ALUM	25.000
ACT CARBON	2.000
NACL	400.000

PLANT USES SURFACE WATER SOURCE

RAW AND PRODUCT CONCENTRATIONS

SOURCE	ALK	BOD	COD	T SOL	TDS	TSS	TVS	AMMONIA	KN	NO3	PHOS	COLOR
RAW CONC$	0.00	0.00	0.00	0.00	400.00	50.00	0.00	0.00	0.00	-1.00	0.00	18.00
PROD CNC$	0.00	0.00	0.00	0.00	380.00	0.50	0.00	0.00	0.00	0.02	0.00	-1.00
LB/MG-PRD	0.00	0.00	0.00	0.00	166.90	413.08	0.00	0.00	0.00	0.00	0.00	150.21
TOTL LB/D	0.00	0.00	0.00	0.00	4840.10	11979.25	0.00	0.00	0.00	0.00	0.00	4356.09
WST CONC#	0.00	0.00	0.00	0.00	1127.73	1851.13	0.00	0.00	0.00	0.00	0.00	672.96

	TURB	CHEM ADN	T HARD	SO4	AL	CL	CA	F	SO2	CD	CN	CO
RAW CONC$	60.00	0.00	300.00	14.00	-1.00	35.00	145.00	0.30	0.00	-1.00	-1.00	0.00
PROD CNC$	-1.00	0.00	160.00	16.00	-1.00	90.00	80.00	0.50	0.00	-1.00	-1.00	0.00
LB/MG-PRD	500.70	29.68	1168.30	0.00	0.00	0.00	542.43	0.00	0.00	0.00	0.00	0.00
TOTL LB/D	14520.30	860.58	33880.70	0.00	0.00	0.00	15730.33	0.00	0.00	0.00	0.00	0.00
WST CONC#	2243.19	1079.77	5394.10	14.00	0.00	35.00	2510.12	0.30	0.00	0.00	0.00	0.00

	CU	FE	NA	MG	HG	CAL TDS	NI	K	SE	PB	ZN	MN
RAW CONC$	0.60	1.20	20.00	18.00	-1.00	550.00	-1.00	2.00	0.00	-1.00	0.01	0.90
PROD CNC$	0.03	0.07	80.00	4.00	-1.00	500.00	-1.00	1.70	0.00	-1.00	-1.00	0.04
LB/MG-PRD	4.76	9.43	0.00	116.83	0.00	417.25	0.00	2.50	0.00	0.00	0.08	7.18
TOTL LB/D	137.94	273.47	0.00	3388.07	0.00	12100.25	0.00	72.60	0.00	0.00	2.42	208.12
WST CONC#	21.34	42.32	20.00	527.41	0.00	2369.32	0.00	12.92	0.00	0.00	0.37	32.19

*-CONTINUOUS SLUDGE REMOVAL
**-INTERMITTANT SLUDGE REMOVAL
$-ZERO INDICATES NO DATA, -1 IS USED TO REPRESENT AN ACTUAL MEASURED ZERO
#-CALCULATED WASTE CONCENTRATION DERIVED FROM PARAMETER REMOVED AND TOTAL WASTE FLOW

Figure III-1. Sample data sheet from data-processing program

The information, as outlined above, was then evaluated in order to determine what levels of technology constituted the "best practicable control technology currently available," and the "best available demonstrated control technology." In identification of such technologies, various factors were considered. These included the feasibility of using technology employed by other industries, the total cost of application of control technology in relation to the effluent reduction benefits to be achieved, non-water quality environmental impact (including energy requirements), and other factors as discussed in Section VIII.

C. Description of the Water-Supply Industry

The water-supply industry is classified by the Department of Commerce as SIC group 4941. This classification includes plants that treat water primarily for domestic, commercial, and industrial use, but excludes facilities that distribute water for irrigation.

The 1963 Inventory of Municipal Water Facilities* listed more than 40,000 water-supply plants that distribute water for domestic or commercial use. However, of these plants, only 4590 plants used treatment processes that can produce water-borne wastes. These plants distribute about 14 billion gallons of water per day.

There are 9402 plants listed in "Water Use in Manufacturing, 1967 Census of Manufacturers" that distribute water primarily for industrial use. However, only 5159 of these plants use processes that can produce water-borne wastes. These 5159 plants distribute approximately 9.6 billion gallons of water per day.

Table III-1 shows the total numbers of municipal water-treatment plants that utilize each type or combination of types of waste-producing process. The average daily productions of treated water in millions of gallons per day (MGD) from each type or combination and the total production from all plants are also shown.

*The results of the 1972 Inventory of Municipal Water Facilities have not been completely processed, and were therefore not used.

Table-III-1

Production of Water for Domestic Use From Waste-Producing Water-Treatment Plants[a]

Treatment process[a]	Number of plants	Average daily production[b] 1000 cu m/day	(MGD)	Total production, 1000 cu m/day	(MGD)
Coagulation	2358	16.2	(4.30)	38082.0	(10061.3)
Softening	353	3.22	(0.85)	1132.5	(299.2)
Iron removal	1117	2.57	(0.68)	2869.0	(758.0)
Coagulation-softening	265	32.10	(8.48)	8502.2	(2246.3)
Coagulation - iron removal	69	5.07	(1.34)	349.7	(92.4)
Softening - iron removal	366	3.60	(0.95)	1317.9	(348.2)
Coagulation - softening - iron removal	45	13.63	(3.60)	612.4	(161.8)
Other	17	6.36	(1.68)	107.9	(28.5)
Total	4590	11.54	(3.05)	52973.7	(13995.7)

a) As listed in the 1963 Inventory of Municipal Water Facilities, U. S. Department of Health, Education, and Welfare, Public Health Service, Washington, D.C.

b) Average per plant.

Table III-2

Production of Water for Industrial Use From Waste-Producing Water-Treatment Plants[a]

Treatment process[a]	Number of plants[a]	Average total daily production per plant 1000 cu m/day	(MGD)	Daily production of all plants, 1000 cu m/day	(MGD)
Coagulation	889	5,825.1	(1539)	14,183.9	(3,747.4)
Filtration	1559	3,652.5	(965)	15,609.7	(4,124.1)
Softening	3159	662.2	(176)	5,771.7	(1,524.9)
Ion-Exchange	1402	571.5	(151)	2,192.3	(579.2)
Settling	480	8,005.3	(2115)	10,529.5	(2,781.9)

a) As listed in Water Use in Manufacturing, 1967 Census of Manufacturers, U.S. Department of Commerce, Bureau of the Census, from U. S. Government Printing Office, Washington, D.C.

Similar data are shown in Table III-2 for waste-producing water-treatment plants that primarily distribute water for industrial use. The source of the data in Table III-2 did not indicate the number of plants that used combinations of the 5 processes given in Table III-1. Obviously many plants used combinations of processes because of the total number of plants that treated water is 5159, and the sum of the plants shown in Table III-1 to use individual processes is 7489. More than 94% of the water treated for use in industry is used by industries in only 6 major SIC categories: pulp and paper products (SIC 26), primary metals (SIC 33), chemicals and allied products (SIC 28), petroleum and coal products (SIC 29), food and kindred products (SIC 200, and textile mill products (SIC 22).

Figure III-2 shows the percentages of the production of the total of the 4590 waste-producing plants that are produced by all plants in each process-type category that are smaller than or equal to the sizes given on the abscissa. Figure III-3 displays the same information, except that the scales on the ordinate and abscissa are greatly expanded so that the initial portions of the curves can be seen more clearly. Water-treatment plants that use the coagulation process either singly (C) or in combination with softening (CS) obviously produce by far the most water (and also the most wastes). Figure III-3 shows that if only plants producing 378.5 cu m/day (0.1 MGD), or more, are the smallest plants to be affected by the effluent guidelines limitations, all but 0.6% of the total wastes would be covered.

D. <u>Description of Water-Treatment Processes</u>

The purpose of a water-treatment plant is to remove or inactivate constituents in the water that are undesirable for the intended use. Constituents that might be removed in water-treatment plants include suspended solids, colloids, iron and manganese, ions that cause hardness, and materials that impart color, odor, or taste. Some water-treatment plants are relatively simple because only one of the constituents

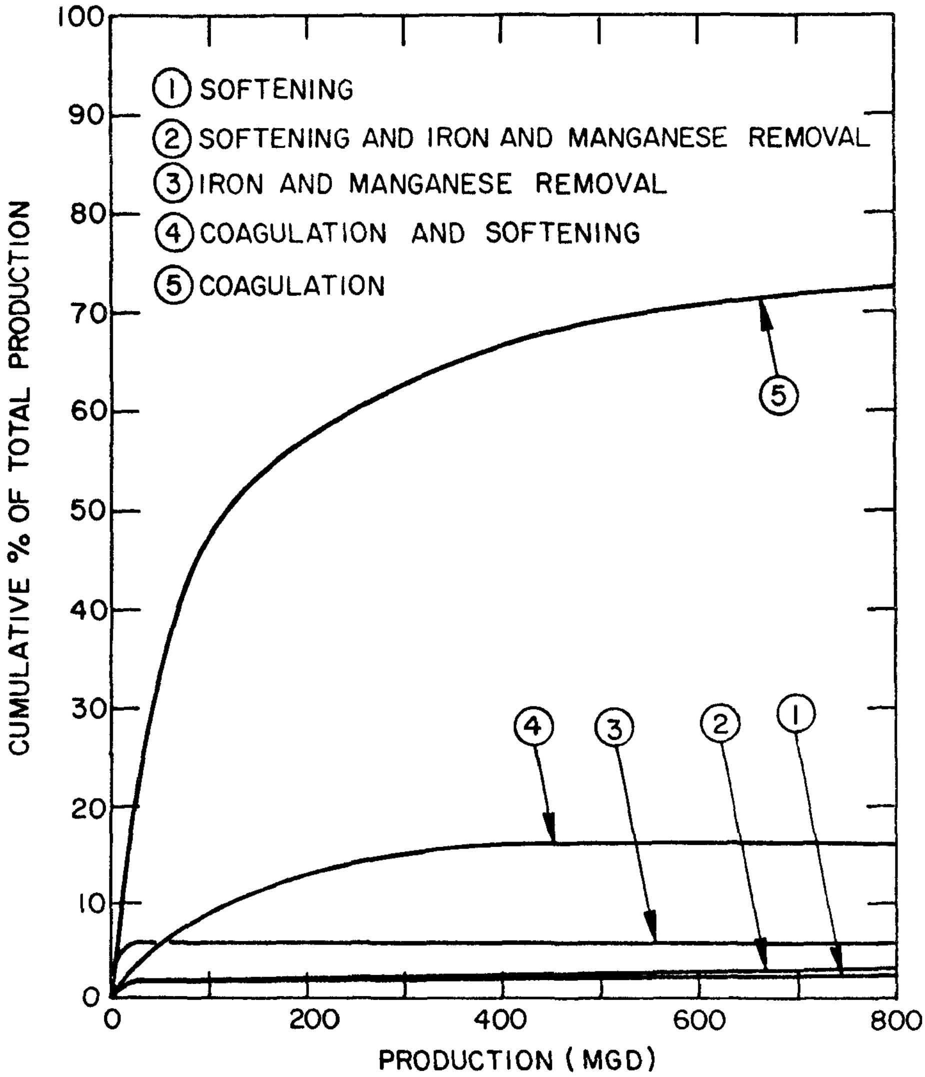

Figure III-2 Cumulative production volume as a percentage of total U.S. production by the major-waste-producing water-treatment plants

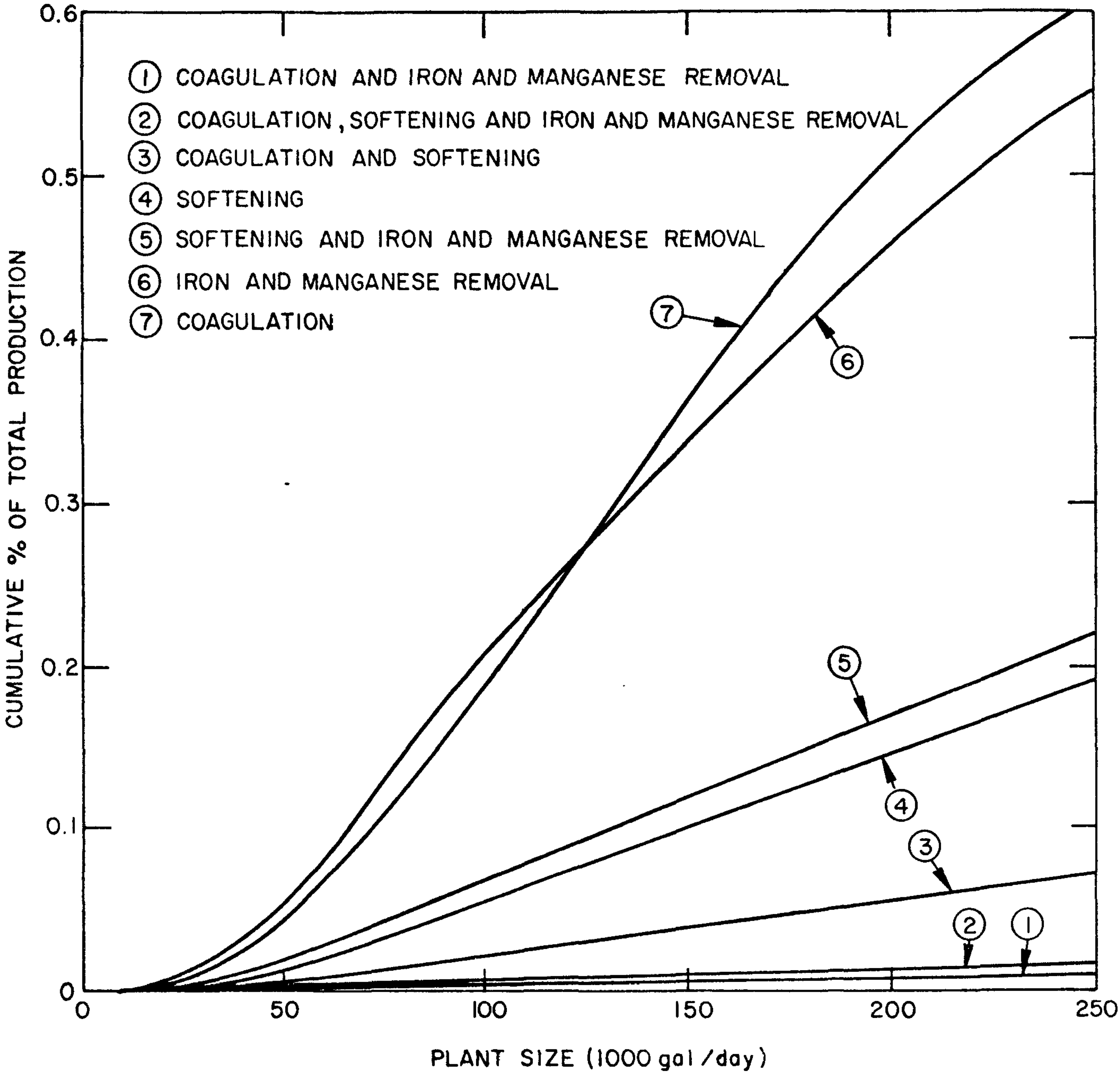

Figure III-3 Cumulative production volume as a percentage of total U.S. production by waste-producing water-treatment plants.

mentioned above must be removed. The processes and sequence of processes used in water-treatment plants depend primarily on the impurities present in the raw water and the intended use of the product water. For example, a plant that has access to raw water with acceptable turbidity, color, odor, taste, and hardness but with undesirably high concentrations of iron needs only to remove the iron and inactivate the bacteria to make the water acceptable for municipal use. Another plant might have access to raw water that contains several of the undesirable constituents listed above. Such a plant would have to use a combination of many processes.

Table III-3 shows the individual processes used in water-treatment plants, the purpose of each process, the type of water-borne waste produced, and typical devices used for each process. Only the last 6 processes in Table III-3 produce water-borne wastes. These processes are discussed briefly, below.

1. Presedimentation

Presedimentation is often used with raw waters that contain relatively high concentrations of easily settled suspended solids, such as sand and silt. Presedimentation is performed in basins designed to provide adequate detention time to allow coarser particles to settle. Normally, only organic polymers are added to the raw water to aid settling, if any additives are used. The designs of presedimentation basins vary, but all design features have the common objective of providing the most quiescent flow possible, since turbulence re-entrains solids that have already settled. Most presedimentation basins are designed for continuous sludge removal or have provisions for frequent sludge removal, so that accumulated sludge will not decrease the effective volume of the basin and thus decrease the detention time. The solids content of the sludges produced in these basins varies widely, and may range up to 20% solids, depending on the method and frequency of sludge removal.

2. Coagulation

Coagulation and flocculation followed by sedimentation and filtration are used to separate fine particles and colloidal

Table III-3

Main Processes Used In Water Treatment

Process	Purpose	Type of water-borne wastes produced	Typical devices used
Aeration	Alteration of the concentrations of volatile materials, oxidation of dissolved metals	None	Contact beds or trays, spray aerators, splash aerators
Disinfection	Inactivation of of bacteria	None	Chlorinators, ozonators, feeders for hypochlorites or chlorine dioxide
Corrosion Control	Stabilization of the water to minimize corrosion in distribution system	None	Feeders for phosphates, hypochlorites, silicates, alkalais
Taste and odor control	Removal or inactivation of constituents that cause objectionable tastes or odors	None	Feeders for activated carbon
Fluoride	To adjust fluoride content to desirable levels	None	Feeders for fluoride-containing chemicals
Pre-sedimentation	Removal of easily settled solids	Slurry of easily settled solids	Basins, lagoons, pits

Table III-3 (continued)

Main Processes Used in Water Treatment

Process	Purpose	Type of water-borne wastes produced	Typical devices used
Coagulation	Removal of small-sized suspended solids, colloids and color	Sludges	Chemical feeders, rapid mixers, thickeners, flocculators, sediment basins, filters
Softening	Removal of ions that cause hardness	Sludges or brines	Chemical feeders, rapid mixers, zeolite (ion-exchange) columns, thickeners, sedimentation basins, centrifuges, filters, calciners, and chemical recovery units
Iron and Manganese removal	Removal of iron and manganese ions	Sludges	Chemical feeders, filters of various types
Filtration	Removal of solids not removed by settling	Sludges	Various types of filters (*e.g.*, multi-media, anthrafilt, slow or rapid gravity, pressure, sand)
Dissolved-solids removal	Reduction in dissolved solids content	Brines	Reverse osmosis, electrodialysis, flash evaporation units

materials from water. Colloids or fine particles in suspensions either have or acquire electrical charges on their surfaces. Ions that have charges opposite in sign to the surface charges collect in the shell of water immediately adjacent to the surface of the particles. These double layers of electrical charge cause the particles to repel each other because of the electrostatic repulsion of like charges. Thus, the electrical double layers inhibit or prevent interparticle collisions so that the fine particles do not collide and agglomerate into larger particles that will settle.

The process of coagulation is used to destabilize suspensions of fine particles. Materials termed coagulants are used to minimize or neutralize the electrical double layers at the surfaces of fine particles. Once the electrical double layers are minimized or neutralized, interparticle collisions can and do occur as a result of Brownian motion. The frequency of collisions is increased by gentle agitation, and flocculation of particles occurs. The agitation, or mixing, used in flocculation must be great enough to enhance particle collisions, but not so great as to break up existing flocculated particles. Within the range of agitation, flocculation of particles occurs and the size of the floc increases until the agglomerated particles are large enough to settle rapidly. The suspension is then fed into sedimentation basins in which quiescent conditions are maintained and settling occurs. The supernatant fluid from the sedimentation basins is then filtered to remove any remaining particulate matter.

Materials used as coagulants include polyelectrolytes and metal salts, such as aluminum sulfate and ferrous sulfate. Sodium aluminate and lime are used in some instances to adjust the pH to optimum ranges, and ozone, chlorine, and other oxidants are used for some waters to oxidize metal salts. Although some polyelectrolytes are used by themselves, polyelectrolytes are more often used in conjunction with metal salts to aid flocculation.

The steps in the coagulation-flocculation process are: (a) pre-oxidation, if needed to overcome difficulties with clarification or color removal; (b) mixing of the coagulant with the water; and (c) gentle agitation to promote the interparticle collision needed for flocculation. The mixers used for mixing coagulant and water are usually termed rapid mixers or flash mixers. The mixing is performed under conditions of high turbulence to ensure adequate dispersion of chemicals in the water. The gentle agitation that promotes flocculation is performed by horizontally and vertically baffled mixing basins, by a variety of mechanical mixing devices, or by aeration in a few plants.

Sedimentation is carried out in basins. A variety of designs for both inlet and outlet devices for settling basins is used in various plants to provide conditions for settling. They all have the goals of elimination of short-circuiting, and the minimization of eddy currents or other agitating actions that would disturb and re-entrain solids already deposited. Sedimentation basins differ in the means provided for removal of sludge. In some plants the sludge is removed continuously by means of rakes or blades that push the sediment to outlets in the bottom of the basins. In other plants sludge is allowed to accumulate in the sedimentation basins until the effective volume of the basins is reduced and the basins need cleaning. The periods between cleanings may vary from a few weeks to more than a year, depending on the basin volume and the turbidity of the raw water. Basins that are equipped for mechanical removal of sludge usually have sloping bottoms, so that most of the sediment flows out with the water when the basins are drained for cleaning. Sediment that does not flow out with the water is usually flushed out with hoses.

The sludges from coagulation plants are low in solids concentration (<2%) and are difficult to dewater. These sludges and methods of treating and disposing of them are discussed in detail in Section VII.

3. Softening

Softening processes are used to reduce the concentration of substances that cause hardness in water. Calcium and magnesium compounds are most common although salts of other bivalent metals contribute to hardness in some waters. "Carbonate hardness" is the term used to designate the hardness that stems from the bicarbonates of calcium and magnesium; "non-carbonate hardness" refers to the hardness caused by sulfates, chlorides, or nitrates of calcium and magnesium.

The two general types of processes used for softening are chemical softening, and zeolite softening. In chemical softening either lime is used alone to remove carbonate hardness, or both lime and soda ash are used to remove both carbonate and non-carbonate hardness.

When lime alone is mixed with the raw water, the calcium and magnesium bicarbonates are converted to calcium carbonate and magnesium hydroxide, which have very low solubilities in water and therefore precipitate. When both lime and soda ash are added, calcium and magnesium sulfate are converted to calcium carbonate and magnesium hydroxide and the calcium and magnesium bicarbonates are converted to the carbonate and hydroxide forms, which precipitate*. Thus, the addition of both lime and soda ash removes both carbonate and non-carbonate hardness while the addition of lime alone removes only carbonate hardness.

Because more lime and higher values of pH are needed to cause precipitation of both calcium and magnesium, and because still more lime is needed if the raw water contains free CO_2 and sodium carbonate, the lime softening process has several variations. If the raw water contains more than about 40 mg/l of magnesium (expressed as $CaCO_3$), the usual practice is to reduce the magnesium content below this value by the addition of lime in excess of that needed to precipitate calcium. The pH of the resulting water is usually too high for distribution. The treated water can be recarbonated with carbon dioxide to convert excess calcium hydroxide to solid calcium carbonate, which can be settled out. Alternatively, only part of the raw water is treated to remove both calcium and magnesium, and the treated water is mixed with raw water to reduce the pH and convert excess calcium hydroxide to calcium carbonate. The process of choice depends largely on the composition of the raw water, as measured by alkalinity, free carbon dioxide, calcium content, magnesium content, and non-carbonate hardness.

Recarbonation is often practiced to stabilize the water for distribution even in plants that only remove carbonate hardness.

Regardless of the variation of the lime-softening process used, the steps in processing include mixing the chemicals with the water, flocculation, and settling. Mechanical rapid-mixers are preferred for mixing the chemicals with water to ensure dissolution and thorough mixing of the lime with water. For

*A detailed discussion of the chemical reactions involved is given in Water Quality and Treatment, compiled and edited by the American Water Works Association and published by the McGraw-Hill Book Co., New York (1971).

the flocculation and sedimentation steps, flocculation and sedimentation basins similar to those used in coagulation plants may be used. However, since calcium carbonate and magnesium hydroxide precipitate more readily on the surface of previously formed particles, recirculation of sludge to the rapid-mix device is usually practiced.

In some water-treatment installations the three functions of mixing, flocculation, and settling are carried out in solids-contact softeners. In these devices a rapid-mixing zone, a zone to allow time for the chemical reactions and floculation and particle growth to occur, and a zone for settling are provided within a single unit.

In plants that recarbonate the water with carbon dioxide gas, a recarbonation basin is required. The carbon dioxide may be provided by combustion of a carbonaceous fuel. If the fuel is used to heat a boiler, the use of stack-gas scrubbers, blowers, control valves, and pipe is required. In some plants fuels such as natural gas are burned in submerged combustion units mounted in the recarbonation basin so that the gases enter the water directly. Some small plants purchase and store carbon dioxide as a liquid.

The water overflowing the sedimentation basin (or settling zone in solids-contact softeners) is filtered with conventional filters (described later) to remove the small amounts of solids in the water from sedimentation basins.

The process known as zeolite softening is an ion-exchange process. Certain solid natural and synthetic materials have the property of exchanging ions in their matrix with ions in water in contact with the solids. These materials have negatively charged ions that are fixed by chemical bonds to the solid matrix, and positively charged ions that are free to move within the interstices of the solid matrix. When granules or particles of these solids are in contact with water that contains ions, the mobile positive ions within the zeolite solid particles can exchange with positive ions in the water. In zeolite softening, a bed of the solid zeolite particles is equilibrated with a strong sodium chloride solution prior to use for softening so that the mobile positive ions within the solid will be sodium ions. The water to be softened is then allowed to flow through the bed of zeolite particles, and the sodium ions within the particles exchange for calcium and magnesium ions in the water. The hardness-causing calcium and magnesium ions are removed from the water and replaced by sodium ions, which will not cause hardness. In this way the water is softened.

A given amount of ion-exchange material will not soften water indefinitely. Calcium and magnesium will continue to enter the solid until most of the fixed negative ions on the solids matrix are associated with calcium and magnesium instead of sodium. The zeolite then loses its capacity to sorb more calcium and magnesium, and the ion exchange capacity must be regenerated.

Regeneration is accomplished by contacting the bed of zeolite with a concentrated solution of sodium chloride (i.e., a brine). During regeneration, sodium ions are driven into the zeolite because of their high concentration in the brine, and calcium and magnesium ions transfer from the zeolite into the brine. After the strong brine is rinsed from the interstices of the zeolite bed with water, water to be softened is admitted to the bed, and sodium ions in the solid are again exchanged for hardness-causing ions in the water.

Zeolite softeners may be operated with either pressure or gravity flow. Gravity flow is almost always used for large plants. The flow may be either upflow or downflow, and the vessel may be made of concrete, steel, or wood. Steel pressure vessels are used with pressurized flows, and the flow is virtually always downflow.

On completion of the softening part of the cycle, the beds are backwashed (upflow) to loosen and expand the zeolite bed and to flush out any particulate matter that may have collected on top of the bed. (With gravity upflow, the backwash part of the cycle is not required.) The zeolite bed is then regenerated by the introduction of sodium chloride brine through distributors arranged above the top of the bed. If good regeneration is to be achieved, the brine must pass uniformly through the bed of particles without channeling or by-passing any portion of the bed. The distributor systems are designed to achieve such uniform distribution.

At the end of the regeneration part of the cycle, the brine must be removed from the bed. Rinse water pumped through the distributor system pushes the brine ahead of it in "piston" flow. During the last part of the rinse cycle, the rinse water is pumped very rapidly through the bed to remove the last traces of brine. Upon completion of the rinse cycle, the bed is returned to softening duty.

In addition to the vessels that contain the zeolite granules, there must be brine tanks, pumps, and timed-control valves to maintain the proper sequence of events.

4. Iron and Manganese Removal

Iron and manganese are objectionable in water for municipal use for several reasons. Precipitates of these elements, which occur upon oxidation of the soluble forms of iron and manganese, result in highly-colored turbid water, which leads to discoloration in the laundry, and on bathroom and kitchen fixtures. In addition, these elements in concentrations greater than a few mg/l impart an undesirable taste to the water. Moreover, the presence of these elements in water can promote the growth of certain bacteria. Iron and manganese are removed from the water as an incidental feature of the lime and lime-soda softening processes. However, certain water plants need to remove iron and manganese but do not need to soften the water.

The main processes used specifically for iron and manganese removal includes precipitation by oxidation, and filtration. Aeration is most often used as the oxidizing step, but other oxidants such as chlorine and potassium permanganate are also used. Chlorine is often added following aeration to provide additional oxidation. If the pH of the water is too low for efficient removal of iron, lime is added to adjust the pH.

Powerful oxidants, such as chlorine, chlorine dioxide, or potassium permangante, are used mainly to treat waters that contain manganese, since oxidation of soluble manganese compounds by air is too slow.

The oxidation of iron and manganese is not rapid. Therefore, time is provided in retention tanks for the reaction to occur and for agglomeration of the precipitates to filterable size. The water with agglomerated precipitates is then filtered. The filter backwash water in iron removal plants contains the precipitated iron and manganese, and is usually highly colored. The filters are usually pressurized rapid-sand filters which will be described in the sub-section on filtration.

5. Filtration

Filtration is usually the final step in removing solids regardless of which processes precede the filtration steps. The filters most often used in water-treatment consist of a thin layer of filter aid deposited by flow on a bed of granular material, such as sand, held in place by gravity or the direction and velocity of flow. The objective of filtration is to reduce the turbidity of the feed water by removal of suspended matter.

The size of the suspended matter removed by filters ranges from a few millimicrons (colloids and viruses) to about 50,000 millimicrons (silt and sands). Types of matter removed include colloids, viruses, algae, bacteria, clay particles, and silt.

Attempts have been made, and are continuing to be made, to develop the theory of filtration to allow prediction of performance. Factors that have been considered in filtration theory include sand size, velocity of the water toward and past the sand, temperature, density of suspended particles, and size of the particles which affect the probability of a suspended particle intercepting a particle in the combination of filter aid and granular matter of the supporting bed, and other factors, such as pH, type of coagulant, and size and strength of floc, which affect the adherence of an intercepted particle to the particles in the filter. At the present, however, the theory of filtration is not adequately predictive, and pilot plant tests are almost always used prior to installation of new filtration facilities.

Several types of filters are used in water-treatment plants. Most widely used is the rapid-sand filter, which usually consists of a support medium of several layers of different sized gravel and a layer of carefully sized sand on top of the gravel. The layers of gravel are graded in size. The bottom layer is coarse gravel, laid in a container, usually concrete, that is provided with an underdrain system for collection of the water into a pipe for transferral to a filtered-water chamber. Subsequent layers are each several inches of sized sand (from 0.4 to 1 mm in diameter). As filtration proceeds, the sand layer collects suspended matter and the resistance of the filter to water flow increases. Eventually the head required to force water through the filter becomes excessive and the filter must then be backwashed. Filters are backwashed by forcing filtered water into the bottom of the container and upward through the layers of gravel and sand. The upward flow of water expands the bed of sand and flushed the collected sediment from the sand.

Of other filters in use in water-treatment plants, the main types are multi-media filters and pressurized filters. Multi-media filters are composed of several layers of sized materials. At the bottom, for example, graded sizes of garnet gravel (density = 3.1) might be overlaid with successive layers of silica gravel (density = 2.6), and alluvial anthracite (density = 1.5). Multi-media filters are designed to permit penetration of the suspended matter through the top-most layer and into the underlying layer of sand. This deep penetration makes possible longer filter runs between washings than are possible with single medium filters in which penetration is only a few inches. The long filter runs are desirable to conserve water used for backwashing and to reduce labor costs.

Pressure filters are similar to gravity-type, rapid-sand filters in construction and operation, but the underdrains, gravel, and sand are housed in a cylindrical tank, and the water is passed through the filter under pressure. The tank axis may be either vertical or horizontal. Pressure filters are used mainly when raw water is furnished under pressure, and filtered water is to be delivered without further pumping.

The waste from the filtration step is the backwash water with its load of sediment that was flushed from the filter. The treatment and disposal of filter backwash water are discussed in Section VII.

6. Dissolved-Solids Removal

Processes for removal of dissolved solids include electrodialysis, reverse osmosis, and distillation processes. Detailed descriptions of these processes are available from The Office of Saline Water, U. S. Department of the Interior. Therefore, only brief descriptions are given here.

Electrodialysis is a process in which many ion-exchange membranes are arranged parallel to each other to form solution compartments held between a pair of electrodes. The feed water flows through every other solution compartment. When a voltage is applied to the electrodes, electrolytic solids in the feed water are removed; transported across the ion-exchange membranes into a waste-brine stream flowing through the solution compartments between the ones that contain feed solution. Electrodialysis units from the various suppliers differ in design but they all produce a waste brine.

Reverse osmosis is a pressure-operated process in which purified water transfers through special membranes that pass water but block impurities. Reverse osmosis equipment is made in a variety of designs. However, in all designs a concentrated brine is left on the high-pressure side of the reverse osmosis membranes after purified water is transferred through the membranes. This concentrated brine is sent to waste.

There are a variety of distillation processes used for dissolved-solids removal. In all of them purified water is removed from feed water as a vapor and condensed to give the product water. The solution left unvaporized contains the impurities originally present in the feed water, but the impurities have been concentrated into a small volume of water. This concentrated brine is sent to waste.

At present, there are no waste-treatment processes or practices that are usable to adequately treat waste brines from dissolved-solids removal processes. These brines are usually disposed of by discharge to a watercourse, or to deep wells.

Schematic diagrams of several types of treatment plants are presented in Figures III-4, III-5, and III-6 to illustrate the sequence of processing steps and the different types of chemical additives used for various purposes.

Figure III-4 illustrates a simple water-treatment plant, which obtains water from wells. The water is relatively hard, but extremely low in turbidity. About 80% of the influent water is softened in six zeolite softeners, and about 20% of it bypasses the softeners. The combined product water (about 6400 cu m/day (1.7 MGD) is disinfected with chlorine, and distributed. The zeolite softeners are regenerated twice a day with a saturated NaCl solution. The waste brine from regenerations is discharged to the sewer, and eventually enters a municipal sewage treatment plant.

Figure III-5 illustrates the steps in a fairly simple processing plan that utilizes sedimentation basins and centrifuges.

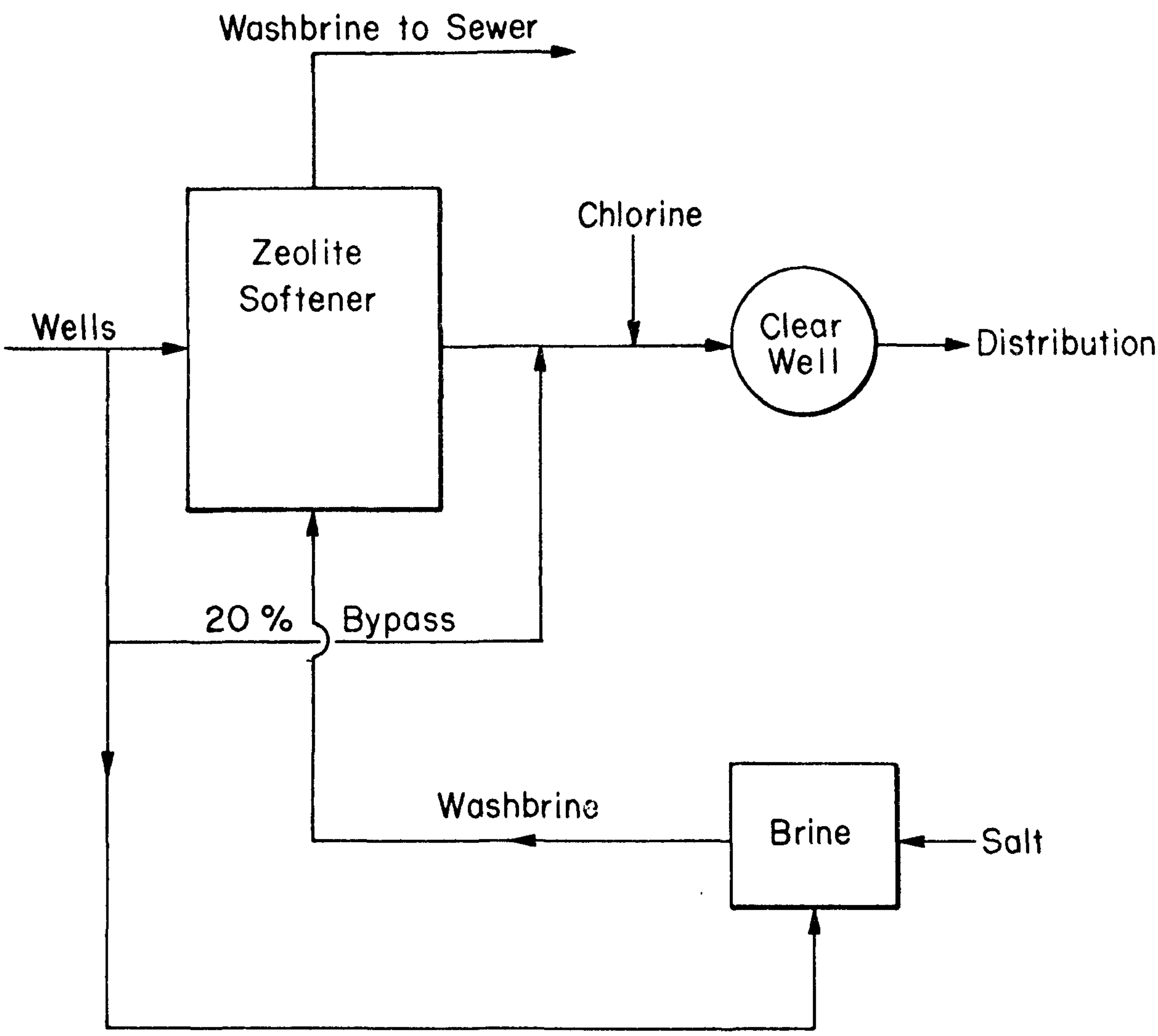

Figure III-4. Processing Steps for Zeolite Softening Plant

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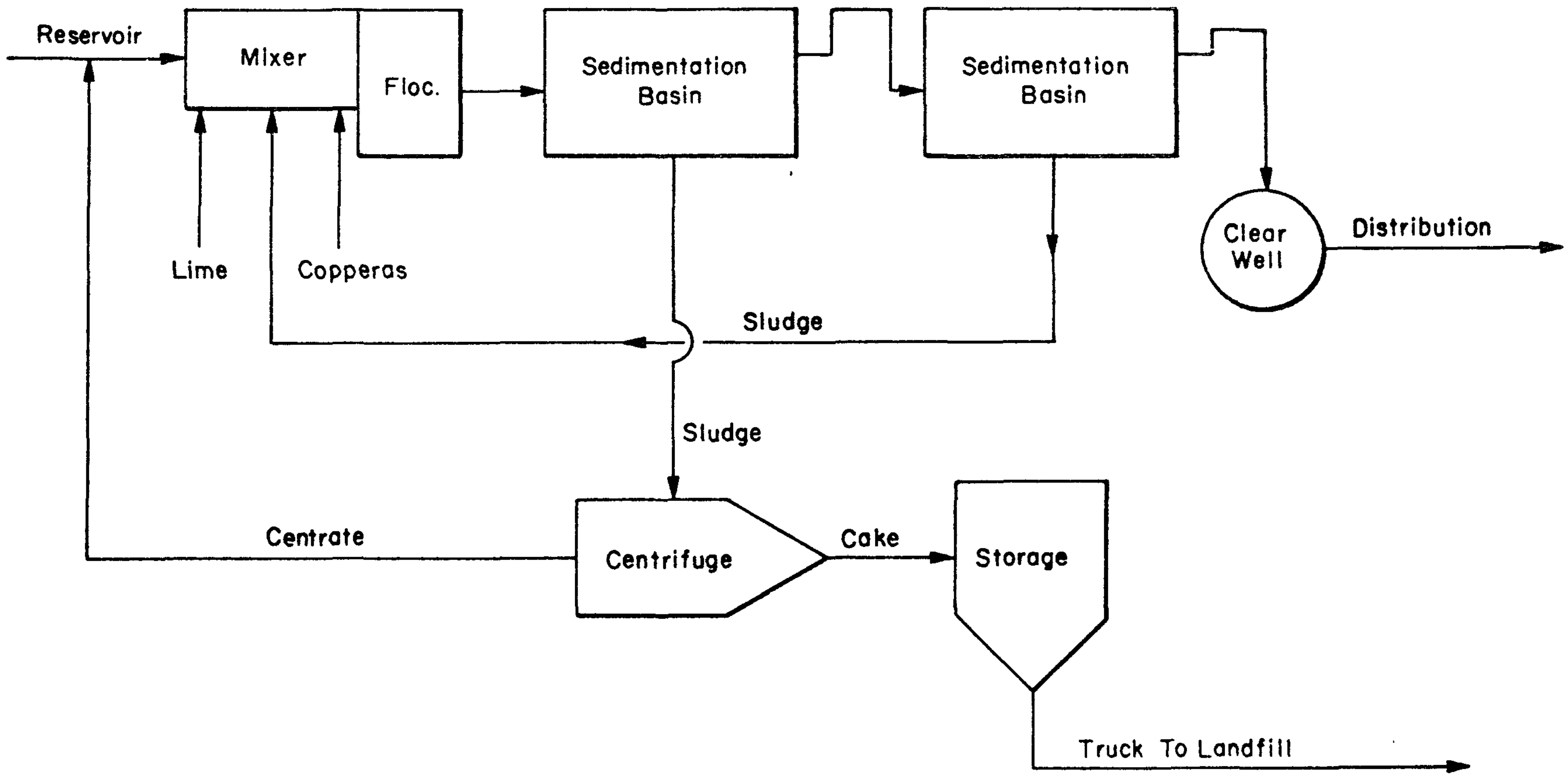

Figure III-5. Processing Steps for Sedimentation Basin - Centrifuge plant

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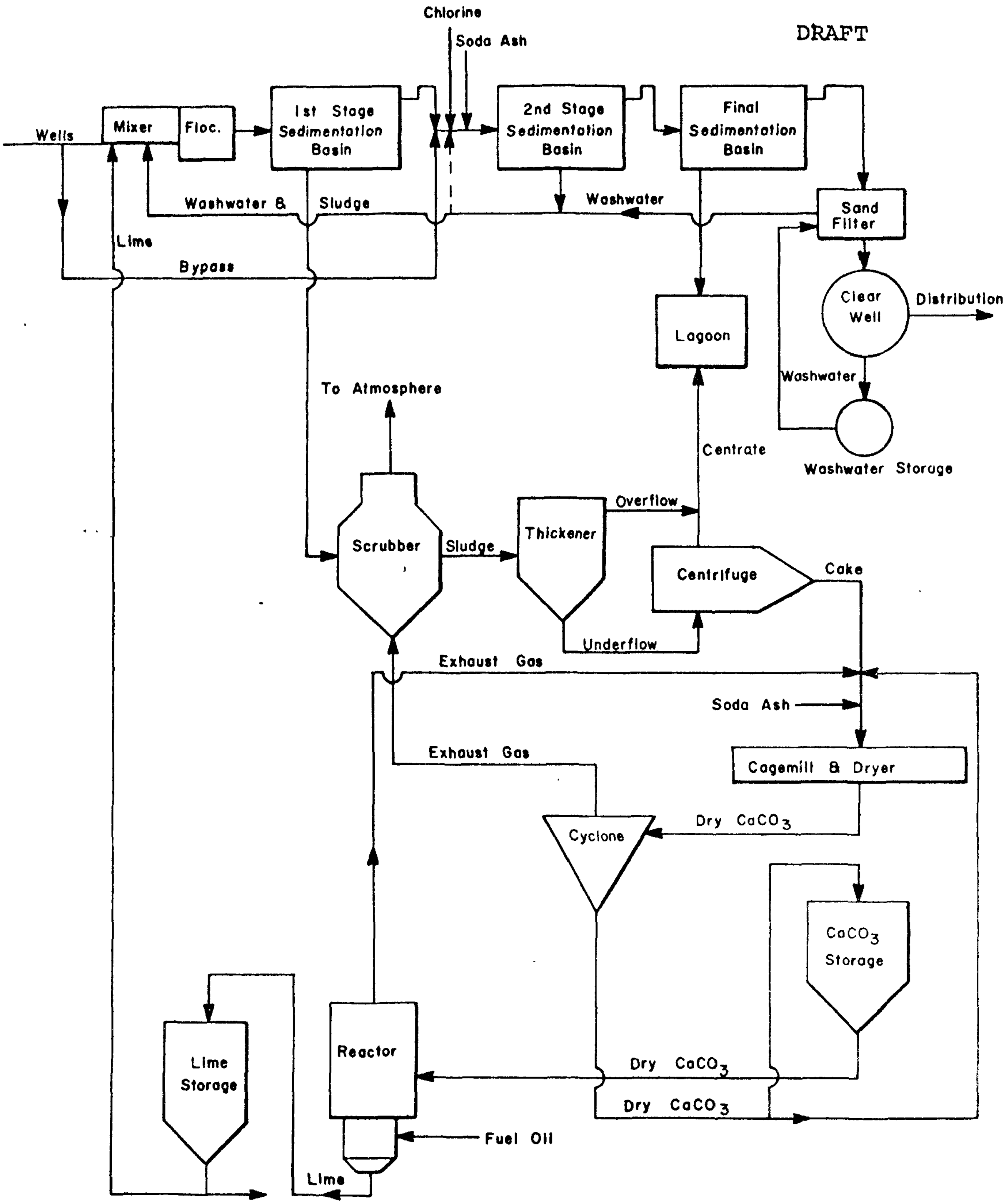

Figure III-6. Processing Steps for Complex Recalcination Water-Treatment Plant

The influent water, which is obtained from a reservoir, is of medium hardness but of high turbidity. The influent water plus a recycled stream of sludge from the second sedimentation basin is mixed with lime and iron sulfate in a rapid mixer, and then allowed to flocculate. The water then goes through two sedimentation basins in series. The sludge from the first basin, about 5% solids, is concentrated to 50-60% solids in a centrifuge. The paste from the centrifuge is pumped with a Moyno pump into a storage hopper. It is eventually hauled to a land-fill site about 20 km (12 miles) distant. The relatively clear centrate (about 0.5% solids) is sent back to the reservoir. The sludge from the second sedimentation basin is recycled to the rapid mixer. The overflow from the second basin is distributed.

Figure III-6 is an example of a relatively complex combination of processing steps for water-treatment. This plant obtains its water from wells. The influent water is hard and also has a relatively high concentration of suspended solids. Most of this influent water is mixed with lime in a rapid mixer, and then flocculation is allowed to occur. The effluent from the flocculator is transferred to a first stage of sedimentation. The effluent from the first sedimentation basin plus part of the influent water is mixed with soda ash and chlorine and sent to two more sedimentation basins operating in series. The effluent from the third sedimentation basin is filtered with sand filters, sent to the clearwell, and then distributed.

Sludge in the first sedimentation basin is removed continuously by scrapers. The solids concentration varies between 12% and 18%. The solids are primarily $CaCO_3$. This sludge is sent to a gas scrubber and then to a thickener in which the solids concentration is raised to 20%. The sludge from the thickener is centrifuged to a sticky cake of about 60% solids. Enough dry $CaCO_3$ is added in a cagemill to reduce the stickiness and form lumps of $CaCO_3$. These lumps are dried with waste gas from the calcination step. The dried sludge travels with the waste gases to a cyclone where separation of solids occurs. Part of the dried sludge is recycled to a cagemill to control stickiness; and the rest is stored in a hopper for feed to the calciner.

In the calciner, $CaCO_3$ is converted to lime by driving off CO_2. Fuel oil is used for heat. Agglomerated pellets of lime are removed at the bottom of the calciner and transferred by bucket elevator to a lime-storage hopper. This lime is ready for recycle to the rapid mixer at the start of the process.

Sludge from the second sedimentation basin and backwash water from the sand filters are recycled to the rapid mixer. Sludge from the third sedimentation basin plus the thickener overflow and the centrate from the centrifuge are sent to a 16-acre lagoon, where the solids settle.

These three figures illustrate the range of complexity of processes employed for water treatment. However, the treatment plants may also differ significantly in the nature of the chemicals and additives employed. These include: lime and soda ash for softening or pH control; iron sulfate, aluminum sulfate, and organic polyelectrolytes for coagulation and flocculation; activated carbon for taste and odor control and for removal of organic matter; sodium chloride for regeneration of ion-exchange materials; chlorine and ozone for disinfection; and potassium permanganate or other oxidants for removal of iron and manganese.

SECTION IV

CATEGORIZATION OF THE INDUSTRY

Rationale for Categorization and Sub-categorization

The goal of this study is the development of effluent limitations that are equitable to all plants but that meet the aim of the Act, which is the elimination of pollutant discharges from all point sources. To achieve this goal a judgment must be made as to whether separate effluent limitations are appropriate for different segments (*i.e.*, subcategories) of the industry.

The quality of raw waters used in the water supply industry varies widely, and the sizes of water treatment plants also vary widely within the industry. Other factors, such as types of processes used, vary also. With such differences in raw water quality, size, and other factors, it is logical to consider the establishment of separate effluent limitations for different subcategories of the industry.

Within the allotted time, adequate categorization of the water-supply industry with such a large number of waste-producing plants required detailed information about a statistically meaningful number of plants, and analysis of the data by statistical techniques. The data for categorizing the industry, and for characterizing the wastes as described in Section V, were obtained from applications for permits to discharge wastes under the Refuse Act Permit Program (RAPP), from the literature, from the files of regional EPA offices and state agencies with responsibility for environmental control, and from discussions during personal visits to water-treatment plants. From these sources, some information was obtained about more than 2500 water-treatment plants, and detailed information about 1467 waste-producing water-treatment plants. Plant visits were made to 151 of the 1467 plants.

Some of the information needed for this study was not available from the raw sources, and some of it, especially that obtained from RAPP applications, was known to be out-of-date. Therefore, the data from raw sources were transcribed onto data forms that had blanks for all items needed for this study. A sample data form is included here as Table IV-1. These

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Table IV-1

Sample Data Form

I. Name of Facility ______________________________

Location ______________________ City ______________ Zip Code ______________

II. Treatment Processes (check blocks of processes used)

		Indicate Type
☐	Pretreatment	________ ________
☐	Coagulation	Alum____ Iron____ Other______
☐	Chemical Softening	Lime____ Lime Soda____
☐	Zeolite Softening	
☐	Iron-Manganese Removal	________
☐	Dissolved Solids Removal	________
☐	Filtration	________ ________
☐	Other Treatment	________ ________

III. Intake Source

(Circle Type)
1. Surface
2. Ground
3. Surface & Ground

Avg. Raw Water Volume ________ MGD
Avg. Distributed Water Volume ________ MGD

Avg. Raw Water Temperature °F for Jan. ______ for July ______

Is the product water primarily for industrial use or public use (circle one).

If industrial, give primary usage. (i.e. cooling, cleaning, etc.) ______________

IV. Chemicals Added - (Prior to Filter)

	Annual Average for 1973 ppm	or lb/day
1. Lime (as CaO)	______	______
2. Alum (specify type)	______	______
3. Iron coagulant (specify type)	______	______
4. Polymer	______	______
5. Activated carbon	______	______
6. Potassium permanganate	______	______
7. Soda Ash	______	______
8. Hexametaphosphates	______	______
9. Sodium chloride	______	______
10. Sodium hydroxide	______	______
11. Other (list all)	______	______

(After Filter)

	ppm	or lb/day
1. Lime	______	______
2. Sodium chloride	______	______
3. Other	______	______

V. Are flocculation or filter aids used? ________ If so, (type) ________ ; lb/day ________

(A) Average daily backwash volume ________ MGD, or
Average no. of backwashes per week ________
Average amount of water per backwash ________ MGD

(B) Average volume basin blowdown for continuous sludge removal ________ MGD

(C) Average discharge for periodic cleaning of basins ________ MG

Number of cleanings per year ________

If above is unknown, please indicate your best estimate of amount of sludge produced per year in the following spaces as million gallons. Also, estimate tons of dry solids per year. ______________________________

____

Table IV-1 (continued)

Sample Data Form

(D) Amount regeneration brine for zoolite softening__________gal/regeneration (if applicable)
Concentration of regeneration brine, weight% __________
Total amount of rinse water __________gal.
How much backwash water used? __________gal.

(E) What is the ultimate fate of the filter backwash; recycled, direct discharge to sewer, direct discharge to stream, or treated in any way before discharge? (circle one).

If treated, describe treatment and ultimate point of discharge.__________

(F) What is the ultimate fate of the sludge; direct discharge to sewer, direct discharge to stream, or treated in any way before discharge? (circle one)

If treated, describe treatment__________

(G) What is the ultimate fate of the brine: recycled, direct discharge to sewer, direct discharge to stream, or treated in any way before discharge? (circle one if applicable).

If treated, describe treatment__________

(H) If lagoons are used indicate the ultimate fate of water overflow and ultimate fate of lagoon sludge__________

VI. Parameter (units in ppm annual average)

	Raw Water	Distributed Water	Waste Discharges: Filter Backwash	Waste Discharges: Sludge	Waste Discharges: Lagoon Overflow	Other (Identify)
Total suspended solids (most important)						
Total solids						
Total dissolved solids						
Total alkalinity (as $CaCO_3$)						
pH						
Total Hardness (as $CaCO_3$)						
Aluminum						
Chloride						
Conductivity (μ mho/cm)						
Calcium						
Iron						
Magnesium						
Manganese						
Turbidity (jtu)						

Are any more complete analyses or studies of wastes available?__________

If you have a turbidity to suspended solids conversion factor, please indicate average factor used______, and the maximum________and minimum________factors.

Over what range of turbidity is the factor usable?________to__________, units__________.

Your Name__________ Telephone No.__________
Position__________ Area Code__________

forms were mailed to each of the plants for which most of the necessary data was available along with instructions for updating and completing the forms (e.g., the use of annual values for flows and concentrations of wastewater constituents). Each company was asked to verify, or correct and verify, data. From this mailing we received verified data for 782 waste-producing water-treatment plants, or about 7% to 8% of the total number of waste-producing water-treatment plants.* These verified data were used as the basis for categorizing the industry and for characterizing the wastes. Table IV-2 shows the ranges of plant sizes and the number of plants using each of the three main water-treatment processes for the plants for which verified data were obtained and for the municipal facilities listed in the USPHS 1963 Survey.

In establishing categories and subcategories, the first step was to prepare a list of factors that could affect the quality and quantity of discharge wastes, and for which data could be obtained from statistically meaningful numbers of water-treatment plants. These factors included the age of the plant, the size of the plant, the continuous or intermittent nature of waste discharges, the use of the water, the raw water quality, the treatment processes used, and the waste-treatment processes used. As data were acquired about individual water-treatment plants, the age of a water-treatment plant was found not to be truly identifiable in most instances, because of frequent expansions or modifications.

Few of the verified data sheets used as a data base for this study were from plants that treat water for use by industry (24 out of 782 total). From statistical analysis of these 24 plants, there appears to be no significant differenc between the wastes from industrial water-treatment plants and the wastes from other plants. Therefore, the industrial plants were included with the total number of plants for the statistical studies to develop effluent limitation guidelines. However, additional data from industrial water-treatment plants may be desirable.

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*Information from the U. S. Public Health Service survey of municipal facilities made in 1973 is not yet fully available, and the 1967 Census of Manufacturers was the most recent source of data for industrial facilities. Therefore, an up-to-date total of the waste-producing plants is not available.

Table IV-2

Comparisons Between Verified Samples and Total Number of Municipal Water-Treatment Plants Listed in USPHS 1963 Survey

Process Used	Sample: Number of plants[a]	Sample: Size Range (Average Production), 1000 cu m/day (MGD)	Total in 1963 Survey: Number of plants	Total in 1963 Survey: Size Range (Average Production), 1000 cu m/day (MGD)
Coagulation	420	<0.4 - 1408 (<0.1 - 372)	2737	<0.4 - 1378 (<0.1 - 364)
Softening[b]	321	<0.4 - 715 (<0.1 - 189)	1029	<0.4 - 613 (<0.1 - 162)
Iron and Manganese	225	<0.4 - 257 (<0.1 - 68)	1597	<0.4 - 231 (<0.1 - 61)

a) Number of plants using the process listed; some plants use more than one of the processes.

b) Includes all types of softening processes.

c) Includes all types of iron-removal processes.

The verified data were analyzed first by assuming that the water-treatment processes or combination of processes used within a plant would significantly affect the quality, quantity, and treatability of the wastewaters discharged from the plant, and then by grouping together all plants employing a given process or combination of processes. Thirty-six tentative subcategories were established based on the use of processes or combinations of processes, and all plants using each process or combination were grouped together. The mean raw and treated waste loads and the standard deviations of the wasteloads for plants grouped in each tentative subcategory were first determined. At this stage of the analysis the standard deviations indicated such a broad distribution of wasteloads within each tentative subcategory that significant differences between waste loads in the subcategories could be discerned in very few cases.

Further statistical analyses were performed to explore the effects on wasteloads of factors such as plant size, raw water quality (primarily hardness, pH, and turbidity), and the amounts and type of chemicals or other additives used to treat the water. In these analyses two statistical techniques were used: the determination of the "best-fit" lines for the data, which turned out to be a log-normal distribution, followed by the application of statistical "F" and "T" tests, modified appropriately for log-normally distributed data; and the application of multiple-linear regression analyses. With these statistical tools and with consideration of differences in treatability and quality of wastes from different processes, the 36 tentative subcategories were reduced to three subcategories. The multiple linear regressions showed that plant size and raw-water hardness had significant effects on the waste loads from plants within each of the three subcategories. An equation which was developed from the regressions provided for differences in allowances in waste loads, plant size, and raw water hardness. This equation and the wasteload allowances which are reached are presented in Section IX.

The three subcategories are:

> Category I - Plants that use only coagulation, oxidative iron and manganese removal, direct filtration, or diatomaceous-earth filtration. Only one of the above solids-removal processes is used. Plants with combinations of two or more solids-removal processes are included in other categories.

Category II - Plants that use the lime or lime-soda softening processes.

Category III - Plants that use combinations of coagulation and chemical softening, or oxidative iron-and-manganese removal and chemical softening.

The wastes from the zeolite softening process or from zeolite iron-removal processes were not included in this categorization plan because there is no adequately demonstrated control and treatment process that could be used in 1977. There is a reclamation process that has been demonstrated on a small plant scale and that will be useable by 1983. The wastes from zeolite processes will be considered individually. Similarly, because of the lack of adequately demonstrated control and treatment, the wastes from dissolved-solids removal processes, and from defluoridation processes, were not placed into categories, but will be judged individually.

SECTION V

WASTE CHARACTERIZATION

The processes used in the water-supply industry are designed to remove materials that are undesirable for the intended use of the product water. The undesirable materials include suspended solids, colloids, ions that cause hardness, substances that cause color or odor or both, iron compounds, managanese compounds, ions, such as fluoride or heavy metals that can have detrimental effects on many of the biota, and toxic chemicals present in the source water. Normally the inactivation or removal of bacteria and other disease producing organisms is common to all plants.

A. Characteristics of Waste Waters

The undesirable materials present in wastes from water-treatment plants depend on the type of process used. Most waste-producing water-treatment plants use one or more of the following processes: softening, iron and manganese removal, and coagulation followed by flocculation and sedimentation. Virtually all plants use some type of filtration. The wastes from each of these processes differ and are described below.

1. Sludges from Processes that Use Coagulation

Coagulant sludges may contain sand or silt, dissolved or colloidal organic material, microscopic organisms, and materials such as aluminum hydroxides or polyelectrolytes that stem from the chemicals used. The sludge has a very low solids content ranging downward from 2%, and is gelatinous in nature and light tan to black in color depending on the constituents in the source water and the type of coagulants used. Because they are gelatinous, coagulant sludges are difficult to dewater. With conventional lagoons, typical solids contents of dewatered coagulant sludges range from 10% to 15% which are not high enough to handle conveniently as a solid when cleaning lagoons. Solids contents of at least 20% are desired for convenience in handling. Lagoons in which freeze-thaw cycles occur produce dewatered sludges of slightly higher solids contents (about 17% to 18%), but these sludges are still difficult to handle. Vacuum filters operating in a precoat mode have produced cakes with solids contents in the range of 20% to 30%, when treating coagulant sludges. However, the weight of the precoat material often equals the weight of dry solids in the sludge. Sand drying beds have also produced dewatered sludges with solids contents greater than 20% from coagulant sludges. The volume of sludge produced by a coagulation-flocculation plant is usually in the range of 1% to 5% of the water treated.

2. Sludges from Plants that Use Chemical Softening

Calcium carbonate is the main constituent in the sludges from chemical softening operations. Generally, 80% to 95% of the weight of solids in the softening sludges is calcium carbonate. Other materials that may be present include hydrated oxides of magnesium, iron, and aluminum, silt, and organic matter. Softening sludges are usually easier to dewater than coagulant sludges, but the ease of dewatering varies widely from plant to plant. Factors that affect the treatability of the sludge include the ratio of calcium to magnesium, and the amount of gelatinous solids present. Gelatinous solids may stem from colloids, iron and manganese, or other materials. The solids content of settled softening sludges can vary from 2% to 30%. The volume of softening sludges is usually in the range of 0.3% to about 5% of the volume of water treated.

3. Sludges from Iron and Manganese Removal Processes

The sludges from iron and manganese removal processes are highly colored and often gelatinous. These sludges are retained by the filters, and constitute a part of filter backwash water in plants that remove iron and manganese. The nature of filter backwash waters is discussed in the next section.

If the ratio of iron and manganese to silt or other easily filtered matter is high (as it is in some groundwaters), the sludges from iron-and-manganese-removal processes are usually gelatinous. Such gelatinous sludges may be almost as difficult to dewater as sludges from coagulation plants.

4. Filter Backwash Water

Filter backwash water may contain particles of silt and clay, hydrated oxides of iron, manganese and aluminum, activated carbon, and suspended organic materials. Typical solids contents range up to 1500 mg/l. The volume of washwater ranges from 1.5% to 5% of the water treated, but this can be deceptive unless the washwater is equalized. If filter backwash is not equalized, the instantaneous flows may be high enough to scour solids from the bottoms of lagoons, or cause serious upsets in the operation of other solids-separation devices. The solids in filter washwater normally can be easily settled unless gelatinous iron and manganese precipitates predominate, as mentioned above. Lagoons are sometimes used to allow settling of filter backwash water. The lagoon supernatant is often recycled to the plant intake or discharged to a sanitary sewer.

Other waste-producing processes used in the water supply industry include zeolite softening, which produces brines containing the chlorides of sodium, calcium, and magnesium, and fluoridation processes, which produce brines containing sodium and calcium fluorides.

B. Basis for Characterizing Wastes

With the analyses normally used for wastewaters, the constituents in wastewaters from the water-supply industry are reported as pH, total solids, total dissolved solids, color, turbidity (as an indicator of suspended solids), hardness, and alkalinity. Other constituents reported in wastewaters from some water-treatment plants include iron, manganese, calcium, magnesium, sulphate, chlorides, phosphate, and silica.

For the wastewaters from the water-supply industry to be adequately characterized, certain information must be available from a statistically meaningful number of individual water-treatment plants in each of the categories and subcategories. The types of information needed and the number of verified data sheets obtained were discussed in Section IV in the discussion of categorization.

It is desirable to characterize both the raw wastes and treated wastes. Information about raw wastes is desirable because even in solids-separation units where sludge is continuously discharged (e.g., settling basins with continuous discharge) some of the solids may accumulate. In solids-separation units with intermittent sludge discharge, most of the solids settle and are only discharged periodically during basin cleaning. Data on the volumes and compositions of treated wastes were reported on the data sheets from some of the plants for which we obtained verified data, but acceptable data on the annual or monthly averages of pollutant loads in raw wastes were almost non-existent. Therefore, raw-waste loads were computed by a mass-balance method, since all materials that enter the plant in either the raw water or as additives must leave in the product water and the effluents from solids-separation units or they must be accumulated in the solids-separation units. In the mass-balance procedure, any changes resulting from chemical reactions (e.g., hydrolysis of alum to aluminum hydroxide) were accounted for.

The mean raw waste loads of TSS for each of the three subcategories are given in Table V-1.

Table V-1

Mean Raw Waste Loads for the Subcategories

Subcategory	Mean Raw Waste Load kg/1000 cu m	(lb/MG)
I	32.2	(268)
II	21.7	(181)
III	54.1	(451)

Wasteloads were expressed as kilograms of pollutant per thousand cubic meters of product water (pounds per million gallons). The use of concentrations of pollutants to express waste loads was avoided for two reasons: (a) low concentrations of pollutants can be achieved even with large quantities of pollutants being discharged by using large quantities of waste water, and (b) some mechanical dewatering devices now in service generate wastewaters with relatively high concentrations of TSS in the wastewaters (50 to 100 mg/l), but the volume of wastewater is so low that the kilograms of pollutant per cubic meter is considerably less than that achieved with lagoons, which can be considered the standard solids-separation device in the water supply industry.

SECTION VI

SELECTION OF POLLUTANT PARAMETERS

A. Definition of Pollutants

Section 502 of the Federal Pollution Control Act Amendments of 1972 defines the term pollution as ". . . the man-induced alteration of the chemical, physical, biological, and radiological integrity of the water." The term pollutant is defined as "industrial, municipal, and agricultural waste discharged into water."

For purposes of this report pollutants are defined as chemical, physical, biological, or radiological constituents of discharged water that are present in measurable concentrations by routine analytical procedures acceptable to the EPA, and that have the potential for being detrimental to the environment.

B. Basis for Selection of Pollutant Parameters

The selection of pollutant parameters was based on consideration of Environmental Protection Agency permits for discharge of wastewaters from a number of water-treatment plants, on discussions with personnel of state agencies with responsibility for environmental control, on discussions with personnel of regional EPA offices, on consideration of information published by the AWWA, on discussions of the discharge of wastewaters by members of the AWWA, and on information about wastewaters found in our survey of the literature.

Suspended solids, pH, iron, manganese, fluoride, and total dissolved solids are considered pollutants for various subcategories according to the definition used for this report. The rationales for selection or rejection of constituents in wastewaters are discussed below.

C. Rationale for Selection of Pollutants

1. Suspended Solids

In the water-supply industry suspended solids in wastewaters stem from the separation of insoluble matter from product water, one of the main functions of a water-treatment plant. The insoluble matter is suspended in the liquid phase of wastewaters as sludge. The total suspended solids (TSS) in sludges from water-treatment plants may include both inorganic and organic matter. The former may include sand and silt, clay, and insoluble hydrated metal oxides, and the latter may include flocculated colloids and compounds that contribute to color, as well as algae and other microorganisms.

Solids in suspension are esthetically displeasing. Because suspended solids increase the turbidity of the water, the penetration of light into the water is reduced, and the photosynthetic activity of aquatic vegetation can be impaired.

Suspended solids can settle out of a stream to form deposits that can be detrimental. These deposits can destroy fauna that breed and grow in or near the bottoms of streams and serve as food for fish and other aquatic life. The deposits can also blanket and destroy spawning grounds for fish.

As pointed out later in Section VII, sludges can be treated by several devices to separate solids from the liquid phase to produce a supernatant with low concentrations of TSS that is suitable for discharge. In addition, it has been shown that recycling of the supernatants from such solids-separation devices to mix with the raw-water feed can be accomplished at low cost without adverse effects. In this way a closed-cycle with no discharge of water-borne wastes can be attained.

For all of the above reasons TSS is selected as a pollutant parameter for all subcategories. However, extensive studies made at plants along one highly turbid river have shown that returning the raw waste sludge to the highly turbid source increases the turbidity of the stream by an insignificant increment. In some instances the incremental increase in turbidity is less than the precision of many turbidimeters used for routine monitoring. These studies have also shown that the benefit-cost ratio for dewatering the sludge and hauling it to landfills is very low, and that the amount of energy used in treating and hauling is high. Because of these factors the disposal of sludge from plants that must use highly turbid water as feeds (>200 JTU on an annual average basis) should be judged on an individual basis.

2. pH

The hydrogen-ion concentration in an aqueous solution is represented by pH, which is defined as the negative logarithm of the hydrogen-ion concentration in a solution. On the pH scale ranging from zero to fourteen, a value of seven represents neutral conditions in which the concentrations of hydrogen and hydroxyl ions are equal. Values of pH less than seven represent acidic conditions; values greater than seven represent basic condition.

In the water-supply industry, pH is easily measured and is a direct indicator of potential detriment to the environment. Wastewaters with pH values markedly different from the pH values of the receiving stream are potentially detrimental to the environment because, at outfalls and prior to complete mixing of wastewaters with receiving waters, there can be a zone in which there is a sudden change of pH, and a sudden change of pH can damage or kill the biota that is engulfed in the change. Therefore, pH is selected as a pollutant parameter.

From the study of the constituents in wastewaters from the 782 plants for which we have verified data, only the categories that utilize chemical-softening processes discharge wastewaters with values of pH that might be detrimental. Because of the nature of chemical-softening processes, the product water and the liquid phase of the wastewaters have essentially the same pH. Figure VI-1 shows the distribution of maximum reported pH values of product water from 215 water treatment plants that reported pH values.

If the pH range recommended by EPA for other industries (i.e., 6.0 to 9.0) were recommended for the categories that use chemical-softening proceses, even the product water from many plants would have values of pH outside that range. Therefore, for categories that use chemical softening, a slightly expanded range of pH is recommended in Sections IX, X, and XI. For other categories, the usual pH range of 6.0 to 9.0 is recommended.

3. Iron and Manganese

Iron and manganese are removed from raw feed water by many plants because of the objectionable tastes they impart to water, and the discolorations and other difficulties that the presence of iron and manganese causes from many uses of water. Iron and manganese are removed by chemical softening and zeolite processes, and by a process that employs oxidation of the soluble lower-valence forms of iron and manganese to the

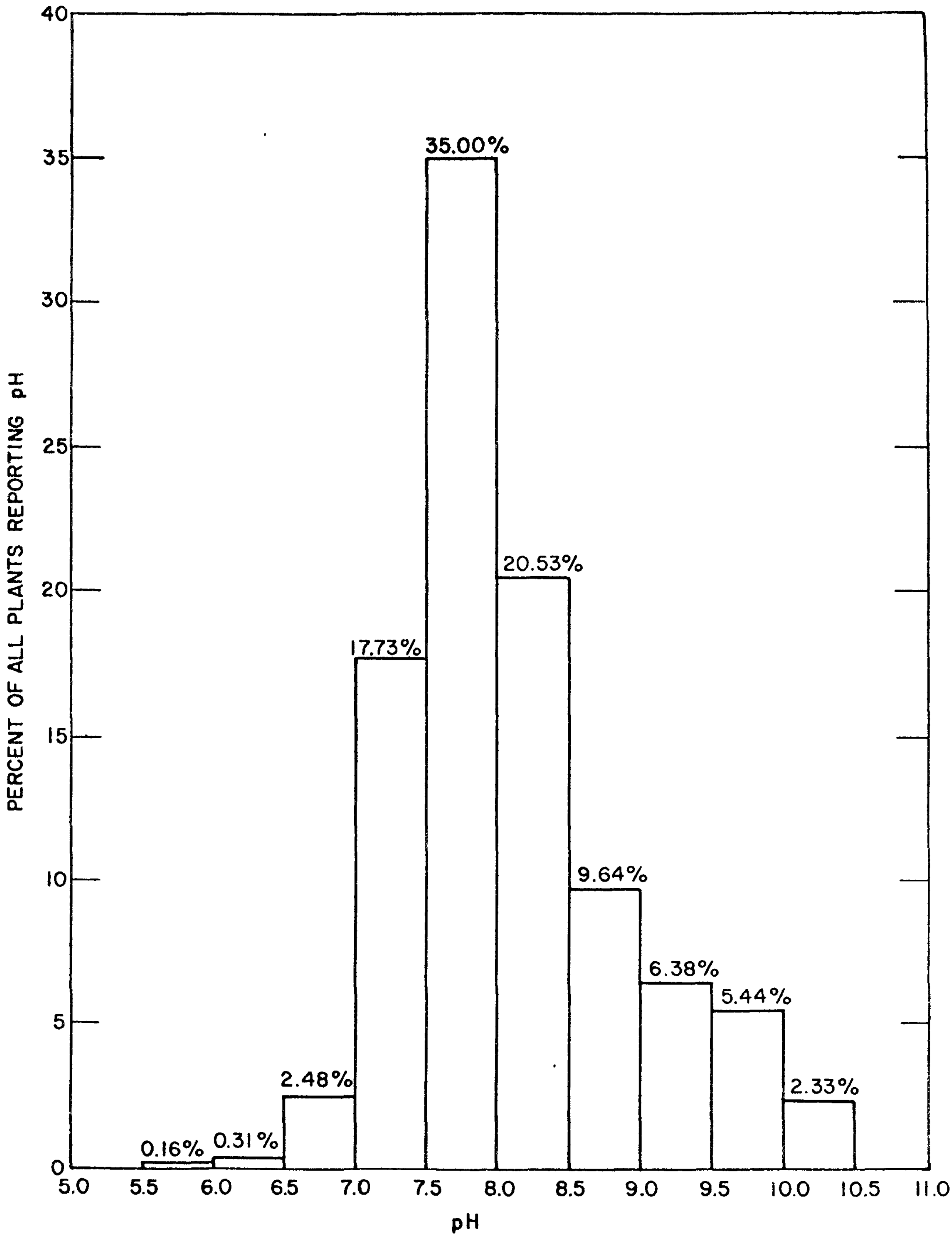

Figure VI-1. Distribution of Product Water for 215 Water Supplies insoluble higher-valence forms. In this oxidative process, precipitates containing the two elements are filtered from the water, and the filter backwash contains the precipitated iron and manganese compounds.

For all categories except those that utilize zeolite processes, the iron and manganese that are removed from the raw water exist in the waters as insoluble hydrated oxides; but in categories utilizing zeolite processes, iron and manganese can exist in soluble forms. Therefore, for categories using zeolite processes, iron and manganese are selected as pollutants.

4. Total Dissolved Solids

The USPHS 1962 Drinking Water Standards set forth a recommended limit of 50 mg/l of TDS. However, many communities use water containing much higher concentrations of TDS (up to 4,000 mg/l). Such waters are not desirable for several reasons, but often they are used as the least objectionable alternatives.

For most categories of water-treatment plants, local water quality requirements and available water supplies will dictate whether TDS will be considered a pollutant. However, mass balances based on data from our survey show that the dissolved solids concentrations are so high in regeneration brines from zeolite-softening or zeolite-iron-removal processes (up to 35,000 mg/l) that TDS should be considered a pollutant parameter for this category.

For the effluent guidelines limitations to be promulgated in 1977, TDS will not be considered a pollutant because an acceptable control and treatment technology has not been demonstrated. However, for the 1983 limitations, TDS is designated a pollutant parameter, since processes for reclaiming zeolite brines have been developed on a pilot-plant scale.

5. Fluoride

In our survey of 782 water-treatment plants, 246 plants reported data on fluoride. For soluble consituents, such as fluoride, the composition of the liquid phase of wastes will be essentially the same as the composition of the product water. The mean concentration of fluoride in the product water from the 246 plants that reported data on fluoride was

0.66 mg/l. The maximum concentration reported was 3 mg/l; the minimum concentration was <0.01 mg/l. Depending on the temperature of the water, fluoride in concentrations higher than 1.4 to 2.4 mg/l tends to cause mottled tooth enamel, especially in children, but a number of communities use water that contains 3 mg/l, or more, because the alternative supplies are even less desirable. Fluoride in concentrations higher than 10 mg/l are potentially detrimental because they can cause nausea, vomiting, and even death if enough of the water is ingested. Since the liquid phase of wastewater is essentially the same composition as product water, for all subcategories of plants except those that use zeolite processes the data indicate the maximum concentration of fluoride in the wastewaters from those categories will not exceed 3 mg/l. Therefore, fluoride is not considered a pollutant parameter for those subcategories. For the subcategories that do use zeolite processes, the fluoride concentrations in the regenerant brines can reach detrimental levels, and it is therefore considered a pollutant parameter for those categories.

D. Rationale for Rejection of Constituents as Pollutant Parameters

Other constituents in wastewaters from water-treatment plants that were considered during the selection of pollutant parameters include: Biochemical oxygen demand (BOD), chemical oxygen demand (COD), sulfate, chloride, and toxic heavy metals. The parameters of temperature and Freon extractibles (oil and grease) were rejected because none of the processes used in the treatment of water results in temperature changes, or is a source a oil and grease.

1. Oxygen Demand Parameters (BOD and COD)

Biochemical oxygen demand (BOD) refers to the amount of oxygen needed to stabilize biodegradable matter under aerobic conditions. BOD is measured by a test in which a seed culture of microorganisms is added to the sample of water to be evaluated, and allowed to metabolize the biodegradable material in the sample over a period of five days. The seeded sample is held under specified standard conditions during the 5-day test. The result of the 5-day test is referred to as BOD_5.

Chemical oxygen demand (COD) provides a measure of the equivalent oxygen required to oxidize the materials in a wastewater sample under specified stringent conditions that include the use of a strong oxidant and a catalyst under acid conditions. The test procedure requires about three hours and is therefore more rapid than the BOD5 test. However, the results of the test give no direct evidence of the potentially detrimental effects to a watercourse because both refractory (resistant to biological action) and non-refractory materials are oxidized in the test for COD. In contrast, the BOD5 test does give direct evidence of potentially detrimental effects despite the disadvantages sometimes mentioned in connection with the BOD5 (e.g., the time required, the sensitivity to toxic materials, and the need for acclimatization of the seed culture in some instances).

The main source of BOD and COD in wastewaters from water-treatment plants is algae that grows in filters, sedimentation ponds, and lagoons. Wastewaters from water-treatment plants almost always have low values of BOD5 (30 to 300 mg/l), but the COD can range higher (30 to 5,000 mg/l). Activated carbon and cell bodies of microorganisms are relatively refractive to the BOD5 test, but are oxidized in the COD test.

Even at the higher levels of BOD that are measured by the BOD5 test in wastes from water-treatment plants, the potential for detrimental effects will be small if reasonable limitations are established for suspended solids as given in Sections IX, X and XI. High levels of COD in wastes have not proved to be detrimental in themselves. Therefore, neither BOD nor COD was selected as a pollutant parameter.

2. Toxic Heavy Metals

Many heavy metals can be detrimental or toxic to aquatic biota, if they are present as dissolved species in concentrations exceeding certain limits, which differ for each metal. The 1962 U. S. Public Health Service Drinking Water Standards list the following mandatory limits for the concentrations of certain metals in drinking water: arsenic, 0.05 mg/l; cadmium, 0.01 mg/l; hexavalent chromium, 0.05 mg/l; lead, 0.05 mg/l; mercury, 0.002 mg/l; and silver, 0.05 mg/l. The same Standards list these recommended limits: copper, 1.0 mg/l; iron (dissolved), 0.03 mg/l; manganese (dissolved), 0.05 mg/l; and zinc, 5.0 mg/l.

In the publication of the U. S. Geological Survey (U. S. Department of the Interior) entitled "Public Water Supplies of the 100 Largest Cities in the United States, 1962" only the concentrations of dissolved iron and manganese exceed the above limits, and then only for a few cities that have no better alternative sources of water. The survey of the drinking water in 702 localities published by the EPA entitled "Chemical Analysis of Interstate Carrier Water Supply Systems, October 1973" showed 2 of the 702 waters analyzed exceeded the mandatory limits of chromium, 1 out of the 702 exceeded the limit on lead, and 6 of 702 exceeded the limit on mercury.

In our survey of 782 plants only 112 plants reported on the concentrations of one or more heavy metals in their product water. The reported maximum, minimum, and mean concentrations of cadmium, copper, nickel, lead, zinc, and mercury are given in Table VI-1 below.

TABLE VI-1

Toxic Heavy Metals Concentrations Reported

Metal	DWS standards[a] mg/l	Concentration, mg/l max.	min.	mean	Number of plants reporting the constituent
Cadmium	0.01	0.01	-0-	<0.01	21
Copper	1.0[b]	0.23	-0-	0.03	90
Nickel	-	0.1	-0-	0.01	21
Lead	0.05	0.05	-0-	0.02	43
Zinc	5.0[b]	0.67	-0-	0.03	44
Mercury	0.002	not reported		0.001	1

a) USPHS mandatory maximum
b) USPHS recommended maximum

For the categories that do not use zeolite processes, the concentrations of heavy metals in the liquid phase of the wastes are essentially the same as the concentrations of the product water. Therefore, based on the data obtained in our survey, none of the plants that reported on heavy metals had concentrations of the metals that exceeded the USPHS Drinking Water Standards.

The combined data from the three surveys indicate that the concentrations of dissolved heavy metals in the product water do not exceed the USPHS mandatory limits except in a few instances. Since the liquid wastes from water-treatment plants have essentially the same composition as the product waters, the concentrations of heavy metals are low enough in most wastes that across-the-board limitations are not warranted. Restrictions on heavy metals may be needed in some instances to meet water quality requirements, but these cases can be judged locally.

3. Sulfate and Chloride

Sulfate and chloride anions are found in almost all wastes from water-treatment plants. For all subcategories except those that utilize zeolite processes or dissolved-solids removal processes, these two anions will be present in the liquid phase of wastes at the same concentrations as those in the product water. The USPHS Drinking Water Standards do not list mandatory limits on these two anions, but do list recommended limits (250 mg/l for each). The reason for the recommended limits is that both in excess impart an unpleasant taste to water, and sulfate is a laxative. However, some communities use water supplies with high concentrations of sulfate, or chloride, or both (up to 990 mg/l) because there are no better alternatives.

For categories that utilize zeolite processes, the concentrations of sulfate and chloride can reach very high levels in the brines. However, both sulfate and chloride are constituents in total dissolved solids, and monitoring TDS is more convenient than monitoring sulfate and chloride. Since TDS is an indirect indicator of sulfate and chloride, sulfate and chloride were not selected as pollutant parameters.

SECTION VII

CONTROL AND TREATMENT TECHNOLOGY

Current technology for the control and treatment of water plant waste consists primarily of solids separation and disposal. These have been accomplished in a number of ways, including: lagooning, thickening, mechanical dewatering, discharging to the sanitary sewer, drying in beds, and disposing on land. Treatment of wastes from dissolved-solids removal processes consists typically of deep well injection, ocean disposal, disposal to sanitary sewer, or dilution of the brine wastes. Recovery of water-treatment chemicals is practiced at a number of water plants. Lime recovery is practiced at eight water-treatment plants at present. Alum recovery is planned for a large water plant now under construction and is currently practiced at water plants in Japan, Scotland, and France. The recovery and recycle of magnesium compounds have been studied in full scale at two water-treatment plants, one of which is under design to include these processes. Brine recovery from ion exchange softening has been practiced on a demonstration scale. The production of magnesium compounds is planned at a large softening plant in the near future.

The large volumes of filter backwash wastes, amounting to 2 to 5% of plant production, generally necessitate separation of these wastes for treatment. Forty-six plants have been identified that recycle the backwash wastewater to the plant influent. While most plants recycle directly, some plants clarify this waste prior to recycling and pump the sludge to the waste treatment system.

Except for filter backwash recycling, most of the currently used technology is of the end-of-plant category, relying on lagoons. For those plants choosing landfills to dispose of lagoon sludge, the landfill operations are generally poor. In many cases, private hauling contractors are responsible for selection of the disposal site, where, in many cases, no means of compacting or covering the sludge are provided.

A. <u>In-Plant Technology</u>

The wastes from water-treatment plants consist primarily of undesired suspended and dissolved constituents found in the raw water. Little can therefore be done to reduce these wastes by source control. Good water conservation results in an increase in waste concentrations, particularly in the filter backwash recycle. The methods discussed below reduce or change chemical additive requirements and subsequently affect wastes produced.

1. Plant operation

The proficiency of water plant operators is often measured by the quality of the finished product and the quantity of chemicals applied for treatment. Well trained operators who are guided by the results of adequate laboratory tests can often reduce chemical requirements without degrading finished water quality. Since larger plants are usually more adequately staffed and equipped they tend to use fewer pounds of chemical additives per million gallons of water treated, when compared with smaller plants having similar raw water.

2. Plant design

Coagulant requirements can be affected by the plant design and greatly reduced, for example, by minor plant alterations, such as properly baffled mixing chambers and settling basins, or by the use of high-energy flocculation.

3. Organic polymers

In many cases, organic polymers have been used to replace part or all of the inorganic coagulants. Their use not only substantially reduces the amounts of waste solids generated, but also produces a sludge that is more readily dewaterable. When raw waters have very low turbidity clays are occasionally added with the polymers, and their addition offsets the advantages otherwise attainable. Polymers are generally effective at low concentrations, they are biodegradable, and they are relatively insensitive to coagulation pH. The use of polymers has been restricted to applications where cost savings can be demonstrated when compared to inorganic coagulants. The determination of cost effectiveness does not generally include waste-treatment alternatives.

4. Filter backwash recycling

As discussed in Section V, filter backwash wastes are extremely voluminous but low in solids concentration. Visits have been made to twenty-nine plants practicing filter-backwash recycle. These plants treated raw waters of widely varying quality with a variety of treatment processes and no technical problems were experienced when the filter backwash was recycled. In most cases, the costs of filter backwash recycling cannot be justified from water savings alone; however, in arid regions net savings may be possible.

Backwash recycle facilities usually include an equalization basin to maintain the recycle feed rates below 5% of the plant raw water flow. In some instances, filter backwash water is clarified and only the supernatant is recycled, while the sludge underflow is pumped to the sludge-treatment system. Where recycle is accomplished without clarification, facilities for the mechanical removal of sludge are not required. The equalization basin is designed to achieve natural scouring of the solids to prevent accumulation.

Recycle of filter backwash water has little effect on the net waste-solids production from a water treatment plant. Some plants treating very low turbidity raw water report some beneficial effects, which might lower coagulant requirements slightly. Other plants report slight increases in coagulant requirements due to recycle.

Some concern has been expressed about possible problems of taste and odor in the finished water when filter backwash is recycled. With the notable exception of one new plant on the West Coast, no problems with taste and odor have been reported at the plants visited. Some plants that were visited do have taste and odor problems in the raw water at times. Water rights may decrease the acceptability of recycle of filter backwash water in certain geographical areas.

These in-plant modifications or suggestions are qualitative in nature. As mentioned earlier, most of the wastes result from raw water contaminants; thus in-plant modifications have only limited effects. The effects appear to be greatest when relatively clear, raw water is treated with inorganic coagulants.

5. Chemical recovery

There has been increased emphasis in recent years on chemical recovery as a means of reducing waste production and chemical costs. The nature of chemical recovery and the processes utilized are discussed below.

a. Alum recovery

Although no alum recovery plants now operate in this country, a large water-treatment plant incorporating alum recovery is presently under construction. Water plants in Scotland, France, and Japan are successfully utilizing alum recovery. The technology involved in alum recovery is comprised of the following steps:

1) The alum sludge is thickened to greater than 2% solids.

2) Sulfuric acid is utilized to recover aluminum values at a pH of approximately 2.0. A contact time of 20 to 30 minutes is usually required.

3) Acidification improves dewatering properties of the sludge and the separation of dissolved aluminum sulfate is accomplished by thickening, pressure filtration, or both.

4) Alum is recycled to the raw water at a controlled rate, and the dewatered sludge is neutralized with lime and disposed of as landfill.

The primary problem area in alum recovery appears to be the dissolution of heavy metals, color-causing materials, and other components of sludge at the low pH. The pilot and laboratory studies in this country have been conducted primarily with good quality raw water, although full scale pilot studies were conducted for one year at Tampa, Florida, where a highly colored water was treated. Problems were experienced with color build up in the recovered alum at this plant.

A recently developed alum recovery process utilizes incineration to destroy organics prior to the acidification step. In this process the alum sludge is thickened, dewatered, incinerated, acidified for alum recovery, separated from the sludge, and reused. This process has been used at a pulp and paper mill recovering alum used for color removal.

Alum recovery reduces waste solids, particularly in the treatment of waters of relatively low turbidity, also increases the filtrability of the residual sludge.

b. Lime recovery

For many years, softening plants have been faced with sludge disposal problems due to the large quantities of sludge generated. Theoretically, 3.57 kg (7.86 lb) of calcium carbonate is produced for each kilogram (2.2 lb) of lime fed in removal of calcium alkalinity hardness. If all of the calcium carbonate were calcined to calcium oxide as:

$$CaCO_3 \rightarrow CaO + CO_2$$

two kilograms (4.4 lb) of lime would be available for each kilogram (2.2 lb) fed. Commercial quicklime usually contains only 85% to 95% calcium oxide, and as lime also reacts with some of the magnesium, CO_2, etc. present in the raw water, the amount of sludge produced is generally assumed to be about 2.5 kg (5.5 lb) dry basis, for each kilogram (2.2 lb) added. This amount would allow recovery of about 1.3 times the amount of lime fed. Thus, lime recovery would not only allow for a great reduction in waste solids, but also provide some recovery of costs from the sale of excess lime. In addition, the carbon dioxide released on calcination would be available for use in finished water stabilization.

Eight water plants in the United States are now recovering lime. Three primary recovery processes are used: the rotary kiln, the multiple hearth furnace, and the fluidized bed calciner. Typically 2.0 to 2.8 million kg cal (8 to 11 million Btu) are required for calcination. The exact heat requirement depends on the moisture content of the sludge and on the efficiency of operation. All lime-recovery plants now in operation treat waters of low turbidity. The primary contaminant is magnesium hydroxide.

In the calcination processes it is desirable to remove magnesium hydroxide before calcination. Magnesium hydroxide, in sludges not separated prior to calcination, will be converted to a hard-burned magnesium oxide, which does not slake readily and tends to build up as an impurity in the lime. Carbonation, *i.e.*, dissolving magnesium hydroxide by treatment of the sludge with the carbon dioxide-containing exhaust gases, converts the insoluble magnesium hydroxide to soluble magnesium bicarbonate as:

$$Mg(OH)_2 + 2\ CO_2 \rightarrow Mg(HCO_3)_2 \text{ (soluble)}$$

The solubility of magnesium ions increases with an increase in the partial pressure of carbon dioxide. Approximately sixty minutes contact time is required for 90% conversion to magnesium carbonate depending on mixing conditions and gas flow rate. Two plants employ the carbonation process and one of these was visited during this study. A more sophisticated system to improve separation efficiency at the plant visited has been designed.

Following carbonation, thickening is provided for separation of the clear magnesium bicarbonate solution and concentration of the calcium carbonate. Dewatering of the thickened sludge can be accomplished by either vacuum filtration or centrifugation. Washing of the filter or centrifuge cake increases the removal of magnesium carbonate by rinsing away the saturated interstitial solution.

Another means of separating the magnesium values is by thickening without carbonation and use of centrifugation to separate the denser calcium carbonate from the magnesium hydroxide. Typically 30% of the total sludge solids must be wasted in the centrate in order to separate 50% of the total magnesium values from the sludge. Lagoons are often provided for the centrate solids. Thus, the centrifugation is only moderately efficient in the separation of magnesium values and produces a sizeable waste in the centrate. Centrifugation will be discussed specifically in a later section.

Separation of the silt fraction from the calcium carbonate has been attempted, prior to calcination, with a hydrocyclone and a centrifuge and after calcination with air classification; but these techniques have been only moderately successful. Froth flotation for separation of silt has been investigated on laboratory scale and has shown promising results. A pilot scale study is now underway for further evaluation of this process for calcium carbonate beneficiation.

Many of the large softening plants in this country utilize surface water containing considerable amounts of suspended solids. An acceptable separation technique for contaminants would allow lime recovery at many of these plants.

i. Fluid bed calcining

Figure VII-1 is a simplified flow diagram of a fluid bed calciner. The dewatered cake from centrifugation is discharged to a pug mill (a mixing device) which combines the moist cake with previously dried calcium carbonate dust. The resulting material, about 80% solids, is delivered to a cage mill where

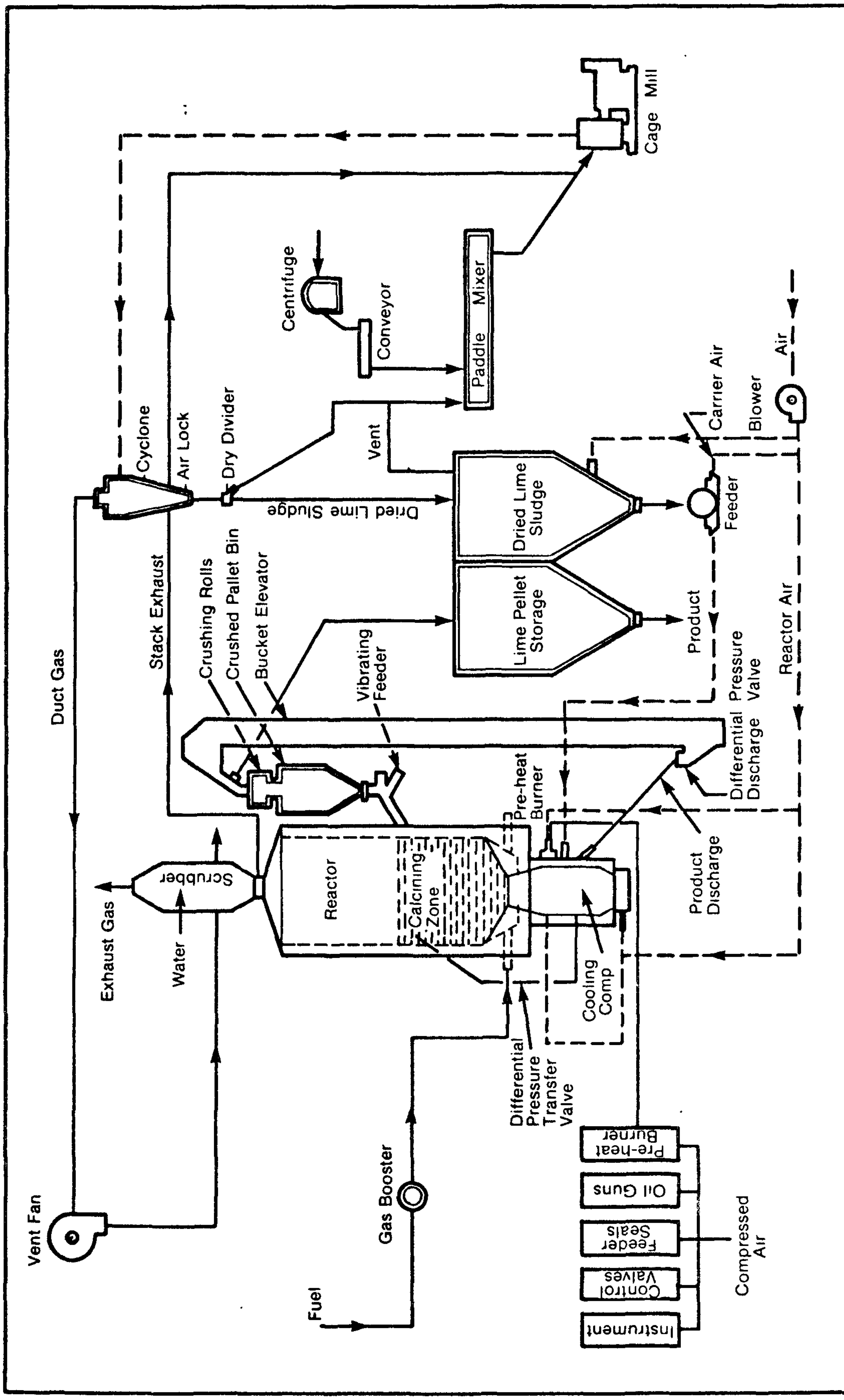

FIGURE VII-1 Recovery of Lime for Reuse—Fluid Bed Process.

the particles are dried by the hot calciner exhaust gases, beaten into a fine powdery dust, and transported by the gas stream to a cyclone. In the cyclone the solids are separated from the hot gases which continue on to the vent fan. The dried particles are either conveyed to a storage bin or added to the raw water thus beginning the cycle again.

The calciner reactor is constructed in two sections. The upper section is the furnace area in which the solids are heated while suspended in a vertical air stream called the "fluidizing air". The lower portion holds the newly formed lime, and permits it to cool prior to removal from the reactor. The lower section serves to preheat the fluidizing air.

The particle size of the lime produced is controlled primarily by the feed of soda ash and the amount of dried sludge recycled. The combination of extremely fine particle sizes and the fluid bed allows calcination temperatures generally in the range of 760-870°C (1400-1600°F) which is considerably below the ranges of the two other calcination processes discussed.

The lime produced is spherical in shape, typically 0.32 cm (1/8 in) in diameter, and practically dust free. A new fluid bed calciner is being planned at one city. Preliminary plans indicate that a 90.7 metric ton/day (100 ton/day) calciner, including sludge thickener, holding tanks, and centrifuge, will be constructed on a 27.4 m x 42.7 m (90 ft x 140 ft) plot of ground.

This process allows considerable flexibility in operating, and it can be easily placed in an attractive, compact building. At one installation only three men are needed to operate the calciner for a 16-hour day, including all routine maintenance.

ii. Rotary-kiln process

A flow diagram of a typical rotary-kiln calcining plant is shown in Figure VII-2. The lime sludge is first dewatered by centrifugation, and the sludge is then fed to the kiln as a slurry of toothpaste consistency consisting of 65% solids. A chain section in the kiln transfers heat from the kiln gas to the cake. The kiln shell has a refractory lining, rotates at approximately 1 rpm, and is inclined to a slope of 4.2 cm/m (1/2 in/ft) to facilitate the travel of the sludge toward the firing end. Retention time in the kiln is usually

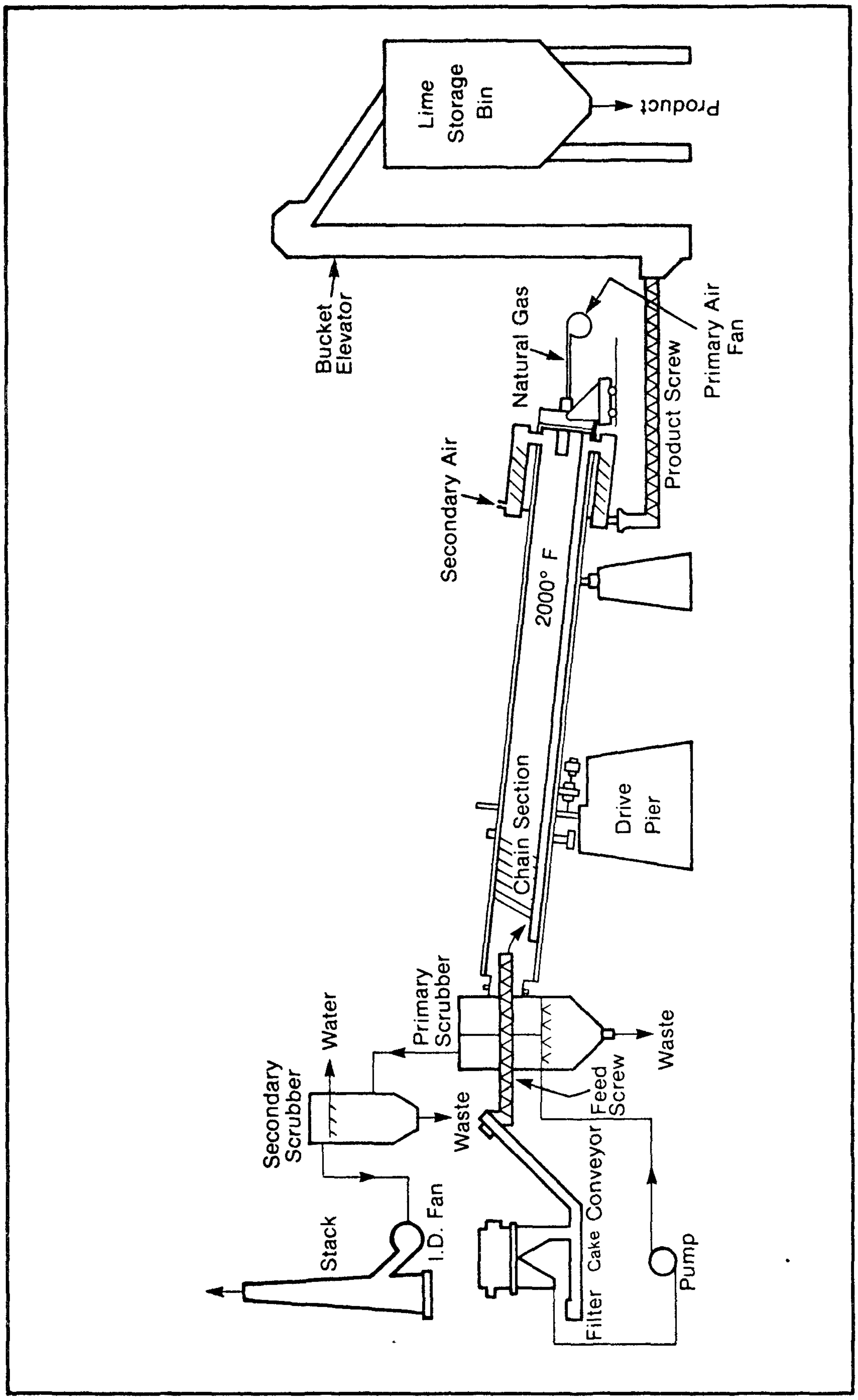

FIGURE VII-2 Recovery of Lime for Reuse—Rotary Kiln Processes.

1-1/2 hours. The sludge is nodulized and converted into quicklime in the calcining zone then discharges into an integral tube cooler. The cooler tubes are mounted in the periphery of the kiln shell and contain flights to move the product uphill and discharge it into a screw conveyor. The lime is then transferred to storage by bucket elevator.

Air is supplied to the gas or oil burner for flame control. Cooling air enters the tube coolers through the product discharge ports. The temperature within the kiln at the calcining zone is maintained at approximately 1100°C (about 2000°F), and the temperature of the kiln exhuast gas at the feed end housing is about 200°C (about 400°F). A scrubber removes traces of dust before releasing the exhaust gas to the atmosphere.

iii. Multiple-hearth furnace

The multiple-hearth furnace is composed of a series of vertically stacked hearths as shown in Figure VII-3. Dewatered calcium carbonate is added to the top hearth where it begins to dry completely. Variable speed rabble arms move the material in a circular motion until it falls to the next hearth. Usually, the top two or three hearths are not fired but are provided to dry the material before it reaches the calcining hearths. The discharge between hearths is alternately on the periphery and in the center and provides a spiralling effect. The angle of the rabble teeth determines the direction of the product movement.

Each hearth can be temperature programmed. Typically, the calcining zone is maintained at 980-1010°C (1800-1850°F) with the bottom two to three hearths not fired but provided for product cooling and pre-heating of the draft air.

Operational variables include feed rates, rabble rate, temperature, air volume, and dust recycle. A dry cyclone is normally provided with recycle of the collected material to lower hearths.

Primary advantages and disadvantages

Rotary kiln

Advantages - Operationally simple. Can be coal fired, relatively low power requirements, present water

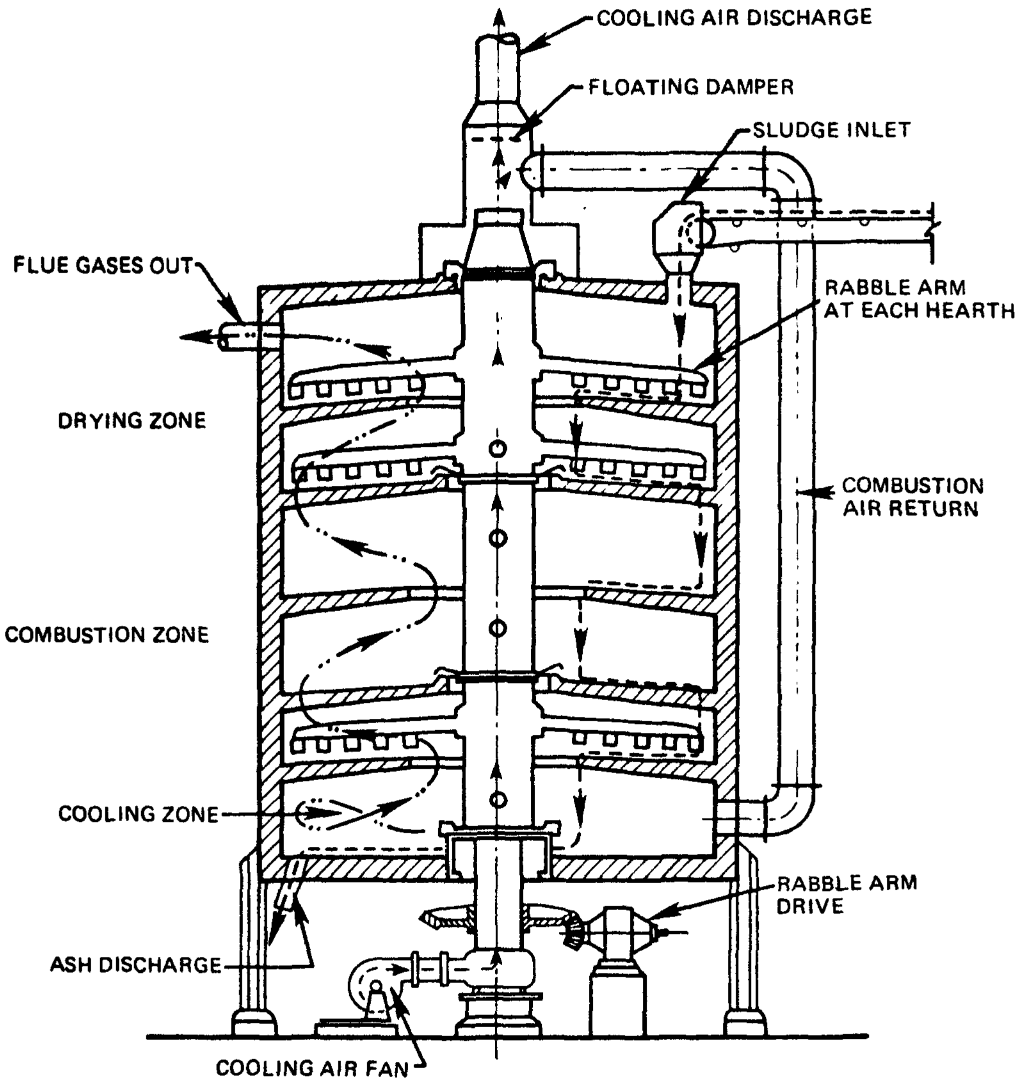

FIGURE VII-3 Cross section of a typical multiple hearth incinerator.

plant applications are successful, small down time reported, pelletized produced

Disadvantages - Large land area required, large tonnages are required for economics, 24-hour operation required, generally unattractive aesthetically.

Fluid bed

Advantages - Small land requirements, intermittent operation feasible, lower fuel requirements due to lower calcining temperatures, product almost dust free, no moving parts in calciner, can be attractively housed.

Disadvantages - High power costs, more operationally sophisticated, can have high soda ash requirements, presently requires fuel oil or natural gas. Extremely noisy due to fans, compressors, etc.

Multiple hearth furnace

Advantages - Small land requirements, intermittent operation feasible, operationlly simple, accurate temperature profile possible.

Disadvantages - Product powdered, maximum temperature available is 1010°C (1850°F), presently requires fuel oil or natural gas.

c. Magnesium bicarbonate recovery

A water-treatment process which has been recently developed uses magnesium bicarbonate as the primary recyclable coagulant. This coagulation process is a combination of water softening and conventional coagulation. Sufficient lime slurry is added to a water containing magnesium carbonate or to which magensium carbonate has been added to precipitate both calcium carbonate and magnesium hydroxide, which have properties similar to aluminum hydroxide. Carbonation of the sludge selectively dissolves the magnesium hydroxide as magnesium bicarbonate, which can be recovered by thickening and vacuum filtration for recycle and reuse. The filter cake, composed primarily of calcium carbonate and clay, may be disposed of as landfill or the calcium fractions recovered for calcination. A froth flotation process has been shown in laboratory studies to be effective for separating calcium carbonate from clay with greater than 90% purity obtainable. A demonstration scale project is underway at present to study this separation technique. In the application, the filter cake composed of calcium carbonate and clay is reslurried and the calcium carbonate floated off for recalcination. The carbon dioxide produced in the recalcination is used for both sludge carbonation and finished water stabilization. The clay in the flotation underflow can be dewatered and disposed of as landfill.

There are three general applications of the processes involved:

1) The use of magnesium bicarbonate as a coagulant with the recycle of magnesium bicarbonate and sludge dewatering as an integral part of the process. This is applicable to those waters relatively low in magnesium content with insufficient lime usage to consider lime recovery.

2) Magnesium bicarbonate recycle using flotation for calcium carbonate beneficiation prior to lime recovery. The carbon dioxide produced in lime recovery is used for sludge carbonation and finished water stabilization. The impurities separated by flotation are dewatered and disposed of as landfill. This process is applicable for waters moderately high in hardness with sufficient lime usage to make recalcination economically feasible.

3) Precipitation of the magnesium ions present in the hard raw water, use of lime recovery with flotation beneficiation, and recovery of magnesium bicarbonate. The separated magnesium bicarbonate is not recycled to the raw water, but processed to recover valuable magnesium compounds. The saturated magnesium bicarbonate solution is warmed to 45°C (113°F), air is used to strip out carbon dioxide, and magnesium carbonate is precipitated. Pilot studies at one city have shown that extremely pure magnesium carbonate can be economically produced. This process, of course, would be applicable to waters high in magnesium content with sufficient lime usage to consider lime recovery. The units required are shown in Figure VII-4.

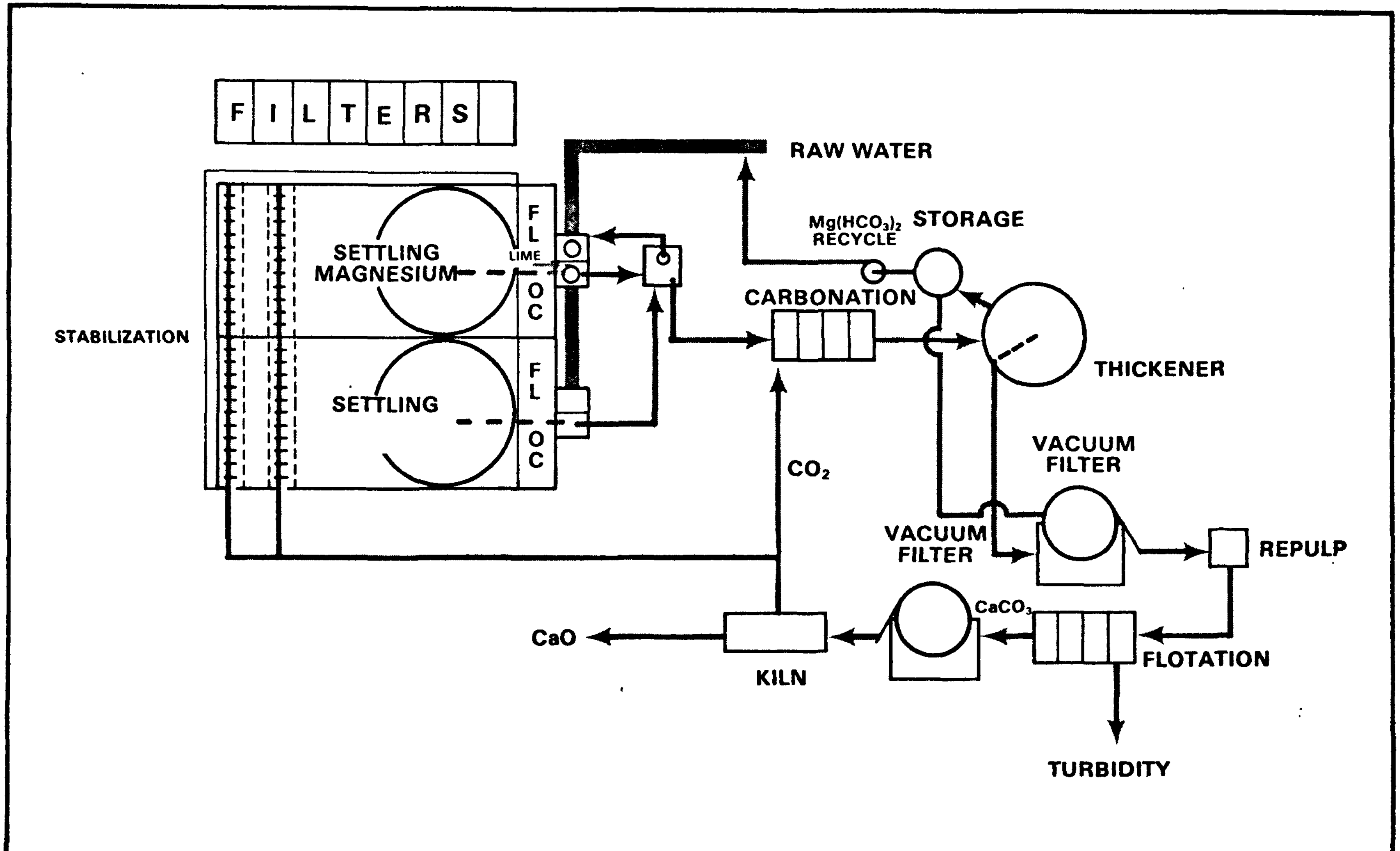

FIGURE VII-4 Lime recovery magnesium process flow diagram.

The primary emphasis of this water-treatment process is the reduction of sludge by the recovery and reuse of the three water-treatment chemicals used: lime, carbon dioxide, and magnesium oxide.

A full scale lime and magnesium bicarbonate recovery system is under design at one water-treatment plant treating a highly colored water of low turbidity. For the application under design there will be no waste discharge. The colored material removed from the water will be converted to carbon dioxide when the sludge is calcined.

Two plant scale studies have been conducted with success on the first of the three applications discussed above. Although separation of clay and calcium carbonate on a continuous basis has not been demonstrated, a demonstration scale study is now underway for the third category.

d. Brine recovery

Ion-exchange softening is used as a water-treatment process for a number of municipal supplies. Industrial water-treatment plants use this process more extensively for water softening than municipalities.

The backwash brine wastes can be recovered by conventional lime-soda ash softening, which precipitates the dissolved magnesium and calcium values as an insoluble sludge. The brine is then filtered and recycled for reuse.

Typical ion-exchange regeneration cycles allow separation of the brine wastes into fractions to improve the economy of this recovery process. The fractions are:

1) Rinse water low enough in salt to be discharged in the most convenient manner without risk of damage to the environment.

2) Brines high enough in concentration to produce risk of damage to the environment if discharged without treatment. These brines are usually mixed chlorides of calcium, magnesium and sodium.

3) Final rinse water, low in hardness, but containing sodium chloride. These may be reconstituted and reused.

Fraction two represents the wastes that are to be treated for recovery.

While the brine waste represents only 2% to 5% of the water treated, chemical requirements for treatment can be more expensive than if the raw water were treated by lime or lime-soda softening initially. In waste regeneration brines, all of the hardness has been converted to non-carbonate hardness, which requires soda ash treatment. Since soda ash is considerably more expensive than lime and is sometimes difficult to obtain zeolite softening with recovery of brine wastes by precipitation may not be financially justified.

Brine recovery would appear to be technically feasible and should be considered for existing zeolite installations. New installations should give careful consideration to the economics of the total treatment. Brine recovery and recycle produce less sludge on a dry-solids basis than conventional lime-soda softening. However, considerable quantities of sludge must be dewatered and disposed of. Another process change which merits attention for new installations is the moving-bed zeolite softener or continuous-regeneration zeolite softener. In this process, the exhausted zeolite is continually replaced with regenerated zeolite to allow an equalization of the waste-brine regeneration stream. Some savings have been reported for continuous regeneration because of more efficient utilization of the exchange media.

The spiractor process has also been found to be a satisfactory device for brine recovery, producing a dense, non-gelatinous sludge which readily dewaters. The spiractor process is shown schematically in Figure VII-5.

B. End-of-pipe Waste Treatment Technology

The following is a discussion of various end-of-pipe technologies presently used in the water supply industry.

1. Preliminary Treatment Systems

a. Sludge flow equalization and storage tanks

Flow equalization and storage facilities may be required to reduce the volume fluctuation of waste effluent streams. A

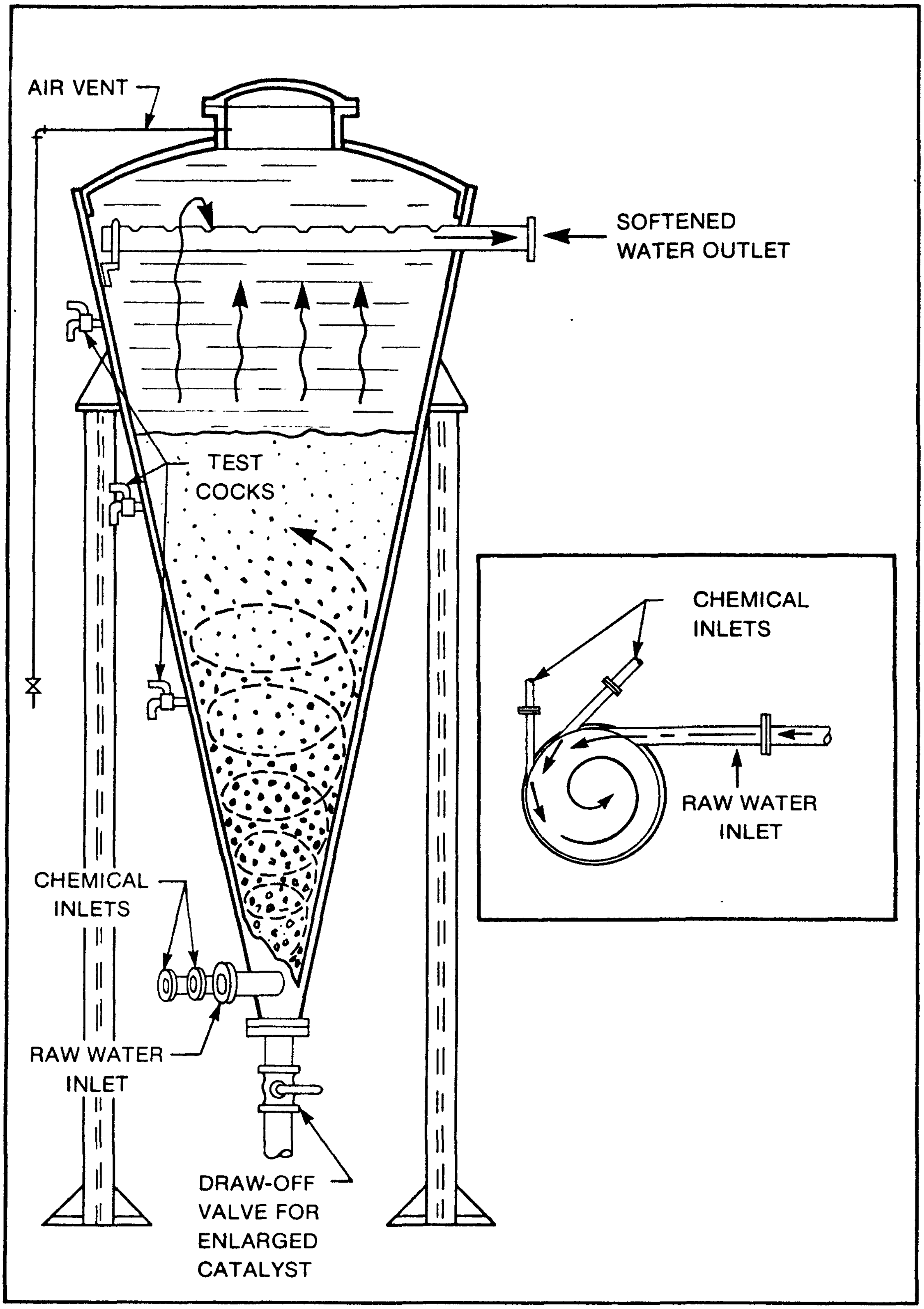

FIGURE VII-5 Cross-Sectional View of Permutt Spiractor Showing Flow.

number of factors must be considered in determining whether such facilities are needed: the waste-treatment process used, plant physical facilities, variation in water production, raw water quality, and operational characteristics of the waste treatment process. Generally, water plants without continuous sludge collection will require some means of sludge flow equalization and storage, particularly if wastewaters are to be discharged to the sanitary sewer system.

b. Thickening of sludges

Thickening of clarifier sludges prior to dewatering performs two functions. It reduces the sludge volume to be treated, and it provides a more concentrated slurry for dewatering. An increase in solids concentration of from 1% to 3% reduces the sludge volume to one-third, and thus reduces the size of the system components because of the smaller volume to be handled. Increasing the slurry solids in the feed to a mechanical dewatering device can greatly increase the loading rate.

Various conditioning agents are used to increase supernatant clarity and sludge solids concentration. Typically, organic polymers are used in concentrations normally in the range of 0.5 to 2.0 kg per metric ton (1-4 lbs/ton) of dry solids. The overflow is generally recycled to the plant influent; however, in at least one case it is sold to a nearby industry for cooling water.

Alum or iron hydroxide sludges generally can be thickened to 2 to 6% solids while lime sludges can be readily thickened to greater than 35% solids. Typical solids loading rates for alum sludges range from 20 to 60 sq m per dry kkg per day (200 to 600 sq ft per dry ton per day) while softening sludge thickeners are designed with loading rates 3 to 5 sq m/kkg/day (30 to 50 sq ft/ton/day).

For discharge to sanitary sewers thickening may not be desirable because of plugging of the collection system. This will be discussed in more detail in a later section.

Gravity thickening is a low energy process that requires little operation attention if properly designed. Attention given to polymer feed, if applicable, and underflow pumping rates. Equalization is often provided by a thickener designed for this purpose; thus in many instances a thickener will serve both functions.

c. pH neutralization

Some water-treatment processes may produce wastes with high or low values of pH not within normal acceptable limits for discharge. Coagulation of organic color can take place at a pH as low as 5.0 while excess-lime softening often exceeds a pH of 11.3. In excess-lime softening, a recycle of the liquid fraction of the sludge discharge will eliminate the need for pH adjustment as well as reduce lime dosage slightly. This should be both technically and economically feasible at most plants. In addition to the sludge flow, the entire contents of the settling basin would represent a waste with an unacceptable pH, if emptied on a periodic basis.

Special sludge treatment processes such as filter pressing and alum recovery may produce wastes that must be neutralized prior to discharge to a receiving water or a sanitary sewage system. Recycle of filter press filtrate has been reported to cause process upsets at one plant treating a low alkalinity raw water.

A waste stream that requires neutralization may be remote from the water-treatment plant. An automatically pH-controlled acid or alkali feed system including an alarm and a failsafe recycle system will ensure proper pH control of waste effluent. If the pH has not been adjusted within the acceptable range, the waste will be recirculated back to its origin (e.g., lagoon). Retention times of 10 minutes should provide adequate contact time for neutralization of wastes before discharging them. Figure VII-6 illustrates a simple system of neutralization.

2. Dewatering Systems

a. Lagoons

Lagoons are one of the oldest methods used to treat water plant wastes. Because of their relatively low cost, lagoons continue to be one of the most popular methods of disposal used today.

Often, lagooning is not so much a method of disposal as it is a method of dewatering, thickening, and temporarily storing the wastes. However, the use of lagoons is somewhat limited by the availability of cheap land relatively close to the plant.

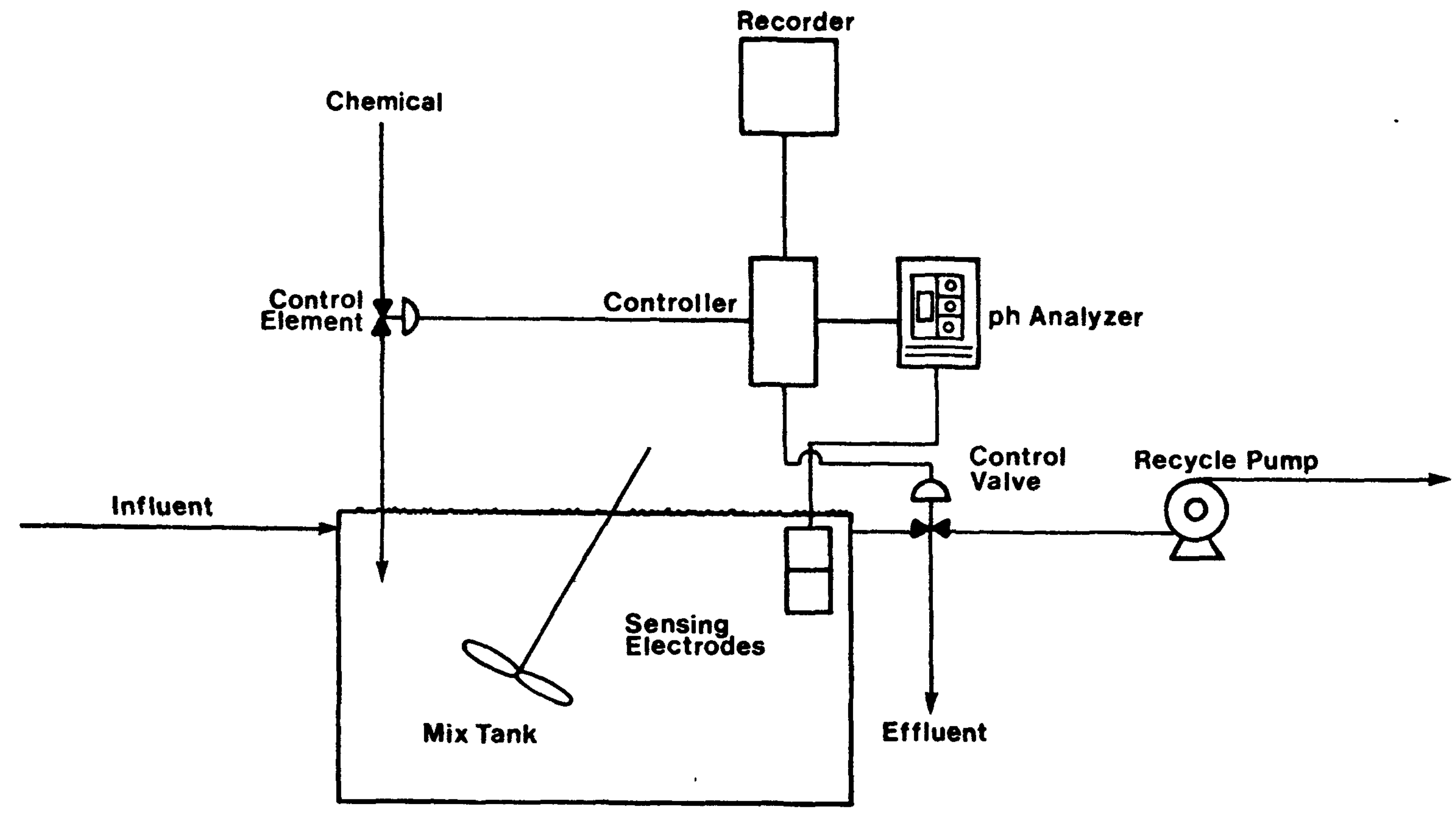

FIGURE VII-6 Elements of pH Control System.

There are basically two types of lagooning operations used in the water industry. There is the continuous-fill or storage type of lagoon, which is used primarily for lime softening sludges where large areas of cheap land are available. When completely filled, the lagoon is abandoned for a new site with eventual reclamation of the old lagoon area.

The other type of lagoon is the fill-and-dry or decanting-type operation, which is used for both lime softening and metal hydroxide water-plant sludges.

Usually, two or three lagoons are necessary for alternate filling, decanting, and drying with subsequent removal of the "dried" sludge.

i. Operational and design factors for lagoons

Although lagoons are being used throughout the water industry, very little specific design criteria are available. Some factors which should be considered in lagoon installations include:

1) The location should be free from flooding with the bottom of the lagoon above the maximum groundwater table.

2) Surrounding areas must be graded to divert surface water from the lagoon.

3) The lagoon should have a minimum depth of 1.2 - 1.5 m (4 - 5 ft).

4) There should be at least two units to allow independent decanting, drying, and cleaning.

5) Adjustable decanting devices should be used - submerged orifice, flash boards, floating outlet, etc.

6) Cleaning should be convenient.

7) The storage capacity should provide for at least one year's production of sludge.

8) Easy-access roads and loading ramps. Dikes should be of a shape and size to permit maintenance and mowing, and for trucks, cranes or front-end loaders to work in or around the lagoons for sludge removal. If clam shell

or drag line is to be used for cleaning, consideration should be given to boom length and lagoon dimensions to allow accessability of all areas of lagoon for cleaning using this method.

9) There should be at least eight hours retention time.

10) Baffles or other devices should be used to prevent short circuiting.

Lagoons are generally built solely by enclosure of a land surface by dikes or by excavation. Drainage is usually not maximized by underdrains, or by surfacing with sand. Sludge is added continuously or intermittently until the lagoon is filled; then the lagoon is abandoned or cleaned. If the lagoon is to be cleaned, a standby lagoon is normally required. This will allow maximum concentration of the lagooned sludge, if excess water is removed by decanting. The sludge is allowed to dry naturally for 6 to 12 months.

The design configuration of lagoons is extremely important to proper operation. Lagoon dimensions and berm width should be designed to allow access to all areas of the lagoon for cleaning. One of the most important factors in lagoon design is the inlet and outlet structures. The inlet should be above the maximum sludge level with baffling to minimize scouring and short circuiting. In addition, the outlet should be designed to accomodate surges of backwash water and to provide a gradual discharge, and thereby maximize the detention time and solids removal. The outlets can be a floating type discharge, overflow weir, pumps, removable flash boards, or submerged orifices. Of these, the multiple submerged orifice or floating overflow types probably have the greatest overall utility and flexibility, if retention time or sludge storage capacity needs to be adjusted.

Some lagoons have naturally permeable bottoms and others have been designed with underdrain systems to aid in dewatering. Depending upon the character of lagoon underflow, it may be recycled or discharged directly.

ii. <u>Application to subcategory</u>

(a) <u>Category I</u>

Alum sludge is difficult to dewater by lagooning. However, it will gradually consolidate sufficiently to provide a 10%

to 15% solids content. Water removal is normally by decantation or by evaporation with some drainage. Evaporation may provide a hard crust on the surface but the sludge below the crust is thixotropic, capable of turning into a viscous liquid upon agitation with near zero shear resistance under static load. Therefore, lagooned alum sludge cannot be easily handled nor does it make good landfill material. An alternative method of lagooning, which works well with alum sludge, combines freezing as part of the process in cold climates. To be successful, the sludge depth should be shallow. Thin layers of sludge, when frozen in winter and later thawed, will dramatically increase in drainage and settling rates, and produce fine granules of material. It has been reported that freeze-thaw can result in a decrease to one-sixth of the original sludge volume, and an increase to 17.5% solids. It should be emphasized that natural freeze-thaw is effective only with shallow sludge because of the insulating effect of the overlying ice and sludge.

(b) Category II & III

Compared with alum sludges, sludges from water softening plants are more easily dewatered in lagoons. The higher specific gravity of the particles aids consolidation. In instances where the sludge must settle through ponded water, a maximum consolidation of 40% by weight of dry solids can be expected; 20% to 30% is more typical. In lagoons in which the supernatant is allowed to flow off, an upper limit of 50% dry solids can be obtained with lime sludge. The lagoon capacity required for disposal of the sludge is dependent upon the physical characteristics of the material and the extent to which it is dewatered during impoundment. Where the lime sludge has been dewatered to about 50% moisture content, the lagoon capacity requirement has been reported as about 160 cu m/yr/1000 cu m/day/100 mg/l (0.5 acre-ft/yr/MGD/100 mg/l) hardness removed.

Lagoons have been used for brine wastes from the regeneration of ion-exchange softeners. Normally lagoons are used for storage or as evaporation ponds. If used for evaporation, the problem of disposing of the residual salts remains. If the soil is porous, brine seepage from the lagoon may result in mineralization of nearby surface streams or ground water. The use of a lagoon for temporary storage and the subsequent release to a water course has been carried out. However, this method requires an adequate water course for discharging and careful control of discharges to avoid environmental damage to the receiving stream.

iii. Plant visits

From existing reports, our literature survey, and actual plant visits, at least 109 plants that use lagoons to treat water plant sludge have been identified. Plant visits were conducted at 66 of these plants, and samples were taken at 15 of these locations. Lagooned alum sludges range from 2.4% to 30% solids with an average of 4.5% solids. Lagooned lime softening sludges range from 20% to 60% with an average of 50% solids.

Loading rates for lagoons ranged from 0.54 to 289.3 kg/year/sq m (0.11 to 59.2 lbs/year/sq ft). In the effluent from those lagoons that have good design and operating features, TSS ranged from 3 to 34 mg/l with an average of 11.0 mg/l for 11 lagoon effluents that were sampled. The data on TSS in the lagoon effluents may not reflect extreme accuracy since many of the samples were grab samples or short-term composite samples.

There are very few data available from the continuous monitoring of lagoon effluents. For this reason, a composite sampler was placed at one lagoon installation, and 24-hour composite samples were taken over one month. The lagoon selected was treating an alum sludge. The TSS in the lagoon effluent ranged from 5 mg/l to 23 mg/l. With a time-averaged value of 10.3 mg/l. The average total aluminum concentration was 0.97 mg/l with a range of from 0.33 to 1.5 mg/l as Al.

iv. Summary

The data accumulated to date on lagoon operations must be appraised in light of the limited amount of monitoring data available. In addition, many lagoons presently in operation are grossly overloaded with very little, if any, attention given to their operation. It has been demonstrated, however, that a well designed, properly operated lagoon can produce an effluent of good quality. This effluent is recycled to the plant influent in a number of the plants visited with no technical problems reported.

The major problem in many lagoons used to treat water plant sludge is that the sludge is not sufficiently concentrated so that it can be removed from the lagoon directly to a landfill. Therefore, further drying is recommended for ease of handling and disposal. This can be accomplished by transferring the wet sludge to a drying area where the sludge can be spread over a larger area to improve drying. Alternatively, sand drying beds or some type of mechanical dewatering device can be used to further dewater the lagooned sludge. However, when used in this manner, the lagoon serves only as a tank for clarifying, thickening, and storing sludge, and the economics of sludge handling in such a system should be closely evaluated.

Advantages and Disadvantages

Advantages - Low capital costs, little maintenance required, simple in design, low energy requirement.

Disadvantages - Poor dewatering efficiency for alum sludge, large land requirements, dependent upon climatic conditions for drying, little operational flexibility.

b. Vacuum Filtration

Vacuum filtration has been used for many years for dewatering sewage sludges. Recently, vacuum filtration has found successful application for dewatering calcium carbonate sludges produced in water softening. Precoat vacuum filters have been used to dewater alum and iron hydroxide sludges. While most of the vacuum filter installations have been of the drum or rotary type in at least one installation a horizontal-belt type vacuum filter is being used.

i. Operational and design features

Figure VII-7 illustrates the basic components of a rotary vacuum filter. The units are a vacuum pump, a filtrate pump, a filtrate receiver, a filter drum, and a filter drive. A number of materials have been used as filter media. Washing of the filter cake can be included along with a number of types of discharge devices, dependant upon filter cake characteristics. A power requirement of 3.07 kw/sq m (0.382 hp/sq ft) of filter area has been reported. Operational variables include vacuum level, drum speed (which controls cake forming and drying time), chemical conditioning, and depth of drum submergence.

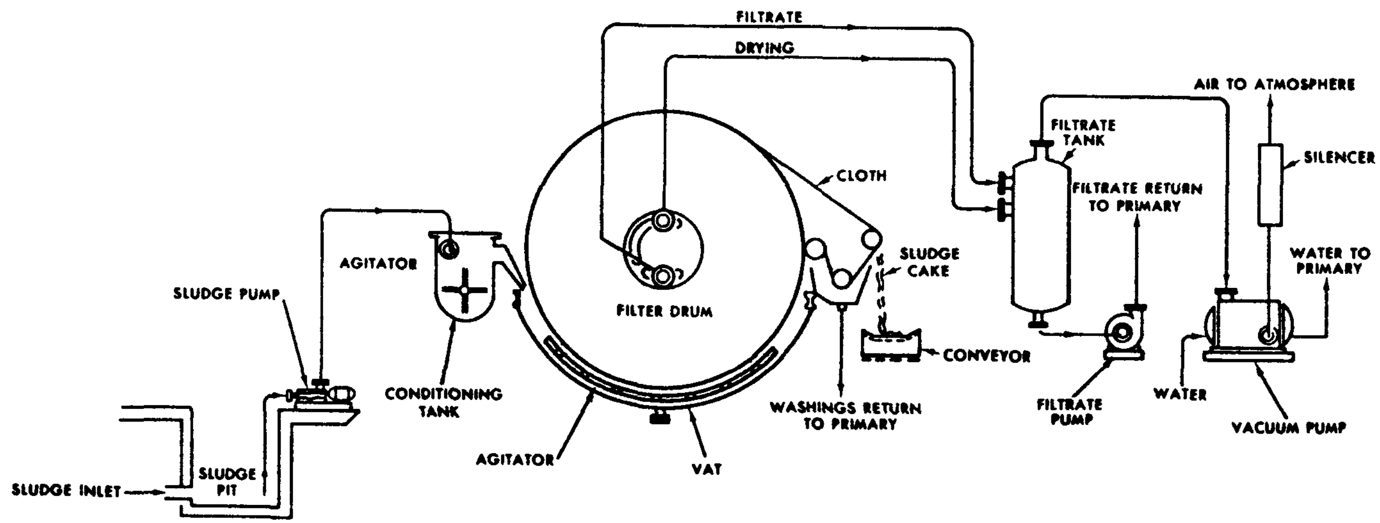

FIGURE VII-7. Rotary vacuum filter system.

The rotary vacuum precoat filter is a modification of a continuous rotary vacuum filter particularly applicable to dewatering metal hydroxide sludges. This type of filter utilizes long filtration cycles (6 to 40 hrs) while eliminating the problem of filter cloth blinding common to continuous rotary vacuum filters. A precoat of filter aid 5 to 10 cm (2 to 4 in) in thickness is applied to the filter by introducing a slurry of filter aid into the filter bowl and applying vacuum to the rotating filter drum. After the precoat is in place and the remaining slurry displaced from the filter bowl, the sludge is introduced into the bowl and the filter cycle is started. The precoated drum is submerged in the sludge from 30% to 50% and is continuously rotated at speeds of one revolution per minute or slower with continuous vacuum applied to the cake. The liquid from the sludge is drawn through the permeable precoat, through the septum and vacuum lines, and into the filtrate receiver. Due to the nature of the filter aid, the sludge solids are entrapped on the surface and in the cake. As filtration proceeds, a precision-mounted sharpened knife is advanced against the cake to shave off the deposited solids (and a very thin layer of precoat) to expose a clean, permeable surface of filter aid to the sludge to be filtered during the next submergence. The knife is continuously advanced at a fixed (but adjustable) rate of a fraction of a millimeter per drum revolution to within about 1 cm (3/8 in) of the filter septum. Thus, in a single revolution of the drum, sludge solids, are deposited, dewatered and removed.

Sludge thickening is usually provided in both a precoat and rotary vacuum filter application. The thickener is usually designed to provide a thickened feed material, equalize sludge flow, and provide sludge storage to allow flexibility in filter operation. A precoat filter is generally operated continuously. However, a non-precoat filter is often designed to operate only eight hours per day, five days a week.

ii. Application to subcategory

(a) Category I

Precoat vacuum filtration has been studied on a demonstration scale for the treatment of an alum sludge. Filtration rates are generally reported in terms of liters per square meter per minute (gallons per square foot per minute). Typical rates for an alum or iron sludge are 122 - 245 l/sq m/min (3 - 6 gal/sq ft/min) which would correspond to a solids loading rate of 1.27 to 2.54 kg/sq m/hr (0.26 to 0.52 lb/sq ft/hr). Excellent filtrate quality has been reported, generally less than 10 mg/l of suspended solids. Precoat material weight can equal or exceed the total kilograms of dry sludge dewatered, and add to disposal cost. Filter cake solids range from 20% to 30%, which also increases ultimate disposal costs because of the quantity of sludge to be disposed of.

In one study a vacuum filter was used without precoat to dewater an alum sludge. Very low cake solids (less than 15%) were reported. In most instances the sticky metal hydroxide sludges have been found to "blind" the filter cloth when the precoat mode was not used.

Precoat vacuum filters are often used in industry to dewater metal hydroxide sludges.

Advantages and Disadvantages

Advantages	-	Low land requirement, low operational requirement, particularly for precoat filter, very high quality filtrate.
Disadvantages	-	High capital cost, requires 24-hour operation for precoat, precoat increases ultimate disposal costs, low cake solids, high power costs, in excess of 82 kw per metric ton (100 hp per ton) dewatered reported.

(b) Category II & III

Vacuum filtration has found greatest application in dewatering softening sludges as indicated by the fact that all but one of the operating vacuum filters identified are for this category. When vacuum filtration is used to dewater $CaCO_3$ sludge, filtration rates of 196 to 293 kg/sq m/hr (40 to 60 lbs/sq ft/hr) have been achieved with the filter cakes containing as much as 80% solids. As the magnesium hydroxide fraction of the sludge increases, the filtrate rate and solids content of the cake decrease. Filter feeds typically contain 25% to 35% solids.

When vacuum filtration is used to dewater a softening-coagulation sludge, filtration rates in the range of 24 - 98 kg/sq m/hr (5 - 20 lbs/sq ft/hr) have been achieved with the lower rates occurring with sludges containing low proportions of calcium carbonate and high portions of coagulation sludge. Cake solids in excess of 60% have been reported. Vacuum filter installations typically operate less than 8 hours per day with no dewatered sludge storage provided. The filters are usually designed to discharge directly into a truck.

Filtrate quality for the above applications is in the range of 100 to 1000 mg/l suspended solids. This is largely dependent upon belt material and sludge characteristics.

iii. Summary

Advantages - Minimal land requirements, excellent cake characteristics, minimal operator attention, low power requirements, less than 0.82 kw/metric ton (1 hp/ton) solids $CaCO_3$ sludge.

Disadvantages - High capital cost, filtrate quality requires recycle or treatment

c. Filter press

The filter press, having been first introduced in the early part of the century, is not a new device, but it received relatively little attention in the water-supply industry in this country until the 1960s. A filter press is a semi-continuous batch device for mechanically dewatering sludges. It is made up of the following basic components, or sub-systems:

1) A frame
2) A limited number of filter plates
3) A sludge feed system
4) A pressure system
5) A power source, and
6) A control system

The frame is usually an overhead or a side-bar frame. It is a rigid structure to insure proper alignment of filter plates for pressing.

The filter plates are usually constructed of forged steel or cast iron with an epoxy-resin coating, or a molded rubber coating, however, some wooden filter plates are used. End plates are permanently affixed to the frame, one end of which is stationary. The frames are circular or rectangular with a raised outer ring. When two adjacent plates are brought together they form chambers of fixed capacity. The surfaces of the plates have means of holding the filter media from the plate surface to allow formation of hydraulic flow channels through which the filtrate may pass. The filter medium is a fabric material and either has a caulked attachment to the plates or is draped over the plates. The filter medium is designed to retain solids and may or may not be pre-coated with a hydraulically applied porous medium. The filtrate passes into and out of the flow channels through ports located at diagonal corners on the rectangular plates and at the tops and bottoms of the circular plates.

The sludge is usually fed into the filter press by a pump although air injectors have been utilized. The capacity and control of the feed system are critical to good operation and under some conditions may require an equalization system. An equalization system usually is an injector type which aids the pump in feeding the sludge to the press at the beginning of the cycle when high feed rates are required. As the filter cycle continues, the need for the high rates of feed is no longer required and the primary means of sludge feeding is utilized by itself.

The primary difference between the two main filter press systems centers around their internal operating pressure. One system operates at about 16.3 atm abs (225 lbs/sq in) and the other system operates at a pressure of 7.8 atm abs (100 lbs/sq in).

A power source is required to produce air for the filtering operations and also to provide power for the ancillary pieces of equipment involved in filter pressing operations. This power requirement varies considerably, but a minimum figure of 33 to 66 kwh/metric ton (30 to 60 kwh/ton) of dry solids produced is often quoted.

The filter press is operated from an electrical panel. The degree of sophistication of control varies with different applications. Manual, remote, semi-automatic or automatic control of filter presses can be obtained.

i. Design and operational features

The sludge to be dewatered is usually a settled precipitate or floc slurry. Such slurries vary in composition, ranging from less than 1% solids by weight to 15%. Very dilute sludges require thickening. The thickeners most commonly used are gravity thickeners although mechanical devices have been used. Thickened sludge then passes to the conditioning tanks. Sludge is conditioned primarily by chemical means, although some physical agents have been used. The purpose of conditioning is to alter the properties of the sludge so water can be removed more readily.

Conditioned sludge is fed to the press at a very high rate initially. The sludge enters the chambers through a central feed system and is driven to the circumferential zone of the chamber by the applied pressure. As the cake builds, the feed rate slows and the pressure builds. Once a predetermined pressure is reached, the cycle is complete and the sludge remaining in the central feed zone is returned to the conditioning tank.

Once the press is opened, the plates are separated one at a time, by mechanical means, to allow the cake to fall free. The cake usually drops out quickly as the plates are separated. Cakes range in weight from 14 kg (30 lbs) to more than 91 kg (200 lb) depending upon the size of the press. The cake may be dropped directly into a truck or to a conveyor system which transports it to a truck or to an incinerator. In one proprosed system, the fly ash from the incinerator is re-circulated within the system and is used as a physical conditioning agent for the sludge.

System variations most commonly encountered are:

1) Application of a pre-coat material to the filter media prior to feeding the conditioned sludge to the press.

2) Backwashing the filter media with an acid solution after completion of the filter cycle.

3) Internal operational pressure of 16.3 atm abs (225 lbs/sq in) (high pressure) as opposed to internal operating pressures of 7.8 atm abs (100 lbs/sq in) (low pressure). Both pressures refer to end-of-cycle pressures.

Generally, it can be stated that systems operating at the higher internal pressures precoat prior to filtering to prevent cloth blinding, whereas systems operating at lower pressures do not precoat but backwash with an acid solution after each cycle. Figures VII-8 and VII-9 illustrate operating features of a filter press.

ii. Operating personnel

At least one operator per shift is required per press regardless of size. Many of the equipment manufacturers advocate a much smaller manning requirement. However, of the installations reviewed to date, the number of personnel per filter is approximately five per shift. Actual requirements are dictated by the level of skill of the personnel, the local union regulations, the degree of automation, and the method of handling chemicals.

Major contributors to manpower requirements are:

1) Maintenance
2) Chemical handling equipment
3) Size of operation.

iii. Building requirements

The total weight of a filter press ranges from 9 to 63.5 metric tons (10 to 70 tons), which necessitates adequate building and structural engineering.

The minimum space requirements are approximately 7.6 m x 12.2 m x 9.1 m high (25 ft x 40 ft x 30 ft high), for a single press with storage tanks on the outside of the buildings. The addition of a second press would increase the minimum building dimensions 1.5 m to 4.6 (5 to 15 ft) in the desired direction.

iv. Chemical/physical conditioners

Chemical conditioning agents:

Metallic salts	-	Alum, or iron salts
Polyelectrolytes	-	High-molecular-weight organic polymers
pH	-	Lime

Physical conditioning agents are primarily filter aids, but physical conditioning may also include ultrasonic vibration, heat, freezing, solvent extraction, or electrodialysis.

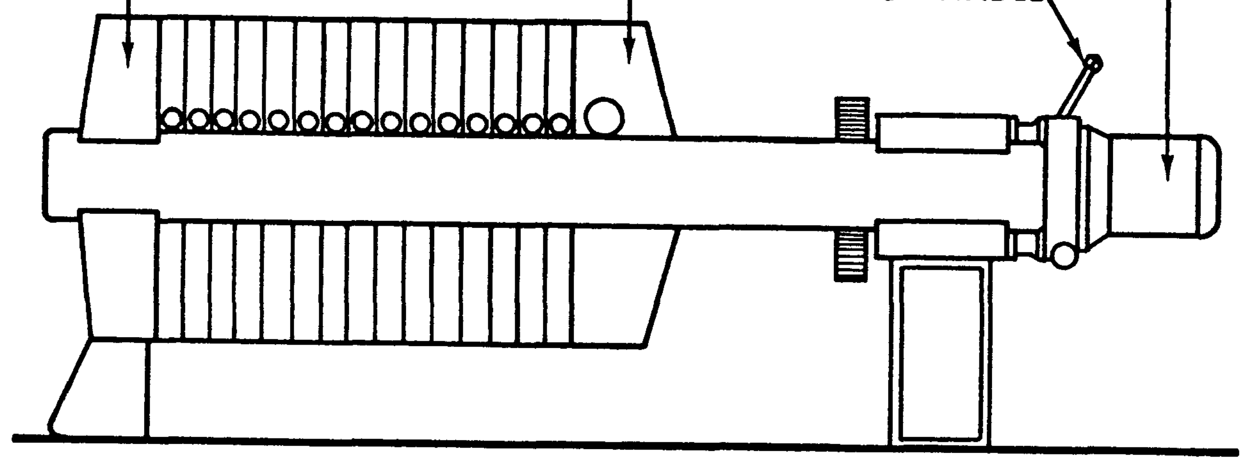

FIGURE VII-8. Side view of a filter press.

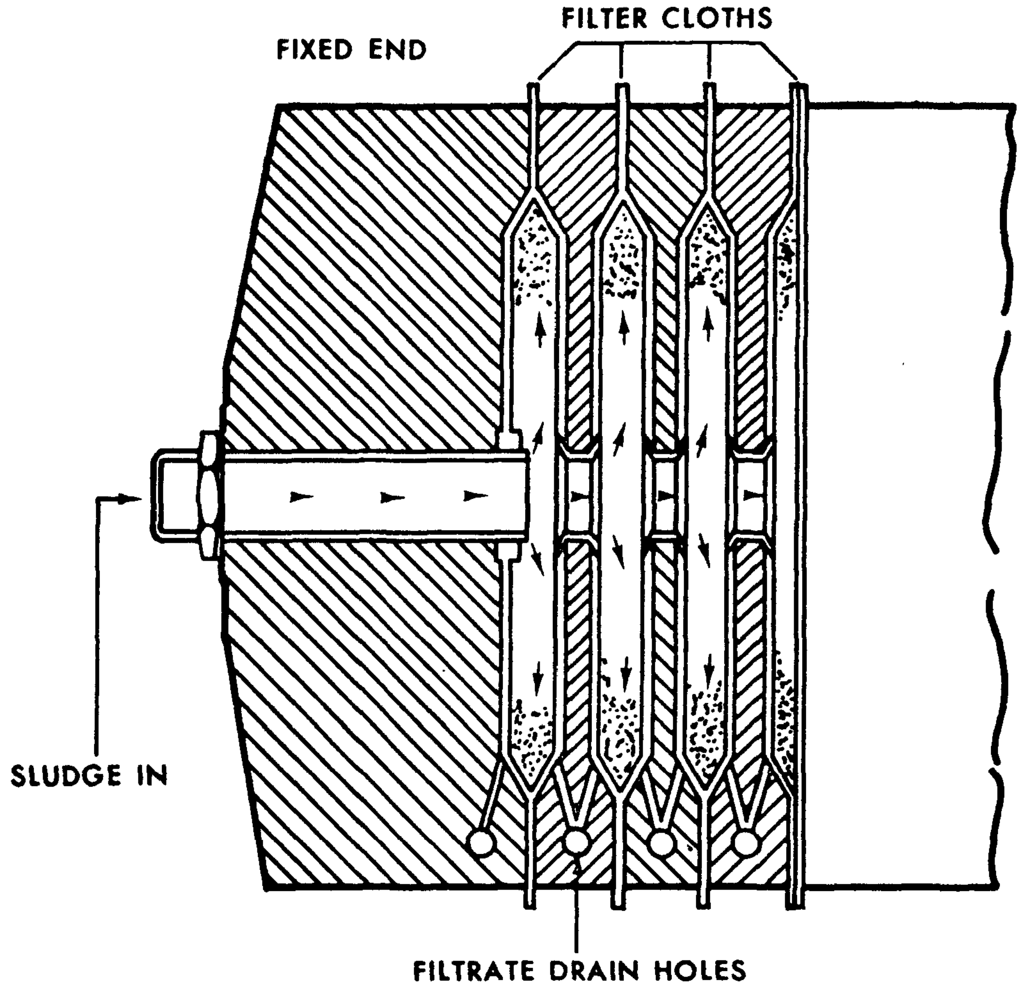

FIGURE VII-9. Cutaway view of a filter press.

v. Precoat materials

Some of the materials used and tested as precoat materials are:

- Fly ash
- Diatomaceous earth
- Marble dust
- Solka Floc
- Peat
- Ground slag
- Coal dust
- Clay
- Cement kiln dust
- Coke breeze
- Talc
- Perlite

vi. Application to subcategories

Presently there are only two operational systems in the country dewatering water-treatment wastes by filter pressing. Both of these are dewatering an alum sludge. However, there are approximately twelve additional systems under construction or in the design phase. Therefore, remarks directed toward this technology are for a large part necessarily drawn from:

1) pilot plant studies,
2) information drawn from application of this technology to other industrial wastes,
3) engineering.

(a) Category I

Alum coagulation sludges are presently being successfully dewatered by filter pressing operations at two solids handling facilities in the southeast. One installation has no thickening facilities, while the other does. Comparing the operations of the two installations over similar operating periods shows no immediately obvious advantages of thickening. The installation without thickeners requires a relatively small increase in conditioning chemicals, primarily attributable to the lower feed solids, operates at the same cycle time as the other installation, and yet produces a drier cake.

There are no iron-removal plants in this subcategory employing this technology and none is currently under design. Generally, iron-removal plants that produce a solid waste use groundwater as a raw water source and the waste would be a metal hydroxide sludge without silt or other large particulates. Such sludges exhibit poor dewatering characteristics. The technology has been successfully applied to a similar waste ($Fe(OH)_3$) in the steel industry. These wastes generally require slightly higher lime dosages and precoat of the filter medium.

(b) Category II

There are no installations utilizing a filter press to dewater lime softening sludge, but a plant presently under construction should be operational in early 1975. A marked difference between the technology as applied to this subcategory compared to other subcategories is that there appears to be no need for conditioning the lime sludge. When filter presses were used in tests to dewater lime sludge without conditioning the sludge solids in the filter cake were in the 40% to 50% range. Limited data also indicated that the filtrate had a high suspended-solids concentration.

Studies done on water-treatment plant sludges, not specifically related to filter pressing operations, have shown that a high magnesium content in the sludge adversely affects the settlability of the solids.

(c) Category III

There are no plants in this subcategory applying this technology and currently none under design. Some preliminary work that has been done on water-treatment plant sludges in general suggests that filter performance will be better as the ratio of softening sludge to coagulant sludge increases.

vii. Summary

Advantages - Long, useful life, low cake moisture, high overload capacity, good filtrate quality, low land requirement.

Disadvantages - High capital cost, restrictive structural and building requirements, moderate maintenance requirements, moderate energy requirements, relatively high labor requirements.

viii. Effluent quality

Cake solids % (by weight)	40 -60
Filtrate suspended solids (mg/l)	<100
Filtrate pH	>10.5

d. Sand Drying Beds

The proven treatment of waste sludges from municipal wastewater treatment plants by sand drying beds suggests utilization of similar techniques in the dewatering of water-treatment plant sludges. With a few notable exceptions, this technology is predominately applied in the southern and western sectors of the United States and generally to small, rural water-treatment plants.

i. Operational and design features

Sand drying beds are constructed similar to a sand filter but with less sand depth. Working down from the top one would encounter from a few centimeters to about 60 centimeters of sand over a layer of gravel that is usually 8 cm to 30 cm (3 in to 12 in) deep. Gradation in the size of the gravel varies according to the designer. If size gradation is not used, the sand and gravel layers are usually separated with a cloth fabric, such as burlap. The beds may or may not be provided with an underdrain system. If underdrains are not provided, the bed is constructed over a permeable soil. A variation not in use in this country, but reported in operation in England, is the wedgewire bottom. This drying bed floods the under chamber during the early days after application to retard draining. This slow draining period is reported to increase the ultimate cake solids concentration.

The mechanisms involved in this dewatering process are:

1) Draining
2) Decanting
3) Drying.

Most of the moisture is removed from the sludge by draining, however, this mechanism alone is not sufficient to produce a handleable cake. Drying is essentially accomplished through evaporation.

The use of drying beds is affected by many factors, which can be broadly grouped into the following:

1) Sludge characteristics
2) Climatic conditions
3) Depth of application of the sludge
4) Composition of the drying beds

ii. Sludge characteristics

Initial moisture content and nature of the sludge are the most important determining factors for design of drying beds. Initial moisture content is the percent solids by weight in the sludge at time of application. The nature of the sludge is characterized by its amorphous quality, compressibility, and resistance to filtration (specific resistance).

iii. Climatic conditions

The effectiveness of air drying is most closely associated with evaporation rate, but is also determined by precipitation, sunshine, air temperature, relative humidity, and wind.

iv. Depth of application

The depth of application is the depth of sludge at the end of the period of the initial rapid dewatering (decanting or draining or both). Generally, less than two hours is required for this initial dewatering.

The principal problems encountered in sand drying operations have been:

1) penetration of the sludge into the sand, thus plugging the bed, and
2) insufficient drying to produce a handleable cake.

Both conditions can be alleviated somewhat by conditioning the sludge.

v. Application of technology to subcategory

(a) Category I

Sludge drying beds similar to those described in preceding paragraphs have been used successfully to dewater alum sludges. At present there are several drying beds being designed, and constructed. The design criteria used and the surface area required vary, dependent on the previously mentioned conditions, and especially the depth of application. One investigation has shown that the drying time increases at applications greater than about 0.3 m (1 ft) by a factor of three, when the depth is doubled and factors of six and nine when the depths are trebled and quadrupled. In some successful drying operations the sludge has been applied at depths up to 0.6 m (2 ft). For one proposed drying operation, it is suggested that the sludge be applied from sprayers to depths of less than 2.5 cm (1 in). The pitfalls of using loadings expressed in kg/sq m (lb/sq ft) without considering drying cycle time are recorded in the history of successful operations.

The use of conditioning agents has been shown to enhance dewatering. The use of polymers at a large plant in the northeast is claimed to be "the prime factor" in successfully dewatering their sludge. In plants where large amounts of powdered activated carbon are used, the need for conditioning is reduced or eliminated because the carbon acts as a physical conditioning agent.

Air drying is often utilized in conjunction with bed drying. In these instances, the sludge cake is removed from the beds just as soon as it is handleable (at about 20% solids and spread on soil for further drying).

The range of loadings at successful drying bed installations are from 0.5 to 12.2 kg/day/sq m (0.1 to 2.5 lbs/day/sq ft).

Little is reported in the literature concerning disposal of iron hydroxide sludges on drying beds. There are two cases where this technology is utilized for a sludge that is predominantly iron hydroxide. A similar waste is generated by metal plating operations and these sludges have been successfully dewatered on drying beds.

One water-treatment plant under construction has been designed to provide a two-cell slow-sand filter for dewatering sludge. The proposed loading rate is 400 l/day/sq m (10 gal/day/sq ft). Based on existing installations and information gained from other industrial designs, considerations for iron sludges should closely parallel those for alum sludges.

(b). Category II

Sand bed drying of sludge has not seen extensive application in subcategory II. Calcium carbonate sludges are so much easier to dewater than metal hydroxide sludges that drying beds are usually not needed. The importance of application depth is lessened and for lime sludges the depth of application is not as important as for wastes from plants in Category I. Lime softening plants, therefore, decrease their surface area requirements by increasing the depth of application. Thus, a drying bed becomes a lagoon in essence. There is only one known installation using drying beds for a lime softening sludge.

(c) Category III

The comments made for Category II apply also to Category III. As the $CaCO_3$ percentage in the mixed sludge increases, the sludge becomes easier to dewater.

vi. Summary

(a) Advantages of drying beds

Low labor requirements (routine)
Low maintenance requirements (routine)
Low power requirements
Low capital expenditure
Unlimited useful life
Mechanically independent
No skilled operators needed

(b) Disadvantages of drying beds

High land-area requirements
High labor requirements periodically
Subject to climatic perturbations
Low overload capacities
May require extensive and costly pretreatment (conditioning, thickening, etc)

(c) Effluent quality

Cake solids % (by weight)	20 to 60
Filtrate suspended solids (mg/l)	200 - 600

e. Disposal to sanitary sewer

The disposal of water-treatment plant wastes into sanitary sewer systems has been practiced at a number of cities for some time. The effect of this discharge on the performance of the waste treatment plant is largely a function of the type of sludge, the method of discharge, the waste treatment process, the waste treatment physical facilities (particularly sludge digestion and dewatering), as well as the adequacy of the collection system. In the past, water plant wastes have generally been discharged to the sanitary sewer at little or no cost to the water utility. However, recent Environmental Protection Agency regulations require that waste treatment utilities which receive grants adopt equitable "user" charges for all industrial discharges. These charges are generally based on hydraulic flow, pounds of BOD, and pounds of suspended solids. The user charge is developed so that the total annual cost for treatment is prorated for each of these constituents in order that an industrial discharger pays an equitable share of the treatment cost. In a number of cities contract negotiations are in progress to reflect these new costs for accepting water plant wastes.

i. Application to subcategories

(a) Category I

Alum sludges have been shown to have some beneficial effects on sewage treatment. Increased removal of solids, BOD, COD, and phosphorous have been found in primary sedimentation after alum sludges have been admitted to the control waste-treatment system. Alum sludges amounting to as much as 50% of the total solids inflow to a waste-treatment plant have reportedly caused no severe difficulty, but some increase in fuel requirements for sludge incineration has been reported due to an increase in the inert fraction and water content. An Environmental Protection Agency-sponsored demonstration project is now underway in California to monitor the effects of alum sludges on an activated sludge treatment plant.

The results of a recently completed study made in Tampa, Florida, indicated that the maximum dosage of water plant sludge in the inflow to the activated sludge plant should not exceed 40 mg/l. Greater dosages caused problems attributable to reduced sludge densities.

At one plant that was visited alum sludge was discharged at a rate of 90.7 metric tons (100 tons) in a 24-hour period to a 946,250 cu m/day (250 MGD) sewage treatment plant. Continuous sludge collection at the water plant was not provided, thus the basins were cleaned at six month intervals. It was reported that no severe problems were experienced at the sewage treatment plant as a result of this practice.

A number of iron-removal water plants discharge their waste to a sanitary system. The effects are similar to the discharge of alum sludges. As these sludges are essentially metal hydroxides with less inert material than most alum sludges, they might be expected to have a more detrimental effect on dewatering than alum sludges, but no detrimental effects were noted.

At one city, a sewer ordinance limited the acceptable iron concentration thus requiring the water-treatment plant to change from ferric sulfate to alum as a primary coagulant. It is possible that some ordinances limit the amount of aluminum acceptable for discharge to sanitary sewers.

Discharge to a sanitary system provides a means for regionalization of sludge treatment and, possibly, a means of lowering the cost of dewatering because of the economies associated with larger sized plants. This is particularly important for small water-treatment plants at which costs of waste treatment could be excessive. It could also have the effect of diminishing monitoring and reporting requirements by the water utility.

(b) <u>Category II & III</u>

Sludges from softening plants have caused problems in plugging of the sewer system, overloading of digestors, and damaging primary sludge collection mechanisms because of excessive torque needed to collect sludge. These problems have been encountered primarily because of the rapid settling characteristics and the large quantities of sludge to be disposed of. Calcium carbonate sludges thicken and dewater well, and it would appear that discharge to the sanitary sewer would be practical only where on-site treatment is restricted by land requirements. The addition of calcium carbonate sludge, which has excellent dewatering characteristics does not materially affect the dewatering properties of the sewage sludge. For this reason it may be considerably more expensive to dewater the combined sludge. An exception may be when chemical-physical waste treatment plants are utilized and the primary clarifier may have been designed for dense sludges. Where lime recovery is practiced, the water plant sludges will provide additional calcium values.

ii. Ion-exchange softening

The disposal of brine wastes into the sanitary sewer systems would generally add only additional hydraulic load to the plant. Normally, the brine wastes are discharged using an equalization system to insure dilution and prevent "slug" loading of the waste treatment plant. The sewage plant serves primarily as a means of further dilution and discharge to the receiving water. There were no systems identified that had set a limit on dissolved solids for discharge to the sanitary sewer. However, increased ionic strength could adversely affect the operation of sewage treatment plants.

iii. Summary

In a number of cases the water and sewer departments are managed under one authority and accurate cost accounting is not undertaken. It would appear that a reasonable cost for solids dewatering at a sewage treatment plant is in excess of $55/dry metric ton solids ($50/dry ton solids).

Advantages - No land area requirements, limited capital expenditure required, no Federal or State permit requirements, dewatering costs could be lower due to economy of scale, ability to handle wider fluctuation in water plant solids, hauling costs for ultimate disposal can be reduced because of economies of scale, Federal and State monitoring requirements would be eliminated.

Disadvantages - Waste sludge may not be compatible with the sewage-treatment-plant process, particularly where primary treatment is not required, wastewater plants will require additional handling facilities, and possibly additional digestor capacity, additional fuel requirements for sludge incineration due to increased water content and inerts, existing ordinances may prohibit discharge.

f. Centrifuge

Centrifuges are continuous, mechanical dewatering devices. Centrifugal force is used to increase the sedimentation rate of the solid materials in the sludge. The basic components of the centrifuge dewatering operation are:

1) Housing and frame
2) Rotating bowl
3) Conveyor
4) Sludge feed system
5) Power source

The housing provides the structural integrity of the unit and shields the high-speed moving parts. The frame provides rigidity needed for the high speed moving parts, and a means to firmly secure the centrifuge to an appropriate base.

The rotating bowl is spun at high revolutions to impart high forces on the solids and speed settling. The bowl also contains the sludge during dewatering.

The conveyor moves the settled solids along the bottom of the bowl to the discharge point.

The sludge feed system must be able to deliver sludge solids ranging from 3% to 30% at feed rates anywhere from 1.3 to 15.8 l/sec (20 to 250 gpm).

The power source is required to drive the motor providing rotational motion to the bowl and the ancillary equipment.

i. Types of centrifuges

Basically the types of centrifuges can be broadly broken down into two groupings: horizontal and vertical shaft units as shown in Figure VII-10 and VII-11.

(a) Horizontal shaft units

Waste sludges are delivered to the centrifuge by a stationary supply pipe, which passes through the conveyor hub discharg-

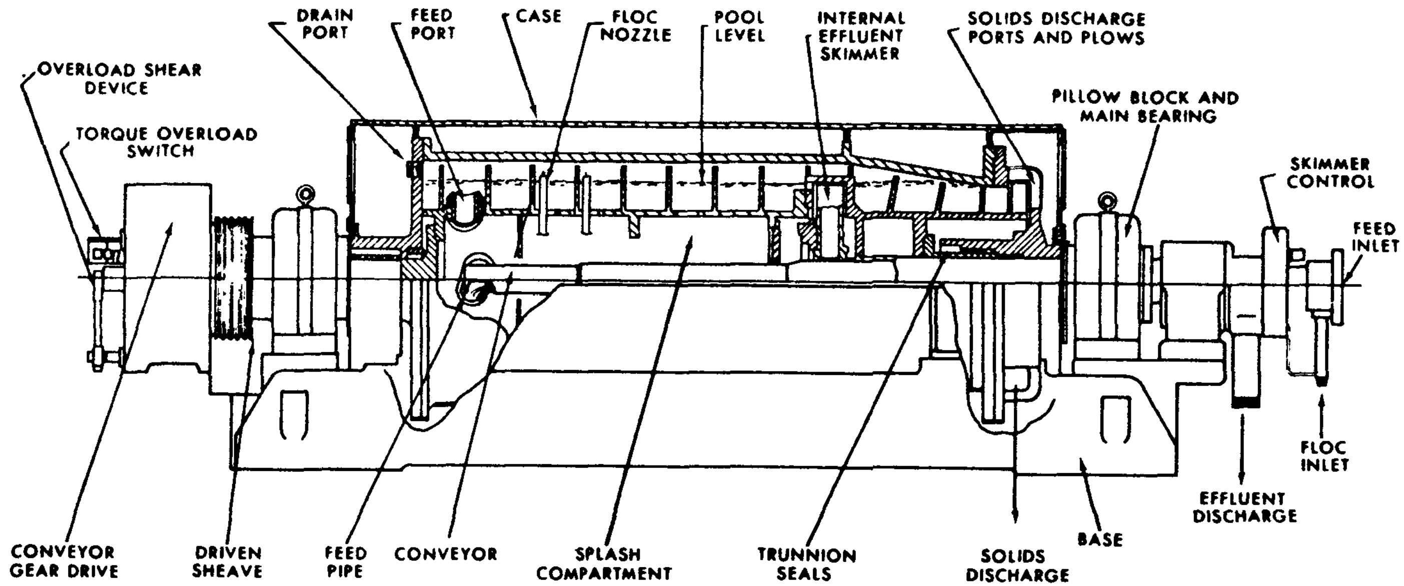

FIGURE VII-10 Cross section of concurrent flow solid-bowl centrifuge.

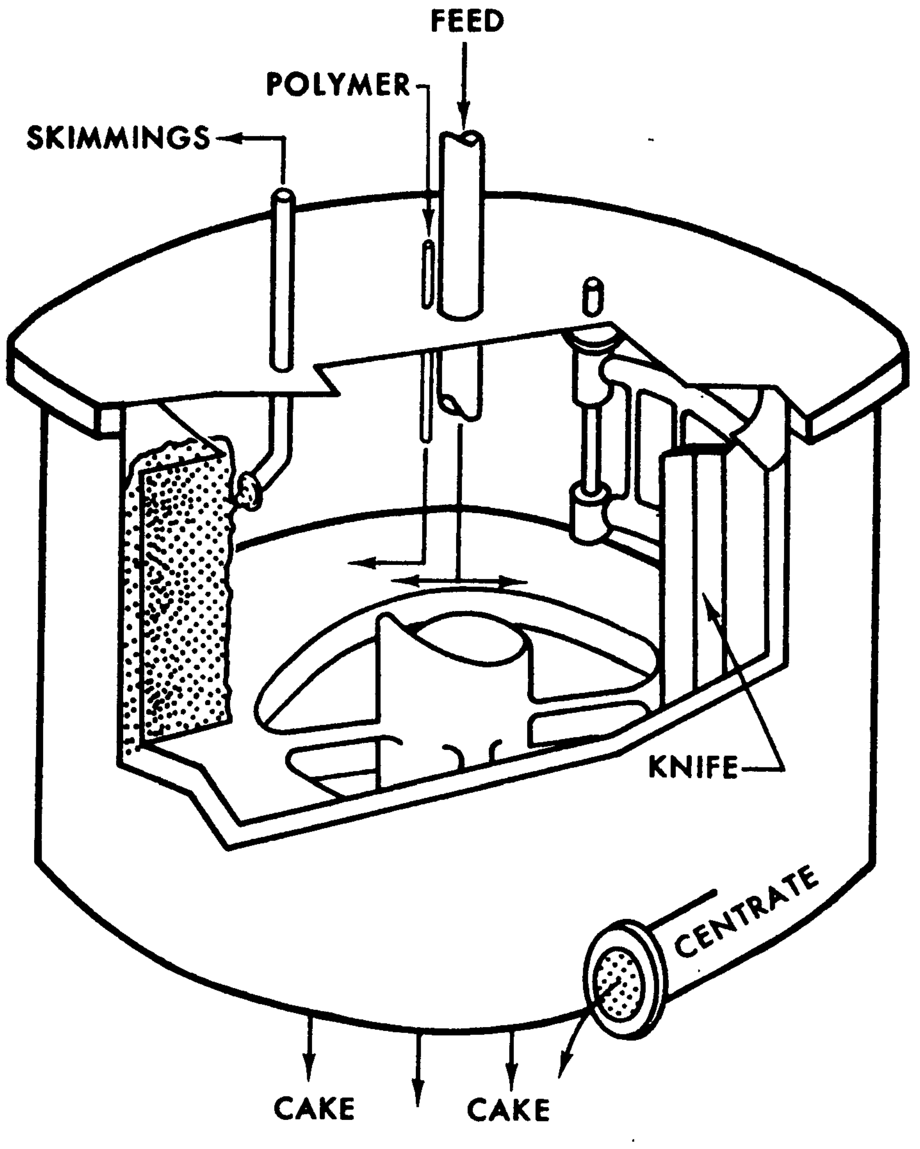

FIGURE VII-11 Schematic diagram of a basket centrifuge.

ing the sludge into the bowl. The rotating bowl imparts a centrifugal force greater than 1000 times the force of gravity, which drives those consitutents with the greatest densities to the circumferential zone of the centrifuge. From this zone the solids are picked up by the conveyor, which is usually a helical screw (scroll), and continuously moved to the discharge. The bowl has a conical shape at the end where the solids are discharged. This reduced diameter section enables the conveyor to move the solids out of the liquid pool for discharge. The bowl is also provided with effluent weirs, which are usually opposite the solids discharge, which pool the sludge. Both the conveyor and the bowl rotate, but the rotation of the conveyor is slightly slower than that of the bowl. The pool depth (pond) is determined by the weirs. The continuous feed forces the clarified liquid (centrate) over the weirs to the discharge. Because centrifugation classifies particles primarily by specific gravity, the separation is generally not clear cut and the resulting centrate is usually high is suspended solids.

Horizontal centrifuges were the earlier units used and are by far the most popular. They are quite often identified as scroll centrifuges receiving their name from the helical screw conveyor. There are two variations among the horizontal units, they are:

1) Countercurrent flow
2) Concurrent flow

<u>Countercurrent flow</u>

These units are of the type initially described where the cake is discharged at the opposite end of the bowl (conical end) from the centrate. This type of centrifuge has the obvious problem of disturbing the settled solids by the opposing direction of movement between the liquid and solids.

<u>Concurrent flow</u>

These units are fed through the conveyor hub in a manner similar to that just described for the countercurrent units with the feed entering the bowl at the cylindrical end. The solids are forced to the outside to form an annular ring, with the solids on the periphery and the liquids near the center. The ring is advanced towards the conical end hydraulically and by the conveyor. The liquid moves with the solids until it reaches the beginning of the conical section where it encounters the effluent weirs. It passes over the weirs and is discharged. The conveyor moves the solids up the conical section to the discharge port.

(b) Vertical shaft units

These units are a relatively new development. They are quite often identified as basket centrifuges. Basket centrifuges are semi-continuous, batch devices. However, for units producing a pumpable cake, an option does exist to introduce a skimmer for continuous operation. Two types of baskets exist:

1) Solid (imperforate)
2) Porous filter (perforate)

In the operation of basket centrifuges, the sludge enters from a stationary, directional feed pipe, which directs the influent sludge towards the walls of the basket. The sludge is discharged from the feed pipe at the bottom of the rotating basket. Centrifugal force concentrates the solids on the basket wall. The top of the basket has a lip (weir) over which the liquid is decanted. When the solids reach a specified level, the feed sludge is stopped, and a knife rotating counter to the basket's direction scrapes the solids from the wall and pushes them through the open bottom of the basket.

The two types of basket centrifuges work identically except for the passage of centrate through the basket wall in the perforate type.

ii. Treatment technology applied to subcategories

(a) Category I

A review of sludge disposal practices in the mid-1960's indicated there were no installations successfully dewatering alum sludges by centrifugation. Several installations have been built for centrifugation of alum sludges but none have proven successful. Several recent pilot-plant studies indicate successful operations are possible. These recent successes are believed attributable primarily to conditioning of the sludges with polyelectrolytes, usually introduced to the sludge within the centrifuge.

A large water-treatment plant on the west coast has designed and constructed a centrifugation installation which should go on line in early 1975. A cake containing 16% solids is anticipated from the centrifuges. It will be trucked to a sanitary landfill for disposal. The centrate will be used to augment low stream flows in the vicinity, when of sufficient quality, or returned to the reclamation clarifier. Another plant in the northeast has a similar installation under design.

(b) <u>Category II</u>

The application of centrifuges in this subcategory is widespread. Centrifuges are used exclusively in all dewatering of calcium carbonate sludges in municipal water-treatment plants prior to recalcining. These applications, shown in Table VII-1, are all solid bowl units. One installation utilizes a basket centrifuge that is in series with a solid bowl unit. When the solid bowl unit is overload, the overload is treated by the basket centrifuge.

(c) <u>Category III</u>

One installation in this subcategory now uses centrifugation for dewatering sludges. This plant has four centrifuges, which were installed primarily for the purposes of dewatering a calcium carbonate sludge. However, the alum sedimentation basins at the filtration plant are cleaned semi-annually and the sludge is dewatered in the centrifuges. It should be noted that there is an appreciable carryover of suspended solids from the softening plant. It is believed this carryover assists in the dewatering. Normally, dewatering is a two-step operation with the first pass being a very coarse cut and yielding a low quality centrate. This initial centrate is stored and the following day rerun with the addition of polymers. The cake is sent to a landfill and the centrate is either discharged to the sewage system or recycled within the plant. The cake solids from the second cut range from 45 to 50%. At this point the centrifuge cake resembles a paste. Watertight bulk storage and trucks are required to handle this material. It appears that the consistency of the cake deteriorates somewhat as the result of the use of a ribbon screw to convey the cake from the centrifuge discharge to the storage hopper.

Table VII-1

Summary of Identified and Visited
Sludge Treatment Processes

Method of Sludge Handling	No. of existing plants use this method	No. of existing plants that use this method & were visited	No. of plants that have this method under construction
Discharge to a sanitary sewer	37	15	1
Recycle of filter backwash water	46	29	6
Drying beds	21	6	1
Lagoons	109	66	9
Filter presses	2	2	4
Centrifuges	13	1	4
Vacuum filters	7	3	
Belt presses			1
Chemical recovery	8*		
Spray Irrigation & Dust Control	3		
Reuse	3		

*All of these are recalcining plants

iii. Summary

Advantages	-	High degree of flexibility, low area requirements, low routine maintenance, no skilled operators needed, low building requirements, low initial costs for a mechanical device.
Disadvantages	-	Low to moderate equipment life, high power requirements, may require extensive and costly pre-treatment (conditioning, thickening, etc.), high labor requirements periodically, does not produce a solid cake, low centrate quality.

iv. Effluent quality

Cake solids % (by weight)	15 - 65
Centrate suspended solids (mg/l)	500 - 300,000+

g. Miscellaneous treatment technologies

This section includes some treatment technologies that have shown promise or have been proposed for use in the treatment of water plant wastes. Also included are several methods that are not treatments per se, but are disposal techniques.

i. Freezing

Freezing has often been proposed as a method for treating coagulation sludges. It is not, in fact, a treatment but is actually a conditioning process. Freezing can occur by natural or mechanical means. Several freezing operations of each type are reportedly operating successfully in Europe. All of the work done to date in this country has been pilot scale. Several investigators have reported the effect of natural freezing on lagooning of alum sludges. These lagoons were not designed specifically to take advantage of natural freezing as discussed briefly under lagoon treatment. However, a dewatering installation being designed will incorporate natural freezing to assist sand drying operations. Results show that the solid fraction will naturally settle to 15 to 20% solids by weight after freezing, and the clarified supernatant will have less than 100 mg/l of total suspended solids.

The principal reasons for not using mechanical freezing have been:

1) High capital costs
2) High initial operating costs*
3) Low mechanical reliability**

ii. Land application

Land application is not a treatment technique, but rather a disposal means. Applications discussed below will be limited to the methods of disposal in which the sludge receives no prior treatment.

iii. Spray irrigation

Early studies showed that the application of alum coagulation sludges to the soil plugged the surface, prevented further passage of water, and killed vegetation. In several cases sludge has been sprayed from a tank-truck on vegetation beside the road for up to one year, and no detrimental effects to the infiltration properties of the soil or to the vegetation were encountered. Rates of application are not known in this case.

Alum sludge spray applications are known to be in use. One is solely for wetting dirt roads within the water shed as a dust-control measure. The second utilizes sprinkler heads, which rotate delivering a rain-type mist over approximately a 0.10 hectare (0.25 acre) area. Application areas are alternated and the quantity of sludge applied varies with the seasons. Generally, the rate of application is 3028 liters per sprinkler head per hour (820 gallons per sprinkler head per hour) limited to no more than six hours during the hotter summer months.

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*A considerable energy input is required for initial cooling cycle.

**Because of stresses attributable to the expansion of the sludge when frozen.

iv. Land reclamation

This method considers the use of the dilute sludges (usually thickened) to improve existing land values, either for aesthetic or for economic reasons. Such methods include disposal to abandoned quarries and mines. In one case, the thickened alum sludge is being used to raise the elevation of the land. Here low dikes are pushed up by earth-moving equipment and the slurry is discharged behind them. The area appears to be dusty, but the local residents do not consider it a nuisance. In one section where it was reported that the sludge has been dumped earlier, sufficient vegetation has sprung up to support the grazing of livestock.

v. Sludge plowing

This method has been tested several places, but apparently has not been carried out routinely. The sludge plow has a large pressurized tank which is mounted over a tractor drawn plow. The sludge is discharged directly into the furrow turned by each plow blade. After several days there is no visible evidence of the sludge, but erosion of the barren soil can be a problem.

vi. Heat drying

Several investigators have suggested heating as a method of destroying the amorphous properties of the coagulation sludges, but they have concluded that the process is uneconomical due to the low fuel value of the sludge. However, a system which utilizes broad-band sonic energy combined with forced draft heat to dry the sludge is proposed for an alum sludge pilot study in early 1975.

vii. Specialty recovery

There have been several studies of the use of water-plant waste in other industrial or agricultural processes. The most widespread use to date has been to use softening sludges for soil conditioners and stabilizers. Coagulation sludges have been used intermittently in building bricks. They have also been used as fillers in fertilizers. Softening wastes have been used as paint pigments. The waste from a spiractor unit has been used for well points to drain foundations during construction and as beach sand. Softening sludges have also been used on occasions to neutralize acidic industrial wastes. One plant in south Florida sells their softening sludges for \$1.65/metric ton (\$1.50/ton) for use as a pH-stabilizer for soil. Calcium carbonate sludges have also been used as stabilizers for ponds and roads.

The establishment of a regional reclamation facility to serve several water-treatment plants has been proposed and offers some promise for recycling and recovery possible regardless of plant size, especially in the case of lime softening plants.

C. Case Studies

1. Case I

Case I is a study of the use of a filter press for a coagulation waste. This plant has a nominal capacity of 132,500 cu m/day (35 MGD). Alum is used to treat a moderately turbid river water.

Waste characteristics

The plant produces two wastes: filter backwash water and sedimentation basin sludge. The approximate composition of the wastes based on information obtained from plant personnel and laboratory analysis of samples collected on August 26 and 27, 1974 are:

Filter backwash water	100 - 600 mg/l TSS
Sedimentation basin sludge	62,000 mg/l TSS

The major contributing elements are:

clays, silts and insoluble organics	94%,
aluminum hydroxide	4%,
activated carbon and inerts in the chemical feed	2%.

Based on the 1973 Annual Report, the plant produces 2755 metric tons (3,037 tons) of dry solids annually.

Waste treatment facilities

The waste treatment facilities include three holding basins with pumping capabilities and two 1.63 m (64 in) high-pressure filter presses with auxiliary equipment.

The filter backwash water is sent to a 1325 cu m (0.35 MG) capacity holding basin from which it is pumped back to the head of the plant.

The sedimentation basin sludge is blowndown "on call" by the filter press operation to a 283 cu m (0.075 MG) holding basin which is provided with a rotating arm and air agitation.

The filter press is precoated with diatomacous earth at approximately 36.5 kg/cycle (80 lbs/cycle). The sludge is conditioned with 6% to 10% by weight hydrated lime before being fed to the press. Cycle times vary from 40 min to about 80 min depending on the solids concentration in the feed sludge. The filtrate is used to wash the filter press prior to precoating, and as a carrier for the precoat material. The excess filtrate is periodically discharged to a sanitary sewer operated by the municipality. The filtrate usually has a pH range from 11 to 12.5 with less than 100 mg/l suspended solids. The filter cake is approximately 45 % solids and is regularly hauled to an approved landfill. Some demand has been generated for the cake as a yard and garden material. The cake has been used on occasions around the plant for fill material and supports a healthy ground cover.

Cost

The entire facility cost $2,807,560 in 1969. The estimated annual operating costs are projected below. The method of retiring the debt is not known, therefore, a reasonable interest rate and expected service life for the equipment were used. Labor, maintenance and chemical costs were taken from the 1973 Annual Report. Power requirements were calculated as follows:

> The connected horsepower for three months in 1974 were averaged and then projected for an annual usage.
> A unit cost of $0.02/kwh was then used to determine this cost, based on the assumption that the power requirements during 1973 were the same as those for the three-month period that was monitored.

Annual Cost

Debt Service (est) ($2,807,560 @ 6% for 30 yrs)	$204,000
Labor and Maintenance	162,457
Power (est) (Connected hp/month x 0.745 x $0.02 x 12)	26,457
Chemicals	17,717
Total annual cost	$410,210

Unit Cost

$/1000 cu m of water produced	($/MG)	$/dry metric ton	($/dry ton)
$8.48	($32.10)	$148.95	($135.10)

Summary

This installation may be considered somewhat atypical as it does not provide a thickener and uses air ejectors rather than pumps to transfer the sludge from the conditioning tank to the press. The capability of this dewatering device has been successfully demonstrated for an alum sludge. Some of the success may be largely attributable to the nature of the sludge, e.g., the high solids to aluminum hydroxide ratio.

2. Case II

Case II, is a 6,056,000 cu m/day (1600 MGD) coagulation plant treating a very low turbidity raw water. This extremely large water-treatment plant was constructed on fill material forming a peninsula in Lake Michigan. Additional land for waste treatment facilities would be extremely expensive [approximately $500,000/hectare ($200,000/acre)], if not impossible to acquire. Therefore, the sludge from the sedimentation basins is sewered.

Waste characteristics

Three primary sources of waste are generated at this plant: filter backwash water, clarifier sludge blowdown, and solids from the raw water mechanical screens.

Filter backwash

Filters are backwashed at this plant utilizing computer control. Filters operate in sets of twelve each. When one filter is indicated to need backwashing, all filters are washed in succession automatically. This backwash cycle requires forty minutes and produces 272,500 cu m (72 MG) of washwater. At present the filter backwash water is disposed of into Lake Michigan.

Clarifier sludge blowdown

Clarifier blowdown consists of a combination of aluminum hydroxide and suspended solids removed from the raw water. This plant represents an unusual case in that the suspended solids during much of the year are primarily due to algae and, therefore, organic in nature. A suspended solids concentration of 0.7% solids is typical with a BOD and COD of 182 and 2,015 respectively. An ammonia concentration of 6 mg/l was reported. The sludge is stored and pumped approximately every five days to the sanitary sewer system. An average of 7570 cu m (2 MG) of waste containing 54.4 metric tons (60 tons) of dry solids are pumped to the sanitary system each time.

Mechanical screen discharge

This material is primarily algae, sticks, small fish, etc. and is returned to Lake Michigan with the filter backwash water. It was reported that as much as 13.61 metric tons (15 tons) per hour of fish have been collected from the screens. It is impossible to characterize or quantify this waste due to its heterogenous nature. This plant reported that future plans may include comminutors with discharge to the sanitary system.

Treatment of waste waters

Plans have been completed and bids taken, for recycling of filter backwash water; however, the project was delayed to secure additional Federal funding, which was not supplied. It is estimated that it will now cost $12 million to construct the recycle system. No firm plans exist for completion of this project.

Local ordinances prohibit the discharge of any waste water to Lake Michigan. For this reason six water-treatment plants, in addition to the plant under discussion, discharge wastes to the regional sanitary system. All industrial dischargers are charged pro rata waste treatment costs. These costs based on the operation of a 3,785,000 cu m/day (1000 MGD) secondary sewage treatment plant are:

> $57.33/dry metric ton of solids ($52.00/dry ton of solids)
> $48.51/metric ton BOD5 ($44.00/ton BOD5)
> $6.61/1000 cu m of flow ($25.00/MG of flow)

The capital cost of the pumping and force system to the collection systems was $600,000. Detailed sludge analysis reports are maintained.

Summary

Discharge to the sanitary system has proved to be an acceptable disposal method for this large treatment plant. No problems were reported at the sewage treatment plant although the water plant sludge represents about 15% of the total solids entering the sewage treatment plant.

While discharge of sludge to the sanitary sewage system has greatly reduced the waste discharge from this plant, considerable waste in the form of filter-backwash water is still being discharged untreated.

3. Case III

Case III illustrates sand-drying operations for a coagulation plant. This plant has a nominal capacity of 208,200 cu m/day (55 MGD) and uses alum and polymers to treat a moderately turbid river water.

Waste characteristics

The plant produces two wastes: filter backwash water and sedimentation basin sludge. The approximate composition of the waste based on information obtained from plant personnel and laboratory analyses of samples collected August 29 and October 3, 1974 indicates that major contributing elements are:

clays, silts, and insoluble organics	85%,
aluminum hydroxide	12.5%,
ferric hydroxide	1.4%,
polymer	1.1%

Based on the nominal capacity of the plant and average raw water conditions the plant produces about 1789 metric tons (1966 tons) of dry solids annually.

Waste treatment facilities

All wastes are sent to a 30.5 meter (100 ft) diameter thickener-clarifier. The overflow from the thickener-clarifier is discharged to the raw water source. The quality of the overflow varies considerably depending on the waste being received. Filter washwater quite often causes short circuiting and agitation of the settled sludge thus reducing the quality of the discharge. It was estimated by plant personnel that with normal operations there is approximately 25 to 50 ppm of suspended solids in the discharge. Underflow from the thickener is applied to one of three sand drying beds, providing a total surface area of 734 sq m (7900 sq ft). The sludge applied to the bed during observation was 12 - 13% solids and the average depth of application was 50 cm (20 in). The cycle time reported was twenty-one days giving an average loading of approximately 4.4 kg/sq m/day (0.9 lbs/sq ft/day). The filtrate from the underdrain is discharged back to the raw water source. The dried sludge is taken from the beds at 20% to 40% solids (32% for the cycle ending 10/3/74). Removal of the dried sludge requires a backhoe and operator, a dump truck and driver, and a laborer. Removal under normal operation requires the use of the above personnel and equipment for eight hours, one day a week. However, drying during the winter months is less complete and an additional truck and laborer are required. The sludge is stockpiled on site.

Cost of operation

Capital expenditures for the dewatering facilities were not available. The costs given reflect only operating and cleaning costs. The costs developed are based on the following assumptions:

- Extra labor and equipment will be required four months per year.

- Annual sludge production is predicted by average chemical dosages and raw water quality.
- The cost of the cleaning in October 3, 1974 is assumed as an average cleaning cost.

Annual Cost

Operation and Maintenance	$15,000/year

Unit Costs

Cost per dry metric ton dewatered	$8.38
(Cost per dry ton dewatered)	($7.60)
Cost per 1000 cu m of water treated	$0.20
(Cost per MG of water treated)	($0.75)

Summary

Presently the plant is investigating the feasibility of putting a surge tank ahead of the thickener and adding more drying beds to nearly double the present capacity. This plant is located in the southeastern United States, where the 1973 annual average temperature was 15.4°C (50.7°F), relative humidity was 71.8%, precipitation was 181.9 cm (71.6 in), wind velocity was 10.5 km/hour (6.5 mph), and the sun shines 52% of the time. A lesser application depth would probably result in a drier cake, however, limitations on the area available for sand-drying beds would not allow this.

4. Case IV

Case IV is a 75,700 cu m/day (20 MGD) softening plant treating a moderately hard well water. Two primary waste streams are produced at the plant, filter backwash and clarifier blowdown. The plant recycles filter backwash water and utilizes a vacuum-filter system to dewater the clarifier sludge.

Waste characteristics

Filter backwash

Approximately 87 cu m/min (23,000 gpm) of backwash wastes are piped to a lagoon for settling. The supernatant is pumped back to the plant influent. The sludge, which is almost pure calcium carbonate, is pumped to the sludge thickener. The filter backwash waste is relatively low in suspended solids, has a pH ranging from 8.0 to 9.5, and is voluminous with intermittent flow.

Clarifier underflow

Approximately 63.5 metric tons/day (70 tons/day) of dry solids are produced consisting primarily of calcium carbonate with a small amount of magnesium hydroxide and lime inerts. The total solids in the blowdown ranges from 3% to 7%. The total solids in the thickened sludge exceeds 30%. Approximately 62.5 cu m/day (16,500 gal/day) of clarifier underflow are produced.

Description of waste handling facilities

Two 14.9 kw, 1.5 cu m/min (20 hp, 400 gpm) pumps are utilized to pump the clarifier blowdown sludge to a 10.7 m (35 ft) diameter thickener. A 3.7 kw, 0.75 cu m/min (5 hp, 200 gpm) pump is used to pump the backwash-lagoon sludge to this same thickener.

The thickened sludge, which is about 30% solids, is pumped to two vacuum filters with a total filter area of 40.9 sq m (440 sq ft) having 66 kw (88.5 hp) connected horsepower. The filter cake, about 65% solids, is discharged directly to a truck where it is disposed of to various civic groups and construction companies.

The filter backwash water is discharged to a lagoon; the supernatnat is recycled back to the plant inlet; and the sludge is pumped to the vacuum filter.

Cost of treatment

System	Capital Cost (1971)	Power Cost ($/yr)	O & M* ($/yr)
Vacuum filter	246,000	2,163	650
Sludge thickener	210,900	1,625	6,900
Washwater recovery	169,700	1,711	500

*Operating and maintenance

Sludge disposal costs are estimated at $13,000 per year. The total cost for dewatering and disposal of the clarifier sludge as well as the filter backwash recycle, amounts to approximately $29.59 per metric ton ($26.84/ton) based on a thirty year service life at 7% interest.

It should be noted that the sludge handling facilities at this water-treatment plant were designed to handle six times the present solids production rate.

Treatment efficiency

Filtration rates in excess of 290 kg/sq m/hr (60 lbs/sq ft/hr) have been achieved, while producing a filter cake of 65% to 70% solids. Presently, 3400 metric tons per year (3,750 tons/year) of dry solids are dewatered. The filtrate is pumped to the municipal waste treatment plant, only a few hundred feet from the filter operation.

Summary

Case IV is a zero discharge plant with the exception of the filtrate from the vacuum filter, which is not recycled only as a matter of convenience. The filter cake produced is given to contractors as a soil stabilizer. The total annual cost for achieving this system of near zero discharge was approximately $8.19/1000 cu m ($31/MG) of water produced.

5. Case V

The water-treatment plant for Case V is a large, 643,000 cu m/day (170 MGD) nominal capacity coagulation-softening plant. However, attention will be focused on the softening process only. Softening is accomplished using zeolite cation-exchange units to remove an average of 325 mg/l of hardness from approximately two-thirds of the plant's throughput. There are two waste streams generated from the softening process, one is discharged to the sanitary sewer and the other is routed to an evaporation pond and the dry cake is landfilled.

Waste characteristics

The wastes from the softening plant come from two sources:

1) Brine filtration
2) Cation-exchange regeneration

This plant produces its own brine solution. The salt is received by railcar and dumped into a large mixing tank. From the mixing tank, the brine is filtered through a sand filter. The brine sand filter must be backwashed periodically. This backwash water is the source of the first waste stream and is sent to an evaporation pond. After evaporation of the water fraction, the remaining cake, which consists primarily of impurities in the salt, is removed and landfilled.

Softening is accomplished by zeolite cation-exchange units. Regeneration of the zeolite is accomplished by passing a solution of sodium chloride (regeneration brine) through the bed of exhausted resin. The average composition of regeneration brine is 0.24 kg of salt per liter of water (2 lbs/gal). Several washings with fresh water following the regeneration with brine are required. The total volume of wastes for regeneration, washwater, and brine solution varies widely. Approximately 136.3 cu m (36,000 gallons) are required for the older zeolite units being used and approximately 276.3 cu m (73,000 gal) are required for the new units. The softening units produce slightly more than 3.785 million cu m (1 billion gallons) of liquid waste annually. The analysis of a composited sample taken on July 31, 1974 is believed to represent the average composition of these wastes. There were slightly greater than 150,000 mg/l of total solids, approximately 500 mg/l of suspended solids, 62,000 mg/l of chlorides and the solution had a conductivity of 96,000 μmhos/cm.

Waste treatment facilities

The brine filters are backwashed periodically. The backwash water is pumped to an evaporation pond. The dried cake from the pond is transported to a landfill. The regeneration brine and washwater are discharged to a sanitary sewer which leads to a 1,324,750 cu m/day (350 MGD) primary waste treatment plant. The regeneration wastes represent less than 1% of the flow into the waste treatment plant the total effluent is piped to an ocean discharge.

Operating costs

Through a long term contract with the sanitary authority this plant is permitted to discharge its regeneration wastes, within a specified upper limit, to the sanitary sewer. The contract had no provisions for renegotiation and the existing arrangement greatly favors the water authority. The water authority further agreed to pay $16,000 annually plus an additional $1 for each 3,875 cu m (1 MG) of waste discharged to the sewer system.

Annual Cost

Debt Service ($100,000 @ 2.4%)	$4,000
Annual service charge	$16,000
Surcharge [@ $1/3,785 cu m (MG)]	$1,000
Annual cost	$21,030

Unit Cost

Cost per 1000 cu m	$5.40
(Cost per MG)	($20.42)
Cost per 1000 cu m of water treated	$0.87
(Cost per MG of water treated)	($0.24)

Summary

The sanitary authority feels that the contract is costing them approximately $100,000 annually. Discharge to the sanitary system primarily provides dilution and a means of waste carriage to the ocean.

6. Case VI

The water-treatment plant for Case VI produces 245,000 cu m/day (65 MGD) of finished water. The feed to the plant is a surface water with high turbidity and high hardness. Coagulation and softening are carried out simultaneously using lime, soda ash, polymers and alum.

Waste characteristics

The main wastes from this plant stem from presedimentation, from the clarifier, and from backwashing the filters.

Presedimentation

Presedimentation is provided at the raw water intake, which is 3 to 5 km (2 to 3 miles) from the treatment plant. The raw water is mechanically screened, chemically treated and clarified. The screenings are returned with the blowdown from the presedimentation clarifier to the raw water source. The chemical treatment consists of chlorination, feed of potassium permanganate when required, and low dosages of alum or polymer during high raw water turbidity. Raw water turbidities in excess of 3,000 mg/l, are typically reduced to 400 mg/l by presedimentation. Under these conditions, some 635 metric tons (700 tons) of dry solids are discharged each day back to the river at a solids concentration of approximately 1%.

Storage is provided in the presedimentation clarifier to equalize pumping of the partially clarified water.

Clarifier blowdown

Sludge blowdown is to one of two fill-and-dry lagoons. Supernatant is recycled to the plant influent. The suspended solids in the supernatant are generally less than 30 mg/l.

The characteristics of the clarifier blowdown are largely a function of presettled water quality. The proportion of calcium carbonate in the sludge ranges from 50% when the raw water is highly turbid, to more than 80% when the raw water is low in turbidity. The clay fraction generally ranges from 18% to 48 % with the remaining 2% consisting of aluminum hydroxide, polymers, and carbon.

Filter backwash water

The flow of a filter backwash water is equalized in a 379 cu m (100,000 gal) equalization basin and is then recycled to the plant influent. These facilities were constructed at a cost of $198,000 in 1956. Both the lagoon overflow and filter backwash are returned to plant influent with a common pumping system. A 2.3 cu m/min (600 gpm) pump and a 5.3 cu m/min (1400 gpm) pump are provided for this purpose. With connected power of 7.5 kw (10 hp) and 14.9 kw (20 hp) respectively.

Lagoon cleaning

The sludge, which is predominantly calcium carbonate, dewaters readily in a lagoon to approximately 60% solids. Six-month cycles are typical. A private contractor cleans the lagoons and hauls the sludge to the nearest landfill approximately

1.6 km (1 mile) away at a cost of $60,000 per year. Based on a solids production of 40.8 metric tons/day (45 tons/day) at a water-treatment rate of 94,625 cu m/day (25 MGD) this would amount to a cost of $4.02/dry metric ton ($3.65/dry ton) ultimate disposal costs. Much longer haul distances are anticipated in the near future.

Capital cost of the two lagoons, one constructed in 1956 and the other in 1963 was $34,000. Little operational costs other than cleaning are experienced. Approximately 2 hectares (5 acres) of land are utilized for the lagoons. Additional lagoon capacity will be required as water production increases.

Summary

With the exception of the presedimentation clarifier blowdown, the plant for Case VI is a zero discharge plant. All filter backwash and clarifier-sludge supernatant is recycled to the plant inlet with no difficulty.

The sludge, which is primarily calcium carbonate, dewaters readily in the lagoon with a modest cost for ultimate disposal.

The presedimentation system is not manned full time. A dewatering system at this location would cost many times more in both capital and operating costs than the system now in existence.

7. Case VII

The plant for Case VII is a 151,400 cu m/day (40 MGD) coagulation-softening plant that used centrifugation to dewater their wastes. The plant uses ferrous sulfate and lime to treat hard water with low turbidity from an impounded source. The finished water has moderate hardness.

Waste characteristics

There are two sources of waste coming from the plant: filter backwash water and sedimentation-basin sludge. The composition of the waste based on information obtained from plant personnel and lab analyses of samples collected on August 20, 1974 is:

$CaCO_3$	95%,
clays, silts, and insoluble organics	4%,
$Fe(OH)_2$, $Mg(OH)_2$ and activated carbon (when added)	1%.

Based on a nominal production of 151,400 cu m/day (40 MGD) of water the plant generates approximately 37.9 metric tons (41.7 tons) of solid waste. Part of the settled sludge is recycled to the head of the plant. Some of the solids produced in the sedimentation basin are carried over onto the filters and discharged from the plant with the filter backwash water. On a typical day, approximately 3,400 cu m (0.9 MG) are used in washing filters, carrying with it about 1067 kg (2,350 lb) of solids. The washwater is discharged to the raw water source.

Waste treatment facilities

The sludge is collected in the sedimentation basins and delivered continuously by several 1.12 kw (1.5 hp) pumps to a sludge holding tank. The holding tank is agitated with air to keep solids in suspension. Air for agitation is provided by an air compressor driven by 18.6 kw (25 hp) motor. The sludge is transferred from the holding tank to each of the two centrifuges at rates varying from 0.3 to 0.6 cu m/min (75 to 150 gpm) at solids concentrations from 5% to 15%. The centrate is discharged to the sanitary sewer. The solids concentration in the centrate range from less than 1% to nearly 5%. The cake (of paste consistency) ranges in solids from 50% to 60% and it is delivered by a 3.7 kw (5 hp) motor driven pump to a hopper building for temporary storage prior to trucking.

The cake (paste) is trucked approximately 19 km (12 miles) to a privately owned landfill for ultimate disposal where no charge for dumping is levied.

The centrifuges were not purchased at the same time, therefore, two capital costs and different interest rates were used in the calculations of costs. One centrifuge was purchased in 1973. The centrifuges are not housed in a building, therefore, no expenses of this type are included. Some assumptions were made in the economic analysis. They were: (a) the salvage value for the equipment at the end of its useful life is zero, (b) the land required for the installation is valued at $20,000 (No true figure could be obtained as the land was already owned by the water company), and (c) the costs for ultimate disposal are not included.

Annual Cost

Capital recovery ($60,000 @ 6%)	$4,700
Capital recovery ($80,000 @ 8%)	7,500
Operation	17,310
Maintenance	4,000
Annual cost	$33,510

Unit Cost

Cost per 1000 cu m of water produced	$0.61
(Cost per MG of water produced)	($2.30)
Cost per metric dry ton dewatered	$2.42
(Cost per dry ton dewatered)	($2.20)

8. Case VIII

Case VIII illustrates the operation of a direct filtration plant that treats 227,100 cu m/day (60 MGD). The raw water is from an impounded source, and is of high quality. This plant utilizes sand drying beds to dewater its wastes after reclaiming a large percentage of the liquid fraction. The water-treatment plant feeds alum, polymers, and when needed, activated carbon.

Waste characteristics

A mass balance was used to determine the waste produced. Average chemical additions and an average raw water quality was assumed for the mass balance. Information concerning backwash volumes and frequency of backwashing was used to determine the theoretical solids concentration in the waste. This calculated figure checked closely with the analysis of a composite sample collected at the plant on August 2,1974. Therefore, it was estimated that a representative composition of the wastes would be:

$Al(OH)_3$	50% to 75%,
organic polymer	7% to 12%,
activated carbon	35%,
turbidity in the raw water	4% to 12%.

Approximately 600 metric tons (660 tons) of dry solids are separated by the filters each year, all of which must be removed in backwashing. An additional 13.6 metric tons (15 tons) of solids are added annually to the backwash water by chemicals used in washwater reclamation. It is estimated that there is a total of 2,537,000 cu m (675 MG) of waste produced annually.

Waste treatment facilities

The backwash water flows to a 3,785 cu m (1 MG) basin from which it is pumped to a 45,420 cu m/day (12 MGD) upflow clarifier where alum and polymers are added as coagulants. The clarified water flows by gravity back to the head of the plant. The excess sludge is pumped to one of five 18.3 m x 30.5 m (60 ft x 100 ft) sand drying beds. The filtrate from the drying bed underdrains flows to the head of the water-treatment plant. The sludge is pumped to the beds and repeatedly applied as it is drawn from the clarifier. The switching from one bed to another is determined primarily by visual observations. When the cake is removed, the dried depth of the sludge is approximately 30 cm (1 ft). All beds are cleaned annually.

SECTION VIII

COST, ENERGY, AND NON-WATER QUALITY ASPECTS

A. Costs of Alternative Control and Treatment Technologies

Three types of financial data are included in this document. The first, in Section VII, reports specific costs in case studies so that the sludge-treatment and disposal costs for the selected study systems could be evaluated. Capital costs and interest rates reported reflect the actual year of installation and are not corrected to present costs. Amortization of capital costs is calculated by a sinking-fund method.

The second type of financial information presented compares sludge-treatment costs for various cities using selected treatment alternatives. This data is intended to present information of a more general nature. The capital costs are for the year of installation. However, operations costs reflect the most recent information available.

The third type of financial information is based on model systems. The costs for these models are intended to reflect conditions slightly above average in construction complexity.

Cost information reported in Section VIII is divided into two segments: treatment costs presently experienced by the water industry, and costs predicted by treatment of model systems. The data for the former were collected from plant visits, the literature, or personal telephone contact. The latter costs were estimated using various assumptions, which are indicated for each model. In this Section the costs for the implementation of the various model treatment alternatives are compared with 1970 water cost and revenue data compiled from Operating Data for Water Utilities 1970, AWWA. A summary of this data is shown in Table VIII-1.

1. Existing Treatment Costs

a. Lime recovery

As discussed in Section VII, lime recovery is practiced at eight water plants in this country. Cost data that were col-

Table VIII-1

Summary of Water Cost Data (1970)*

Type Plant	Nominal Size		Average Production		Cost		Revenue	
	1000 cu m per day	(MGD)	1000 cu m per day	(MGD)	$/1000 cu m of product	($/MGD of product)	$/1000 cu m of product	($/MGD of product)
Coagulation	3.8	(1)	5.4	(1.4)	81.6	(309)	155.6	(589)
Coagulation	75.7	(20)	76.8	(20.3)	59.2	(224)	126.0	(477)
Coagulation	189.3	(50)	196.2	(51.8)	41.7	(158)	79.2	(300)
Softening	3.8	(1)	4.7	(1.2)	140.8	(533)	214.0	(810)
Softening	75.7	(20)	75.7	(19.9)	84.0	(318)	131.6	(498)
Softening	189.3	(50)**	75.7	(19.9)	65.0	(246)	101.5	(384)
Coagulation & Softening	3.8	(1)	5.4	(1.4)	136.6	(517)	198.4	(751)
Coagulation & Softening	75.7	(20)	71.5	(18.9)	66.6	(252)	155.1	(587)
Coagulation & Softening	189.3	(50)	184.7	(48.8)	61.6	(233)	117.3	(444)

* - Updated to December 1974 using Consumer Price Index

** - No plants of this size reporting

lected during plant visits are shown in Table VIII-2. The data on the multiple-hearth installation at the Lake Tahoe sewage treatment plant were added for comparison purposes. These data allow some general economic comparison between lime recovery devices. Specific comparison is impossible due to variations in the sizes of the facilities, dates of construction, and unit costs. While the economics of lime recovery are not always competitive with purchased lime, consideration of the cost of sludge disposal makes recalcination very attractive in many cases.

b. Disposal to sanitary sewer

Fifteen plants were visited that discharge wastes to sanitary sewer systems. In most cases no charge was made to the water treatment plant. However, this policy is changing as a result of increased waste treatment costs and increased regulation. In most cases where there is a charge and where filter backwash water is recycled, the primary charge is based on suspended solids. The cost for disposal to a sanitary sewer, not including capital costs or operating costs, ranged from $22.05 to $239.25 per dry metric ton ($20.00 to $217.00 per dry ton) of solids. Table VIII-3 contains a summary of cost information obtained from plants visited that currently discharge wastes to sanitary sewers. Total disposal costs of $82.69 to $110.25 per metric ton ($75.00 to $100.00 per ton) may be considered normal.

c. Vacuum filtration

Five plants were visited that use vacuum filters to dewater sludges which are predominantly calcium carbonate. A number of reports were available from the literature or pilot or demonstration studies of the use of pre-coat vacuum filters for dewatering iron-hydroxide or alum sludges. As indicated in Table VIII-4 the operating costs are considerably higher for dewatering these sludges than for dewatering calcium carbonate sludges. Ultimate disposal costs can also be expected to be higher for these sludges because of the higher moisture contents and the additional loading of pre-coat materials.

2. Model Cost Systems

Three plant sizes were chosen for each category; 3,785 cu m/day (1 MGD), 75,700 cu m/day (20 MGD), and 189,250 cu m/day

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Table VIII-2

Lime Recalcination Plants Visited

(1974 Data Except Where Noted)

City	Production		Date installed	Type calciner	Costs $/metric ton ($/Ton)					Capital Cost, $
	Metric tons per day	(Tons/day)			Fuel	Power	Operation	Maintenance	Total	
Miami	81.63	(90)	1948	Rotary	10.47 (9.50)	0.97 (0.88)	6.14 (5.57)	2.00 (1.81)	19.58 (17.76)	856,000
Dayton[a]	83.44	(92)	1960	Rotary	8.57 (7.77)	(c)	11.08 (10.05)	(b)	19.65 (17.82)	1,500,000
Ann Arbor	6.98	(7.7)	1968	Fluid-Solids	8.37 (7.59)	5.49 (4.98)	15.52 (14.08)	2.35 (2.13)	31.73 (28.78)	1,200,000
Lansing	14.51	(16)	1954	Fluid-Solids	15.95 (14.47)	4.47 (4.05)	13.21 (11.98)	3.90 (3.54)	37.54 (34.05)	440,000
St. Paul[d]	22.68	(25)	1968	Fluid-Solids	9.37 (8.50)	6.80 (6.17)	22.57 (20.47)	6.54 (5.93)	45.28 (41.07)	1,750,000
Lake Tahoe[e]	9.98	(11)	1968	Multiple Hearth	14.55 (13.20)	1.43 (1.30)	8.03 (7.28)	4.98 (4.52)	28.70 (26.03)	

a) 1973 data

b) Included in operation costs

c) Included in fuel cost

d) Soda ash cost of $13.34/metric ton ($12.10/ton) of lime

e) Sewage sludge, 1969 costs

Table VIII-3

Disposal To Sanitary Sewer

Plant ID No	Water Plant Size & Type cu m/day (MGD)	Cost Basis: $/metric ton of solids ($/ton)	Cost Basis: $/1000 cu m of waste ($/MG)	Cost Basis: $/kg BOD ($/lb BOD)	Annual Cost $	Sewage Plant Size & Type cu m/day (MGD)	Dewater Device	Remarks
85	113,550 (30) Alum	68.05 (61.72)	52.47 (198.00)		150,000	30,280 (8) Secondary	Vacuum Filter	50% of total solids due to WTP - no problems reported
86	189,250 (50) Alum		153.24 (580.00)		12,460			
87	473,125 (125) Zeolite		4.49 (17.00)		16,794	1,324,750 (350) Primary		Charge based on volume, plant operating cost affected by salinity
1436	1,994,695 (527) Alum	57.33 (52.00)	6.61 (25.00)	96.92 (44.00)	400,000	946,250 (250)	Lagoons	15.3% of solids handled at STP. Advise keeping below 20%
1437	3,785,000 (1000) Alum	57.33 (52.00)	6.61 (25.00)	96.92 (44.00)	660,000	3,785,000 (1000)	Vacuum filter, drying beds	4.9% of dry solids at STP
M.W.D. of S.C., Jenson WTP	757,000 (200)	22.05 (20.00)			27,000			
Detroit	193,035 (51) Alum	34.18 (31.00)			24,000	946,250 (250) A.S.		Incinerator problems were reported at times. The value of sludge dropped. Combustion was not self-supporting. Basin cleaned each 6 months. 100 ton in 24-hour period.

Table VIII-4

Vacuum Filtration of Water Plant Sludge

City I D No	Status	Date installed	Type sludge	Capital cost($)	Size sq m (sq ft)	Operating cost[a] $/metric ton ($/dry ton)	Operating time (hr/wk)	Cake solids per cent	Remarks
91	Plant visit	1972	$CaCO_3$	50,000[b]	13.9 (150)	6.2 (5.6)	15	65-80	
92	Plant visit	1974	"	265,242	29.3 (315)	--	--	65-80	Under construction
1442	Plant visit	1969	"	56,000[b]	27.9 (300)	--	40	65-80	
1444	Plant visit	1968	"	49,454[b]	13.9 (150)	--	20	65-80	
93	Plant visit	1971	"	246,700	40.9 (440)	3.2 (2.9)	20	65-80	
94	Report	1972	Alum	76,000	38.6 (416)	18.5 (16.8)	40	15	Pilot study
95	Report	1971	Alum	61,000	13.9 (150)	189.4 (172)	168	18-22	Pilot study
96	Report	1974	Iron hydroxide	200,000	32.5 (350)	133.3 (121)	168	25-30	Laboratory study
97	Report	1969	Alum	331,000	111.5 (1200)	123.3 (112)	168	25	Model study
98	Report	1969	D.E.	60,000	5.0 (54)	33.0 (30)	--	--	

a) Excludes capital cost

b) Equipment cost only

(50 MGD). The model sludge-dewatering systems chosen were based on engineering judgment for the plant size and category under consideration. In some instances more than one model was chosen for illustrative purposes.

As discussed in Section VII the selection of alternative treatment systems is complex and, in many cases, governed by specific plant conditions. Thus, while it would appear that one alternative should be used exclusively from a cost standpoint, local conditions may make this impossible. Considerable study is required in selecting a sludge dewatering and disposal system for a specific plant.

In the case of industrial water treatment plants, costs presented would be applicable in only isolated cases. Solids-removal facilities are often already present, with the solids production from water treatment only a small percentage of the total industrial waste solids production. Thus, in many cases, industry may be capable of treating their water plant sludges at lower costs than the municipal utilities can.

The alternative sludge-treatment systems generally are composed of two separate operations: dewatering, and ultimate disposal. The costs are calculated independently and summarized for the various models.

a. Costs of pH control

A detailed cost estimate for the pH-control system described in Section VII is given below. The costs estimates are based on lagoon overflows for the different sized model plants. For purposes of computing annual chemical costs, concentrated sulfuric acid is used to reduce a hypothetical hydroxide alkalinity of 70 mg/l as $CaCO_3$.

	Costs
1) pH sensor, signal converter, multi-position controller, alarm contact and recorder	$3,200
2) Neutralization (mixing) tank	
(a) 3,785 cu m/day (1 MGD) plant	1,800
(b) 75,700 cu m/day (20 MGD) and 189,300 cu m/day (50 MGD) plants	6,000

	Costs
3) Valves - Emergency shut-off auto control	
(a) 3,785 cu m/day (1 MGD) plant	$3,000
(b) 75,700 cu m/day (20 MGD) and 189,300 cu m/day (50 MGD) plant	4,400
4) Mixing device (all applications)	1,000
5) Chemical storage	
(a) 3,785 cu m/day (1 MGD)	None
(b) 75,700 cu m/day (20 MGD) and 189,300 (50 MGD) plant	10,000
6) Chemical feed pump (all applications)	1,000
7) Emergency recycle pump	
(a) 3,785 cu m/day (1 MGD)	1,000
(b) 75,700 cu m/day (20 MGD)	2,000
(c) 189,300 cu m/day (50 MGD)	3,000
8) Piping (10% of sub-total)	
9) Electrical & instrumentation (20% of sub-total)	

Capital Cost (Sub-total)

3,785 cu m/day (1 MGD)	75.7 x 1000 cu m/day (20 MGD)	189.3 x 1000 cu m/day (50 MGD)
$11,100	$27,600	$26,600*

Annual Chemical Cost

3,785 cu m/day (1 MGD)	75.7 x 1000 cu m/day (20 MGD)	189.3 x 1000 cu m/day (50 MGD)
$50	$2,920	$7,160*

*For an alum recovery system it is assumed that the plant size would be 189,300 cu m/day (50 MGD) and lime is used for neutralization, the capital cost of this system is estimated at $24,000 and the annual lime costs would be determined by the amount of wasting required.

b. Ultimate disposal costs

The cost analysis for ultimate disposal is based on the hauling of wet cake. Alum and iron hydroxide sludges are assumed to have a bulk density of 1200 kg/cu m (75 lbs/cu ft). Softening-coagulation sludges are assumed to have a density of 1800 kg/cu m (111 lb/cu ft). Two truck sizes, 3.82 cu m (5 cu yd) and 9.17 cu m (12 cu yd), were considered in calculating hauling costs. Models requiring hauling more than 11.74 cu m (15 cu yd) of waste sludge each haul period are assumed to use the 9.17 cu m (12 cu yd) truck. In practice this is dictated by the availability of trucks, access roads, haul distances, etc. The following assumptions were made in this cost analysis.

Labor (including fringes)		$5.50/hour
Diesel fuel, oil & maintenance:		
9.17 cu m (12 cu yd) truck	$0.12/km	($0.19/mile)
3.82 cu m (5 cu yd) truck	$0.10/km	($0.16/mile)
Truck cost:		
9.17 cu m (12 cu yd) truck		$38,000
3.82 cu m (5 cu yd) truck		$25,000
Capital recovery: [8% for 5 years assuming 643,600 km (400,000 miles)]		
9.17 cu m (12 cu yd) truck	$0.07/km	($0.11/mile)
3.83 cu m (5 cu yd) truck	$0.04/km	($0.07/mile)
Landfill disposal charge:	$1.96/cu m	($1.50/cu yd)

Costs for hauling and disposal are illustrated in Table VIII-4a.

c. Operation

Water plants are considered to operate twenty-four hours a day and 365 days a year. Sludge-treatment devices have been designed with a reasonable overload factor to handle reasonable variations in sludge production because of changes in raw water quality and water production. Forty-eight hour filter runs are assumed with a backwash rate of 10.2 l/sec/sq m (15 gpm/sq ft) for twelve minutes duration. Filtration rates of 1.4 l/sec/sq m (2 gpm/sq ft) are used for sizing the filters;

Table VIII-4 (a)

Hauling and Disposal Cost

Haul Distance		$/wet cu m ($/wet cu yd) Truck Size			
kilometers	(miles)	9.17 cu m	(12 cu yd)	3.82 cu m	(5 cu yd)
16.09	(10)	3.61	(2.76)	5.55	(4.24)
32.18	(20)	5.26	(4.02)	9.14	(6.99)
48.27	(30)	6.84	(5.23)	12.74	(9.74)

The following is an illustration for the use of these tables. Assume:

Alum sludge: 907 metric tons (1,000 tons)/year of dry solids 30% solids content in cake to be landfilled at a haul distance of 16.09 km (10 miles) using a 3.82 cu m (5 cu yd) truck.

Total sludge weight $= \frac{907}{0.3}$

= 3023 metric tons (3333 tons)/year

Volume $= \frac{3023 \times 1000 \text{ kg/metric ton}}{1199 \text{ kg/cu m}}$

= 2522 cu m (3336 cu yd)

Cost = $5.55 x 2522

Annual cost = $14,000

$/dry metric ton = $15.44 ($14.14/dry ton) two filters are used in the 1 MGD plant, eight filters in the 20 MGD plant, and twenty filters in the 50 MGD plants.

To prevent surging problems at the plant influent when filter backwash is recycled flow-equalization tanks are provided in all cases. The size is dependent upon several factors related to providing the ability to wash filters during off-peak water demand periods.

d. Economics

In developing the economics for these models a number of assumptions are made:

Land purchase @ $24,700 per hectare ($10,000 per acre)

8% interest for capital recovery

Capital recovery period is proportional to the expected life of the facility

Piping is calculated as 10% of the unit-price subtotal, except for filter backwash piping,which was estimated separately since it constitutes a large percentage of the recovery system

Construction interest @ 8%

Power @ $0.02/kwh

Taxes & insurance @ 2% of capital cost

Labor @ $5.50/hour

e. Coagulation plants

Three plant sizes are considered for each subcategory. The three sizes, 3,785 cu m/day (1 MGD), 75,700 cu m/day (20 MGD), and 189,250 cu m/day (50 MGD), are presented to represent plants in the range of 378.5 to 37,850 cu m/day (.1 to 10 MGD), 37,850 to 113,500 cu m/day (10 to 30 MGD), and in excess of 113,500 cu m/day (30 MGD). Based on the 1963 USPHS survey, in terms of numbers of coagulation plants, the percentage falling into each size group were 92%, 5%, and 3%, respectively. In terms of total water production the percentages were 28%, 19%, and 53%, respectively.

In each of these models a number of assumptions are made for raw water quality and chemical feeds. For this subcategory these assumptions are:

Raw Water Quality	30 mg/l turbidity slight taste or odor
Chemical Feed	20 mg/l alum 15 mg/l hydrated lime 5 mg/l activated carbon

A constant relationship between turbidity in JTU and suspended solids in mg/l is assumed to be 1:1.

Ten per cent of the feed lime is insoluble and inert and will be removed with the other solid wastes.

The activated carbon (AC) is assumed to be non-reactive and does not alter the reactions in any way. Thus, each ppm of activated carbon fed appears in the waste.

Two wastes are assumed to be produced by the water treatment plants in this subcategory. They are:

Filter backwash water, and
Sedimentation-basin sludge

These wastes are assumed to be produced in the following manner and in the quantities indicated for each MG of water treated.

Raw Water Contribution (Dry Weight Basis)	kg/1000 cu m	(lb/MG)
Turbidity - 30 mg/l	30	(250)
Feed-Chemical Contribution (Dry Weight Basis)		
Alum - 30 mg/l	7.9	(66)
Lime - 15 mg/l (10% insoluble)	1.5	(12.5)
Activated carbon - 5 mg/l	5.0	(42)
Total Wastes Produced	44.4	(370.5)

The average backwash volume is assumed to be three percent (3%) of the filtered water. For the small plants, 3,785 cu m/day (1 MGD), it is assumed that no sludge-collection mechanisms are installed and sedimentation-basin sludge is removed semi-annually. In plants in which collection devices are provided, 75,700 cu m/day (20 MGD) and 189,250 cu m/day (50 MGD), 1.5% of the daily throughput of water is used for transport of the solids (clarifier blow-down).

For the 3,785 cu m/day (1 MGD) plant in which basins are cleaned semi-annually, all of the clarified water is assumed to be used in washing down the basin. An additional 113.6 cu m (30,000 gal) of water are assumed to be used in washing the basin with fire hoses. Two (2) sedimentation basins are assumed. They provide four (4) hours retention time. Each basin holds 317.9 cu m (84,000 gal); thus, 836 cu m (228,000 gal) [2(113.6 + 317.9)] of liquid wastes are produced semi-annually. In the larger water treatment plants, hourly blow-down is assumed.

i. <u>Lagoon - 3,785 cu m/day (1MGD) plant</u>

This model represents the most commonly used method of treating wastes for small plants with reasonable land area available. As discussed in Section VII lagooning of alum sludge often does not produce a material suitable for landfill and additional air drying may be required. This model assumes that the sludge cleaned from the lagoon can be landfilled directly.

Two lagoons are utilized in the model providing five years of sludge storage in each. Filter backwash is recycled directly to the plant influent and the costs for this system are shown in the first column. The costs shown in the second column are without recycle.

Capital Cost

	With Filter Backwash Recycle	Without Filter Backwash Recycle
Land purchase	9,000	11,000
Washwater holding basin	19,000	
Washwater piping	18,000	32,000
Valves & fittings	2,700	4,800
Recirculation pumping	5,000	
Lagoon construction	6,600	8,500
Inlet and outlet construction	2,000	2,000
Yard piping & electrical (20%)	12,460	11,660
Engineering & contingencies (20%)	14,952	13,992
Construction interest	1,200	1,100
Total Capital Cost	$90,912	$85,052

Annual Cost

	With Filter Backwash Recycle	Without Filter Backwash Recycle
Debt service (8% for 30 years)	8,075	7,555
Labor & maintenance (Lagoon operations, contractural removal)	1,075	1,880
Labor (Monitoring requirements) 2 hr/wk	858	858
Power (17 hr/day)	150	
Taxes & insurance (2% of Capital Cost)	1,818	1,701
Annual Dewatering Cost	$11,976	$11,994

Ultimate disposal cost

61.5 metric tons/year (67.6 tons/year) of sludge at 15% solids to be hauled 16 km (10 miles) using a 9.17 cu m (12 cu yd) truck

Total cost

$/1000 cu m of water treated ($/MG)		$/metric ton of solids	$/ton
With filter back-wash recycle	$9.57 ($36.24)	$214.43	($194.50)
Without filter backwash recycle	$9.58 ($36.28)	$214.72	($194.76)

ii. Disposal to the sanitary sewer - 3,785 cu m/day (1 MGD)

In some cases land availability may be a problem for even the small water treatment plants. The best alternative for these plants may be in disposing to the sanitary sewer. The model assumes a one mile force main to the sanitary system.

As stated, the 3,785 cu m/day (1 MGD) plant was assumed not to have a continuous sludge removal in the settling basin. The filter backwash basin was oversized to equalize the flow from basin cleaning to the sanitary sewer.

Capital Cost

Washwater and sludge holding basin	70,000
Washwater piping	18,000
Valves & fittings (15%)	2,700
Recirculation pumping	5,000
Construction of 1.6 km (1 mile) of 10 cm (4 in) force main and pumps to connect with existing sewage system	38,000
Rights of way and easements	10,000
Engineering & contingencies (20%)	28,740
Construction interest	6,897
Total Capital Cost	$179,337

Annual Cost

Debt service (179,337 @8% for 30 years)	15,932
Labor & maintenance	825
Power	175
User charge for disposal to sewer*	8,687
Taxes & insurance	3,586
Total Annual Cost	$28,205

Annual sludge production	60,291 kg (132,800 lb)
Sludge transport water	1741 cu m (460,000 gal)
Total annual wastes produced (dry weight)	61.5 metric tons (67.6 tons)

Total Cost

$/1000 cu m of water produced	($/MG)	$/metric ton of solids	($/dry ton)
$21.14	($80.01)	$473.49	($429.49)

iii. Sand drying beds - 75,700 cu m/day (20 MGD)

In this model 1,233.5 metric tons (1,369 tons) of solids will be dewatered annually by the sand drying operations. It is assumed that the water plant has sludge-collection equipment installed. The sludge will be periodically "blowndown" to a

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*It is assumed that no cost recovery charge will be levied against the water authority since their waste flows are seldom expected to exceed 10% of the waste-water-treatment plant's average flow, therefore, no charge is required. There is a user charge based on solids and flow only. A charge of $15.85/1000 cu m ($60/MG) for flow and a fixed charge of suspended solids in excess of "normal domestic" sewage (taken as 200 mg/l) of $0.055/kg ($0.025/lb) is assumed. No credit is given for waste characteristics below "normal domestic" sewage.

thickener. A thickener is provided for sludge storage as well as for increasing the solids concentration and reducing the volume of sludge applied to the beds. The overflow is assumed to be of sufficient quality to be recycled to the plant influent.

A 20% safety and inclement weather factor has been added in sizing the beds, which are sized for 3.9 kg/sq m /10 day drying cycle (0.8 lb/sq ft/10 day drying cycle).

Capital Cost

Land	45,000
Washwater holding basin	70,000
Washwater recovery piping	90,000
Valves & fittings @ 15%	13,500
Recirculation pumping	15,000
Thickening facilities	220,000
Drying bed construction	556,667
Yard piping & electrical (20%)	202,033
Engineering & contingencies (20%)	202,033
Construction interest	73,000
Total Capital Cost	$1,487,233

Annual Cost

Debt service ($1,487,233 @8% for 30 years)	132,157
Labor & maintenance	16,000
Power	1,510
Taxes & insurance	38,040
Total Dewatering Cost	$187,707

Ultimate disposal cost

1,229 metric tons/year (1,352 tons/year) of sludge at 30% solids to be hauled 16 km (10 miles) using a 9.17 cu m (12 cu yd) truck.

Total cost

$/1000 cu m of water produced	($/MG)	$/metric ton of solids	($/dry ton)
$7.48	($28.33)	$167.76	($152.16)

iv. Filter press - 189,250 cu m/day (50 MGD)

Large plants are generally located in areas with limited available land. Mechanical dewatering devices will find greatest application for these plants. For alum sludges filter pressing is the most widely accepted of the mechanical dewatering systems.

For the filter press operation 15% (by weight) lime is used for conditioning, 34.2 kg (75.2 lb) of diatomaceous earth per 100 sq m (1076 sq ft) of filter area is used for precoating. Cyle time for the filter press is assumed to be 2.5 hours. Thickeners are provided for partial dewatering of the sludge. The filtrate will be returned to the thickener and the thickener overflow is assumed to be of sufficient quality to be recycled to the plant influent. The filter presses will be operated 8 hours a day initially and will be of sufficient size to allow for the addition of enough plates to increase the initial capacity by 30% without an increase in operating time. This provides a 300% overload capacity for expansion, water production peaks and fluctuations in raw water quality when 24-hour operation is used. The building will provide sufficient space to allow for installation of a second filter press should the need arise. The climatic and aesthetic conditions permit bin storage of chemicals outside the building.

Capital Cost

Land	7,500
Washwater holding basin	70,000
Washwater recovery piping	90,000
Valves & fittings (15%)	13,500
Recirculation pumping	25,000
Thickening facilities	556,000
Chemical storage bins	100,000
Building	250,000
Filter press & ancillary equipment	2,000,000
Piping (10%)	311,200
Electrical	622,400
Engineering & contingencies (20%)	809,120
Construction interest	223,000
Total Capital Cost	$5,077,720

Annual Cost

Debt service ($5,088,820 @8% for 30 years)	491,710
Labor	62,500
Power	10,090
Chemicals	59,250
Taxes & insurance	101,554
Annual Dewatering Cost	$725,104

Ultimate disposal costs

Solids production, metric tons/year (tons/year) - 3,084 (3,400) sludge
91 (100) lime inerts
176 (194) diatomaceous earth

3,350 metric tons/year (3,684 tons/year) of sludge at 40% solids to be hauled 32 km (20 mi) using a 9.17 cu m (12 cu yd) truck.

Annual ultimate disposal cost = $37,161

Total cost

$/1000 cu m of water produced	($/MG)	$/metric tons of solids	($/dry ton)
$13.00	($49.22)	$247.41	($224.40)

f. Coagulation-softening plants

The three plant sizes evaluated, 3,785 cu m/day (1 MGD), 75,700 cu m/day (20 MGD), and 189,250 cu m/day (50 MGD), represent water plants in the size range of 378.5 to 37,850 cu m/day (.1 to 10 MGD), 37,850 to 113,550 cu m/day (10 to 30 MGD), and greater than 113,550 cu m/day (greater than 30 MGD). The percentage of plants in each of the above size groups was 86%, 6.5% and 7.5% according to the 1963 USPHS Survey. The percentages of the total water produced in each size group were 19.5%, 14.1% and 66.4%.

The dewaterability of sludges in this subcategory depends on the ratio of coagulant sludge to softening sludge, as was discussed in Section VII. Hard, turbid, river water is assumed to be the feed to these plants. The average composition of the raw water is assumed to be:

Turbidity (JTU)	600
Hardness removed (mg/l as $CaCO_3$)	115

The following chemical dosages are assumed:

Lime (CaO) for the 75,700 cu m/day (20 MGD) and 189,250 cu m/day (50 MGD)	200 mg/l
Hydrated lime ($Ca(OH)_2$) for the 3,785 cu m/day (1 MGD) plant	264 mg/l
Alum	7 mg/l
Ferric sulfate	3 mg/l
Activated carbon	1 mg/l
Potassium permanganate	1 mg/l

Hydrated lime ($Ca(OH)_2$) is used for the 3,785 cu m/day (1 MGD) plant. It is assumed that 1.7 parts of waste are produced for each part of hydrated lime fed. For the 75,700 cu m/day (20 MGD) and 189,250 cu m/day (50 MGD) plants, it is assumed that quick lime (CaO) is used, and 2.25 parts of solid waste is produced for each part of lime fed. Thus, 3,271 kg (7,205 lb) of solid waste are produced for each 3,785 cu m (1 MG) of water treated regardless of the form of lime used. Automatic sludge-collection devices are assumed to be used in all plants.

Contribution	kg of waste/ 1000 cu m	(lb/MG)
Turbidity - 425 mg/l	425	(3539)
Lime - 200 x 0.9 x 2.25) mg/l	405	(3372)
Lime inerts - (20 x 0.1) mg/l	20	(167)
Alum - (7 x 0.26) mg/l	1.8	(15)
Ferric sulfate	1.4	(12)
Potassium permanganate - (1 x 0.55) mg/l	0.6	(5)
Activated carbon - 1 mg/l	1.0	(8)
Total Wastes Produced	854.8	(7118)

i. <u>Lagoon - 3,785 cu m/day (1 MGD) & 75,700 cu m/day (20 MGD)</u>

Lagooning was assumed to be the method of dewatering the sludges from the 3,785 cu m/day (1 MGD) and the 75,700 cu m/day (20 MGD) plants in this subcategory. Two lagoons are assumed to be used for each size of plant. For the 3,785 cu m/day (1 MGD) plant it is assumed that each lagoon can store the wastes accumulated over 3 years. For the 75,700 cu m/day (20 MGD) plant, the storage capacity of each lagoon is assumed to be sufficient for 6 months. Decanting devices will be provided to allow for drawing off the clarified supernatant from different levels. The quality of the supernatant is assumed to be satisfactory for discharge to receiving waters after pH correction. Thickening is not deemed necessary for either lagooning operation.

Lagoon - 3,785 cu m/day (1 MGD)

Capital Cost

	With Filter Backwash Recycle	Without Filter Backwash Recycle
Land purchase	18,500	20,000
Washwater holding basin	19,000	0
Washwater piping	18,000	32,000
Valves & fittings (15%)	2,700	4,800
Recirculation pumping	5,000	0
Inlet & outlet pumping	2,000	2,000
Lagoon construction	15,565	16,005
pH control system	14,300	14,300
Yard piping & electrical (20%)	16,153	17,821
Engineering & contingencies (20%)	19,384	21,385
Construction interest	1,700	2,000
Total Capital Cost	$118,002	$130,311

Annual Cost

	With Filter Backwash Recycle	Without Filter Backwash Recycle
Debt Service (@8% for 30 years)	10,482	11,575
Labor & maintenance (lagoon operations)	12,280	13,290
Labor (monitoring requirements) 3 hr/wk	858	858
Power	280	130
Chemicals	40	72
Taxes & insurance	2,360	2,606
Annual Dewatering Costs	$26,300	$28,531

Ultimate disposal costs

1181 metric tons/year (1299 tons/year) of sludge at 50% solids has to be hauled 16 km (10 miles) using a 9.17 cu m (12 cu yd) truck.

Annual ultimate disposal cost = $4,828

Total cost

$/1000 cu m of water produced	($/MG)	$/metric ton of solids	($/dry ton)
With filter backwash $22.53	($85.28)	$26.36	($23.96)
Without filter backwash $24.15	($91.39)	$28.25	($25.68)

Lagoon - 75,700 cu m/day (20 MGD) plant

Capital Cost

	With Filter Backwash Recycle	Without Filter Backwash Recycle
Land purchase	51,000	56,000
Washwater holding basin	70,000	
Washwater piping	90,000	234,000
Valves & fittings (15%)	13,500	35,100
Recirculation pumping	5,000	
Lagoon construction	39,000	41,500
Inlet & outlet structures	4,000	4,000
pH control system	35,900	35,900
Yard piping & electrical (20%)	61,680	81,300
Engineering & contingencies (20%)	74,016	97,560
Construction interest	12,000	17,000
Total Capital Cost	$456,096	$602,360

Annual Cost

Debt service (@8% for 30 years)	40,539	53,539
Labor & maintenance (lagoon operations - contracted removal)	134,000	135,000
Labor (monitoring requirements) 3 hrs/wk	858	858
Power	280	130
Chemicals	2,920	5,256
Taxes & insurance	9,122	12,047
Annual Dewatering Cost	$187,719	$206,830

Ultimate disposal cost

23,620 metric tons/year (25,982 tons/year) of sludge at 50% solids has to be hauled 16 km (10 miles) using a 9.17 cu m (12 cu yd) truck.

Annual ultimate disposal cost = $96,579

Total cost

$/1000 cu m of water treated ($/MG)			$/metric ton of solids	($/dry ton)
With filter backwash	$10.29	($38.94)	$12.04	($10.94)
Without filter backwash	$10.98	($41.56)	$12.90	($11.67)

iii. Filter press - 189,250 cu m/day (50 MGD)

As discussed previously, filter pressing is considered only where land limitations require the use of a mechanical dewatering device. For filter press operations of this combination sludge, a model is developed to handle 59,050 metric tons (64,950 tons) of solid waste annually. The presses are sized to operate 20 hours a day. A cycle time of one hour is assumed for normal operations. The presses will be capable of a 30% expansion by simply adding plates, thus, with additional plates a 50% overload capacity is provided. For the purposes of this model, conditioning of the sludge and precoat of the filter are assumed to be unnecessary. A holding tank with air agitation is used to provide storage and uniformity of the feed sludge. Sedimentation basins are assumed to have collection mechanisms installed and afford sufficient control to provide uniform sludge density to the press.

Capital Cost

Land	5,000
Washwater holding basin	70,000
Washwater recovery piping	90,000
Valves & fittings (15%)	13,500
Recirculation pumping	25,000
Sludge holding basin	155,000
Filter press & auxiliary equipment	1,900,000
Building	250,000
Piping (10%)	250,850
Electrical (20%)	501,700
Engineering contingencies (20%)	652,210
Construction interest	156,530
Total Capital Cost	$4,069,790

Annual Cost

Debt service ($4,069,790 @ 8% for 30 years)	401,292
Labor (21 x $10,000)	210,000
Power (@ $0.02/KWH)	44,900
Taxes & insurance	79,000
Annual Dewatering Cost	$735,192

Ultimate disposal costs

59,050 metric tons/year (64,950 tons/year) of sludge at 40% solids has to be hauled 32 km (20 miles) using a 9.17 cu m (12 cu yd) truck.

Annual ultimate disposal cost = $439,559

Total cost

$/1000 cu m of water produced	($/MG)	$/metric ton of solids	($/dry ton)
$17.01	($64.37)	$19.89	($18.09)

g. Softening plants

In the softening category there are no plants greater than 113,550 cu m/day (30 MGD) indicated in the 1963 USPHS Survey. However, several large softening plants are known to exist now. Therefore, 3,785 cu m/day (1 MGD), 75,700 cu m/day (20 MGD), and 189,250 cu m/day (50 MGD) size plants will be evaluated.

Based on data in the 1963 USPHS Survey, the size range of 378.5 to 37,850 cu m/day (0.1 to 10 MGD) represents 98.4% of the total number of plants and 66.5% of the total water produced. The remainder are in the 37,850 to 75,700 cu m/day (10 to 20 MGD) category.

A hard, clear ground water of the following average composition is assumed:

Turbidity (JTU)	2
Hardness removed (mg/l) (as $CaCO_3$)	100

The following chemical dosages are assumed:

Lime (CaO) for the 75,700 cu m/day (20 MGD) and 189,250 cu m/day (50 MGD) plants	139 mg/l
Hydrated lime ($Ca(OH)_2$) for the 3,785 cu m/day (1 MGD) plant	184 mg/l

Hydrated lime ($Ca(OH)_2$) is used for the 3,785 cu m/day (1 MGD) plant. It is assumed that 1.9 parts of waste are produced for each part of hydrated lime fed. For the 75,700 cu m/day (20 MGD) and 189,250 cu m/day (50 MGD) plants, quick lime (CaO) is used, and 2.5 parts of solid waste are produced for each part of lime fed. Thus, 1314 kg (2,894 lb) of calcium carbonate are produced for each 3,785 cu m (1 MG) of water treated regardless of the form of lime used. Automatic sludge collection devices are assumed to be used in all plants.

i. Lagoon - 3,785 cu m/day (1 MGD) & 75,700 cu m/day (20 MGD) plants

Lagooning has been the selected method of dewatering the sludges from the 3,785 cu m/day (1 MGD) and the 75,700 cu m/day (20 MGD) plants in the softening subcategory. Two lagoons will be constructed for each plant size. It is assumed that each lagoon has sufficient capacity to store the wastes produced in three years by the 3,785 cu m/day (1 MGD) plant recycling filter backwash water, and the waste produced in 2 years by the plant not recycling backwash water. For the 75,700 cu m (20 MGD) plant each lagoon is assumed to be large enough to store the wastes produced in 6 months regardless of washwater disposition.

Capital Cost

	With Filter Backwash Recycle	Without Filter Backwash Recycle
Land purchase	12,200	12,200
Washwater holding basin	19,000	
Washwater piping	18,000	32,000
Valves & fittings (15%)	2,700	4,800
Recirculation pumping	5,000	
Lagoon construction	11,030	11,030
Inlet & outlet structures	2,000	2,000
pH control system	14,300	14,300
Yard piping & electrical (20%)	16,846	15,266
Engineering & contingencies (20%)	20,215	18,319
Construction interest	1,700	1,500
Total Capital Cost	$122,191	$114,415

Annual Cost

	With Filter Backwash Recycle	Without Filter Backwash Recycle
Debt service (@ 8% for 30 years)	10,932	9,903
Labor & maintenance (lagoon operations - contractual removal)	5,000	6,300
Labor (monitoring requirements) 3 hr/wk	858	858
Chemicals	40	75
Power	280	130
Taxes & insurance	2,459	2,288
Annual Dewatering Cost	$19,632	$19,554

Ultimate disposal cost

479 metric tons/year (528 tons/year) of sludge at 50% solids is to be hauled 16 km (10 miles) using a 9.17 cu m (12 cu yd) truck.

Annual ultimate disposal cost = $3,015/year

Total cost

$/1000 cu m of water treated ($/MG)			$/metric ton of solids	($/dry ton)
With filter backwash	$16.39	($62.05)	$47.29	($42.89)
Without filter backwash	$16.34	($61.83)	$47.13	($42.74)

ii. Lagoon - 75,700 cu m/day (20 MGD) plant

Capital Cost

	With Filter Backwash Recycle	Without Filter Backwash Recycle
Land purchase	35,000	40,000
Washwater holding	70,000	
Washwater piping	90,000	234,000
Valves & fittings (15%)	13,500	35,100
Recirculation pumping	5,000	
Lagoon construction	26,900	34,000
Inlet & outlet structures	4,000	4,000
pH control system	35,900	35,900
Yard piping & electrical (20%)	56,060	76,600
Engineering & contingencies (20%)	67,272	91,920
Construction interest	10,000	16,000
Total Capital Cost	$413,632	$567,520

Annual Cost

Debt service (@ 8% for 30 years)	36,742	50,097
Labor & maintenance (lagoon operations - contractual removal)	74,000	75,000
Labor (monitoring requirements) 3 hr/wk	858	858
Chemicals	2,920	5,256
Power	1,030	130
Taxes & insurance	8,273	11,350
Annual Dewatering Cost	$123,823	$142,691

Ultimate disposal cost

9,578 metric tons/year (10,560 tons/year) of sludge at 15% solids has to be hauled 16 km (10 miles) using a 9.17 cu m (12 cu yd) truck.

Annual ultimate disposal cost = $38,772

Total cost

$/1000 cu m of water treated ($/MG)			$/metric ton of solids	($/dry ton)
With filter backwash	$5.88	($22.27)	$16.98	($15.40)
Without filter backwash	$6.57	($24.86)	$18.95	($17.18)

iii. Centrifuge - 189,250 cu m/day (50 MGD)

Centrifugation is the method of choice assumed for illustrating the costs for dewatering the sludge from the 189,250 cu m/day (50 MGD) softening plant. The system is assumed to handle 23,945 metric tons (26,400 tons) of sludge annually. It is assumed that a thickener-clarifier will be provided to reduce the flow to the centrifuge, to allow storage, and to provide flexibility for the system. The thickener overflow is recycled to the washwater holding basin and from there to the intake of the plant. The centrifuge building provides the necessary plumbing, wiring and space for installation of a second centrifuge at a later date. The centrifuge is assumed to be capable of providing 60% overload capability without appreciable decrease in performance.

The purpose of this model is to present costs for a centrifuge operation. As previously mentioned in Section VII, centrifugation produces a liquid waste stream (centrate) of lesser quality than that from the other mechanical devices, and the centrate may not meet proposed standards. Further treatment or recycling may be required.

Capital Cost

Land	10,000
Washwater holding basin	70,000
Filter backwash recovery piping	90,000
Valves & fittings (15%)	13,500
Recirculation pumping	25,000
Thickener-clarifier	300,000
Centrifuge	53,000
Building with storage hopper for centrifuge cake	240,000
Piping (10%)	80,150
Electrical (20%)	176,330
Engineering & contingencies (20%)	211,596
Construction interest	43,000
Total Capital Cost	$1,312,576

Annual Cost

Debt service ($1,312,576 @ 8% for 20 years)	133,758
Labor & maintenance (1,725 man-hours)	9,500
Power	19,000
Taxes & insurance	26,251
Annual Dewatering Cost	$162,258

Ultimate disposal cost

23,945 metric tons/year (26,400 tons/year) of sludge at 50% solids has to be hauled 32 km (20 miles) using a 9.17 cu m (12 cu yd) truck.

Annual ultimate disposal cost = $142,931

Total cost

$/1000 cu m of water treated	($/MG)	$/metric ton of solids	($/dry ton)
$4.42	($16.72)	$12.75	($11.56)

iv. Lime recovery - 189,250 cu m/day (50 MGD)

For comparative purposes the costs for lime recovery are compared to the 189,250 cu m/day (50 MGD) model for dewatering and disposal of lime sludge. The lime kiln is assumed to be a rotary kiln rated at 54.4 metric tons/day (60 tons/day) of CaO, which will provide 50% excess capacity for future requirements. Operating and power costs are based on those shown earlier in this section. A credit of $30.93/metric ton CaO ($28/ton) is assumed for the lime recovered. The credit for carbon dioxide (for use in settled water stabilization) is assumed to be $16.52/metric ton ($15/ton) based on a plant usage of 2,512 metric tons (2,281 tons) each year.

Capital Cost

Land	20,000
Washwater holding basin	70,000
Filter backwash recovery piping	90,000
Valves & misc. fittings (15%)	13,500
Recirculation pumping	25,000
Thickener-clarifier	300,000
Centrifuge	53,000
Building with transfer conveyors, bins, etc.	275,000
lime kiln	800,000
Piping (10%)	164,650
Electrical (20%)	329,300
Engineering & contingencies (20%)	428,090
Construction interest	102,742
Total Capital Cost	$2,671,282

Annual Cost

Debt service ($2,671,282 @ 8% for 20 years)	272,226
Labor & maintenance	228,916
Power & fuel	153,457
Taxes & insurance	53,426
Annual Lime Recovery Cost	$608,025

Total annual cost for lime recalcination

$/Metric ton of sludge	($/ton)	$/Metric ton of CaO	($/ton)
$25.36	($23.03)	$44.29	($41.12)

Value of lime @ $30.87/metric ton CaO = $413,952/year ($28/ton)
Value of carbon dioxide @ $16.50/metric ton ($15/ton) $ 34,216/year
Total chemical recovery credit = $448,168/year

$/1000 cu m of water treated	($/MG)
$2.31	($8.76)

B. Reduction Benefits of Alternative Control and Treatment Technologies

The costs estimated in this section indicate that except for centrifugation of softening sludge the use of the technologies described in Section VII will result in a solids loading of less than 0.6 kg/1000 cu m (5 lb/MG) product, when recycle of the filter backwash is practiced. If recycle of filter backwash is not practiced, the load on the receiving water is nearly doubled, again excluding centrifugation of softening wastes. Table VIII-5 (a) through (c) presents the reduction benefits achieved by the treatment systems assumed for the models.

In Table VIII-6 the amount of total suspended solids now produced in this county by water treatment processes has been estimated. The solids produced per million gallons of water treated was determined from the data obtained for the 782 plants covered by our survey. The municipal water production

Table VIII-5 (a)

Reduction Benefits* Derived From Model Treatment of Wastes

Water Treatment Process-Coagulation

Model (size-waste treatment/ disposal)	Waste Produced Metric tons/year	(Tons)/(Year)	Waste Discharged to Receiving Waters Metric tons/year	(Tons)/(year)	kg/1000 cu m	(lbs)/(MG)	Reduction in loading %
3785 cu m - lagoon (1 MGD)							
Filter backwash recycled	62	(68)	0.03	(0.03)	0.02	(0.17)	99.96
Filter backwash not recycled	62	(68)	0.85	(0.94)	0.94	(7.85)	98.62
3785 cu m/day - sanitary sewer (1 MGD)	62	(68)	0		0		100
75,700 cu m/day - drying beds (20 MGD)							
Thickener recycle	1234	(1360)	2.04	(2.25)	0.08	(0.64)	99.83
Without thickener recycle	1234	(1360)	3.98	(4.39)	0.15	(1.25)	99.68
189,250 cu m/day - filter press (50 MGD)							
Thickener recycle	3084	(3400)	0		0		100
Without thickener recycle	3084	(3400)	6.35	(7.00)	0.10	(0.80)	99.79

*Benefits computed based on reduced solids loading to the receiving waters

Table VIII-5 (b)

Reduction Benefits* Derived From Model Treatment Of Wastes
Water Treatment Process-Coagulation-Softening

Model (size-waste Treatment/ Disposal	Waste Produced Metric tons/year	(Tons)/(year)	Metric tons/year	Waste Discharged To Receiving Waters (Tons)/(year)	kg/1000 cu m	(lb)/(MG)	Reduction in Loading %
3785 cu m/day - lagoon (1 MGD)							
Filter backwash recycled	1193	(1315)	0.66	(0.73)	0.51	(4.21)	99.94
Filter backwash not recycled	1193	(1315)	1.38	(1.52)	1.05	(8.77)	99.88
75,700 cu m/day - lagoon (20 MGD)							
Filter backwash recycled	23,854	(26,300)	13.20	(14.60)	0.51	(4.21)	99.94
Filter backwash not recycled	23,854	(26,300)	27.57	(30.40)	1.05	(8.77)	99.88
189,250 cu m/day - filter press (50 MGD)							
Filter backwash recycled and thickener recycled	59,635	(65,600)	8.86	(9.77)	0.13	(1.07)	99.99
Filter backwash and thickener not recycled	59,635	(65,600)	14.73	(16.24)	0.21	(1.78)	99.98

*Benefits computed based on reduced solids loading to the receiving waters

Table VIII-5 (c)

Reduction Benefits* Derived From Model Treatment Wastes
Water Treatment Process-Softening

Model (size-waste treatment/ disposal)	Waste Produced Metric tons/year	Waste Produced (Tons)/(year)	Waste Discharged to Receiving Waters Metric tons/year	Waste Discharged to Receiving Waters (Tons)/(year)	kg/1000 cu m	(lb)/(MG)	Reduction in loading %
3785 cu m/day - lagoon (1 MGD)							
Filter backwash recycled	479	(528)	0.66	(0.73)	0.51	(4.21)	99.94
Filter backwash not recycled	479	(528)	1.38	(1.52)	1.05	(8.77)	99.88
75,700 cu m/day - lagoon (20 MGD)							
Filter backwash recycled	9,578	(10,560)	13.20	(14.60)	0.51	(4.21)	99.94
Filter backwash not recycled	9,578	(10,560)	27.57	(30.40)	1.05	(8.77)	99.88
189,250 cu m/day - centrifuge (50 MGD)							
Filter backwash recycled	23,945	(26,400)	245.43	(270.59)	3.74	(31.21)	
Thickener and filter backwash recycled	23,945	(26,400)	239	(264)	3.65	(30.46)	99.00
189,250 cu m/day (50 MGD) Centrifuge & recalcination							
Filter backwash recycled Thickener recycled Centrate recycled	23,945	(26,400)	0		0		100

*Benefits computed based on reduced solid loading to the receiving waters

Table VIII-6

Calculations of Total Sludge Production

Category	kg/1000 cu m[a] (lb/MG)	Municipal[b] 1000 cu m per day (MGD)	Municipal[b] Metric tons per day (tons/day)	Industrial[c] 1000 cu m per day (MGD)	Industrial[c] Metric tons per day (tons/day)	Total 1000 cu m per day (MGD)	Total Metric tons per day (tons/day)
Coagulation	43.90 (366)	38,080.9 (10,061)	1,669.8 (1,841)	5,174.1 (1,367)	226.8 (250)	43,255.0 (11,428)	1,896.5 (2,091)
Softening	382.75 (3,191)	1,131.8 (299)	432.6 (477)	2,108.2 (557)	806.3 (889)	3,240.0 (856)	1,239.0 (1,366)
Iron removal	29.39 (245)	2,869.0 (758)	84.4 (93)			2,869.0 (758)	84.4 (93)
Coagulation Softening	236.54 (1,972)	8,501.1 (2,246)	2,009.0 (2,215)			8,501.1 (2,246)	2,009.0 (2,215)
All Categories		50,582.7 (13,364)	4,195.8 (4,624)	7,282.3 (1,924)	1,033.1 (1,139)	57,865.1 (15,288)	5,228.9 (5,765)

a) From data base developed in our survey
b) 1963 USPHS Survey
c) 1967 Census of Manufacturers, Water Use in Manufacturing

figures were estimated from data in the 1963 USPHS Survey. Industrial water production in the various treatment categories was estimated from data in the 1967 Census of Manufacturers, "Water Use in Industry."

The estimated total amount of suspended solids in the wastes from the water-supply industry is given in the last column of Table VIII-6. The data used in Table VIII-6 were the most recent data available. Thus the current total amount of suspended solids is undoubtedly greater. Rather than arbitrarily estimate the current total suspended solids, the value of 1,908,000 metric tons/year (2,104,000 tons/year) will be used.

The use of BPCTCA, as identified in Section IX, would reduce the amount of TSS discharged to 423 metric tons/year (465 tons/year).

There are numerous process configurations of the proposed treatment systems and with judicious water management zero discharge of water may be accomplished. The benefits gained by closing the cycle are not great as would be indicated by the last column of Table VIII-6. However, in some instances the additional costs are also relatively small. There are a number of water-treatment plants presently discharging no liquid wastes, which demonstrates the applicability of the discussed alternatives.

C. Non-water quality aspects

There are several non-water-quality aspects of the treatment and disposal of water plant wastes, and there are both benefits and liabilities as well as uncertainties involved. The areas in which the non-water-quality aspects will have their greatest impact are: land use, energy use, by-product generation and recovery, air pollution, noise, and odors. Each of these will be discussed in the following paragraphs.

1. Land Use

One of the more obvious impacts is the additional land required for installation of treatment systems. In some cases, the land requirements are minimal; but in others, such as drying beds and lagoons, the land requirements can be quite substantial, depending on the size of the plant, and the unit processes employed. Rather large land areas may be required for ultimate disposal of the dewatered sludge. These land requirements may prevent maximum beneficial land utilization and present an esthetically unpleasant site. The use of land in this way could also serve to reduce the tax base for the affected governmental unit, which in turn would reduce its gross revenues. However, use of the land for lagoons or landfills is not always a liability. Short-term liabilities such as ultimate disposal sites, abandoned quarries and strip mines, can and have been turned into long-term assets by proper planning and reclamation projects. Additionally, use of deep shaft mines and deep well injection of wastes have helped to alleviate subsidence problems in several areas. The effects of leachates from land application of these wastes is believed to be negligible, but this belief has not been confirmed.

2. Energy Use

The energy required to treat and dispose of the wastes from water treatment plants was estimated with the use of two models. The first model was an energy-intensive system with a mechanical dewatering device and recycle of filter backwash, filtrate, and centrate. The second model was an energy-conserving system in which there was no recycle, and lagoons were used to treat the waste. For both models wastes were generated by a hypothetical 75,7000 cu m/day (20 MGD) water-treatment plant. For the energy-intensive systems it was assumed that 64 km (40 mile) roundtrip was required for ultimate disposal, and for the conservative system it was assumed that a 32 km (20 mile) round trip was needed.

If it is assumed that there are 1.91 million metric tons (2.1 million tons) of dry waste generated annually, then the energy-intensive system would add approximately 373 million kwh to our existing energy budget. This figure represents less than 0.002% of the Nation's 1970 total energy consumption. Approximately 55% of this expenditure is utilized in ultimate disposal of the dewatered waste.

In the second system the energy expenditure for dewatering the waste in lagoons, cleaning the lagoons and ultimate disposal represents less than 0.0006% of the 1970 energy consumption. Almost all of the energy is utilized for removing and hauling the dewatered waste.

Based on the above estimates, the impact of the additional energy needed to properly treat and dispose of wastes from water-supply plants appears to be negligibly small.

3. By-Product Generation and Recovery

The use of these wastes to produce a saleable product outside the water industry has been proven feasible in a few isolated cases. More attention to this area is anticipated and recommended for the future. From an ecological and conservational standpoint, processes such as alum recovery, lime recovery, and magnesium carbonate recovery should be thoroughly evaluated.

4. Air Pollution Aspects

If all of the sludge to be disposed of were trucked 64 km (40 miles) roundtrip as specified in the energy intensive system then approximately 34.9 million km (21.7 x 10^6 miles) would be logged in disposing of the dewatered sludge. This would result in a total emission from gasoline-powered vehicles of 2,195 metric tons (2,421 tons) annually and would represent roughly 0.003% of the total 1965 automotive emissions. If all of the sludge were to be carried by diesel powered trucks the total annual emission would be reduced by approximately 40%.

Noise

Most water-treatment plants generate a fairly high level of noise (85-95 dB(A)) within battery limits because of such equipment as pumps, compressors, etc. Equipment associated with in-process, or end-of-pipe systems could produce similar levels, depending upon the device selected. If noise levels become too great they can be attenuated somewhat by protective devices (earplugs), walls, acoustical shields, and physical separation (sound levels decrease with the square of the distance from the source). Another source of noise pollution is from trucks hauling wastes. These levels can exceed those given above if uncontrolled, and could be a source of irritation to the people in the immediate vicinity.

Depending upon the frequency, 85 dB can be considered a critical level for ear damage. In California a noise limit has been set at 82 dB for highway traffic.

5. Odors

Some odor problems have been reported with lagooning operations, but this is not considered a serious problem as such operations are customarily in sparsely populated areas.

SECTION IX

BEST PRACTICABLE CONTROL TECHNOLOGY

CURRENTLY AVAILABLE--EFFLUENT LIMITATIONS

Effluent limitations commensurate with the best practicable control technology currently available (BPCTCA) have been established for each subcategory within the water-supply industry. These effluent limitations are based on the information presented in Sections III through VIII. Factors that were specifically considered include:

a. The total cost of application of technology in relation to the effluent reduction benefits to be achieved from such application.

b. The processes employed in water-treatment plants.

c. The processes employed for treatment of wastes.

d. The treatability of the wastes.

e. The engineering aspects of the application of various types of control techniques.

f. Changes in the processes, or sequence of processes used to treat water.

g. Non-water-quality environmental impact of the application of technology to reduce waste loadings with special emphasis on the requirements for energy.

The BPCTCA is based on both in-plant and end-of-pipe technology. BPCTCA in-plant technology is based on control practices widely known and used within the water-supply industry, and includes the following:

a. Equalization of filter backwash water to minimize periodic excursions of the volumetric flowrate to solids-separation devices.

b. Utilization of continuous effluent discharge instead of intermittent discharge.

c. Reclamation of lime where practicable.

d. Modification of existing lagoons to minimize scouring and short-circuiting.

The end-of-pipe treatment technology for BPCTCA is based on waste-treatment processes now in use in the water-supply industry, and includes lagooning, thickening, mechanical dewatering, disposal to sanitary sewers, drying beds, and land disposal. Because of differences in the treatability among sludges, pilot plant tests are almost always necessary before a specific treatment system can be selected for application in a given water treatment plant.

In a water-supply plant, the waste-treatment systems should be used to treat only polluted water. Unpolluted storm run-off water should be diverted from lagoons, since an increased flowrate into lagoons can increase the pounds of solids being discharged.

A. Procedure for Determining Effluent Limitations

The annual average wasteloads that are the basis for the effluent limitations guidelines to be used by plants that discharge wastes to a watercourse instead of discharging to a sanitary sewer were determined by the "flow-and-concentration" method. In this method the annual average concentration of a pollutant that can be attained reliably in the discharge from a properly designed and well operated waste-treatment system is determined. Then, the mean annual average wastewater flow from plants in each subcategory (expressed as a percentage of the product-water flow) is determined. The attainable annual average concentrations and the mean annual average wastewater flows expressed as a percentage of product water flow are used to calculate the effluent limtations for each pollutant and each subcategory. The effluent limitations are expressed in terms of kilograms of pollutant per thousand cubic meters of product water and in English units (lb/MG). Since the concentrations and waste flows are annual averages, the effluent limitations will be in terms of annual averages at this stage of the determination.

A long-term parameter, such as the annual average waste load, is not adequate in itself to establish short-term limits that should not be exceeded. However, the effluent limitations, which are short-term limits, can be established from annual averages by statistical analysis of the variations in waste loads, if the variations from day-to-day are known or measured over a sufficient period.

The methods used in this study to determine the attainable annual average concentrations of TSS in wastewaters, to find the mean annual average waste flows, and to statistically analyze the day-to-day variations in waste loads are described below.

The attainable annual average concentrations of TSS in wastewaters were established from studies of TSS concentrations in the effluents from lagoons. Since lagoons are used more often within the industry than other methods of solids-separation because of their low cost and low energy requirements, and since other means of solids separation result in lower loadings of TSS in the effluent than is attainable with lagoons, lagoons were considered the standard solids-separation method in the water-supply industry. Data on the loadings of TSS in effluents from lagoons were used for establishing effluent limitations. From existing reports and plant visits, 109 plants that use lagoons to treat sludges from water-treatment processes were identified. Interviews with personnel and studies of existing plant data were made during 66 visits to plants with lagoons, and a sampling program was conducted at 15 of these plants. Eleven of these 15 lagoons were judged to be well designed and operating properly. The concentration of TSS in the effluents from these 11 lagoons ranged from 3 mg/l to 34 mg/l. The average concentration of TSS in the effluents from these 11 lagoons was 11 mg/l. The data obtained during the sampling programs must be viewed with caution because the sampling was carried out, of necessity, only over a short period (a day or less). However, studies conducted by others over extended periods ranging to more than a year show that with well designed and properly operated lagoons an annual average TSS concentration of 20 mg/l can be maintained, which is in line with the data obtained in our short-term sampling programs.

The mean annual average waste flows expressed as a percentage of the flow of product water were determined for each subcategory by statistical analysis of the data on annual averages of the backwash flowrates, blowdowns from sedimentation basins and production rates of finished water. A combination of statistical techniques was used including determination of means and standard deviations, and the application of statistical "F" and "T" tests and multiple regression analyses to determine the factors that significantly affect the annual average waste flows.

For each subcategory, linear regression equations were developed that expressed the waste flow as a function of plant size (i.e., annual average production rate) and of raw water hardness, which were the only two factors found to have statistically significant effects on the waste flow. From these equations and the attainable concentration of TSS in wastewaters (20 mg/l) the following equation was developed.

Eq. IX-1a $L = 0.6 + S + H$
in which L is in kg/1000 cu m

Eq. IX-1b or $L = 5 + S + H$
in which L is in lb/MG

where: L = annual average waste load of TSS, kg/1000 cu m (lb/MG)

S = allowance for plant size, taken from Table IX-1 kg/1000 cu m (lb/MG)

H = allowance for hardness of raw water, taken from Table IX-1, kg/1000 cu m (lb/MG)

For all categories an annual average waste load of 0.6 kg/1000 cu m (5 lb/MG) of product is recommended for what is termed the "base-load" plant. The basis for the 0.6 kg/1000 cu m (5 lb/MG) waste load stems from the multiple regression analysis of the data. The base-load plant is a large plant [>1.89 million cu m/day (>500 MGD)] that does not use lime or lime-soda softening processes. For smaller plants an additional allowance for plant size, S, is recommended. The magnitude of the allowance depends on the plant size as shown in Table IX-1.

For plants in Category I lime or lime-soda softening is not performed. Therefore, no allowance is given for the hardness of the raw water, and only the size allowance, S, in Table IX-1 is applicable. For plants in Category II and III, in which lime or lime-soda softening is performed, the hardness allowance, H, in Table IX-1 is also used.

A long-term parameter, such as annual average TSS loading, is not adequate in itself to establish effluent guideline limits, which are short-term maxima that must not be exceeded. The quantity and quality of the effluent from a properly designed and well operated waste-treatment system changes continually for several reasons.

Table IX-1

Allowances to Adjust the Annual Average Waste Load for Plant Size and Raw Water Hardness

Plant size,[a] 1000 cu m/day	<3.8	3.8-11.4	11.4-38	38-114	114-379	379-1136	1136-1893	>1893
MGD	(<1)	(1-3)	(3-10)	(10-30)	(30-100)	(100-300)	(300-500)	(>500)
S(allowance), kg/1000 cu m	0.70	0.50	0.40	0.30	0.20	0.10	0.05	(0)
lb/MG	(5.8)	(4.2)	(3.3)	(2.5)	(1.7)	(0.8)	(0.4)	(0)
Hardness,[a] mg/l	0-100	100-200	200-300	300-400	400-500	500-600	600-700	
H(allowance), kg/1000 cu m	0.13	0.24	0.35	0.46	0.56	0.67	0.78	
lb/MG	(1.1)	(2.0)	(2.9)	(3.8)	(4.7)	(5.6)	(6.5)	

a) Annual average total hardness expressed as mg/l of $CaCO_3$

It should be emphasized that the variability factor that was developed from the available data on TSS loadings in the effluents from lagoons (i.e., V = 6.6) is presented here for tentative use because the maximum period of time for which there were data to establish the variability factor was three months. Additional data are being sought and a more definitive value of V may be designated when the additional data become available.

The pH ranges recommended as limitations for the three categories are:

Subcategory I - pH from 6.0 to 9.0
Subcategories II and III - pH from 6.0 to 10.5

Zeolite brines

If any water-treatment plant that uses the unit processes listed in Categories I, II, or III also uses either zeolite softening or zeolite iron and manganese removal, the spent brines may contain the following pollutants: total dissolved solids, dissolved iron, dissolved manganese, and fluoride. For the BPCTCA effluent guidelines, no across-the-board limitations are recommended for these pollutants because there is no adequately demonstrated control or treatment technology. However, it is recommended that segregation and equalization of the brines be practiced and that the following disposal technologies be considered for each plant on an individual basis: discharge to sewer, controlled dilution prior to discharge to a watercourse, deep-well injection, and discharge into the ocean.

SECTION X

BEST AVAILABLE TECHNOLOGY ECONOMICALLY ACHIEVABLE--EFFLUENT LIMITATIONS

The best available technology economically achievable (BATEA) was determined by identifying the very best control and treatment technology employed by a specific point source within the industrial category or subcategory.

The following factors were considered in determining BATEA technology:

a. The processes employed.

b. The engineering aspects of the application of various types of control techniques.

c. Process changes.

d. The cost of achieving the effluent/reduction resulting from application of BATEA technology.

e. The non-water-quality environmental impacts (including energy requirements).

With the best available technology economically achievable by 1983, the waste effluents from solids-separation systems are recycled for use as feed water, and spent brines from zeolite regeneration are segregated from other wastewaters, reclaimed, and reused for regeneration.

A number of water treatment plants recycle filter backwash water at present, and when the BPCTCA is promulgated, the discharges from solids-separation systems will have 20 mg/l of TSS on an annual average basis. The concentration of TSS in many raw waters used by water treatment plants often exceeds 20 mg/l so that the discharges from solids-separation systems will be an acceptable feed. Discussions have been given in the literature about the possibility of tastes and odors in product water resulting from recycling filter backwash water and lagoon effluents. However, in our survey and personal visits to plants, out of the 782 plants surveyed, 46 recycled backwash water, and none had difficulties with odors and tastes.

Spent zeolite brines have been reclaimed in a concentration and composition suitable for reuse as regeneration brines on a demonstration scale. The basic technology, which is lime-soda softening, has been in use to remove calcium and magnesium from waters for many years.

In 1983 the BATEA will be to recycle zeolite brines and effluents from solids-separation systems. The only discharges from these processes will be the rinse waters from the regeneration part of the cycle used in zeolite processes; dissolved solids concentrations in these rinse waters are not to exceed 4000 mg/l. The rinse waters will be equalized prior to discharge.

SECTION XI

NEW SOURCE PERFORMANCE STANDARDS AND PRETREATMENT STANDARDS

A. New Source Performance Standards

A new source is defined as "any source, the construction of which is commenced after the publication of the proposed regulations prescribing a standard of performance."

The technology and effluent limitations utilized for new sources should be that defined in Section IX as the Best Practicable Control Technology Currently Available. After the necessary developmental work is performed to demonstrate the reliability and acceptability of recycling the waterborne discharges from solids-separation systems and of reclaiming and reusing spent zeolite brines, the technology defined as best available technology economically achievable may eventually provide a more effective treatment system; the performance standards should then be revised accordingly.

B. Pretreatment Standards

The wastewater characteristics that could be incompatible with a well designed and operated publicly owned wastewater treatment plant are the suspended solids content and the pH of wastes from solids-separation units, and the TDS content and possible detrimental concentrations of heavy metals and fluoride in waste zeolite brines. To avoid malfunctions of the publicly owned wastewater treatment plants, a judgment should be made individually as to the levels of suspended solids, pH, TDS, heavy metals, and fluoride that should be allowed to enter a particular treatment system along with the normal municipal waste load. Consideration should be given to the concentrations of the above pollutants, the present municipal waste load, and the capacity of the treatment systems to insure that a proper degree of dilution is maintained.

SECTION XII

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SECTION XIII
GLOSSARY

Definitions and Terminology

Absorption: The taking up of one substance into the body of another.

Acre-foot: A volume of water 1 ft deep and 1 acre in area, or 43,560 cu. ft.

Activated carbon: Carbon particles usually obtained by carbonization of cellulosic material in the absence of air and possessing a high adsorptive capacity.

Adsorption: The adherence of a gas, liquid, or dissolved material to the surface of a solid.

Aeration: (1) The bringing about of more intimate contact between air and a liquid by one or more of the following methods: (a) spraying the liquid in the air, (b) bubbling air through the liquid, or (c) agitating the liquid to promote surface absorption of air. (2) The supplying of air to confined spaces under nappes, downstream from gates in conduits, etc., to relieve low pressures and to replenish air entrained and removed from such confined spaces by flowing water. (3) the relieving of the effects of cavitation by admitting air to the section affected.

Aerator: A device that promotes aeration.

Agglomeration: The coalescence of dispersed suspended matter into large flocs or particles which settle rapidly.

Algae: Primitive plants, one- or many-celled, usually aquatic, and capable of photosynthesis.

Alkali: Any of certain soluble salts, principally sodium, potassium, magnesium, and calcium, that have the property of combining with acids to form neutral salts and may be used in chemical processes such as water and wastewater treatment.

Alkaline water: (1) Water have a pH greater than 7.0. (2) Water high in percent sodium (approaching and exceeding 6.0), but relatively low in total dissolved solids.

Alkalinity: The capacity of water to neutralize acids, a property imparted by the water's content of carbonates, bicarbonates, hydroxides, and occasionally borates, silicates, and phosphates. It is expressed in milligrams per liter of equivalent calcium carbonate.

Alum: A common name, in the water and wastewater treatment field, for commercial-grade aluminum sulfate ($Al_2(SO_4)_3 \cdot 14H_2O$).

Amortization: (1) Gradual reduction, redemption, or liquidation of the balance of an account according to a specified schedule of times and amounts. (2) Provision for the extinguishment of a debt by means of a sinking fund.

Analysis: (1) The record of an examination of water or wastewater. (2) The resolution of complex problems, bodies, or liquids into their elements.

Anion: A negatively charged ion in an electrolyte solution, attracted to the anode under the influence of electric potential.

Annual flood: The maximum 24-hr average rate of flow occurring in a stream during any period of 12 consecutive months. It is the usual practice to consider the 12-month period as extending from October 1 of one year to September 30 of the following year.

Annual variation: The general pattern of a particular element throughout the year, obtained by plotting the normal values of the element for each month and connecting the points by a smooth curve.

Anode: Positive pole of an electrolytic system.

Arid: (1) A term applied to regions where precipitation is so deficient in quantity, or occurs at such times, that agriculture is impracticable without irrigation. (2) In climatology, a term applied to climates which have rainfall insufficient to support vegetation.

Artificial recharge: Replenishment of the groundwater supply by means of spreading basins, recharge wells, irrigation, or induced infiltration of surface water.

Assimilative capacity: The capacity of a natural body of water to receive: (a) wastewaters, without deleterious effects; (b) toxic materials, without damage to aquatic life or humans who consume the water; (c) BOD, within prescribed dissolved oxygen limits.

Back wash: The reversal of flow through a filter to wash clogging material out of the filtering medium and reduce conditions causing loss of head. Also called filter wash.

Backwashing: The operation of cleaning a filter by reversing the flow of liquid through it and washing out matter previously captured in it. Filters would include true filters such as sand and diatomaceous-earth types but not other treatment units such as trickling filters.

Basin: (1) A natural or artificially created space or structure, surface or underground, which has a shape and character of confining material that enable it to hold water. The term is sometimes used for a receptacle midway in size between a reservoir and a tank. (2) The surface area within a given drainage system. (3) A shallow tank or depression through which liquids may be passed or in which they are detained for treatment or storage.

Biochemical oxygen demand (BOD): (1) The quantity of oxygen used in the biochemical oxidation of organic matter in a specified time, at a specified temperature, and under specified conditions. (2) A standard test used in assessing wastewater strength.

Blowdown: (1) The removal of a portion of any process flow to maintain the constituents of the flow within desired levels. Process may be intermittent or continuous. (2) The water discharged from a boiler or cooling tower to dispose of accumulated salts.

Brine: Concentrated salt solution remaining after removal of distilled product; also, concentrated brackish, saline or sea waters containing more than 36,000 mg/l of total dissolved solids.

Broad-crested weir: A weir having a substantial width of crest in the direction parallel to the direction of flow of water over it. This type of weir supports the nappe for an appreciable length and produces no bottom contraction of the nappe. Also called wide-crested weir.

Buffer: Any of certain combinations of chemicals used to stabilize the pH values or alkalinities of solutions.

Carbonation: The diffusion of carbon dioxide gas through a liquid to render the liquid stable with respect to precipitation or dissolution of alkaline constituents.

Cathode: The pole of an electrolytic cell which attracts positively charged particles or ions (cation).

Cation: The ion in an electrolyte which carries the positive charge and which migrates toward the cathode under the influence of a potential difference.

Centrifugal dewatering of sludge: The partial removal of water from wastewater sludge by centrifugal action.

Centrifuge: A mechanical device in which centrifugal force is used to separate solids from liquids and/or to separate liquids of different densities.

Chemical coagulation: The destabilization and initial aggregation of colloidal and finely divided suspended matter by the addition of a floc-forming chemical.

Chemical gas feeder: A feeder for dispensing a chemical in the gaseous state. The rate is usually graduated in gravimetric terms. Such devices may have proprietary names.

Chemical oxygen demand (COD): A measure of the oxygen-consuming capacity of inorganic and organic matter present in water or wastewater. It is expressed in the amount of oxygen consumed from a chemical oxidant in a specific test. It does not differentiate between stable and unstable organic matter and thus does not necessarily correlate with biochemical oxygen demand. Also known as OC and DOC, oxygen consumed and dichromate oxygen consumed, respectively.

Chemical sludge: Sludge obtained by treatment of wastewater with chemicals.

Chlorine: An element ordinarily existing as a greenish-yellow gas about 2.5 times as heavy as air. At atmospheric pressure and a temperature of -30.1°F, the gas becomes an amber liquid about 1.5 times as heavy as water. The chemical symbol of chlorine is Cl, its atomic weight is 35.457, and its molecular weight is 70.914.

Cipolletti weir: A contracted weir of trapezoidal shape, in which the sides of the notch are given a slope of one horizontal to four vertical to compensate as much as possible for the effect of end contractions.

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

Clarifier: A unit of which the primary purpose is to secure clarification. Usually applied to sedimentation tanks or basins.

Clay: (1) Soil consisting of inorganic material the grains of which have diameters smaller than 0.002 mm. (2) A mixture of earthy matter formed by the decay of certain minerals. The composition of clays varies widely and dictates its use. It is sometimes used in water to aid coagulation and to remove tastes and odors.

Clear well: A reservoir for storage of filtered water of sufficient capacity to prevent the necessity of frequent variations in the rate of filtration with variations in demands.

Coagulant: A compound responsible for coagulation; a floc-forming agent.

Coagulant aid: Any chemical or substance used to assist or modify coagulation.

Coagulation: In water and wastewater treatment, the destabilization and initial aggregation of colloidal and finely divided suspended matter by the addition of a floc-forming chemical or by biological processes.

Coagulation basin: A basin used for the coagulation of suspended or colloidal matter, with or without the addition of a coagulant, in which the liquid is mixed gently to induce agglomeration with a consequent increase in settling velocity of particulates.

Coefficient of fineness: The ratio of suspended solids to turbidity; a measure of the size or particles causing turbidity, the particle size increasing with coefficient of fineness.

Colloids: (1) Finely divided solids which will not settle but may be removed by coagulation of biochemical action or membrane filtration; they are intermediate between true solutions and suspensions.

Combined water: Water held in chemical combination and remaining after hygroscopic water evaporates; it will not evaporate and is driven off only by heating.

Composite wastewater sample: A combination of individual samples of water or wastewater taken at selected intervals, generally hourly for some specified period, to minimize the effect of the variability of the individual sample. Individual samples may have equal volume or may be roughly proportional to the flow at time of sampling.

Conductance: A measure of the conducting power of a solution is expressed in mhos.

Conductivity bridge: A means of measuring conductivity whereby a conductivity cell forms one arm of a Wheatstone bridge, a standard fixed resistance forms another arm, and a calibrated slide wire resistance with end coils provides the remaining two arms. A high-frequency alternating current is supplied to the bridge.

Continuous sludge-removal tank: A sedimentation tank equipped to permit the continuous removal of sludge.

Contracted weir: A rectangular notched weir with a crest width narrower than the channel across which it is installed and with vertical sides, extending above the upstream water level, which produce a contraction in the stream of water as it leaves the notch.

Copper sulfate: A chemical prepared from copper and sulfuric acid and having the formula $CuSO_4 \cdot 5H_2O$. Usually used to control algal growths. Also called blue vitriol, blue copperas, bluestone, cupric sulfate.

Data: Records of observations and measurements of physical facts, occurrences, and conditions, reduced to written, graphical, or tabular form.

Decantation: Separation of a liquid from solids, or from a liquid of higher density, by drawing off the upper layer after the heavier material has settled.

Degree of treatment: A measure of the removal effected by treatment process with reference to solids, organic matter, BOD, bacteria, or other specified matter.

Demineralization: Reduction of the mineral content of water by a physical, chemical, or biological process; removal of salts.

Detention time: The theoretical time required to displace the contents of a tank or unit at a given rate of discharge (volume divided by rate of discharge).

Detergent: (1) Any of a group of synthetic, organic, liquid or water-soluble cleaning agents that are inactivated by hard water and have wetting-agent and emulsifying-agent properties but, unlike soap, are not prepared from fats and oils. (2) A similar substance that is soluble in oil and capable of holding insoluble foreign matter in suspension. (3) Any cleansing agent, including soap.

Dewater: (1) To extract a portion of the water present in a sludge or slurry. (2) To drain or remove water from an enclosure.

Dialysate: Stream being depleted of salt in electrodialysis.

Dialysis: The separation of a colloid from a substance in true solution by allowing the solution to diffuse through a semipermeable membrane.

Diatomaceous-earth filter: A filter used in water treatment, in which a built-up layer of diatomaceous earth serves as the filtering medium.

Diatomite: A type of earth composed of diatomic skeletons, used for filtering water and other liquids; diatomaceous earth.

Dilution: Disposal of wastewater or treated effluent by discharging it into a stream or body of water.

Discharge: (1) As applied to a stream or conduit, the rate of flow, or volume of water flowing in the stream or conduit at a given place and within a given period of time. (2) The passing of water or liquid through an opening or along a conduit or channel. (3) The rate of flow of water, silt, or other mobile substance which emerges from an opening, pump, or turbine, or passes along a conduit or channel, usually expressed as cubic feet per second, gallons per minute, or million gallons per day.

Disinfection: The art of killing the larger portion of microorganisms in or on a substance with the probability that all pathogenic bacteria are killed by the agent used.

Dissolved oxygen: The oxygen dissolved in water, wastewater, or other liquid, usually expressed in milligrams per liter, parts per million, or percent of saturation. Abbreviated DO.

Dissolved solids: Theoretically, the anhydrous residues of the dissolved constituents in water. Actually, the term is defined by the method used in determination. In water and wastewater treatment the Standard Methods tests are used.

Distillation: A process of evaporation and recondensation used for separating liquids into various fractions according to their boiling points or boiling ranges.

Distribution system: (1) A system of conduits and their appurtenances by which a water supply is distributed to consumers. The term applies particularly to the network or pipelines in the streets in a domestic water system.

Domestic consumption: The quantity, or quantity per capita, of water supplied in a municipality or district for domestic uses or purposes during a given period, usually one day. It is usually taken to include all uses included within the term municipal use of water and quantity wasted, lost, or otherwise unaccounted for.

Dose: (1) The quantity of substance applied to a unit quantity of liquid for treatment purposes. It can be expressed in terms of either volume or weight, e.g., pounds per million gallons, parts per million, grains per gallon, milligrams per liter, or grams per cubic meter. (2) Generally, a quantity of material applied to obtain a specific effect.

Drifting-sand filter: In the United States, an obsolete type of rapid sand filter in which the sand drifts from the point where it enters to the point where it is drawn off to be washed. This type of operation causes the sand to be removed continuously and returned clean with the raw water as the filter operates, there being no interruption in the operation of the filter for sand washing.

Drinking-water standards: (1) Standards prescribed by the U. S. Public Health Service for the quality of drinking water supplied to interstate carriers. (2) Standards prescribed by state or local jurisdictions for the quality of drinking water supplied from surface-water, groundwater, or bottled-water sources.

Dry feeder: A feeder for dispensing a chemical or other fine material in the solid state to water or wastewater at a rate controlled manually or automatically by the rate of flow. The constant rate may be either volumetric or gravimetric.

Dry suspended solids: The weight of the suspended matter in wastewater or other liquid after drying 1 hr. at 103°C.

Effluent: (1) A liquid which flows out of a containing space. (2) Wastewater or other liquid, partially or completely treated, or in its natural state, flowing out of a reservoir, basin, treatment plant, industrial treatment plant, or part thereof.

Electrodialysis: Process for removing ionized salts from water through the use of ion-selective ion-exchange membranes and an applied electrical potential.

Electrometric titration: A titration in which the end point is determined by observing the change of potential of an electrode immersed in the solution titrated.

Equalizing basin: A holding basin in which variations in flow and composition of a liquid are averaged. Such basins are used to provide a flow of reasonably uniform volume and composition to a treatment unit. Also called balancing reservoir.

Evaporation rate: The quantity of water, expressed in terms of depth of liquid water, evaporated from a given water surface per unit of time. It is usually expressed in inches depth per day, month, or year.

Ferric sulfate: A soluble iron salt, $Fe_2(SO_4)_3$ formed by reaction of ferric hydroxide and sulfuric acid or by reaction of iron and hot concentrated sulfuric acid. Also obtainable in solution by reaction of chlorine and ferrous sulfate.

Ferrous sulfate: A soluble iron salt, $FeSO_4 \cdot 7H_2O$, containing seven molecules of water. Sometimes called copperas, sugar of iron, green vitriol, iron vitriol.

Filter: A device or structure for removing solid or colloidal material, usually of a type that cannot be removed by sedimentation, from water, wastewater, or other liquid. The liquid is passed through a filtering medium, usually a granular material but sometimes finely woven cloth, unglazed porcelain, or specially treated paper. There are many types of filters used in water or wastewater treatment.

Filtering medium: (1) Any material through which water, wastewater, or other liquid is passed for the purpose of purification, treatment or conditioning. (2) A cloth or metal material of some appropriate design used to intercept sludge solids in sludge filtration.

Filter plant: In water treatment works, the processes, devices, and structures used for filtration of water.

Filter press: A press operated mechanically for partially separating water from solid materials.

Filter rate: The rate of application of material to some process involving filtration, for example, application of wastewater sludge to a vacuum filter, wastewater flow to a trickling filter, water flow to a rapid sand filter.

Filter run: (1) The interval between the cleaning and washing operations of a rapid sand filter. (2) The interval between the changes of the filter medium on a sludge-dewatering filter.

Filter wash: The reversal of flow through a rapid sand filter to wash clogging material out of the filtering medium and reduce conditions causing loss of head.

Filtrate: The liquid which has passed through a filter.

Filtration: The process of passing a liquid through a filtering medium (which may consist of granular material, such as sand, magnetite, or diatomaceous earth, finely woven cloth, unglazed porcelain, or specially prepared paper) for the removal of suspended or colloidal matter.

Filtration rate: The rate of application of wastewater to a filter, usually expressed in million gallons per acre per day or gallons per minute per square foot.

Flash mixer: A device for quickly dispersing chemicals uniformly throughout a liquid.

Floc: Small gelatinous masses formed in a liquid by the reaction of a coagulant added thereto, through biochemical process, or by agglomeration.

Flocculation: In water and wastewater treatment, the agglomeration of colloidal and finely divided suspended matter after coagulation by gentle stirring by either mechanical or hydraulic means.

Flocculation agent: A coagulating substance which, when added to water, forms a flocculent precipitate which will entrain suspended matter and expedite sedimentation; examples are alum, ferrous sulfate, and lime.

Flocculator: (1) A mechanical device to enhance the formation

Effluent: (1) A liquid which flows out of a containing space. (2) Wastewater or other liquid, partially or completely treated, or in its natural state, flowing out of a reservoir, basin, treatment plant, industrial treatment plant, or part thereof.

Electrodialysis: Process for removing ionized salts from water through the use of ion-selective ion-exchange membranes and an applied electrical potential.

Electrometric titration: A titration in which the end point is determined by observing the change of potential of an electrode immersed in the solution titrated.

Equalizing basin: A holding basin in which variations in flow and composition of a liquid are averaged. Such basins are used to provide a flow of reasonably uniform volume and composition to a treatment unit. Also called balancing reservoir.

Evaporation rate: The quantity of water, expressed in terms of depth of liquid water, evaporated from a given water surface per unit of time. It is usually expressed in inches depth per day, month, or year.

Ferric sulfate: A soluble iron salt, $Fe_2(SO_4)_3$ formed by reaction of ferric hydroxide and sulfuric acid or by reaction of iron and hot concentrated sulfuric acid. Also obtainable in solution by reaction of chlorine and ferrous sulfate.

Ferrous sulfate: A soluble iron salt, $FeSO_4 \cdot 7H_2O$, containing seven molecules of water. Sometimes called copperas, sugar of iron, green vitriol, iron vitriol.

Filter: A device or structure for removing solid or colloidal material, usually of a type that cannot be removed by sedimentation, from water, wastewater, or other liquid. The liquid is passed through a filtering medium, usually a granular material but sometimes finely woven cloth, unglazed porcelain, or specially treated paper. There are many types of filters used in water or wastewater treatment.

Filtering medium: (1) Any material through which water, wastewater, or other liquid is passed for the purpose of purification, treatment or conditioning. (2) A cloth or metal material of some appropriate design used to intercept sludge solids in sludge filtration.

Filter plant: In water treatment works, the processes, devices, and structures used for filtration of water.

Filter press: A press operated mechanically for partially separating water from solid materials.

Filter rate: The rate of application of material to some process involving filtration, for example, application of wastewater sludge to a vacuum filter, wastewater flow to a trickling filter, water flow to a rapid sand filter.

Filter run: (1) The interval between the cleaning and washing operations of a rapid sand filter. (2) The interval between the changes of the filter medium on a sludge-dewatering filter.

Filter wash: The reversal of flow through a rapid sand filter to wash clogging material out of the filtering medium and reduce conditions causing loss of head.

Filtrate: The liquid which has passed through a filter.

Filtration: The process of passing a liquid through a filtering medium (which may consist of granular material, such as sand, magnetite, or diatomaceous earth, finely woven cloth, unglazed porcelain, or specially prepared paper) for the removal of suspended or colloidal matter.

Filtration rate: The rate of application of wastewater to a filter, usually expressed in million gallons per acre per day or gallons per minute per square foot.

Flash mixer: A device for quickly dispersing chemicals uniformly throughout a liquid.

Floc: Small gelatinous masses formed in a liquid by the reaction of a coagulant added thereto, through biochemical process, or by agglomeration.

Flocculation: In water and wastewater treatment, the agglomeration of colloidal and finely divided suspended matter after coagulation by gentle stirring by either mechanical or hydraulic means.

Flocculation agent: A coagulating substance which, when added to water, forms a flocculent precipitate which will entrain suspended matter and expedite sedimentation; examples are alum, ferrous sulfate, and lime.

Flocculator: (1) A mechanical device to enhance the formation of floc in a liquid. (2) An apparatus for the formation of floc in water and wastewater.

Flow: (1) The movement of a stream of water or other mobile substance from place to place; a stream of water; movement of silt, water, sand, or other material. (2) The fluid which is in motion. (3) The quantity or rate of movement of a fluid; discharge; total quantity carried by a stream. (4) To issue forth or discharge.

Grab sample: A single sample of wastewater taken at neither set time nor flow.

Grain per gallon: A measure of the concentration of solutions, equal to 17.1 mg/l.

Gravity filter: A rapid sand filter of the open type, the operating level of which is placed near the hydraulic grade line of the influent and through which the water flows by gravity.

Greensand: Sand consisting entirely or in large part of particles of the mineral glauconite, a hydrous potassium iron silicate. At one time used extensively in water-softening processes.

Groundwater: (1) Subsurface water occupying the saturation zone, from which wells and springs are fed. In a strict sense the term applies only to water below the water table. Also called phreatic water, plerotic water.

Hardness: A characteristic of water, imparted by salts of calcium, magnesium, and iron such as bicarbonates, carbonates, sulfates, chlorides and nitrates, that cause curdling of soap and increased consumption of soap, deposition of scale in boilers, damage in some industrial processes, and sometimes objectionable taste. It may be determined by a standard laboratory procedure or computed from the amounts of calcium and magnesium as well as iron, aluminum, manganese, barium, strontium, and zinc, and is expressed as equivalent calcium carbonate.

Head: (1) The height of the free surface of liquid above any point in a hydraulic system; a measure of the pressure or force exerted by the fluid. (2) The energy, either kinetic or potential, possessed by each unit weight of a liquid, expressed as the vertical height through which a unit weight would have to fall to release the average energy possessed. It is used in various compound terms such as pressure head, velocity head, and loss of head.

Heavy metals: Metals that can be precipitated by hydrogen sulfide in acid solution, for example, lead, silver, gold, mercury, bismuth, copper.

Hydrologic cycle: The circuit of water movement from the atmosphere to the earth and return to the atmosphere through various stages or processes such as precipitation, interception, runoff, infiltration, percolation, storage, evaporation, and transpiration. Also called water cycle.

Imhoff cone: A cone-shaped graduated glass vessel used to measure the appproximate volume of settleable solids in various liquids of wastewater origin during various settling times.

Impoundment: A pond, lake, tank, basin, or other space, either natural or created in whole or in part by the building of engineering structures, which is used for storage, regulation, and control of water.

Ion: A charged atom, molecule, or radical, the migration of which affects the transport of electricity through an electrolyte or, to a certain extent, through a gas. An atom or molecule that has lost or gained one or more electrons. By such ionization it becomes electrically charged. An example is the alpha particle.

Ion exchange: (1) A chemical process involving reversible interchange of ions between a liquid and a solid but no radical change in structure of the solid. (2) A chemical process in which ions from two different molecules are exchanged.

Ion-exchange treatment: The use of ion-exchange materials such as resin or zeolites to remove undesirable ions from a liquid and substitute acceptable ions.

Ionization: The process of adding electrons to, or removing electrons from, atoms or molecules, thereby creating ions. High temperatures, electrical discharges, and nuclear radiation may cause ionization.

Lagoon: (1) A shallow body of water, as a pond or lake, containing raw or partially treated wastewater.

Lagooning: The placement of solid or liquid material in a basin, reservoir, or artificial impoundment for purposes of storage, treatment, or disposal.

Land disposal: Disposal of wastewater onto land.

Lime: Any of a family of chemicals consisting essentially of calcium hydroxide made from limestone (calcite) which is composed almost wholly of calcium carbonate or a mixture of calcium and magnesium carbonate.

Lime and soda-ash process: A process for softening water by the addition of lime and soda ash to form the insoluble compounds of calcium carbonate and magnesium hydroxide.

Lime-soda softening: A process whereby calcium and magnesium ions are precipitated from water by reaction with lime and soda ash.

Liquor: Water, wastewater, or any combination; commonly used to designate liquid phase when other phases are present.

Loss of head: (1) The decrease in energy head between two points resulting from friction, bends, obstructions, expansions, or any other cause. It does not include changes in the elevation of the hydraulic grade line unless the hydraulic and energy grade lines parallel each other. (2) The difference between the total heads at two points in a hydraulic system.

Loss-of-head gage: A gage, on a rapid sand filter, that indicates the loss of head involved in the filtering operation, whereby the operator is able to ascertain the need for filter washing. Some gages are of the indicating-recording type.

Median: In a statistical array, the value having as many cases larger in value as cases smaller in value.

Membrane filter: A filter made of plastic with a known pore diameter. It is used in bacteriological examination of water.

Membrane selectivity: Ability of a membrane to allow passage of only cations or anions. Usually expressed as a fraction, with 1.0 being the ideal value.

Methyl-orange alkalinity: A measure of total alkalinity of an aqueous suspension or solution. It is measured by the quantity of sulfuric acid required to bring the water pH to a value of 4.3, as indicated by the change in color of methyl orange. It is expressed in milligrams $CaCO_3$ per liter.

Milligrams per liter: A unit of concentration of water in wastewater constituent. It is 0.001 g of the constituent in 1,000 ml. of water. It has replaced the unit formerly used commonly, parts per million, to which it is approximately equivalent, in reporting the results in water and wastewater analysis.

Navigable water: Any stream, lake, arm of the sea, or other natural body of water that is actually navigable and that, by itself or by its connections with other waters, is of sufficient capacity to float watercraft for the purposes of commerce, trade, transportation, or even pleasure for a period long enough to be of commercial value; or any waters that have been declared navigable by the Congress of the United States.

Neutralization: Reaction of acid or alkali with the opposite reagent until the concentrations of hydrogen and hydroxyl ions in the solution are approximately equal.

Nonionic surfactant: A general family of surfactants so called because in solution the entire molecule remains associated. Nonionic molecules orient themselves at surfaces not by an electrical charge, but through separate grease-solubilizing and water-soluble groups within the molecule.

Optimum point of coagulation: The hydrogen-ion concentration (pH value) at which the best floc occurs in the shortest time in the coagulation process.

Osmosis: The process of diffusion of a solvent through a semi-permeable membrane from a solution of lower to one of higher concentration.

Oxidation: The addition of oxygen to a compound. More generally, any reaction which involves the loss of electrons from an atom.

Oxidizable salt: A salt occurring in solution in groundwater, such as ferrous sulfate or carbonate or the corresponding salts of iron and manganese, that may be oxidized to other forms and that is deposited from solution upon exposure to air or to dissolved oxygen in surface water.

Parshall flume: A calibrated device developed by Parshall for measuring the flow of liquid in an open conduit. It consists essentially of a contracting length, a throat, and an expanding length. At the throat is a sill over which the flow passes at Belanger's critical depth. The upper and lower heads are each measured at a definite distance from the sill. The lower head need not be measured unless the sill is submerged more than about

67 percent.

Parts per million: The number of weight or volume units of a minor constituent present with each one million units of the major constituent of a solution or mixture. Formerly used to express the results of most water and wastewater analyses, but more recently replaced by the ratio milligrams per liter.

Percolation: (1) The flow or trickling of a liquid downward through a contact or filtering medium. The liquid may or may not fill the pores of the medium. Also called filtration. (2) The movement or flow of water through the interstices or the pores of a soil or other porous medium. (3) The movement of groundwater in streamline flow in any direction through small interconnected and saturated interstices of rock or earth, principally of capillary size. (4) The water lost from an unlined conduit through its sides and bed.

Permeability: The property of a material that permits appreciable movement of water through it when it is saturated and the movement is actuated by hydrostatic pressure of the magnitude normally encountered in natural subsurface water. Perviousness is sometimes used in the same sense as permeability.

pH: The reciprocal of the logarithm of the hydrogen-ion concentration. The concentration is the weight of hydrogen ions, in grams, per liter of solution. Neutral water, for example, has a pH value of 7 and a hydrogen-ion concentration of 10^{-7}.

Phenolphthalein alkalinity: A measure of the hydroxides plus one half of the normal carbonates in aqueous suspension. Measured by the amount of sulfuric acid required to bring the water to a pH value of 8.3, as indicated by a change in color of phenolphthalein. It is expressed in parts per million of calcium carbonate.

Postchlorination: The application of chlorine to water or wastewater subsequent to any treatment, including prechlorination.

Potable water: Water that does not contain objectional pollution, contamination, minerals, or infective agents and is considered satisfactory for domestic consumption.

Potassium permanganate: A purple crystalline salt of potassium and manganese used as an oxidizing agent for tastes and odors or for iron or manganese removal ($KMnO_4$).

Prechlorination: The application of chlorine to water or wastewater prior to any treatment.

Precipitate: (1) To condense and cause to fall as precipitation as water vapor condenses and falls as rain. (2) The separation from solution as a precipitate. (3) The substance precipitated.

Precipitation: (1) The total measurable supply of water received directly from clouds as rain, snow, hail, or sleet, usually expressed as depth in a day, month, or year, and designated as daily, monthly, or annual precipitation. (2) The process by which atmospheric moisture is discharged onto a land or water surface. (3) The phenomenon that occurs when a substance held in solution in a liquid passes out of solution into solid form.

Presettling: The process of sedimentation applied to a liquid before subsequent treatment.

Pressure filter: A rapid sand filter of the closed type, having a vertical or horizontal cylinder of iron, steel, wood, or other material inserted in a pressure line.

Private water supply: A water supply not available to the general public because it is located on or has outlets on private property to which the public does not have access or legal right of entry.

Rapid sand filter: A filter for the purification of water, in which water that has been previously treated, usually by coagulation and sedimentation, is passed downward through a filtering medium. The medium consists of a layer of sand, prepared anthracite coal, or other suitable material, usually 24-30 in. thick, resting on a supporting bed of gravel or a porous medium such as carborundum. The filtrate is removed by an underdrainage system which also distributes the wash water. The filter is cleaned periodically by reversing the flow of the water upward through the filtering medium, sometimes supplementing by mechanical or air agitation during washing, to remove mud and other impurities which have lodged in the sand. It is characterized by a rapid rate of filtration, commonly from two to three gallons per minute per square foot of filter area.

Raw wastewater: Wastewater before it receives any treatment.

Raw water: (1) Untreated water; usually water entering the first treatment unit of a water treatment plant. (2) Water used as a source of water supply taken from a natural or impounded body of water, such as a stream, lake, pond, or underground aquifer.

Recarbonation: (1) The process of introducing carbon dioxide as a final stage in the lime-soda ash softening process in order to convert carbonates to bicarbonates and thereby stabilize the solution against precipitation of carbonates. (2) The diffusion of carbon dioxide gas through liquid to replace the carbon dioxide removed by the addition of lime. (3) The diffusion of carbon dioxide gas through a liquid to render the liquid stable with respect to precipitation of dissolution of alkaline constituents.

Receiving body of water: A natural watercourse, lake, or ocean into which treated or untreated wastewater is discharged.

Recharge: Addition of water to the zone of saturation from precipitation, infiltration from surface streams, and other sources.

Recharge well: A well constructed to conduct surface water or other surplus water into an aquifer to increase the groundwater supply. Sometimes called diffusion well.

Recycling: An operation in which a substance is passed through the same series of processes, pipes, or vessels more than once.

Regeneration: (1) In ion exchange, the process of restoring an ion-exchange material to the state employed for adsorption. (2) The periodic restoration of exchange capacity of ion-exchange media used in water treatment.

Regeneration efficiency: In ion exchange, regeneration level divided by breakthrough capacity.

Reservoir: A pond, lake, tank, basin, or other space, either natural or created in whole or in part by the building of engineering structures, which is used for storage, regulation, and control of water. Sometimes called impoundment.

Revolving screen: A screen or rack in the form of a cylinder or continuous belt, which is revolved mechanically. The screenings are removed by water jets or automatic scrapers, or manually.

Saline water: Water containing dissolved salts--usually from 10,000 to 33,000 mg/l.

Sanitary sewer: A sewer that carries liquid and water-carried wastes from residences, commercial buildings, industrial plants, and institutions, together with minor quantities of ground-, storm, and surface waters that are not admitted intentionally.

Schmutzdecke: A "dirty skin" or layer of flocculent material that forms on the surface of a sand filter.

Screen: A device with openings, generally of uniform size, used to retain or remove suspended or floating solids in flowing water or wastewater and to prevent them from entering an intake or passing a given point in a conduit. The screening element may consist of parallel bars, rods, wires, grating wire mesh, or perforated plate, and the openings may be of any shape, although they are usually circular or rectangular.

Sedimentation: The process of subsidence and deposition of suspended matter carried by water, wastewater, or other liquids, by gravity. It is usually accomplished by reducing the velocity of the liquid below the point at which it can transport the suspended material. Also called settling.

Sedimentation basin: A basin or tank in which water or wastewater containing settleable solids is retained to remove by gravity a part of the suspended matter. Also called sedimentation tank, settling basin, settling tank.

Sediment concentration: The ratio of the weight of the sediment in a water-sediment mixture to the total weight of the mixture. Sometimes expressed as the ratio of the volume of sediment to the volume of mixture. It is dimensionless and is usually expressed in percentage, for high values of concentration in parts per million for low values.

Sequestering agent: A chemical that causes the coordination complex of certain phosphates with metallic ions in solution so that they may no longer be precipitated. Hexametaphosphates are an example: calcium soap precipitates are not produced from hard water treated with them. Also, any agent that prevents an ion from exhibiting its usual properties because of close combination with an added material.

Settleable solids: (1) That matter in wastewater which will not stay in suspension during a preselected settling period, such as one hour, but either settles to the bottom or floats to the top. (2) In the Imhoff cone test, the volume of matter that settles to the bottom of the cone in one hour.

Settling tank: A basin or tank in which water or wastewater containing settleable solids is retained to remove by gravity a part of the suspended matter. Also called sedimentation basin, sedimentation tank, settling basin.

Slow sand filter: A filter for the purification of water in which water without previous treatment is passed downward through a filtering medium consisting of a layer of sand or other suitable material, usually finer than for a rapid sand filter and from 24 to 40 in. thick. The filtrate is removed by an underdrainage system and the filter is cleaned by scraping off and replacing the clogged layer. It is characterized by a slow rate of filtration, commonly 3-6 mgd/acre of filter area.

Sludge: (1) The accumulated solids separated from liquids, such as water or wastewater, during processing, or deposits on bottoms of streams or other bodies of water. (2) The precipitate resulting from chemical treatment, coagulation, or sedimentation of water or wastewater.

Sludge cake: The sludge that has been dewatered by a treatment process, the moisture content depending on type of sludge and manner of treatment.

Sludge collector: A mechanical device for scraping the sludge on the bottom of a settling tank to a sump from which it can be drawn.

Sludge dewatering: The process of removing a part of the water in sludge by any method such as draining, evaporation, pressing, vacuum filtration, or centrifuging. It involves reducing from a liquid to a solid condition rather than merely changing the density of the liquid (concentration) on the one hand or drying (as in a kiln) on the other.

Sludge dryer: A device for removal of a large percentage of moisture from sludge or screenings by heat.

Sludge filter: A device in which wet sludge is partly dewatered by means of vacuum or pressure.

Sludge solids: Dissolved or suspended solids in sludge.

Sodium carbonate: A salt used in water treatment to increase the alkalinity or pH value of water or to neutralize acidity. Chemical symbol is Na_2CO_3. Also called soda ash.

Sodium hexametaphosphate: Graham's salt; sodium 1:1 phosphate glass; sodium polyphosphate; glassy sodium phosphate. The molecule is currently considered to be an amorphous linear polymer of more than six units; in the past $(NaPO_3)_6$ has been given as the formula. It is soluble in water and insoluble in organic solvents. In general, it is used as a sequestering, dispersing, and deflocculating agent.

Sodium hydroxide: A strong caustic chemical used in treatment processes to neutralize acidity, increase alkalinity, or to raise the pH value. Also known as caustic soda, sodium hydrate, lye, and white caustic. Chemical symbol is NaOH.

Soft water: Water having a low concentration of calcium and magnesium ions. According to U.S. Geological Survey criteria, soft water is water having a hardness of 60 mg/l or less.

Soil porosity: The percentage of the soil (or rock) volume that is not occupied by solid particles, including all pore space filled with air and water. The total porosity may be calculated from the formula:

Percent pore space = (1 - volume weight/specific gravity) x 100

Split treatment: The treatment of as large a part of water as possible by water softening and the subsequent neutralization of excess calcium hydroxide with untreated water or with water treated in a different manner.

Sump: (1) A tank or pit that receives drainage and stores it temporarily, and from which the drainage is pumped or ejected. (2) A tank or pit that receives liquids.

Sump pump: A mechanism used for removing water or wastewater from a sump or wet well; it may be energized by air, water, steam, or electric motor. Ejectors and submerged centrifugal pumps, either float- or manually controlled, are often used for the purpose.

Supernatant: The liquid standing above a sediment or precipitate.

Surface wash: A supplementary method of washing the filtering medium of a rapid sand filter by applying water under pressure at or near the surface of the sand by means of a system of stationary or rotating jets.

Suspended solids: (1) Solids that either float on the surface of, or are in suspension in, water, wastewater, or other liquids, and which are largely removable by laboratory filtering. (2) The quantity of material removed from wastewater in a laboratory test, as prescribed in "Standard Methods for Examination of Water and Wastewater" and referred to as nonfilterable residue.

Titration: The determination of constituent in a known volume of solution by the measured addition of a solution of known strength to completion of the reaction as signalled by observation of an end point.

Total solids: The sum of dissolved and undissolved constituents in water or wastewater, usually stated in milligrams per liter.

Turbidimeter: An instrument for measurement of turbidity, in which a standard suspension usually is used for reference.

Turbidity: (1) A condition in water or wastewater caused by the presence of suspended matter, resulting in the scattering and absorption of light rays. (2) A measure of fine suspended matter in liquids. (3) An analytical quantity usually reported in arbitrary turbidity units determined by measurements of light diffraction.

Unaccounted-for water: Water taken from a source into a distribution system that is not delivered to the consumers or otherwise accounted for.

Volatile solids: The quantity of solids in water, wastewater, or other liquids, lost on ignition of the dry solids at 600°C.

Wash water: Water used to wash filter beds in a rapid sand filter.

Wash-water gutter: A trough or gutter used to carry away the water that has washed the sand in a rapid sand filter. Also called wash-water trough.

Wash-water rate: The rate at which wash water is applied to a rapid sand filter during the washing process. Usually expressed as the rise of water in the filter in inches per minute or gallons per minute per square foot.

Wash-water tank: An elevated tank at a rapid sand filtration plant, into which water is pumped at a rate such that the tank will be filled between washings and set at a height such that the wash water will have a pressure of about 15 psi at the strainers.

Waste: Something that is superfluous or rejected; something that can no longer be used for its originally intended purpose.

Wastewater disposal: The act of disposing of wastewater by any method. Not synonymous with wastewater treatment.

Wastewater outfall: The outlet or structure through which wastewater is finally discharged.

Wastewater reclamation: Processing of wastewater for reuse.

Wastewater treatment: Any process to which wastewater is subjected in order to remove or alter its objectional constituents and thus render it less offensive or dangerous.

Watercourse: (1) A natural or artificial channel for passage of water. (2) A running stream of water. (3) A natural stream fed from permanent or natural sources, including rivers, creeks, runs, and rivulets. There must be a stream, usually flowing in a particular direction (though it need not flow continuously) in a definite channel, having a bed or banks and usually discharging into some other stream or body of water.

Water quality: The chemical, physical, and biological characteristics of water with respect to its suitability for a particular purpose. The same water may be of good quality for one purpose or use, and bad for another, depending on its characteristics and the requirements for the particular use.

Water softening: The process of removing from water, in whole or in part, those cations which produce hardness.

Water supply: (1) In general, the sources of water for public or private uses. When U.S. Public Health Service and state standards have been met, the supply is termed "an approved water supply." (2) The furnishing of a good potable water under satisfactory pressure for domestic, commercial, industrial, and public service, and an adequate quantity of water under reasonable pressure for fire fighting.

Water supply facilities: The works, structures, equipment, and processes required to supply and treat water for domestic, industrial, and fire use.

Water supply source: A stream, lake, spring, or aquifer from which a supply of water is or can be obtained.

Water supply system: (1) Collectively, all property involved in a water utility, including land, water source, collection systems, dams and hydraulic structures, water lines and appurtenances, pumping system, treatment works, and general properties. (2) In plumbing, the water distribution system in a building or complex of buildings, including appurtenances.

Water system: Collectively, all of the property involved in the operation of a water utility, including land, water lines and appurtenances, pumping stations, treatment plants, and general property.

Water treatment: The filtration or conditioning of water to render it acceptable for a specific use.

Waterway: (1) Any body of water, other than the open sea, that is or can be used by boats as a means of travel. (2) Any natural or artificial channel or depression in the surface of the earth that provides a course for water flowing either continuously or intermittently.

Weir: A device that has a crest and some side containment of known geometric shape, such as a V, trapezoid, or rectangle, and is used to measure flow of liquid. The liquid surface is exposed to the atmosphere. Flow is related to upstream height of water above the crest, to position of crest with respect to downstream water surface, and to geometry of the weir opening.

Well: (1) An artificial excavation that derives water from the interstices of the rocks or soil which it penetrates. (2) A shaft or hole into which water may be conducted by ditches to drain other portions of a piece of work.

Well field: A tract of land containing a number of wells.

Zeolite: A group of hydrated aluminum complex silicates, either natural or synthetic, with cation-exchange properties.

Zeolite filter: In water softening, a filter designed to remove certain chemical constituents from water by base exchange, where the zeolite takes the place of the filtering medium.

Zeolite process: The process of softening water by passing it through a substance known in general as a zeolite, which exchanges sodium ions for hardness constituents in the water.

TABLE 14

CONVERSION FACTORS

Multiply (English Units)		by		To Obtain (Metric Units)
English Unit	Abbreviation	Conversion	Abbreviation	Metric Unit
acre	ac	0.405	ha	hectares
acre - feet	ac ft	1233.5	cu m	cubic meters
barrel (376 lb)	bbl	0.207	kkg	metric tons
British Thermal Unit	BTU	0.252	kg cal	kilogram - calories
British Thermal Unit/pound	BTU/lb	0.555	kg cal/kg	kilogram calories/kilogram
cubic feet/minute	cfm	0.028	cu m/min	cubic meters/minute
cubic feet/second	cfs	1.7	cu m/min	cubic meters/minute
cubic feet	cu ft	0.028	cu m	cubic meters
cubic feet	cu ft	28.32	l	liters
cubic inches	cu in	16.39	cu cm	cubic centimeters
degree Fahrenheit	°F	0.555(°F-32)[1]	°C	degree Centigrade
feet	ft	0.3048	m	meters
gallon	gal	3.785	l	liters
gallon/minute	gpm	0.0631	l/sec	liters/second
horsepower	hp	0.7457	kw	kilowatts
inches	in	2.54	cm	centimeters
inches of mercury	in Hg	0.03342	atm	atmospheres
pounds	lb	0.454	kg	kilograms
million gallons/day	MGD	3,785	cu m/day	cubic meters/day
mile	mi	1.609	km	kilometer
pound/square inch (gauge)	psig	(0.06805 psig +1)[1]	atm	atmospheres (absolute)
square feet	sq ft	0.0929	sq m	square meters
square inches	sq in	6 452	sq cm	square centimeters
tons (short)	t	0.907	kkg	metric tons (1000 kilograms)
yard	y	0.9144	m	meters

1. Actual conversion, not a multiplier.