TABLE 75. SUMMARY OF SWIRL/HELICAL SOLIDS CONCENTRATOR-FLOW REGULATOR FACILITIES

Project location	Type of facility	Unit size diameter, ft[a]	Process application	Period in service
Denver, Colorado [38]	Swirl	6	Sanitary and simulated wet-weather swirl regulator concentrate-pilot scale grit removal	1975 - currently out of service
Lancaster, Pennsylvania [41]	Swirl - Unit 1	24	Solids concentration and flow regulation-prototype.	Under construction
	Swirl - Unit 2	8	Degritter for foul flow from Unit 1 - prototype	
Lasalle, Quebec, Canada [29, 39, 40]	Swirl	3	Solids concentration and flow regulation - hydraulic model studies with synthetic combined sewage	.. . .
Lasalle, Quebec, Canada [30]	Helical bend	.	Solids concentration and flow regulation - hydraulic model studies with synthetic combined sewage	. ...
Nantwich, England [30]	Helical bend	.	Solids concentration and flow regulation - prototype.	1971 to present
Rochester, New York [36]	Swirl - Unit 1	3	Degritter - pilot.	1975 to 1976
	Swirl - Unit 2	6	Primary treatment - pilot.	
Syracuse, New York [35, 42]	Swirl	12	Solids concentration and flow regulation - prototype.	1974 to present
Toronto, Ontario, Canada [39]	Swirl	12	Primary treatment of combined sewer overflows and municipal wastewater - pilot	1975 to early 1977

a. Outer chamber diameter

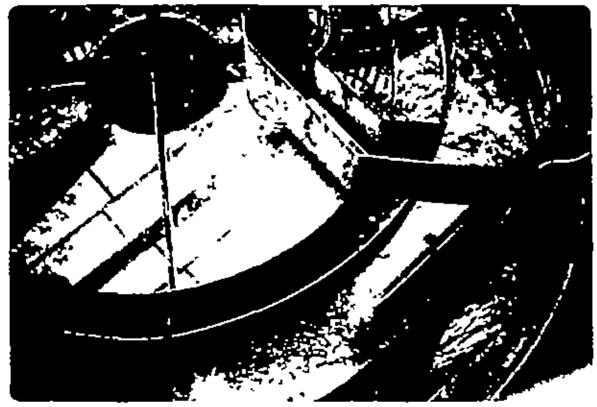
ft x 0 3048 = m

- Dual use - screening provides either main treatment or pretreatment of stormwater and is used as an effluent polisher during periods of dry weather

Several distinct types of screening devices have been developed and used in stormwater treatment and are described in Table 76 [2, 32]. A summary of typical screening installations is presented in Table 77. Photographs of screening installations are shown in Figure 36.

Dissolved Air Flotation--

Dissolved air flotation has been demonstrated as an efficient treatment method to remove suspended solids and floatables such as oil and grease found in combined sewer discharges [43-45]. Solids are removed from the wastestream by small bubbles of air which are released in the reaction tank after depressurization, and rise to the surface carrying the solids. The pressurized flow carrying the dissolved air to the flotation tank is either (1) the entire stormwater flow, (2) a portion of the stormwater flow (split flow pressurization), or (3) recycled dissolved air flotation effluent [2].



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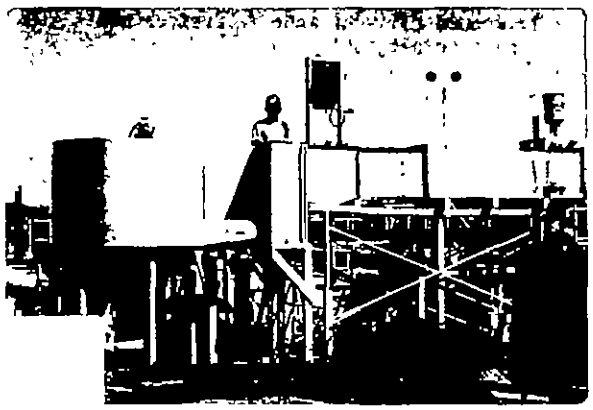

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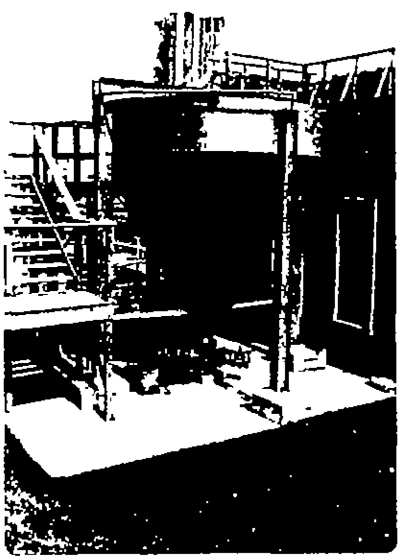

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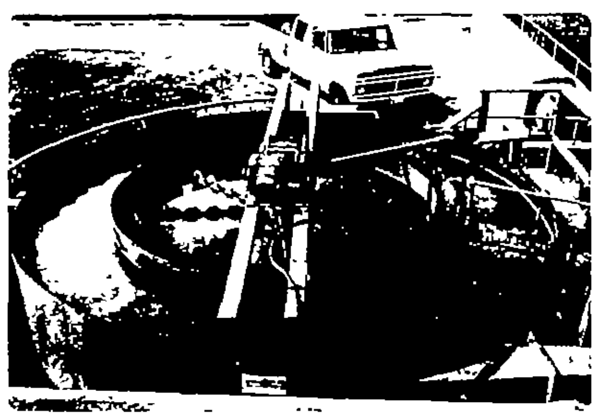


(e)

Figure 35. Swirl concentrator installations.
(a) West Newell Street swirl concentrator/regulator during dry-weather flow-Syracuse, New York. (b) Syracuse swirl concentrator/regulator during a combined sewer overflow. (c) Pilot swirl degritler - Denver, Colorado. (d) Swirl primary separator - Toronto, Canada. (e) Weir arrangement of Toronto swirl.

TABLE 76. DESCRIPTION OF TYPES OF FINE MESH SCREENING DEVICES USED IN COMBINED SEWER OVERFLOW TREATMENT [2, 32]

Type of screen	General description	Process application	Comments
Drum screen	Horizontally mounted cylinder with screen fabric aperture in the range of 100 to 841 microns. Operates at 2 to 7 r/min.	Pretreatment	Solids are trapped on inside of drum and are backwashed to a collection trough
Microstrainers[a]	Horizontally mounted cylinder with screen fabric aperture in the range of 20 to 70 microns. Operates at 2 to 7 r/min	Main treatment	Solids are trapped on inside of drum and are backwashed to a collection trough
Rotostrainer	Horizontally mouned cylinder made of parallel bars perpendicular to axis of drum. Slot spacing in the range of 250 to 2500 microns Operates at 1 to 10 r/min.	Pretreatment	Solids are retained on surface of drum and are removed by a scraper blade.
Disc strainer	Series of horizontally mounted woven wire discs mounted on a center shaft. Screen aperture in the range of 45 to 500 microns. Operates at 5 to 15 r/min.	Pretreatment, main treatment, or post treatment of concentrated effluents	Unit achieves a 12 to 15% solids cake.
Rotary screen	Vertically aligned drum with screen fabric aperture in the range of 74 to 167 microns. Operates at 30 to 65 r/min.	Main treatment	Splits flow into two distinct streams: unit effluent and concentrate flow, in the proportion of approximately 85·15.
Static screen	Stationary inclined screening surface with slot spacing in the range of 250 to 1600 microns.	Pretreatment	No moving parts. Used for removal of large suspended and settleable solids.

a. A vertically mounted microstrainer is available, which operates totally submerged and operates at approximately 65 r/min Aperture range 10 to 70 microns. Solids are moved from the screen by a sonic cleaning device.

A description of pilot and full-scale demonstration dissolved air flotation facilities is presented in Table 78.

High Rate Filtration--

Several high rate filtration pilot study installations have been demonstrated for control of combined sewer overflow pollution [46, 47]. These facilities have used 15.2 and 76.2 cm (6 and 30 in.) diameter pilot-scale filter columns with anthracite and sand media, together with various dosages of coagulants and polyelectrolytes to develop basic process criteria and optimum operating conditions. Descriptions of the high rate filtration facilities are summarized in Table 79 and shown in Figure 37.

TABLE 77. DESCRIPTION OF TYPICAL SCREENING INSTALLATIONS

Project location	Type of screening equipment	No of screening units	Screen aperture, microns	Screening application	Period in service
Belleville, Ontario [48]	Rotary screen Static screen Static screen Rotostrainer	1 1 1 1	105 305 762 500	Pilot plant operation to test effectiveness of screening combined sewer overflows	1974 to 1975
Cleveland, Ohio [2, 47]	Drum screen	1	420	Pilot pretreatment to dual media filtration	1970 to 1971
Euclid, Ohio [49]	Microstrainer	4	30	Dual use. dry-weather effluent polishing 98% of time plus main treatment of combined sewer overflow	Under construction
Flint, Michigan [49]	Microstrainer	6	20	Effluent polishing	Under construction
Ft Wayne, Indiana [50]	Static screen Drum screen Rotary screen	12 1 8	1525 147 105	Parallel screening facility to test effectiveness of various screens, main treatment and pretreatment	1975 to present
Milwaukee, Wisconsin [44, 51]					
Hawley Road					
Test 1	Drum screen	1	297	Pretreatment to dissolved air flotation	1969 to 1972
Test 2	Drum screens Microstrainer	2 1	841 149 63	Sequential screening main treatment, screens operated in series	1971
Test 3	Microstrainer	1	20	Main treatment of combined sewer overflow and dissolved air flotation effluent polishing	1973
Test 4	Drum screen	1	297	Pretreatment to dissolved air flotation with chemical addition	1974
Mt Clemens, Michigan [52]	Microstrainer	1	20 and 60	Polish pond effluent	1972 to 1975
New York City, New York [23. 53]	Rotostrainer Disc strainer	1 1	297 250 and 420	Pretreatment to high-rate filtration	1975-1976 1976 to present
Norwalk, Connecticut [49]	Microstrainer	6	35 or 70	Dual use: dry-weather effluent polishing and main treatment of combined sewer overflow	Under construction
Oil City, Pennsylvania [49, 54]	Microstrainer	2	35	Dual use effluent polishing and main treatment	1976 to present
Philadelphia, Pennsylvania [55, 56, 57]	Microstrainer	1	23 and 35	Main treatment with disinfection	1969 to 1974
Racine, Wisconsin [43]					
Site I Site II Site IIA	Drum screen Drum screen Drum screen	2 4 1	297 297 297	Pretreatment to dissolved air flotation Main treatment	1973 to present
Rochester, New York [36]	Microstrainer	1	70	Pilot main treatment	1975 to 1976
Syracuse, New York [35]	Rotary screen Microstrainer	1 2	105 20 and 71	Pilot main treatment	1974 to present

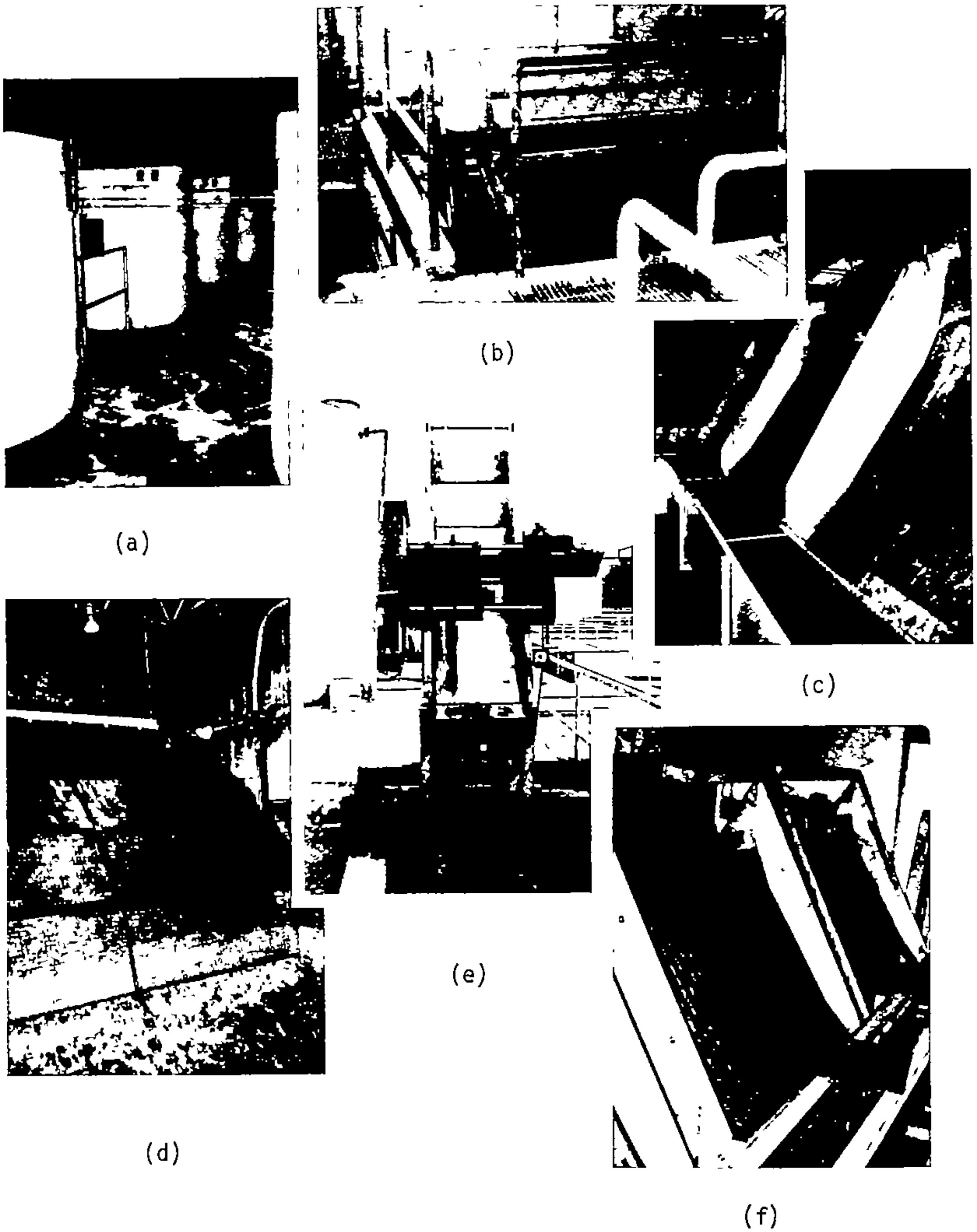


Figure 36. Stormwater screening installations.
(a) Rotary screens - Ft. Wayne, Indiana. (b) Microscreen, Oil City, Pennsylvania. (c) Static screens - Ft. Wayne, Indiana. (d) Drum screen - Ft. Wayne, Indiana. (e) Static screen with brush cleaner - Belleville, Canada. (f) Static screens - Franklin, Pennsylvania.

TABLE 78. SUMMARY OF TYPICAL DISSOLVED AIR FLOTATION INSTALLATIONS

Project location	No of tanks	Pressurization mode	Design flow, Mgal/d	Process description	Period of operation
Milwaukee, Wisconsin [44]					
Hawley Road	1	Effluent recycle and split flow	5.0	Pilot main treatment dissolved air flotation system with pretreatment screening and chemical addition.	1969 to 1974
Racine, Wisconsin [43]					
Site I	3	Split flow	14.1	Full scale main treatment utilizing screening for pretreatment	1973 to present
Site II	8	Split flow	44.4	Full scale main treatment utilizing screening for pretreatment.	1973 to present
San Francisco, California [45]					
Baker Street	2	Either split flow or effluent recycle	24.0	Full scale main treatment with chemical addition; facility has both float and bottom scrapers, with no pretreatment	1970 to present

Mgal/d x 43.808 = L/s

Other Physical and Physical/Chemical Systems--

Bench scale and pilot plant testing of high gradient magnetic separation was evaluated on combined sewer overflows and raw sewage in Boston, Massachusetts [28]. The process involves seeding the wastestream with magnetic iron oxide (magnetite) and adding coagulants and polyelectrolytes to form a floc amenable to removal in a magnetic gradient. The flow is passed through a matrix where the magnetic gradient is induced and the removal occurs. Backwash facilities are included to flush the accumulated floc and particles from the matrix during the backwash cycle when the magnetic gradient is reduced to zero. Removal was found more efficient than sedimentation because the magnetic forces on fine particles may be many times greater than gravitational forces.

A high rate demonstration physical/chemical treatment system for removal of suspended solids, phosphorus, and nitrogen has been evaluated [58]. The process involves inline alum addition and coagulation, polymer addition and flocculation, filtration, and clinophtilolite ion exchange. Suspended solids and phosphorus are removed by alum addition, coagulation, and high rate filtration; and ammonia nitrogen is removed by exchange/adsorption. The system is considered a single unit process, removing phosphorus and ammonia simultaneously.

TABLE 79. DESCRIPTION OF COMBINED SEWER OVERFLOW HIGH RATE FILTRATION PILOT PLANT DEMONSTRATION FACILITIES[a,b]

Project location	Process description	No. of filter columns	Diameter of columns, in.	Pretreatment facilities	Filter media	Period of operation
Cleveland, Ohio [47, 59, 60, 61]	Pilot deep bed, dual media high rate filtration, with chemical addition. Facilities included pretreatment, storage, and filtration.	3 1	6 12	420 micron drum screen	5 ft of No 3 anthracite over 3 ft of No. 612 sand	1970 to 1971
New York City, New York, Newtown Creek [23, 46, 53]	Pilot deep bed, dual media high rate filtration, with polyelectrolyte addition Facilities include pretreatment, storage, and filtration. Dry-weather and combined sewer flow is pumped from grit chamber of Newtown Creek plant.	1 2	30 6	420 micron rotostrainer later replaced with a 420 micron disc strainer	5 ft of No 3 anthracite over 2 ft of No. 612 sand	1975 to present
Rochester, New York [36]	Pilot deep bed, dual media high rate filtration with chemical addition.	3	6	Screening.	5 ft of No 1-1/2 or No.2 anthracite over 3 ft of No.1220 sand	1975 to 1976

a. Systems operated at flux rates ranging from 8 to 30 gal/ft^2 min

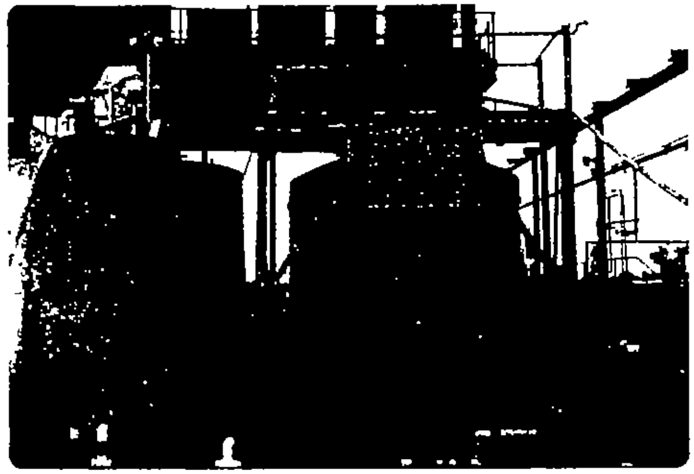
b. High-rate deep-bed filtration has recently, (October-November 1976), been piloted directly on stormwater runoff in the Minnehaha Creek Watershed near Wayzata, Minnesota, under USEPA demonstration grant S-802535. Pretreatment storage was provided to lengthen filtration runs. Publication of results is expected shortly.

in x 2.54 = cm
ft x 0.305 = m
$gal/ft^2 \cdot min \times 0.679 = L/m^2\ s$

Other physical/chemical systems employing chemical addition, activated carbon, and filtration are reported in the literature [2], however, most applications involve conventional sewage and no recent information is available for storm and combined sewer overflow applications.

Evaluation of Physical Treatment Technologies

Process performance, including suspended solids and pollutant removal efficiencies; operational problems, both process control and equipment; design criteria; and costs of unit processes are presented as a guide for planners and designers faced with implementing and evaluating complex stormwater treatment systems.



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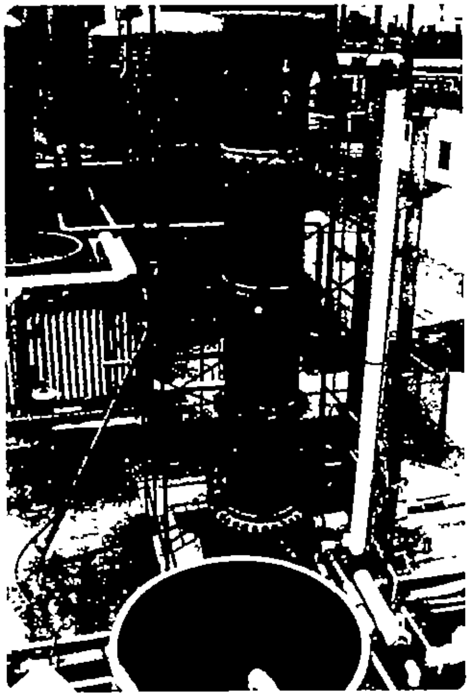

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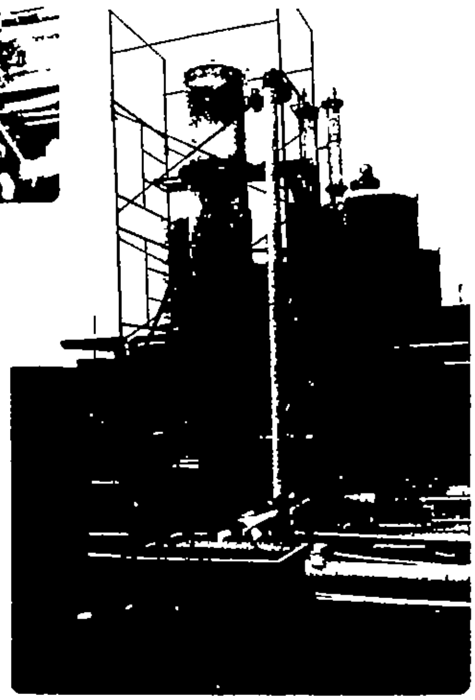

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Figure 37. Newtown Creek high rate filtration facilities. (a) 30 in. diameter dual media filter column. (b) Storage tanks prior to screening. (c) View showing 30 in. and two 6 in. filter columns with high rate chlorine contact tank in foreground.

Process Performance--

Pollutant removal was evaluated for the physical treatment processes, and is summarized in Table 80. Removal of suspended solids is used as the key indicator of process performance. Removals of BOD, COD, settleable solids, nitrogen, and phosphorus are reported when available; however, removal efficiencies of these constituents are often erratic and unpredictable, and vary to greater extremes when compared to suspended solids. Ranges of removals are given for those processes where changes in loading rates or other process variables affect removal efficiencies, and sufficient data are available for analyses.

TABLE 80. COMPARISON OF TYPICAL PHYSICAL TREATMENT REMOVAL EFFICIENCIES FOR SELECTED POLLUTANT PARAMETERS

Physical unit process	Percent reduction					
	Suspended solids	BOD_5	COD	Settleable solids	Total phosphorus	Total Kjeldahl nitrogen
Sedimentation						
Without chemicals	20-60	30	34	30-90	20	38
Chemically assisted	68	68	45	.....	..	..
Swirl concentrator/flow regulator	40-60	25-60	..	50-90	..	..
Screening						
Microscreens	50-95	10-50	35	.....	20	30
Drum screen	30-55	10-40	25	60	10	17
Rotary screens	20-35	1-30	15	70-95	12	10
Disc strainers	10-45	5-20	15	....	..	..
Static screens	5-25	0-20	13	10-60	10	8
Dissolved air flotation[a]	45-85	30-80	55	93[b]	55	35
High rate filtration[c]	50-80	20-55	40	55-95	50	21
High gradient magnetic separation[d]	92-98	90-98	75	99	..	..

a. Process efficiencies include both prescreening and dissolved air flotation with chemical addition.

b. From pilot plant analysis [45]

c. Includes chemical addition.

d. From bench scale and small scale pilot plant operation, 1 to 4 L/min (0.26 to 1.06 gal/min).

Process performance curves and removals of other pollutant parameters such as heavy metals have been developed and reported for each unit process. Where possible, these curves reflect changes in removal efficiencies as a result of changing loading rates or critical process variables.

The effects of chemical addition to enhance the physical removal efficiencies have been demonstrated for most unit processes, and generally show increased pollutant removals at higher loading rates. Chemical addition to dissolved air flotation and high rate filtration processes have shown the greatest performance improvement, generally ranging from 20% and higher [43, 44, 47]. Coagulant addition to form a floc is used in high gradient magnetic separation [28].

Typical chemical additives include cationic, anionic, and nonionic polyelectrolytes; and coagulants, such as alum and ferric chloride. Bench and pilot scale studies to select the polymer, coagulant type, and dose rates should be developed for each wastewater and unit process under investigation to optimize pollutant removal rates, as was shown for the high rate filtration project in Cleveland [47].

Sedimentation--Removal of pollutants by sedimentation has shown erratic results for both suspended solids and BOD for stormwater applications. Suspended solids removal as a function of hydraulic loading rates is presented in Figure 38 for typical combined sewer overflow sedimentation facilities. The results represent average suspended solids removals for a storm event, using average hydraulic loading rates during the overflow period. The data scatter is indicative of high and changing hydraulic loading rates and variable influent concentrations.

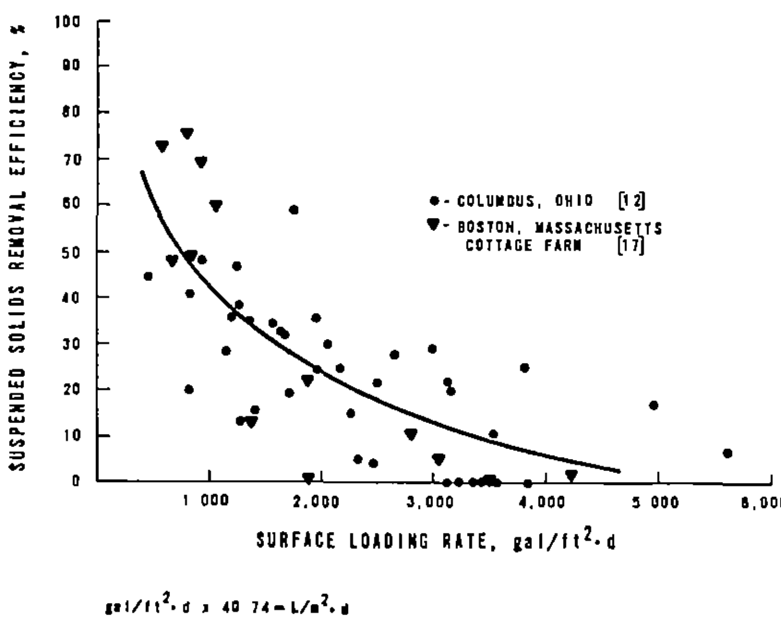


Figure 38. Typical suspended solids removal efficiencies for storage/sedimentation facilities without chemical addition.

Typical removal of suspended solids by conventional sanitary sewage settling tanks with surface loading rates at or near 1.698 $m^3/m^2 \cdot h$ (1000 $gal/ft^2 \cdot d$) is approximately 50 to 60% [31]. Similar removals are obtained for stormwater loadings in this range; however, loading rates can vary up to 6 times this value with removals in the range of 0 to 35%.

When removals attributed to total flow capture during small overflow events and that retained by storage/sedimentation during large events are included, removals can range 60% and higher.

Removal of BOD is more erratic than for suspended solids and ranges from 0 to 50% for most loading rates and influent concentrations. Based on typical performance of several sedimentation facilities, average BOD removal rates in excess of 20% are common [12, 17, 33].

Removal of heavy metals, nitrogen, phosphorus, and other constituents by sedimentation has been reported and is summarized in Table 81 [24].

TABLE 81. POLLUTANT REMOVAL FOR VARIOUS CONSTITUENTS BY SEDIMENTATION [24]

Pollutant	Average removal, %
Heavy metals[a]	
Copper	24.1
Chromium	32 3
Nickel	26 6
Zinc	27.2
Lead	30.6
Iron	16.6
Cadmium	38.8
Calcium	19.2
Magnesium	23.5
Sodium	18.5
Potassium	23.5
Mercury	8.4
Nitrogen[b]	
Ammonia	22.1
Organic	50.5
Total Kjeldahl	38.4
Nitrate	15 4
Nitrite	0
Phosphorus[b]	
Total	22.2
Ortho	6.7
Other constituents[b]	
COD	34.4
TOC	21.3
Oil and grease[c]	11.9

a. Average of 10 samples.
b. Average of 2 to 3 samples.
c. Average of 6 samples.

Swirl and Helical Concentrator/Regulators--Suspended solids removals for swirl concentrators average approximately 50% (total mass basis) for combined sewer overflows. In addition to the removal obtained by the physical splitting of flows, as with conventional regulators, the additional 20 to 30% reduction in the suspended solids concentration is attributed to the action of the swirl. Limited tests indicate a BOD mass removal of approximately 67% with a reduction of BOD concentration in the effluent of approximately 47%. However, these tests were conducted at flowrates substantially less than the swirl's design capacity of 0.3 m^3/s (6.8 Mgal/d), and these values may be unrealistically high [35]. Performance of the swirl concentrator/flow regulator is presented in Figure 39, for both overall suspended solids mass removal and concentration reduction. Hydraulic loading rates to the swirl ranged from 8.5 to 51 $m^3/m^2 \cdot h$ (5000 to 30 000 $gal/ft^2 \cdot d$).

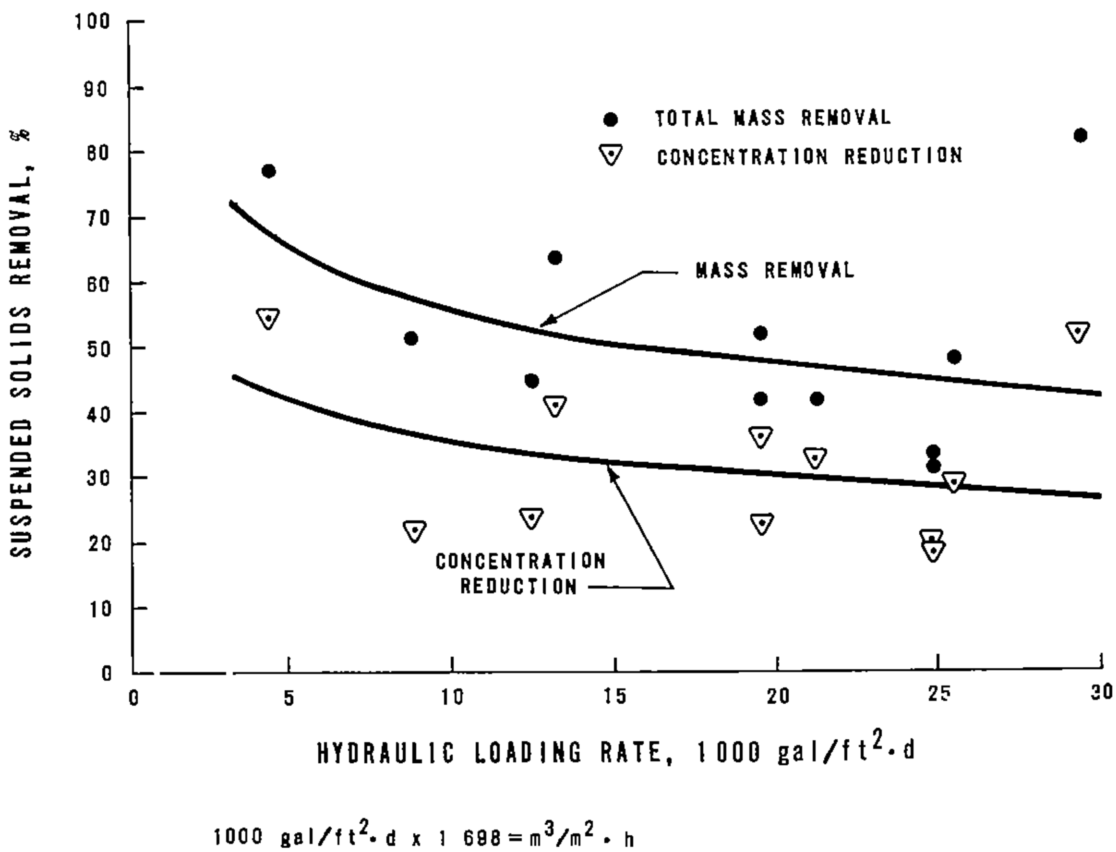


Figure 39. Swirl concentrator/flow regulator suspended solids removal efficiency as a function of hydraulic loading rate [35].

Although no prototype helical bend facilities have been constructed in the United States, it was found through model studies that the helical bend is capable of higher removal efficiencies, with less headloss than the swirl concentrator [30]. The studies also developed design criteria and guidelines for field installations.

Swirl Degritter--Removal of grit was demonstrated on a pilot scale using influent sanitary sewage and sanitary sewage spiked with sand to simulate wet-weather flow conditions [38]. Grit removal efficiencies for flows at less than design capacities ranged from 50 to 87% with an average of approximately 70%. Swirl efficiencies at flows greater than design capacity fall off markedly with an average removal of approximately 34%. Suspended solids removal based on three runs averaged approximatley 7%. The efficiency of removing grit particles of 2.65 S.G. and sizes greater than 0.2 mm was equal to that of conventional sanitary sewage grit removal devices; however, the detention time of the swirl degritter is less than 1 minute as compared to about 3 minutes for conventional aerated grit chambers.

Swirl Primary Separator--A swirl device was also evaluated as a primary separator using sanitary sewage and combined sewer flows at the Humber Wastewater Treatment Plant Toronto, Ontario [39]. The pilot unit was tested at a design flow of 1137 m^3/d (0.3 Mgal/d) and at 1700 m^3/d (0.45 Mgal/d). Approximately 40% suspended solids removal was achieved by the swirl at a hydraulic loading rate of 108 $m^3/m^2 \cdot d$ (2650 $gal/ft^2 \cdot d$) at a detention time of 0.34 hours. In comparison, the conventional settling basins at the Humber facilities had similar suspended solids removal efficiencies at hydraulic loading rates of approximately 81.5 $m^3/m^2 \cdot d$ (2000 $gal/ft^2 \cdot d$) at a detention time of 1.06 h. The treatment efficiency of the swirl primary separator is presented in Table 82 for several pollutant parameters.

TABLE 82. TREATMENT EFFICIENCIES OF A SWIRL PRIMARY SEPARATOR [39][a]

Swirl flow, Mgal/d	Hydraulic loading rate, $gal/ft^2 \cdot d$	Percent removal			
		Suspended solids	Settleable solids	Volatile suspended solids	Fixed suspended solids
0 30	2 650	43	60	46	26
0.45	3 980	25	48	26	22

a. 3.66 m (12 ft) diameter chamber.

Mgal/d x 43.813 = L/s
$gal/ft^2 \cdot d \times 1.698 \times 10^{-3} = m^3/m^2 \cdot h$

Screening--A comparison of suspended solids treatability as a function of influent suspended solids for microstrainers, drum screens, rotary screens, and static screens is presented in Figures 40 through 43. From this comparison, microstrainers show the best performance as a main treatment device; however, hydraulic loading rates for this type of screen are the lowest. For all screens, removal performance tends to improve as influent suspended solids concentrations increase.

In a particle size analysis from the backwash on a 23-micron microstrainer, 2.4% of the particles (by weight) captured were larger than 41 microns and only 3% of the particles were larger than 27 microns. Most of the particles, 81%, were in the range of 7 to 0.07 microns indicating that the effective

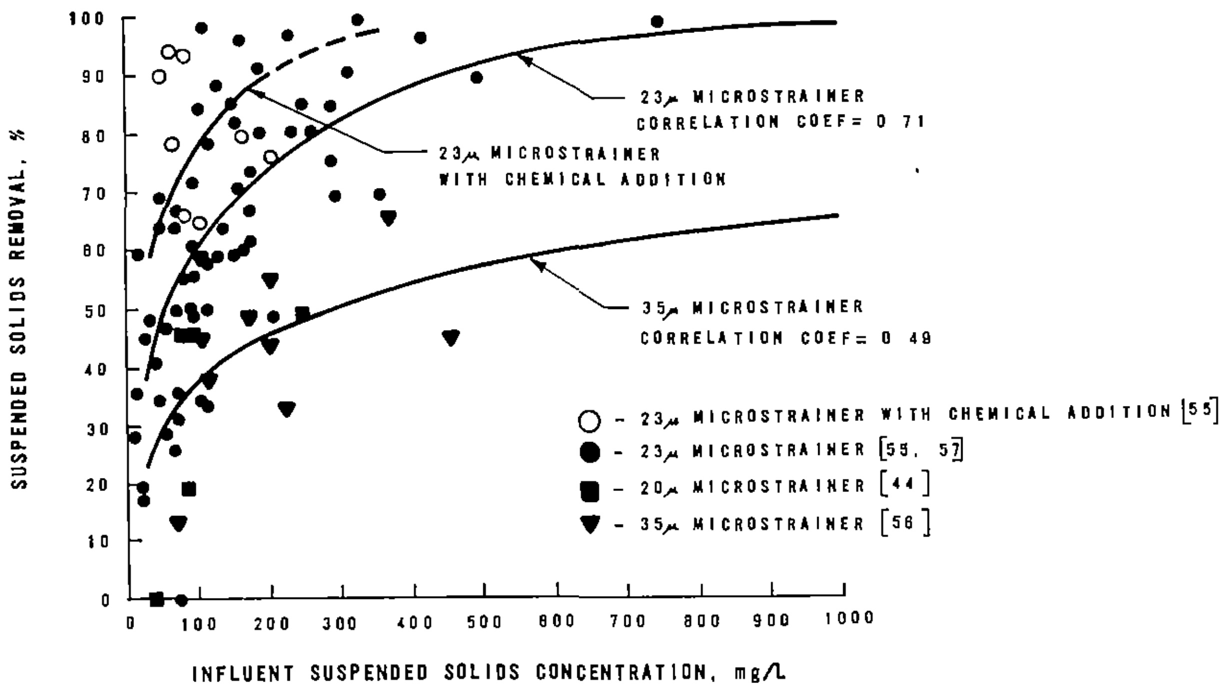


Figure 40. Microstrainer performance as a function of influent suspended solids concentration.

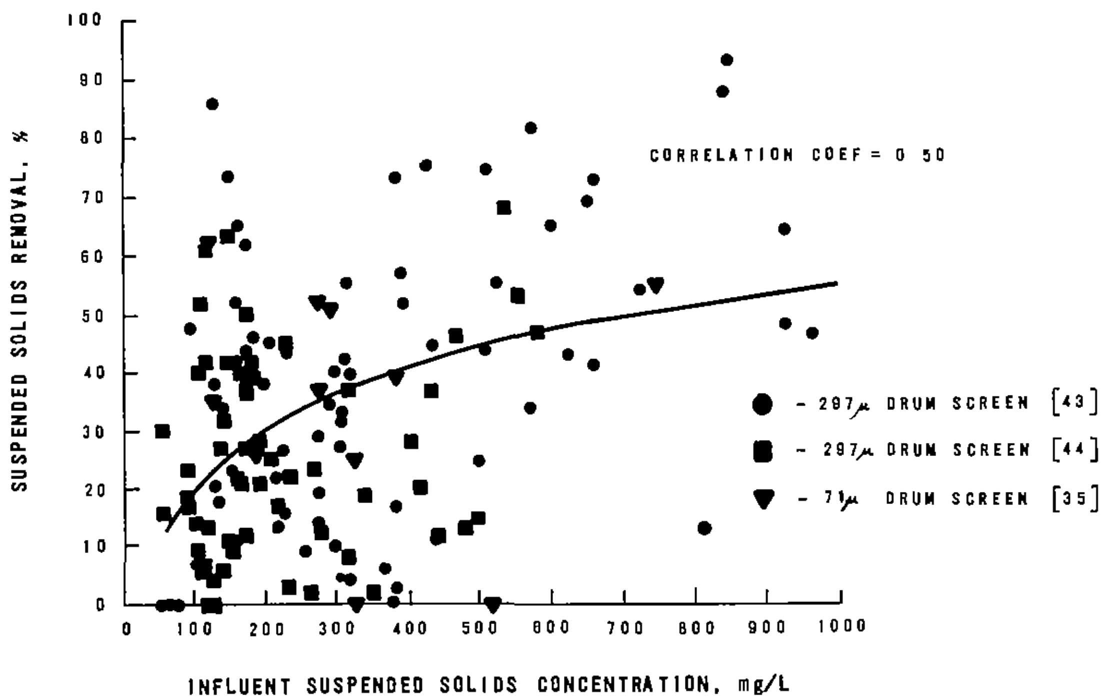


Figure 41. Drum screen performance as a function of influent suspended solids concentration.

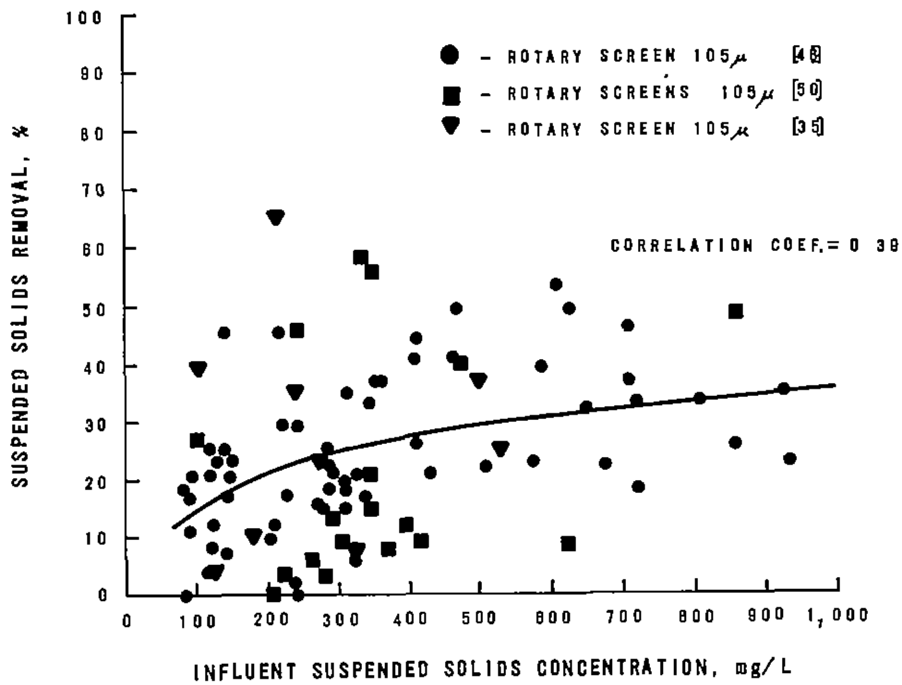


Figure 42. Static screen performance as a function of suspended solids concentration.

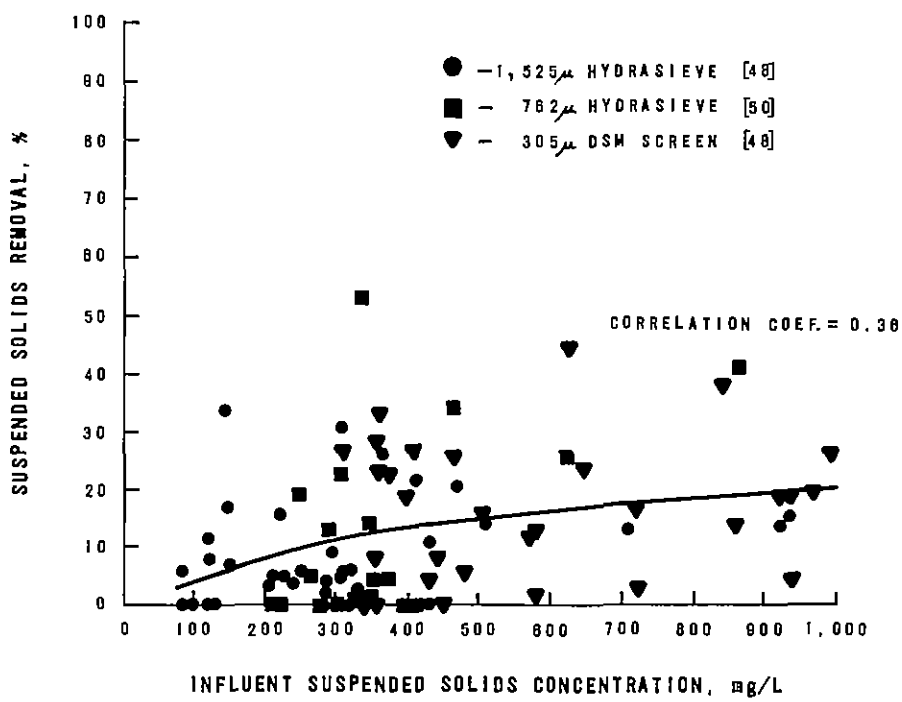


Figure 43. Rotary screen performance as a function of suspended solids concentration.

filtration of a 23 micron screen is better than 23 microns [55]. Microstrainers and drum screens actually develop a mat of screened particles that acts as a strainer retaining particles smaller than the screen aperture. Drum screens, rotary screens, and static screens capture less suspended solids than microstrainers; however, they have been used as pretreatment devices screening out coarse and settleable solids and protecting downstream equipment.

BOD and other pollutant removals are more erratic and have greater data scatters than suspended solids removals. BOD removals for all screens average between 10 and 30%.

Polymer addition to microstrainers improved suspended solids removal efficiency by approximately 10% with increases in average flux rates of 39 to 88 $m^3/m^2 \cdot h$ (16 to 36 $gal/ft^2 \cdot min$). Moderately charged, high molecular weight cationic polyelectrolytes (Betz 1150 and Atlasep 105C) resulting in concentrations between 0.25 to 1.5 mg/L were most suitable for increasing efficiency of the screening operation. The use of polymers also showed increased reduction of volatile suspended solids, COD, and TOC [55].

Dissolved Air Flotation--Dissolved air flotation (DAF) performance has been found to vary with the following control and operational variables [44, 45].

- Surface loading rate to the flotation tank
- Chemical addition
- Influent suspended solids concentration to the flotation tank
- Mode of flow pressurization
- Saturation tank pressure
- Air to solids ratio
- Float skimmer height and speed

A comparison of dissolved air flotation performance efficiency with and without the use of chemicals is presented in Figure 44, incorporating both hydraulic loading rate and influent suspended solids variables as mass solids loading rate. Individual performance data were grouped for each unit solids loading rate and averaged for runs with polymer and/or coagulant addition, and for runs without chemical addition. Limited data were available at high mass loading rates; therefore, individual DAF run data were used instead of average grouped data to represent process efficiency. Data on flotation performance without chemical addition are limited as most applications of this process use chemicals to greatly enhance pollutant removals.

Treatment efficiency on a mass basis showed an increase over the arithmetic mean which gives equal weight to each event without regard to volume treated. Treatment efficiency is usually greater for longer duration high total volume storms than for short duration low volume storms. A comparison of pollutant removals on an arithmetic mean and mass basis is shown in Table 83. The cause of this difference was attributed to the startup lag time of 30 to 45 minutes before good quality effluent was achieved [43]. Higher mass loadings and suspended solids concentrations will also affect DAF efficiency, providing a greater chance for physical contact with the float bubbles.

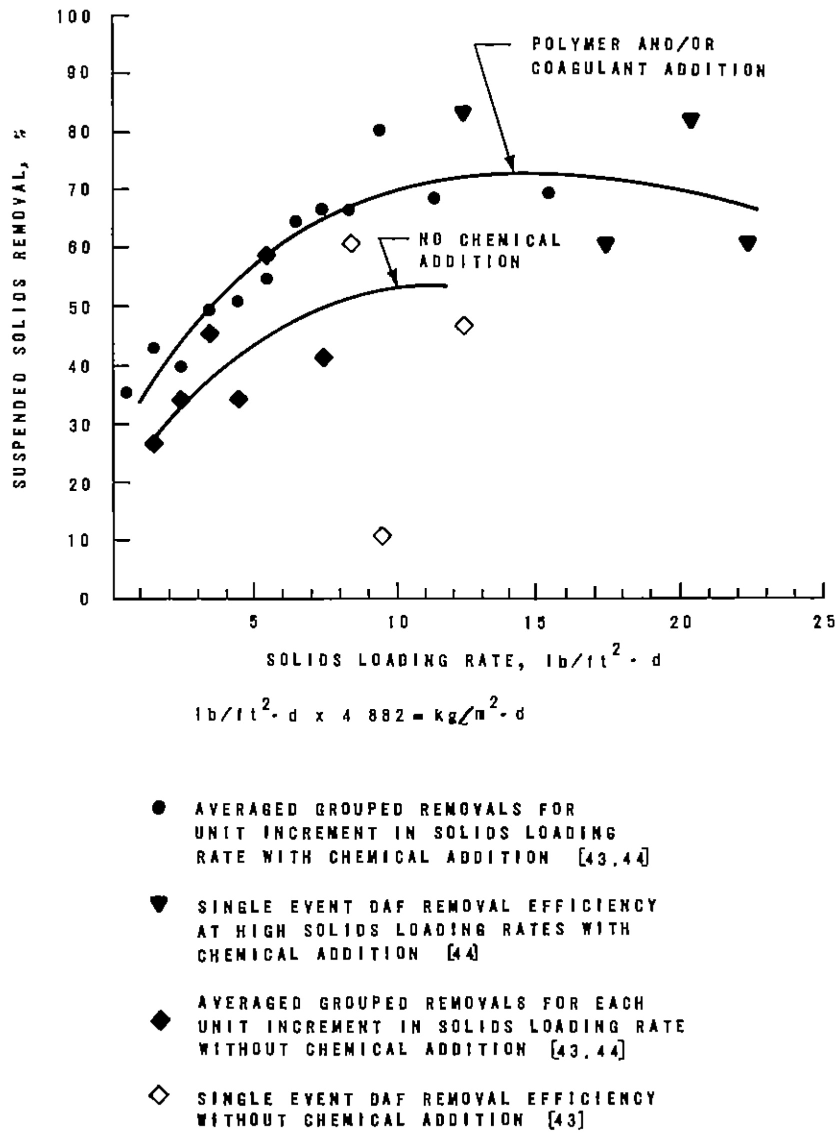


Figure 44. Dissolved air flotation performance as a function of suspended solids loading rate with and without chemical addition.

Low and high hydraulic loading rates affect removal efficiency, as shown in Table 84. Rates were increased from approximately 6.72 to 9.17 $m^3/m^2 \cdot h$ (2.75 to 3.75 $gal/ft^2 \cdot min$). Split flow pressurization of the influent wastewater will result in less hydraulic load to DAF facilities than operating with effluent recycle, which is added to the total wastewater flow entering the tank. Chemical addition to the dissolved air flotation process also affects pollutant removal and should be considered an integral part of the process contributing to higher efficiencies, as shown in Table 85 [44].

TABLE 83. COMPARISON OF POLLUTANT REMOVALS ON AN ARITHMETIC MEAN AND MASS BASIS FOR DISSOLVED AIR FLOTATION FACILITIES AT RACINE, WISCONSIN [43]

Site	Parameter	Avg percent removed	
		Arithmetic mean	Mass basis
I	BOD	50.1	62.4
	Total organic carbon	47.1	60.0
	Total solids	25.7	28.1
	Suspended solids	59 7	67 6
	Volatile suspended solids	64.7	73.6
	Total phosphorus	46.6	53.2
II	BOD	60.4	69.5
	Total organic carbon	50.4	66.6
	Total solids	37.6	47.2
	Suspended solids	66.1	69.8
	Volatile suspended solids	57.0	67 3
	Total phosphorus	60.3	62 4

TABLE 84. COMPARISON OF DISSOLVED AIR FLOTATION PERFORMANCE FOR LOW AND HIGH HYDRAULIC LOADING RATES [44]

Parameter	Percent removal	
	Low rate, 2 75 gal/ft^2·min	High rate, 3.75 gal/ft^2 min
BOD	59	52
COD	57	54
Suspended solids	70	61
Volatile suspended solids	71	64

gal/ft^2·min x 2.445 = m^3/m^2·h

Chemical coagulants, such as alum, ferric chloride, and polymers, are typically used in dissolved air flotation [43-45]. It was found that a ferric chloride dose in the range of 21 to 50 mg/L produced the most significant removals of suspended solids, as summarized in Table 86.

Tests were also conducted on a pilot plant scale evaluating the use of alum as a chemical conditioner. Results of this study showed that alum used singly was more effective than polymer used singly [45]. Optimization of process variables including alum dosage at 75 mg/L, and a hydraulic loading rate at 6.05 m^3/m^2·h (2.49 gal/ft^2·in.), resulted in the pollutant removals summarized in Table 87. Ranges of optimized hydraulic loading rate and alum dosage for various pollutant constituents on an individual basis are presented in Table 88.

TABLE 85. COMPARISON OF DISSOLVED AIR FLOTATION PERFORMANCE WITH AND WITHOUT CHEMICAL ADDITION[a] [44]

	Percent removal	
Parameter	Without chemical flocculant addition	With chemical flocculant addition
BOD	35	60
COD	41	57
Suspended solids	43	71
Volatile suspended solids	48	71
Nitrogen	29	24

a. Includes prescreening.

TABLE 86. OPTIMIZATION OF FERRIC CHLORIDE DOSE FOR DISSOLVED AIR FLOTATION [43]

	Ferric chloride dose, mg/L					
	0	1-10	11-20	21-50	51-70	>70
Mean percent removal	47.2	71.0	70.6	82.2	71.0	71.5
No of runs considered	5	3	7	5	6	4

High Rate Filtration--Suspended solids removal by high rate dual media filtration was found to vary directly with influent suspended solids concentration and inversely with hydraulic loading rate [2, 47, 59]. Both variables were combined to evaluate process performance of high rate filtration as a function of solids loading rate, as shown in Figure 45. The data represent groupings of hydraulic loading rates from 19.6 to 78 $m^3/m^2 \cdot h$ (8 to 32 $gal/ft^2 \cdot min$). For each grouping of hydraulic loading rates, average influent suspended solids were determined and used to compute average solids loading rate. It was found that there was no correlation between BOD removal and hydraulic loading rate because of the independent variation between dissolved and suspended BOD [47].

Addition of chemicals greatly enhance removal of suspended solids, BOD, phosphorus, and COD [47, 60]. Chemicals include polyelectrolytes, generally resulting in concentrations of approximately 1 mg/L; and coagulants, usually alum, resulting in concentrations of approximately 10 to 30 mg/L. At the

TABLE 87. DISSOLVED AIR FLOTATION PERFORMANCE AT OPTIMIZED PROCESS VARIABLES [45]

Parameter	Concentration		Percent removal
	Influent	Effluent	
Total suspended solids, mg/L	99 5	48.6	51
Settleable solids, mL/L	1 8	0.1	94
Floatable solids, mg/L	1.6	0 5	68
Turbidity, JTU	53 2	17.9	66
BOD, mg/L	32.1	5 9	82
COD, mg/L	97.3	58 4	40
Oil and grease, mg/L	1.8	2.8	0
Kjeldahl nitrogen, mg/L	5 9	3.1	47

Cleveland project, anionic polyelectrolytes proved more effective; however, it is stressed that chemical selection tests be run for each specific site under consideration to obtain optimum removal efficiency. Polyelectrolyte addition increases removals of suspended solids, BOD, and COD by approximately 20 to 35%. A comparison of suspended solids removals with and without polyelectrolyte addition is shown in Figure 46 for specific optimized test runs using the average of 4 to 20 grab samples per run. Addition of phosphorus reducing coagulants such as alum increased removals to approximately 60 to 70% as compared to 40 to 45% without alum addition [47].

Limited tests were also run to determine the reduction of heavy metals by high rate filtration. Results of the tests are presented in Table 89. Removals represent composite samples.

High Gradient Magnetic Separation--High gradient magnetic separation is a new treatment technology applied to storm and combined sewer overflow management. To date only bench scale tests and a pilot plant scale system of 1 to 4 L/m (0.26 to 1.06 gal/m) have been operated, therefore caution must be exercised when scaling up to full scale installations until more information and data are available on treatability and costs for large and variable flowrates and pollutant concentrations.

Operational parameters which have the most effect on removal efficiency are coagulant (alum) concentration and pH. Influent suspended solids loading and the magnetic seed concentration affect matrix loading which controls backwash cycling and solids breakthrough. Magnetic field strength above 0.5 kilogauss was not critical to separation efficiency. Ranges of chemical addition for the pilot plant operation include alum at approximately 50 to 120 mg/L, magnetite (size classification 5 to 40 micron) at approximately 0.05 to 0.8 mg/L, and polyelectrolyte at 1 to 3 mg/L.

TABLE 88. RANGE OF HYDRAULIC LOADING RATES AND ALUM DOSAGE FOR SEVERAL POLLUTANT CONSTITUENTS [45]

Stormwater constituent	Alum dosage, mg/L[a]	Hydraulic loading rate, gal/ft^2·min
Total suspended solids	75-150	2.49
Turbidity, JTU	75	2 49
Floatables	75-100	2.49-3.10
Settleable solids, mL/L	50	2.49
BOD	150	1.76-2.49
COD	75-150	2.49
Oil and grease	<100-150	2.78-3.47
Organic nitrogen	Indeterminable	2.49
Ammonium	0-75	2.78

a. Unless otherwise noted.
gal/ft^2·min x 2.445 = m^3/m^2·h

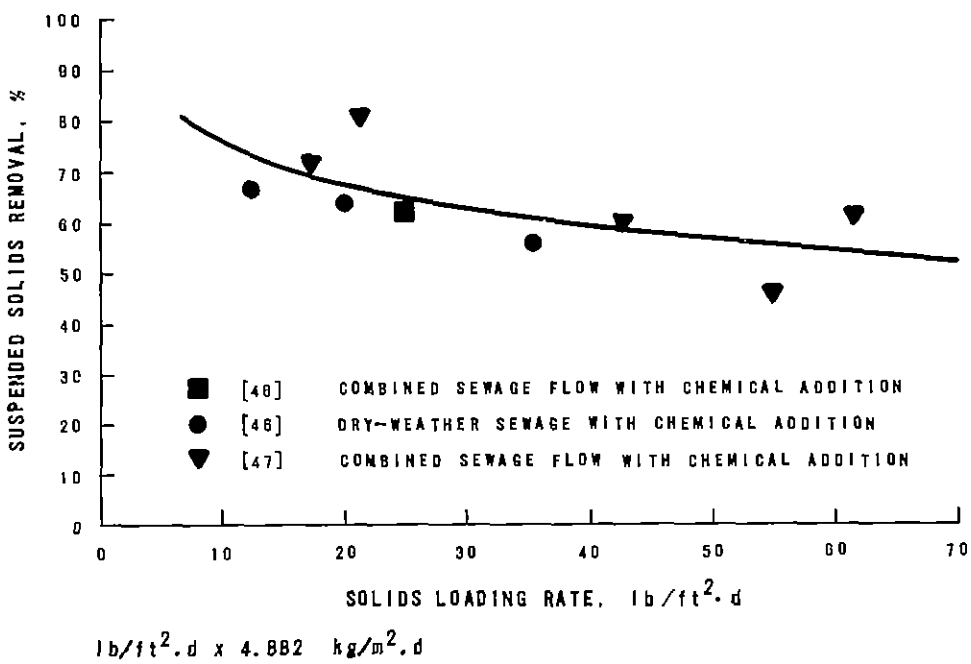


Figure 45. Mean high rate filtration performance as a function of solids loading rate.

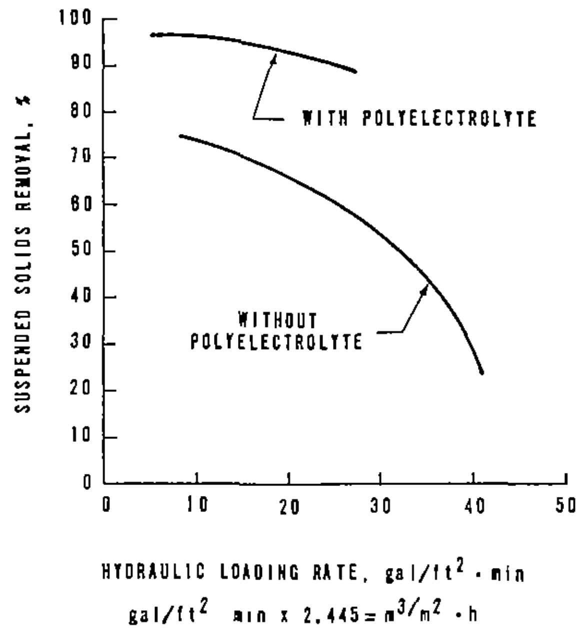


Figure 46. Optimized high rate filtration suspended solids removal with and without polyelectrolyte addition as a function of hydraulic loading rate [47].

TABLE 89. REMOVAL OF HEAVY METALS BY HIGH RATE FILTRATION [46]

	Heavy metal constituent						
	Cadmium	Chromium	Copper	Mercury	Nickel	Lead	Zinc
Average removal, %[a]	56	50	39	0	13	65	48

a. Concentration basis.

Removals of pollutants from bench and pilot scale testing show high removals on a single pass through basis. Pollutant removals of solids, biological material, and heavy metals are summarized in Tables 90 through 92, representing the average of all bench and pilot plant tests [28].

Physical/Chemical Nutrient Removal--The physical/chemical system utilizing inline chemical addition, flocculation, filtration with 1.52 to 2.13 m (5 to 7 ft) of No. 3 Anthrafilt, and ammonia ion exchange through a 1.52 m (5 ft) deep clinoptilolite resin bed showed an 80 to 99% reduction in suspended solids with alum addition at 110 mg/L and polymer addition at 1 mg/L. A 73 micron microstrainer is used as a pretreatment device to remove coarse solids. With aluminum/phosphorus molar ratios larger than 1.0, 80 to 90% phosphorus removal was obtained. Influent ammonia nitrogen concentrations ranging between 0.20 to 0.97 mg/L were reduced to less than 0.20 mg/L [58].

TABLE 90. REMOVAL OF SOLIDS BY HIGH GRADIENT MAGNETIC SEPARATION FOR COMBINED SEWER OVERFLOW AND RAW SEWAGE SAMPLES[a]

	Removal, %[b]	
Solids parameter	Combined sewer overflow	Raw sewage
Suspended solids	95	91
Settleable solids	99+	99+
Apparent color, PCU	87	82
Turbidity, FTU	93	88

a. All samples concentration basis except as noted.

b. Operated at 1 to 4 L/min (0.26 to 1.06 gal/min), (3 to 12 min residence times).

TABLE 91. REMOVAL OF BIOLOGICAL AND CHEMICAL CONSTITUENTS BY HIGH GRADIENT MAGNETIC SEPARATION

Pollutant parameter	Avg removal, %
BOD	92
COD	74
Total coliforms on EMB agar at 37°C	99.3
Fecal coliforms on EMB agar at 37°C	99.2
Algae	99.9
Virus, bacteriophage T7	100
Virus, polio	99-100

TABLE 92. REMOVAL OF HEAVY METALS BY HIGH GRADIENT MAGNETIC SEPARATION

	Heavy metal constituent						
	Cadmium	Chromium	Copper	Mercury	Nickel	Lead	Zinc
Average removal, %	>43	>41	53	>71	0-67	0-67	84

Operational Problems--

Many operational problems encountered in stormwater treatment facilities are also common to conventional dry-weather treatment systems. These problems are generally equipment and process control related and include: instrumentation, pumping, level recording and monitoring, and sampling systems. Most problems can be avoided by effective planning and equipment and material selection. Operation and maintenance problems involving installed monitoring and sampling equipment are often able to be field corrected or replaced with more suitable equipment. Several guides for assessing and evaluating flow monitoring and sampling equipment suitability to storm and combined sewer applications are available [62, 63, 64]. Equipment characteristics and requirements, and desirable features are discussed for a compendium of 70 different types of primary flow measurement devices and over 200 models of commercially and custom designed sampling systems.

The following discussion of major problems experienced in operating demonstration and prototype stormwater treatment projects evaluates process application, control, and equipment reliability for several physical process alternatives.

Sedimentation--Application of tube settlers at the Akron, Ohio, and Dallas, Texas, stormwater treatment projects has shown no benefit in improving suspended solids removal [21, 33]. High flowrates at Akron rendered the tube settlers installed at the void space storage project ineffective and deposited large amounts of solids on the exposed media of the storage cell, greatly reducing inflow infiltration rates. Two parameters which affect tube settler performance are (1) rate of flow, and (2) variability of flowrate. Tube settlers operate most effectively with constant flow generally not exceeding loading rates of 9.8 $m^3/m^2 \cdot h$ (4 $gal/ft^2 \cdot min$) [21].

Evaluation of a chemically assisted primary sedimentation process using waste lime from a water purification plant showed marginal benefits in pollutant reduction efficiency. The waste lime sludge contributed to the suspended solids content of the facility effluent. The major operational problem was identified as inadequate control of the waste lime sludge addition to variable flowrates and influent suspended solids concentrations. Polymer addition was also evaluated but results were inconclusive due to inadequate polymer feed equipment [33].

Potential problems for all types of sedimentation facilities are sludge collection and removal, and tank washdown equipment and procedures. Positive sludge removal and cleanup systems are recommended to prevent solids buildup, odors, and excessive maintenance costs [12].

Swirl and Helical Concentrator/Regulators--Although both the swirl and helical concentrator/regulators have no mechanical parts, pumping is often required for swirl installations because of the head requirement through the unit. Potential operational problem may exist with this and other equipment, including control valves, disinfection, flow metering, and sampling equipment commonly used at swirl installations. Automatic flushing or spray washing is also essential to reduce the need for manual cleaning and maintenance after each storm [35].

Screening--Operational and control problems associated with screening have been experienced at most demonstration facilities and are limited to drum screens, microstrainers, and rotary screens. Static screens, since they have no mechanical parts, need little service except for routine cleaning.

Mechanical problems have been reported with the operation of drum screens and microstrainers. Slippage and reduced speed of rotation of the drum were experienced under increased headloss across the drum and under hydraulic loadings. Main bearing support failures, roller bearing support failures, V-belt drive slippage, screen panel support damage, and excessive vibration were also reported [50, 54].

Typical operational problems include screen blinding due to oil and grease buildup and biological growth on the screen panels. These problems have been reduced by adding cleaning agents and solvents to the backwash cleaning system for oil and grease, and by providing ultraviolet light to control the growth of biological slimes.

The principal operational problems attributed to rotary screens include: screen life; backwash cycling; turbulence and high impact velocities of the water striking the screen panels; breaking up solids; and floc, if chemicals are used, forcing them through the screen.

Screen failure is the result of high rotational speeds, high hydraulic loading rates, and impact and abrasion by coarse solid objects in the influent feed. By varying flowrates and rotational speeds, ultimate screen life was increased from an average of 34.3 hours to 346 hours, with an average of approximately 3.5 repairs per screen [65]. A statistical analysis for the Ft. Wayne, Indiana, facilities revealed that the mean time between failures for any one rotary screen unit was 13.25 hours. The useful life for each screen was 30.5 hours. It is expected that with the addition of coarse screening prior to rotary screening, screen life can be increased to several hundred hours [50].

Backwash cycling in the automatic mode when specified hydraulic splits are reached has caused major hydraulic problems and flooding by backwashing all unit simultaneously. This problem can be solved by putting backwash cycling on a timer and providing lockouts allowing only one unit out of service at a time [50].

Rotary screens create two flow streams, a clarified effluent, and a concentrate flow in the ratio of approximately 85:15. The concentrate flow may require additional facilities for collection disposal of solids.

Other Physical Treatment Alternatives--Dissolved air flotation, high rate filtration, and other physical/chemical treatments systems have operational problems similar to conventional treatment systems. These systems generally use some type of physical pretreatment. Process efficiency depends on chemical addition in proportion to flow, suspended solids or other influent pollutant concentrations, therefore requiring complicated chemical feed and metering equipment.

Operational difficulties for dissolved air flotation which affect process performance include:

- Destruction of air bubble-particle aggregates in the inlet zone of the tank because of increasing hydraulic loading and turbulence
- Hydraulic overloading of the effluent launders
- Breakup of float by excessive agitation of the liquid surface in the flotation tank
- Hydraulic short-circuiting in the flotation tank

The major operational problem for high rate filtration is the accumulation of compressible organic solids on the filter media, greatly reducing hydraulic capacity and reducing the length of filter runs. These problems are overcome by using pretreatment devices such as drum screens or disc strainers, which effectively remove coarse and organic solids [47, 66].

Possible operational problems for high gradient magnetic separation include sludge/solids generation and disposal. Further testing is required to determine sludge and mass balances or the possibility of magnetic seed regeneration. Recycle of the magnetic seed up to 5 to 6 times may be a possibility.

Design Criteria--

The design criteria developed for the physical treatment alternatives [2] can be used to determine and evaluate the size and the resulting costs of the various unit processes, or combinations of unit processes, in planning stormwater treatment systems. The design criteria also represent a range of parameters by which process efficiency may be altered to achieve specific treatment requirements, or to optimize the process in terms of cost effectiveness.

Commonly practiced treatment processes, such as sedimentation, are applied at extreme design limits to handle the variable characteristics of storm and combined sewer overflows. Design criteria for other processes such as the swirl concentrator/regulator have been developed through model studies [29], with some field verification to back up the design rational. Design criteria for process equipment such as screens, dissolved air flotation, and high gradient magnetic separators are recommended by the manufacturers and are supported by field operating data.

<u>Sedimentation</u>--The basic design criteria developed for offline storage facilitites also apply when using the storage facility as a sedimentation basin. The principal design criteria affecting both the physical size and treatment efficiency include (1) hydraulic detention time, and (2) surface loading rate. Because stormwater flowrate and volume vary over time and are

different for each storm, sedimentation facilities must be designed to operate over a broad range of loadings, as shown in Table 93 for selected sedimentation installations. It is recommended that sedimentation detention times at peak design flowrates be in the range of approximately 20 to 30 minutes, however, some facilities have been designed as low as 6 minutes. Peak hydraulic loading rates generally average 11.9 $m^3/m^2 \cdot h$ (7000 $gal/ft^2 \cdot d$). Normal loading rates for most storm overflows are in the range of 3.4 to 5.1 $m^3/m^2 \cdot h$ (2000 to 3000 $gal/ft^2 \cdot d$).

TABLE 93. AVERAGE AND EXTREME DESIGN VALUES FOR SELECTED SEDIMENTATION FACILITIES

Project location	Surface loading rate, gal/ft^2 d		Detention time, min	
	Average	Peak design	Average	Minimum at peak flow
Boston, Massachusetts [17]				
Cottage Farm Detention and chlorination facility	2 000	6 000	117	8
Columbus, Ohio [12]				
Whittier Street	2 120	7 100	63	13
Dallas, Texas [33][a]				
Bachman stormwater plant	715	1 728	159	66
Milwaukee, Wisconsin [13]				
Humboldt Avenue	.....	7 800	...	23
New York City, New York [25]				
Spring Creek Auxiliary Pollution Control Facilities	4 000[b]	20 300	20[c]	6
Saginaw, Michigan [34]				
Hancock Street	.....	7 260	...	15

a Chemically assisted sedimentation with waste lime sludge

b. Estimate to occur at less than this value 98% of the time.

c. Detention tims is 20 min or greater, 98% of the time.

gal/ft^2 d x 1.698×10^{-3} = $m^3/m^2 \cdot h$

The large hydraulic loading rate for New York City's sedimentation facility does not account for the large volume of trunk sewer storage which will greatly reduce the peak flow to the facility [25]. The average loading rate for this installation was estimated from a rainfall intensity of 1.27 cm/h (0.5 in./h). Rainfall intensities less than this amount were estimated to occur for over 98% of the time. Using a runoff coefficient of 0.5, surface loading rates less than 6.8 $m^3/m^2 \cdot h$ (4000 $gal/ft^2 \cdot d$) are estimated to occur 98% of the time.

Swirl and Helical Concentrator/Regulators--Design criteria for the swirl and helical concentrator/regulators have been developed through hydraulic model studies using synthesized combined sewage particles [29, 30]. Both units are designed as a function of the inlet diameter. For the swirl concentrator, the inlet diameter is related to the chamber diameter by curves developed for different efficiencies of settleable solids removal [29]. Some problems do exist, however, when using the design curves for inlet dimensions and flows that do not fall within the range presented in the curves. Additional modeling and study are required to expand the curve usability to meet flow and inlet sizes encountered in field applications. It is also recommended that emergency side overflow weirs be provided in the swirl design [41, 67]. A general design layout of the swirl concentator/regulator is shown in Figure 47.

General design layouts of the helical bend concentrator/regulator are shown in Figure 48. Model studies showed that the optimum interior angle was approximately 60 degrees. The design details for the helical bend are for 100% grit (0.2 mm, S.G. = 2.65) removal.

Swirl Degritter--Design criteria and design curves for discharges from 0.1 to 2.5 m^3/s (2.3 to 57 Mgal/d) have been developed through hydraulic model studies using synthetic grit particles [68].

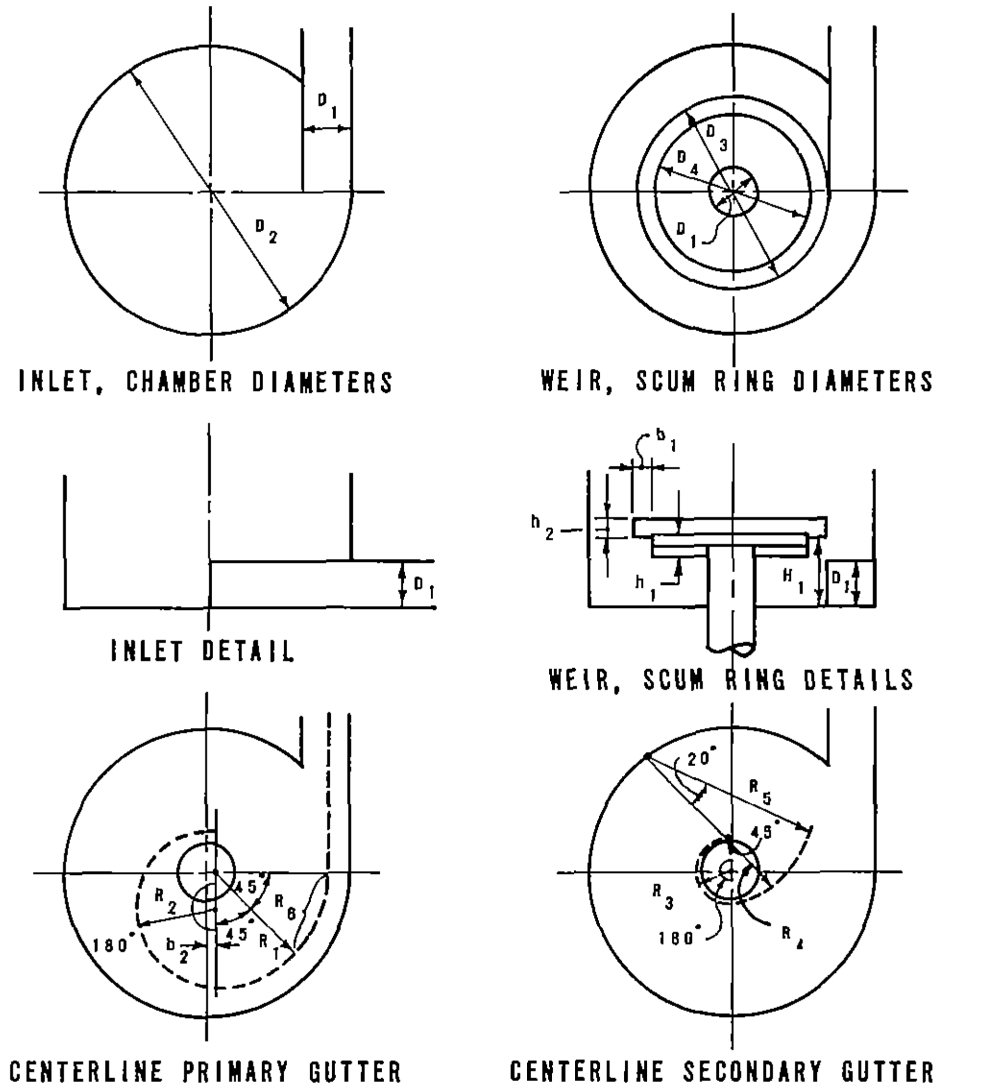
Swirl Primary Separator--Detailed design instructions, criteria, and design curves for flowrates from 0.5 to 500 L/s (0.01 to 11.4 Mgal/d) have been developed from hydraulic and mathematical models for the swirl primary separator [39]. The conical shaped configuration of the device utilizes a height equal to its diameter, which should enhance sludge concentrations but also may decrease cost competitiveness in large sizes.

Design Criteria for Physical Process Equipment--Design and operational criteria have been reported for the screening alternatives, dissolved air flotation, high rate filtration, and high gradient magnetic separators, and are summarized in Tables 94 through 99 [2, 28]. The design parameters generally reflect ranges of operational limits experienced in a number of field installations.

Costs of Physical Treatment Alternatives--

Construction cost and average operation and maintenance costs for physical treatment processes are presented as a guide for planners to determine the relative economic impacts of various treatment alternatives on a first cut basis. Detailed cost studies are still required, including local conditions or changing design requirements, when preparing estimates for specific application or final selection of alternatives.

Construction cost and operation and maintenance cost curves have been developed for combined sewer overflow treatment facilities ranging in size from 0.2 to 8.8 m^3/s (5 to 200 Mgal/d), and for storage facilities ranging in size from 3.8 to 908 ML (1 to 240 Mgal) [27]. Facilities include: storage, sedimentation, screening, swirl concentrator/regulator, dissolved air flotation, filtration, disinfection, chemical feed systems, flow measurement, and raw wastewater and sludge pumping stations. Costs represented by these curves do not include cost of land, engineering, and contingencies.



D_1 = USE EFFICIENCY	D_4 = 5/8 D_2	R_1 = 7/18 D_2	R_5 = 11/18 D_2
D_2 = CURVES [018]	h_1 = $D_1/2$	R_2 = $D_2/4$	R_6 = CURVE SMOOTHED IN TO MEET INLET CENTERLINE
H_1 = $D_2/4$	h_2 = $D_1/3$	R_3 = 5/48 D_2	
D_3 = 2/3 D_2	b_1 = $D_2/18$	R_4 = 3/16 D_2	

Figure 47. General swirl concentrator/regulator design details [29].

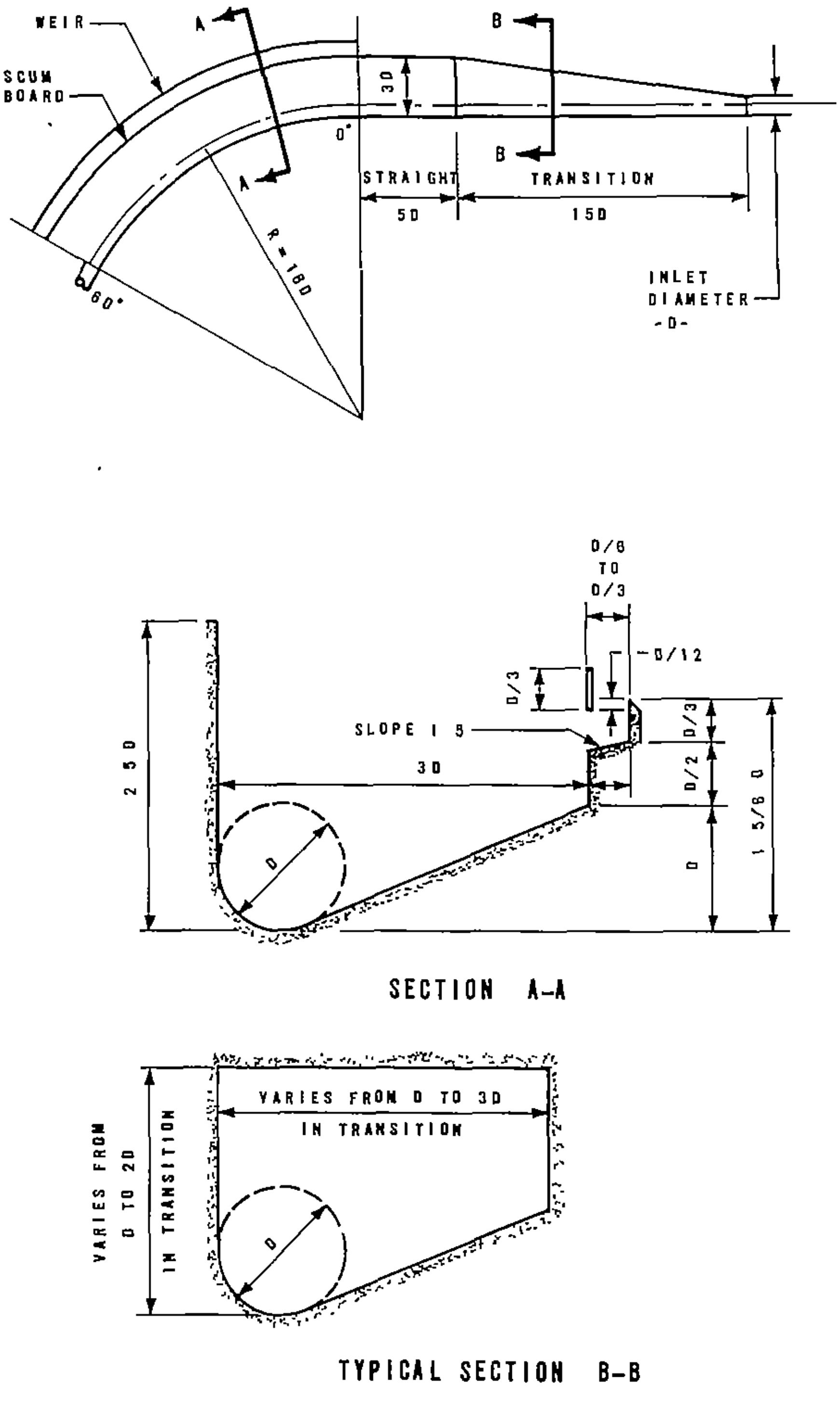


Figure 48. Recommended plan and section details for the helical bend concentrator/regulator [30].

TABLE 94. DESIGN PARAMETERS FOR MICROSTRAINERS, DRUM SCREENS, AND DISC SCREENS

Parameter	Microstrainers	Drum screen	Disc screens
Screen aperture, microns	23-100	100-420	45-500
Screen material	Stainless steel or plastic	Stainless steel or plastic	wire cloth
Drum speed, r/min			
Speed range	2-7	2-7	5-15
Recommended speed	5	5	....
Submergence of drum, %	60-80	60-70	50
Flux rate, gal/min per ft^2 of submerged screen	10-45	20-50	20-25
Headloss, in.	10-24	6-24	18-24
Backwash			
Volume, % of inflow	0.5-3	0.5-3	...[a]
Pressure, lb/in^2	30-50	30-50	....

a. Unit's waste product is a solids cake of 12 to 15% solids content.

$gal/min \cdot ft^2 \times 2.445 = m^3/h \cdot m^2$
in. x 2.54 = cm
ft x 0.305 = cm
$lb/in.^2 \times 0.0703 = kg/cm^2$

TABLE 95. DESIGN PARAMETERS FOR ROTARY SCREENS

Screen aperture, microns	
Range	74-167
Recommended aperture	105
Screen material	Stainless steel or plastic
Peripheral speed of screen, ft/s	14-16
Drum speed, r/min	
Range	30-65
Recommended speed	55
Flux rate, $gal/ft^2 \cdot min$	70-150
Hydraulic efficiency, % of inflow	75-90
Backwash	
Volume, % of inflow	0.02-2.5
Pressure, lb/in^2	50

ft/s x 0.305 = m/s
$gal/ft^2 \cdot min \times 2.445 = m^3/m^2 \cdot h$
$lb/in^2 \times 0.0703 = kg/cm^2$

TABLE 96. DESIGN PARAMETERS FOR STATIC SCREENS

Hydraulic loading, gal/min per ft of width	100-180
Incline of screens, degrees from vertical	35[a]
Slot space, microns	250-1 600
Automatic controls	None

a. Bauer Hydrasieves (TM) have 3-stage slopes on each screen. 25°, 35°, and 45°

gal/min·ft x 0.207 = L/m·s

TABLE 97. DESIGN PARAMETERS FOR DISSOLVED AIR FLOTATION

Overflow rate, gal/ft^2 min	
Low rate	1.3-4.0
High rate	4.0-10.0
Horizontal velocity, ft/min	1.3-3.8
Detention time, min	
Flotation cell range	10-60
Flotation cell average	25
Saturation tank	1-3
Mixing chamber	1
Pressurized flow, % of total flow	
Split flow pressurization	20-30
Effluent recycle pressurization	25-45
Air to pressurized flow ratio, standard ft^3/min·100 gal	1 0
Air to solids ratio	0.05-0.35
Pressure in saturation tank, lb/in^2	40-70
Float	
Volume, % of total flow	0.75-1.4
Solids concentration, % dry weight basis	1-2

gal/ft^2·min x 2 445 = m^3/m^2·h
ft/min x 0 00508 = m/s
standard ft^3/min 100 gal x 0.00747 = m^3/min·100 L
lb/in^2 x 0.0703 = kg/m^2

TABLE 98. DESIGN PARAMETERS FOR DUAL MEDIA HIGH RATE FILTRATION

Filter media depth, ft	
No. 3 anthracite	4-5
No. 612 sand	2-3
Effective size, mm	
Anthracite	4
Sand	2
Flux rate, gal/ft^2·min	
Range	8-40
Design	24
Headloss, ft	5-30
Backwash	
Volume, % of inflow	4
Air	
Rate, standard ft^3/min·ft^2	10
Time, min	10
Water	
Rate, gal/ft^2·min	60
Time, min	15-20

ft x 0.305 = m
gal/ft^2·min x 2.445 = m^3/m^2·h
standard ft^3/min·ft^2 x 0.305 = m^3/m^2·min

TABLE 99. PRELIMINARY DESIGN PARAMETERS FOR HIGH GRADIENT MAGNETIC SEPARATORS [28]

Magnetic field strength, kG[a]	0.5-1.5
Maximum flux rate, gal/ft^2·min	100
Minimum detention time, min	3
Matrix loading, g solids/g of matrix fiber	0 1-0.5
Magnetite addition, mg/L	100-500
Magnetite to suspended solids ratio	0.4-3.0
Alum addition, mg/L	
Range	90-120
Average	100
Polyelectrolyte addition, mg/L	0.5-1.0

a. kG = kilogauss

gal/ft^2·m x 2.445 = m^3/m^2·h

Representative facilities costs are presented in the following paragraphs, utilizing actual construction cost bid tabulations and estimates from stormwater facilitiestogether with data used to develop the detailed cost curves [27]. All costs are adjusted to the ENR 2000 cost index to be compatible with values presented in "Urban Stormwater Management and Technology, An Assessment" [2].

A general comparison of the cost of the various physical treatment processes is presented in Table 100. The ranges of costs were estimated, and in some cases, adjusted to a plant capacity of 1.10 m^3/s (25 Mgal/d). Average capacity costs reflect an approximate cost for a treatment process group indicating relative differences in magnitude between other processes.

TABLE 100. SUMMARY OF AVERAGE CONSTRUCTION COSTS FOR 25 Mgal/d PHYSICAL TREATMENT FACILITIES[a]

Physical treatment process	Construction costs, $	Average cost, $/Mgal·d
Sedimentation[b]	238 000-850 000	23 000
Swirl concentrator/ regulator[c]	50 000-65 000	4 500[d]
Screening[c]	400 000-600 000	19 000
Dissolved air flotation[f]	600 000-1 200 000	34 000
High rate filtration	1 400 000-1 700 000	58 000[g]
High gradient magnetic separation	2 113 000	84 500

a ENR 2000.

b. Adjusted to 25 Mgal/d costs.

c. Range for 90 and 100% grit removal.

d. Based on a 12 Mgal/d facility

e. Estimates include supplemented pumping where used.

f. Based on hydraulic loading rate of 5 760 $gal/ft^2 \cdot d$--includes processing and chemical addition facilities.

g. Based on hydraulic loading rate of 24 gal/ft^2 min--includes prescreening and chemical addition facilities.

Mgal/d x 0.0438 = m^3/s
gal/ft^2 d x 1.698×10^{-3} = $m^3/m^2 \cdot h$
$gal/ft^2 \cdot min$ x 2.445 = $m^3/m^2 \cdot h$

Costs of Sedimentation Facilities--Costs of sedimentation facilities are summarized in Table 101, with flow capacities based on a theoretical 30 minute detention time to provide an equal basis of comparison. Actual detention times based on maximum flowrates range from approximately 8 minutes [17] to over 1 hour [33].

Concentrator/Regulators Costs--Costs of swirl concentrator/regulators are based on estimates and actual construction costs excluding land costs, bypass sewers, and engineering and contingencies [27, 30]. Construction costs for swirl facilities are presented in Figure 49 for swirl chamber diameters of 3.05 to 15.2 m (10 to 50 ft).

TABLE 101. SUMMARY OF COSTS OF TYPICAL SEDIMENTATION FACILITIES[a]

Project location	Flow capacity, Mgal/d[b]	Construction costs, \$/Mgal·d	Cost, \$/acre	Annual operation and maintenance cost, \$/Mgal·d
Boston, Massachusetts				
Cottage Farm [17]	62 4	104 000	420	1 280
Charles River [19, 20]	57 6	164 700	3 160	1 690
Columbus, Ohio [12]				
Whittier Street	180.0	34 000	210	....
Dallas, Texas [33]				
Bachman Stormwater Plant	57.6	31 900	....	720
Milwaukee, Wisconsin [13]				
Humboldt Avenue	187 0	9 500	3 100	270
New York City, New York				
Spring Creek [2, 22, 25][c]	595 0	20 060	3 660	170
Saginaw, Michigan [34]	168.0	19 760	2 040	200

a. ENR = 2000.

b. Based on 30 minute detention time.

c Neglecting 13.0 Mgal of trunk sewer storage.

Mgal/d x 0 0438 = m^3/s
Mgal x 3785 = m^3
acre x 0.405 = ha

Operation and maintenance costs have been developed based on the number of overflow events per year, and on an annual manhour basis [27]. Actual operation and maintenance costs have been reported at approximately \$2000 per year (ENR 2000) for the West Newell Street installation at Syracuse, New York [69].

A comparison of costs for various levels of grit removal for the swirl concentrator/regulator and the helical bend concentrator/regulator is presented in Figure 50. Swirl design was based on figures generated from model studies, with ENR 2000 costs applied from Figure 49. Only in cases where low probability peak flows are being considered should designs based on 80 and 70% grit removal be considered for use [29].

Swirl Degritter Costs--Swirl degritter construction and operation and maintenance costs were estimated for units with capacities of 44, 131, and 438 L/s (1, 3, and 10 Mgal/d) and are presented in Table 102 [38]. The estimates include miscellaneous costs for piping, weirs, plates, and costs for a grit washer and screw conveyor. Engineering and contingencies are not included. Operation and maintenance costs include labor, materials and supplies, and energy costs.

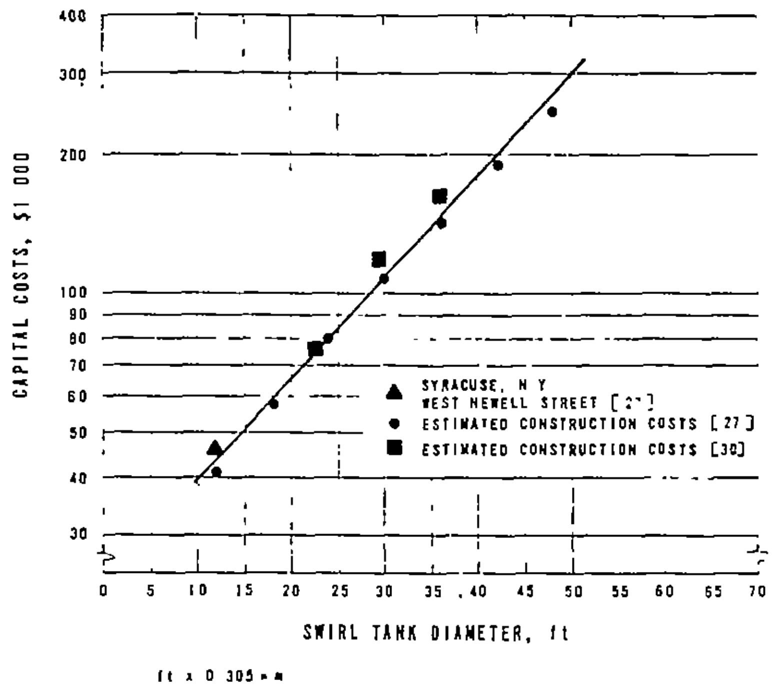


Figure 49. Estimated construction cost for swirl concentrator/regulators (ENR 2000).

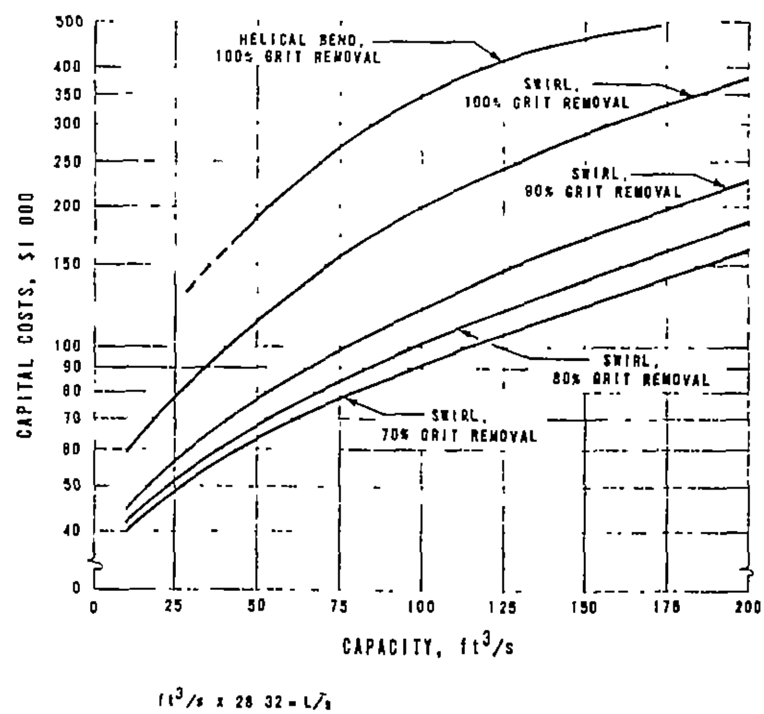


Figure 50. Comparison of costs for swirl and helical bend concentrator/regulator for various degrees of grit removal (ENR 2000).

TABLE 102. ESTIMATED SWIRL DEGRITTER CONSTRUCTION AND OPERATION AND MAINTENANCE COSTS[a]

Swirl degritter capacity, Mgal/d	Construction cost, $	Cost/Mgal·d, $/Mgal·d	Annual operation and maintenance cost, $/yr
1	29 100	29 100	3 600
3	33 400	11 100	5 900
10	40 800	4 100	10 600

a. ENR = 2000.

Mgal/d x 0.0438 = m^3/s

Costs of Screening Facilities--Costs of drum screens and microstrainers, rotary screens, and static screens are based on cost estimates from actual demonstration scale facilities, and are summarized in Table 103. For several installations, costs were also estimated for various levels of capacity based on the configuration of the demonstrated installation. Capital construction costs for all screening alternatives range from \$78 to \$166/m^3·h (\$12 300 to \$26 000/Mgal/d) and average approximately \$120/m^3·h (\$19 000/Mgal/d). The range of capital cost values generally reflects special construction methods, type of building, and/or support facilities such as separate pumping stations or structural and architectural requirements at specific sites. Operation and maintenance costs average approximately \$0.013/m^3 (\$0.05/1000 gal), and range from approximately \$0.005 to \$0.026/m^3 (\$0.02 to \$0.10/1000 gal) for static screens and all other types of screens.

Costs of Dissolved Air Flotation Facilities--Costs of dissolved air flotation facilities used for stormwater treatment have varied widely, from approximately \$127 and \$165/m^3·h (\$20 000 and \$26 000/Mgal·d) [43, 44], to over \$443/m^3·h (\$70 000/Mgal·d) [45]. These differences can be attributed to special structural and architectural requirements, requirements for pretreatment, and more importantly, to the design hydraulic loading rate which can change the cost per design flow capacity by a factor up to 3. For this reason, costs for dissolved air flotation facilities are presented as a function of tank surface area as shown in Figure 51. The cost curves represent data developed for several different sizes of facilities based on the experienced cost of the demonstration facilities [45], and cost curves developed from data from dissolved air flotation facilities used in conventional solids thickening applications [27]. The curves present a range of cost with the San Francisco data [45] considered on the high side. These costs, therefore, should be considered as a preliminary guide and should be followed by detailed cost analysis for specific site applications. Operation and maintenance costs have ranged from approximately \$0.013 to \$0.059/m^3 (\$0.05 to %0.22/1000 gal) treated, including pretreatment [43, 44].

Costs of High Rate Filtration--Costs of high rate filtration facilities are summarized in Table 104 [28]. These costs are based on facilities similarly designed to that of the Cleveland demonstration project and include a low lift

TABLE 103. COST SUMMARY OF SELECTED SCREENING ALTERNATIVES[a]

Project location	Type of screen	Screening capacity, Mgal/d	Capital cost, $	Cost, $/Mgal d	Annual operation and maintenance cost, $/1000 gal
Belleville, Ontario [48][a]	Rotary screen	1 8	33 500	18 600	0.083
		5.4	97 700	17 900	0 083
		7 2	128 400	17 800	0.083
	Static screen	0 75	14 900	19 900	0 042
		5.3	95 600	18 200	0 042
		7 5	130 700	17 400	0 042
Cleveland, Ohio [47][b,c]	Drum screen	25	608 500	24 340	.....
		50	887 800	17 750	. ...
		100	1 745 200	17 450	....
		200	3 340 300	16 700	. .
Ft Wayne, Indiana [50]	Static screen	18	272 400	15 100	0.020
	Drum screen	18	254 300	14 100	0 039
	Rotary screen	38	584 700	15 400	0.046
Mt Clemens Michigan [52]	Microstrainer	1 0	26 200	26 200	.. .
Philadelphia, Pennsylvania [55]	Microstrainer with chemical addition	7.4	90 800	12 270	0 048
	Microstrainer without chemical addition	7 4	147 900	19 980	0.049
Racine, Wisconsin [43]	Drum screen	3 9	22 600	5 800	.....
Seattle, Washington [70][b]	Rotary screen	25	600 000	24 000	0.098
Syracuse, New York [27][c]	Rotary screen	5	129 500	25 900	. ..
	Drum screen	10	257 000	25 700	. ..

a. ENR 2000.

b. Estimated costs for several sizes of facilities.

c Estimates include supplemental pumping stations and appurtenances.

Mgal/d x 0 0438 = m^3/s
$/1000 gal x 0 264 = $\$/m^3$

pumping station, pretreatment by 420 micron drum screens, and chemical addition facilities [47]. Operation and maintenance costs are based on 300 hours of operation per year.

Costs of High Gradient Magnetic Separation--Costs of high gradient magnetic separation have been evaluated for a 1.10 m^3/s (25 Mgal/d) facility and are summarized in Table 105 [28]. Capital costs include pretreatment, chemical addition, thickening and dewatering equipment, pumps, backflush system, instrumentation, and disinfection system. Operation and maintenance costs include chemicals, labor, electrical utilities, and maintenance.

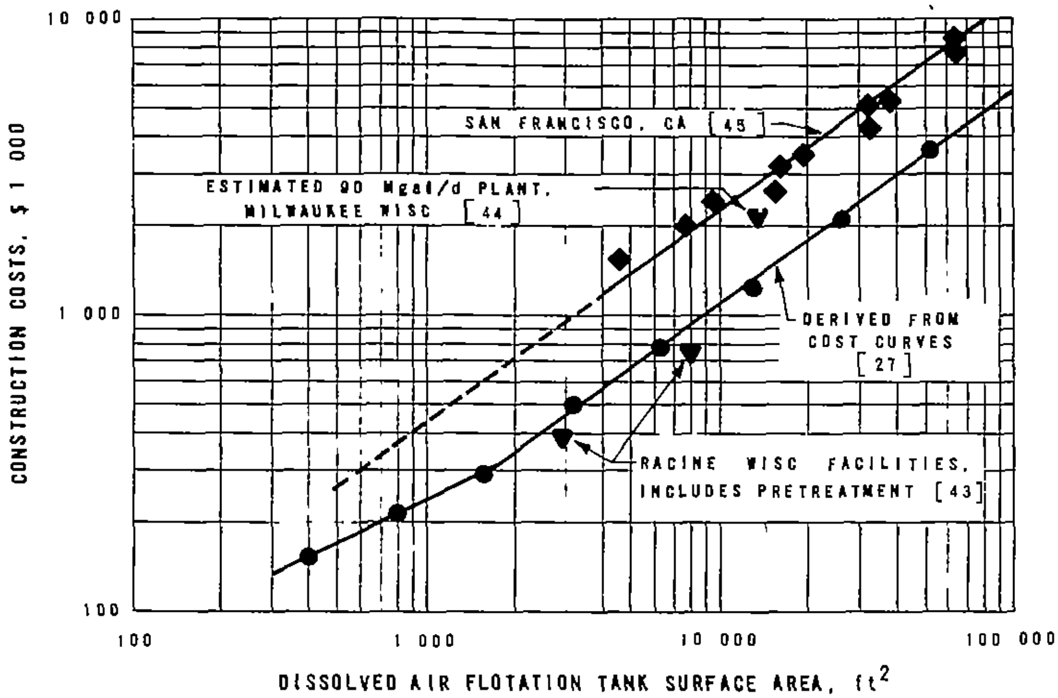
Costs of Physical/Chemical Treatment Systems--Costs of complete physical/chemical treatment systems including chemical clarification and chemical recovery, carbon adsorption, and activated carbon regeneration have been developed [2]. Costs of these facilities for a 1.10 m^3/s (25 Mgal/d) plant range from approximately $4 000 000 to over $50 000 000 or $3 600 000 to over $45 000 000/$m^3 \cdot s$ ($160 000 to over $2 000 000/Mgal·d). Operation and maintenance costs range from approximately $0.01 to $0.69/$m^3$ ($0.03 to $0.26/1000 gal) treated. Many of the treatment components include physical treatment processes previously described.

Physical Treatment Systems

The various physical treatment alternatives are generally combined with storage and, in some cases with each other, to form integrated full scale storm and combined sewer management and control systems. In most treatment situations, storage/detention should be considered an essential element of the overall plan to provide flow equalization and/or primary treatment.

Screening devices, particularly microstrainers and drum screens, have been the most widely used physical treatment device in physical treatment systems. They have been used primarily as pretreatment devices to such processes as dissolved air flotation and high rate filtration. By using a 297 micron drum screen before dissolved air flotation, the overall suspended solids removal was increased from an average of 50 to approximately 70% for the facilities in Racine, Wisconsin [43]. Similar results have been obtained by using prescreening with a 420 micron drum screen before high rate filtration [47]. Screens have also been used as effluent polishers after sedimentation and dissolved air flotation.

Typical physical treatment process schematics are shown in Figures 52 through 54. These process systems are the most commonly found for the control of stormwater on a demonstration and full-scale plant level.



NOTE. $ft^2 \times 0.0929 = m^2$
$Mgal/d \times 0.0438 = m^3/s$

Figure 51. Cost of dissolved air flotation facilities.

TABLE 104. SUMMARY OF COSTS FOR DUAL MEDIA HIGH RATE FILTRATION FACILITIES [47]

Plant capacity, Mgal/d	Construction costs, $[b]		Construction costs, $/Mgal·d		Operation and maintenance costs, $	
	24 gal/ft²·min	16 gal/ft²·min	24 gal/ft²·min	16 gal/ft·min	24 gal/ft² min	16 gal/ft²·min
25	1 440 000	1 680 000	57 600	67 200	44 000	45 000
50	2 170 000	2 620 000	43 400	52 400	55 000	57 000
100	3 980 000	4 860 000	39 800	48 600	98 000	102 000
200	6 760 000	8 020 000	33 800	40 100	129 000	134 000

a ENR 2000

b. Includes low lift pumping station, prescreenigg, and chemical addition facilities; and excludes engineering and administration.

$Mgal/d \times 0.0438 = m^3/s$
$gal/ft^2 \cdot min \times 2.445 = m^3/m^2 \cdot min$