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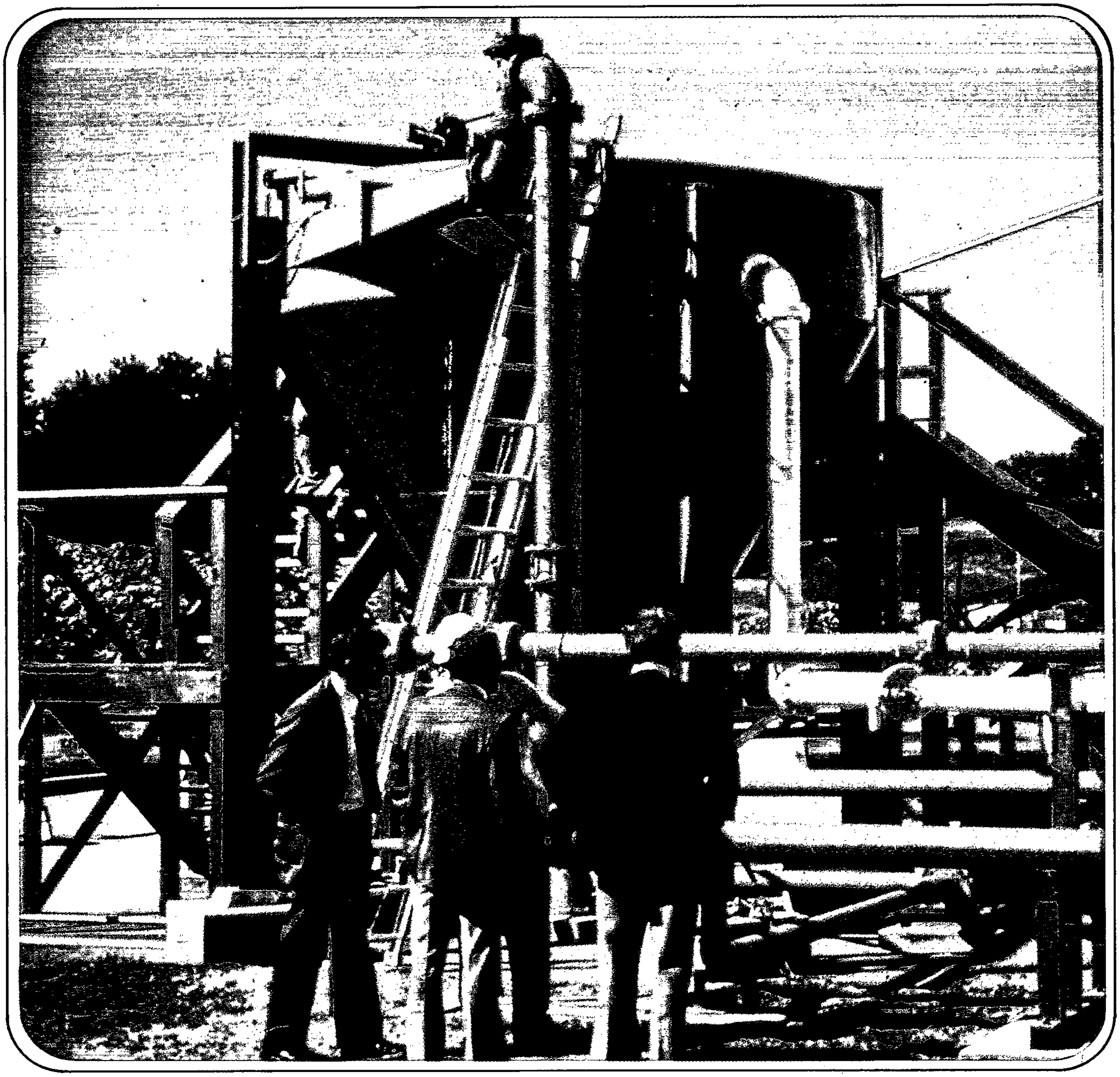
EPA TECHNOLOGY TRANSFER

CAPSULE REPORT

SWIRL DEVICE FOR REGULATING AND TREATING COMBINED SEWER OVERFLOWS

PREPARED BY U.S. ENVIRONMENTAL PROTECTION AGENCY



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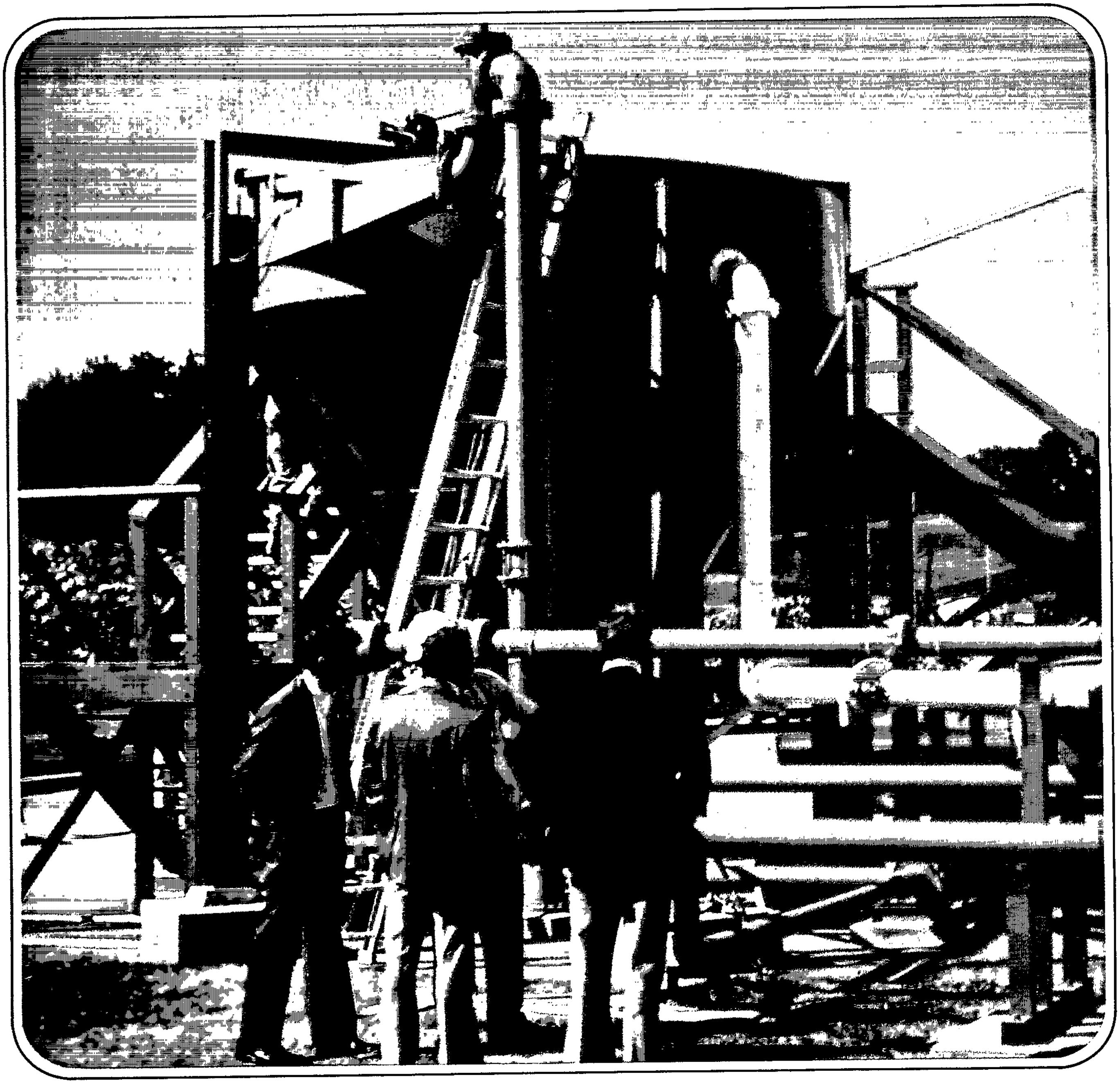


Prototype Swirl Primary Separator

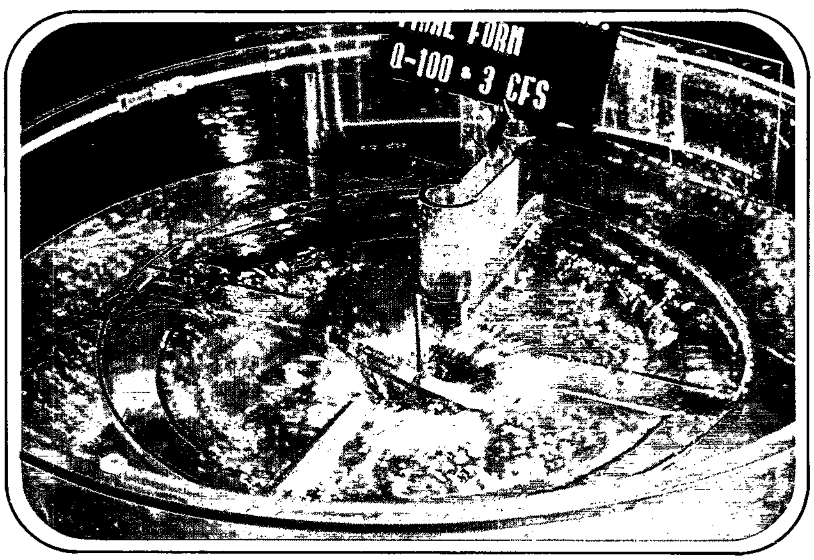
1. THE SIGNIFICANCE

Untreated storm overflows from combined (storm and sanitary) sewers are a substantial water pollution source during wet-weather periods. There are roughly 15,000 to 18,000 combined sewer overflow points in the USA that emanate from 40 to 80 percent of the total organic load in municipalities during wet-weather flow periods. It has been estimated that, on a national level, the expenditure for combined sewer overflow pollution abatement would be $25 billion.

In considering wet-weather water pollution abatement, attention must first be directed to control of the existing combined sewerage system and replacement (or stricter maintenance) of faulty regulators. Consulting and municipal engineers will agree that regulator mechanical failures and blockages persist at the overflow or diversion points resulting in unnecessary by-passing, which is also a problem during dry weather. Malfunctioning overflow structures, both of the static and dynamic varieties, are major contributors to the overall water pollution problem.

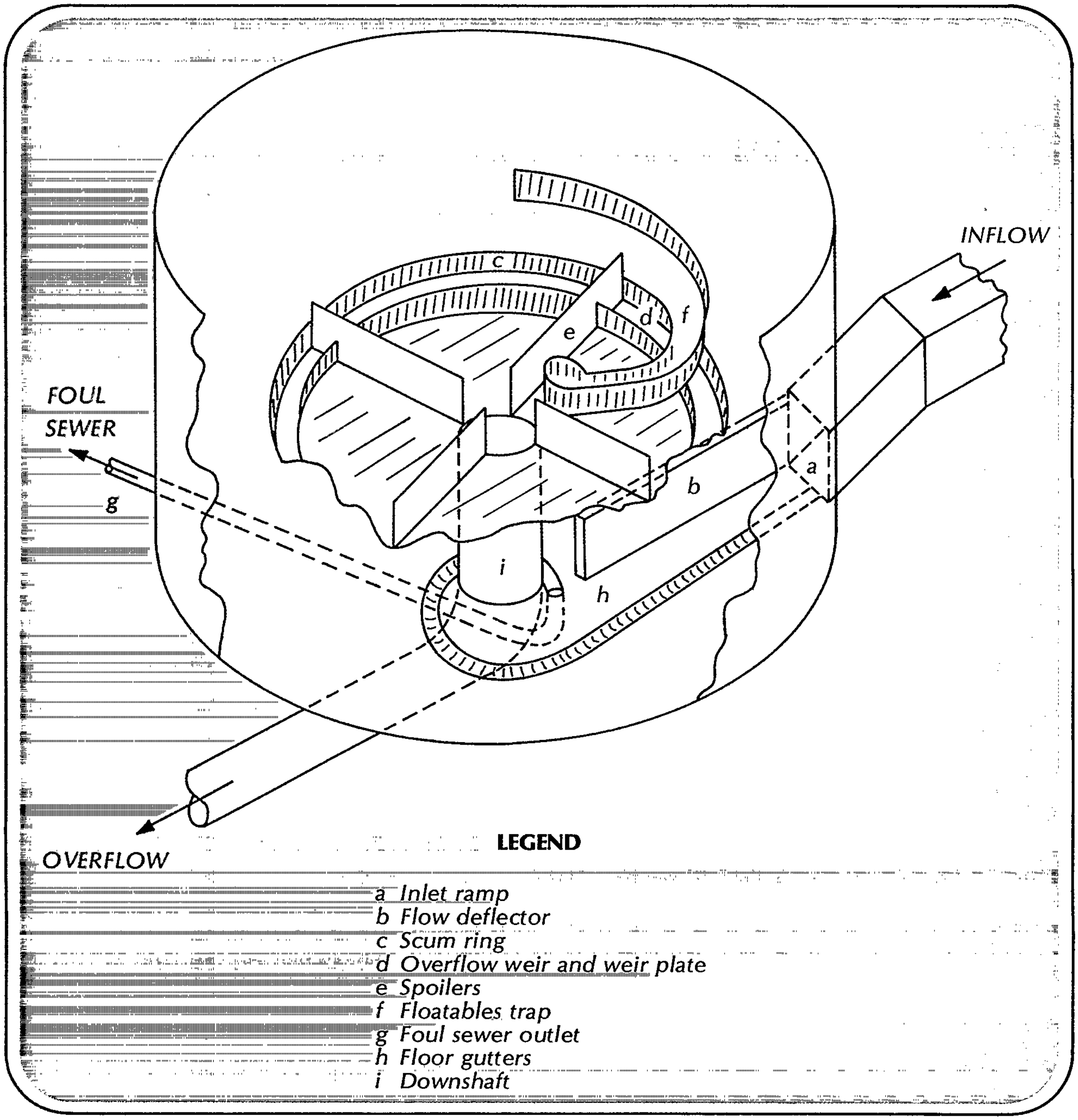
The practice in the USA of designing regulators exclusively for flow-rate control or diversion of combined wastewaters to the treatment plant and overflow to receiving waters must be reconsidered. Sewer system management that emphasizes the dual function of combined sewer overflow regulator facilities for improving overflow quality will pay significant dividends. The dual function is concentration of wastewater solids to the sanitary interceptor, and diversion of excess storm flow to the outfall. A new phrase has been coined, the "two Q's," to represent both the quantitative and qualitative aspects of overflow regulation. Regulators and their appurtenant facilities should be recognized as devices which have the responsibility of controlling both quantity and quality of overflow to receiving waters, in the interest of more effective pollution control.

An intensive study to develop a new type of combined sewer overflow regulator device, called swirl, was conducted under the general supervision of the U.S. Environmental Protection Agency's Storm and Combined Sewer Technology Program, Municipal Environmental Research Laboratory, Cincinnati, Ohio. The design of this device was based on hydraulic and mathematical modeling to optimize its configuration. This report describes the results of a full-scale prototype swirl unit that controlled real overflows in the city of Syracuse, New York, and discusses other areas of operation. The prototype evaluation project is jointly sponsored by EPA and Onondaga County, New York, under ongoing EPA Demonstration Grant No. S-802400.



Swirl Hydraulic Model in Operation

2. THE NEW PROCESS



Isometric View of Swirl Regulator/Separator

ELEMENTS OF THE SWIRL REGULATOR/SEPARATOR

The swirl flow regulator/separator is of simple annular-shaped construction and requires no moving parts. An essentially static device performing under such variable conditions requires careful design of its internal elements, as shown in the isometric drawing.

(a) Inlet ramp. The inlet ramp should be designed to introduce the incoming flow at the bottom of the chamber, while preventing problematical surcharges on the collector sewer immediately upstream. Introducing the inflow at the chamber floor will allow the solids to enter at as low a position that is possible. It is essential that this ramp and its entry port introduce the flow tangentially so that the "long path" maximizing the solids separation in the chamber may be developed.

(b) Flow deflector. The flow deflector is a vertical, free-standing wall which is a straight line extension of the interior wall of the entrance ramp. Its location is important because it directs flow which is completing its first revolution in the chamber to strike and be deflected inwards, forming an interior water mass which makes a second revolution in the chamber, thus creating the "long path."

(c) Scum ring. The purpose of the scum ring is to prevent floating solids from overflowing.

(d) Overflow weir and weir plate. The weir plate is a horizontal circular plate that connects the overflow weir to a central downshaft which carries the overflow liquid to discharge. Its underside acts as a storage cap for floating solids directed beneath the weir plate through the floatables trap. The vertical element of the weir is extended below the weir plate to retain and store floatables.

(e) Spoilers. Spoilers reduce rotational energy of the liquid above the weir plate and between the scum ring and weir, thus increasing the overflow capacity of the downshaft and improving the separation efficiency.

(f) Floatables trap. This trap is a surface flow deflector which extends across the outer rotating flow mass, directing floating materials into a channel crossing the weir plate to a vertical vortex cylinder located at the wall of the overflow downshaft. The floating material is then drawn down beneath the weir plate by the vortex and dispersed under the plate around the downshaft.

(g) Foul sewer outlet. This outlet is the exit orifice designed to direct peak dry-weather flow and separated combined sewage solids in the form of a concentrated slurry to the interceptor.

(h) Primary floor gutter. The primary floor gutter is the peak dry-weather flow channel connecting the inlet ramp to the foul sewer outlet, avoiding dry-weather solids deposition.

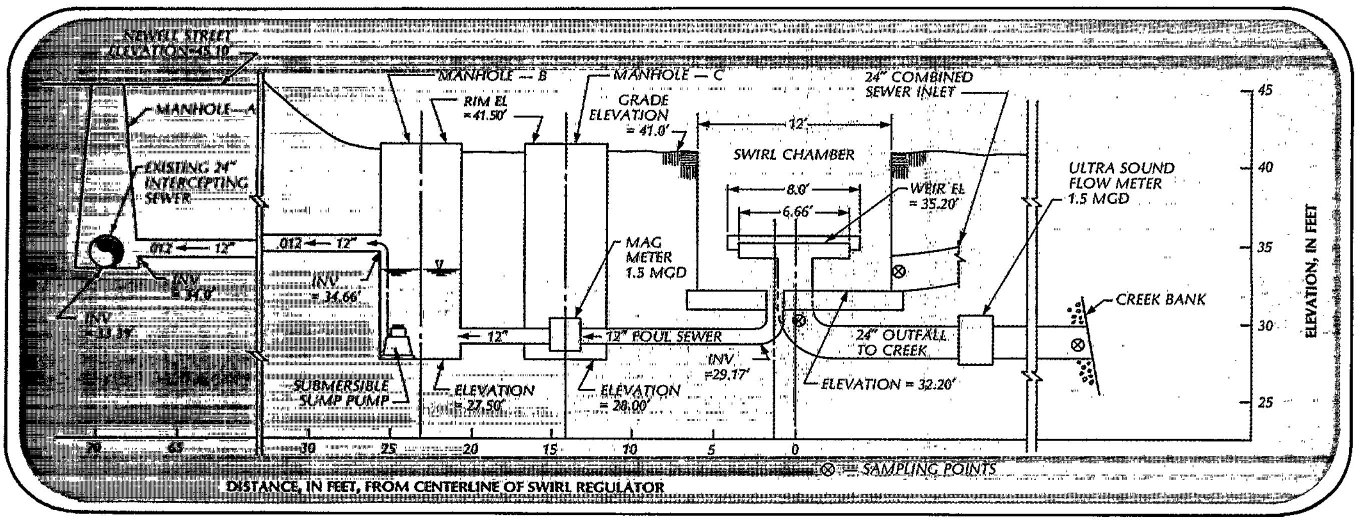
(i) Downshaft. During higher-flow storm conditions, the low-volume concentrate is diverted to the intercepter via the foul sewer outlet, and the excess relatively clear, high-volume supernatant overflows the center circular weir into the downshaft for storage, treatment, or discharge to the receiving stream.

The swirl device is capable of functioning efficiently over a wide range of combined sewer overflow rules and has the ability to separate settleable light-weight organic matter and floatable solids at a small fraction of the detention time required for primary separation—seconds to minutes as opposed to hours.

SYRACUSE PROTOTYPE

A 3.6 m (12 ft) diameter swirl combined sewer overflow regulator was installed at West Newell Street in Syracuse, New York. Preconstruction inspections at the test site confirmed that full-pipe flow conditions occurred during normal springtime overflows from the 54-acre tributary area. Design flood flow to the swirl device was based on maximum carrying capacity of the 24-inch diameter combined sewer—8.9 mgd—and a design flow for quality control, in accordance with scale model investigations of 6.8 mgd.

An ideal installation would not require a pump. Unfortunately, however, it was not possible to avoid pumping at the test site. The Syracuse swirl prototype did not fit between the hydraulic gradients of the combined sewer inlet and the interceptor receiving the foul concentrate flow. Without a pump, dry-weather flow would have caused a standing depth of about 0.9 m (3 ft) of sewage in the swirl chamber, resulting in solids accumulation and a possible septicity condition between storms. A submersible pump that operates during dry weather was therefore installed downstream of the outlet.



Profile of Syracuse Swirl Regulator

Overflow Operation

The facility was designed for immediate response to an overflow condition. A flowmeter on the 0.3 m (12 in) foul sewer outlet line measures dry-weather flow and the foul concentrate to the interceptor during wet-weather flow. The average dry-weather flow range is approximately 1.3 to 2.0 cu m/min (0.50 to 0.75 mgd).

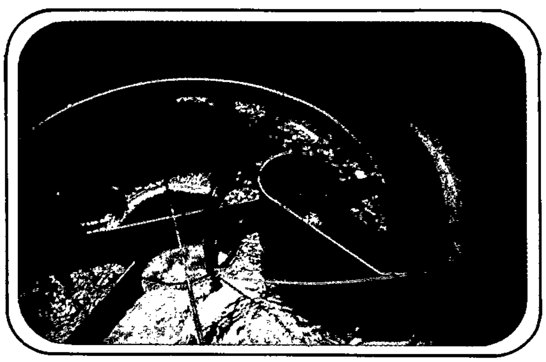
Since the downstream capacity of the interceptor is 3.4 cu m/min (1.3 mgd), maximum flow is reached. Flow in excess of 3.4 cu m/min (1.3 mgd) will be forced over the central overflow weir where it is measured by another flowmeter, disinfected, and discharged to the receiving stream.

When the overflow subsides, the pump reactivates and lowers the water level in the swirl chamber to allow free gravity flow in the floor gutter to prevent solids from settling. Scour velocity is maintained between storms. Sampling is performed at the inlet and outfall locations at 15- or 5-minute intervals during overflow events.

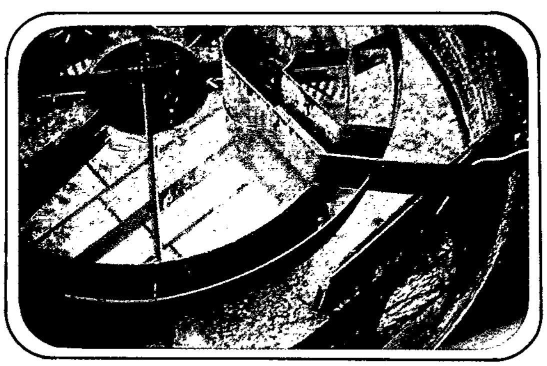
Coarse Floatables Removal

The coarse floatables/scum removal mechanism has worked satisfactorily. During overflows, floatables are contained by the scum ring *(c)* in the outer ring of the chamber, and forced into the floatables trap *(f)* and under the weir plate for wet-weather containment by the swirl action. These pollutants are subsequently drawn down and removed to the foul sewer during dry weather.

SWIRL REGULATOR
SYRACUSE PROTOTYPE



Wet Weather Operation



Dry Weather Operation

Floatables Entrapment During Wet Weather Operation

Maintenance

As the period between storms increases, more frequent maintenance will be required because of solids build-up during dry-weather flow. Periodic pump clogging also occurs from the accumulation of debris during overflow when the pump is not operating.

Manual hosing of the chamber walls and floor was necessary after each overflow. As an overflow subsided, the flow-through time in the swirl increased from 23 seconds at maximum flow to 9 minutes at minimum flow. This resulted in shoaling of solids on the chamber floor. Subsequent dry-weather flowrates and velocities were not great enough to carry accumulated solids to the floor gutter and through the foul sewer outlet. Automatic washdown facilities can eliminate the need for manual hosedown, and thus reduce maintenance. The frequency of swirl chamber cleaning is approximately once per month.

Estimated manpower requirements for the swirl at West Newell Street are 48 hr/yr (4 hr/clogging × 12 clogs/yr) for submersible (single-vaned impeller) pump cleaning, and 40 hr/yr (4 hr/overflow × 10 overflows/yr) for chamber cleaning, totalling 88 hr/yr. Cost-wise, maintenance amounts to $1,800/yr.

3. PERFORMANCE

SOLIDS SEPARATION EFFICIENCIES

Hydraulic Model

Based on laboratory hydraulic model studies, suspended solids (SS) removal efficiency for the swirl treating combined sewer overflows should be approximately 65 percent. Particle removal effectiveness was determined to be a function of effective diameter and specific gravity (or settling velocity). For grit with specific gravity of 2.65 and greater than 0.3 mm, removals were over 90 percent; removals decreased to less than 40 percent for 0.1 mm (0.04 in) grit. For settleable organics with specific gravity of 1.20, and larger than 1.0 mm, efficiency ranged from 80 to 100 percent; and for 0.3 mm particles, efficiencies decreased to less than 20 percent.

Prototype

Relatively good SS removal efficiencies were determined over the entire storm flow range of the Syracuse prototype (Table 1). Total mass loading and concentration removal efficiencies ranged from 33 to 82 percent and 18 to 55 percent, respectively, with flowrates from 0.54 cu m/min (0.2 mgd) to 20.5 cu m/min (7.6 mgd). Figures 1 and 2 illustrate the total SS mass removals with respect to time and storm flowrate. The shaded areas between curves indicate a trend of higher removals at storm onset when concentrations are generally higher, and again near the end of the storm when flowrates drop.

Table I
SUSPENDED SOLIDS REMOVAL

	Swirl Concentrator						Conventional Regulator		
	Average SS per storm, mg/l			Mass Loading kg			Mass Loading kg		
Storm #	Inf.	Eff.	(%) Rem.[b]	Inf.	Eff.	(%) Rem.[b]	Inf.	Underflow	(%) Rem.[a]
2-1974	535	345	36	374	179	52	374	101	27
3-1974	182	141	23	69	34	51	69	33	48
7-1974	110	90	18	93	61	34	93	20	22
10-1974	230	164	29	256	134	48	256	49	19
14-1974	159	123	23	99	57	42	99	26	26
1-1975	374	167	55	103	24	77	103	66	64
2-1975	342	202	41	463	167	64	463	170	37
6-1975	342	259	24	112	62	45	112	31	28
12-1975	291	232	20	250	168	33	250	48	19
14-1975	121	81	33	83	48	42	83	14	17
15-1975	115	55	52	117	21	82	117	72	62

[a]For the conventional regulator removal calculation, it is assumed that the SS concentration of the foul underflow equals the SS concentration of the inflow.

[b]Data reflecting negative SS removals at tail end of storms not included.

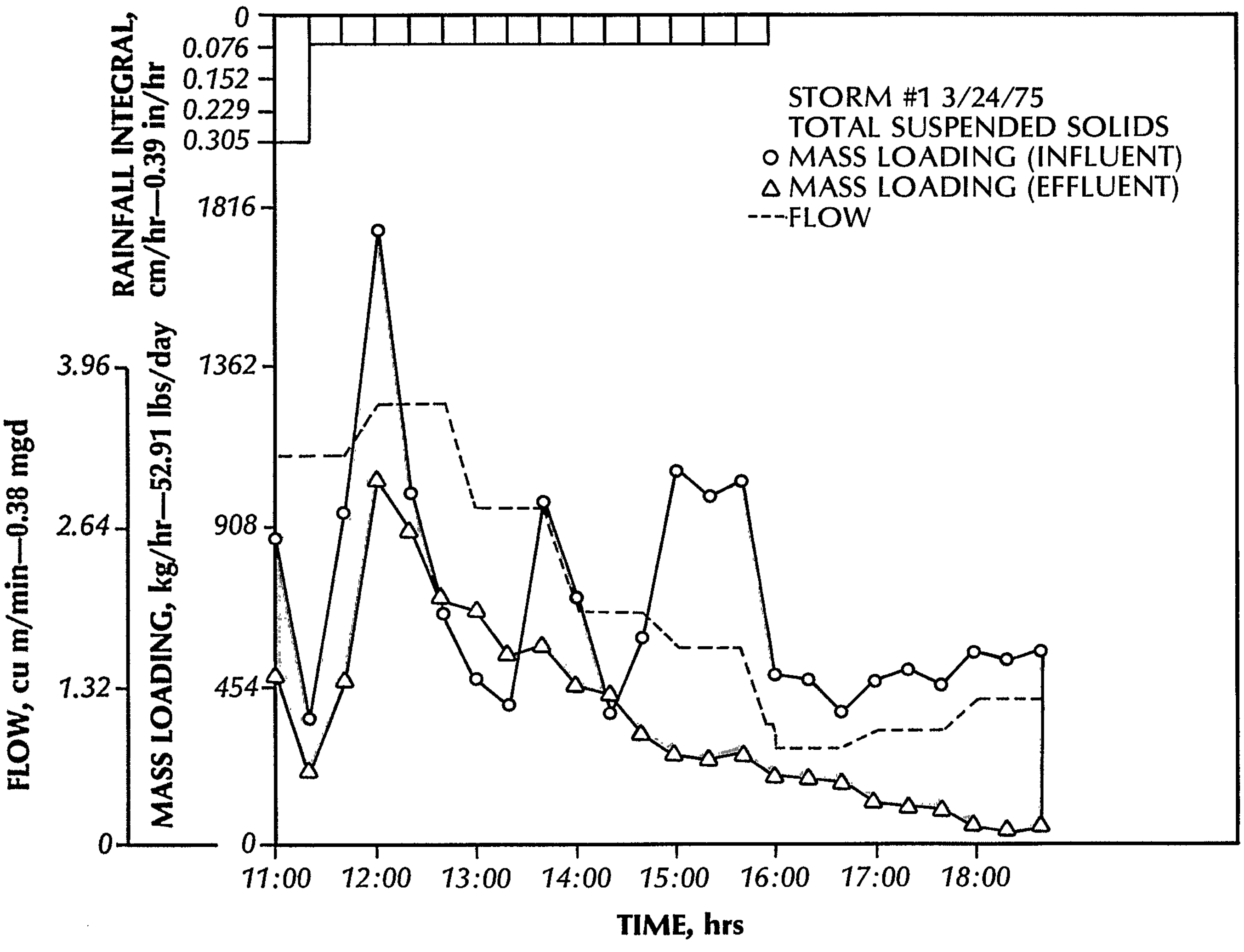


Figure 1. Swirl Regulator Suspended Solids Removal, Syracuse, N.Y., Storm #1.

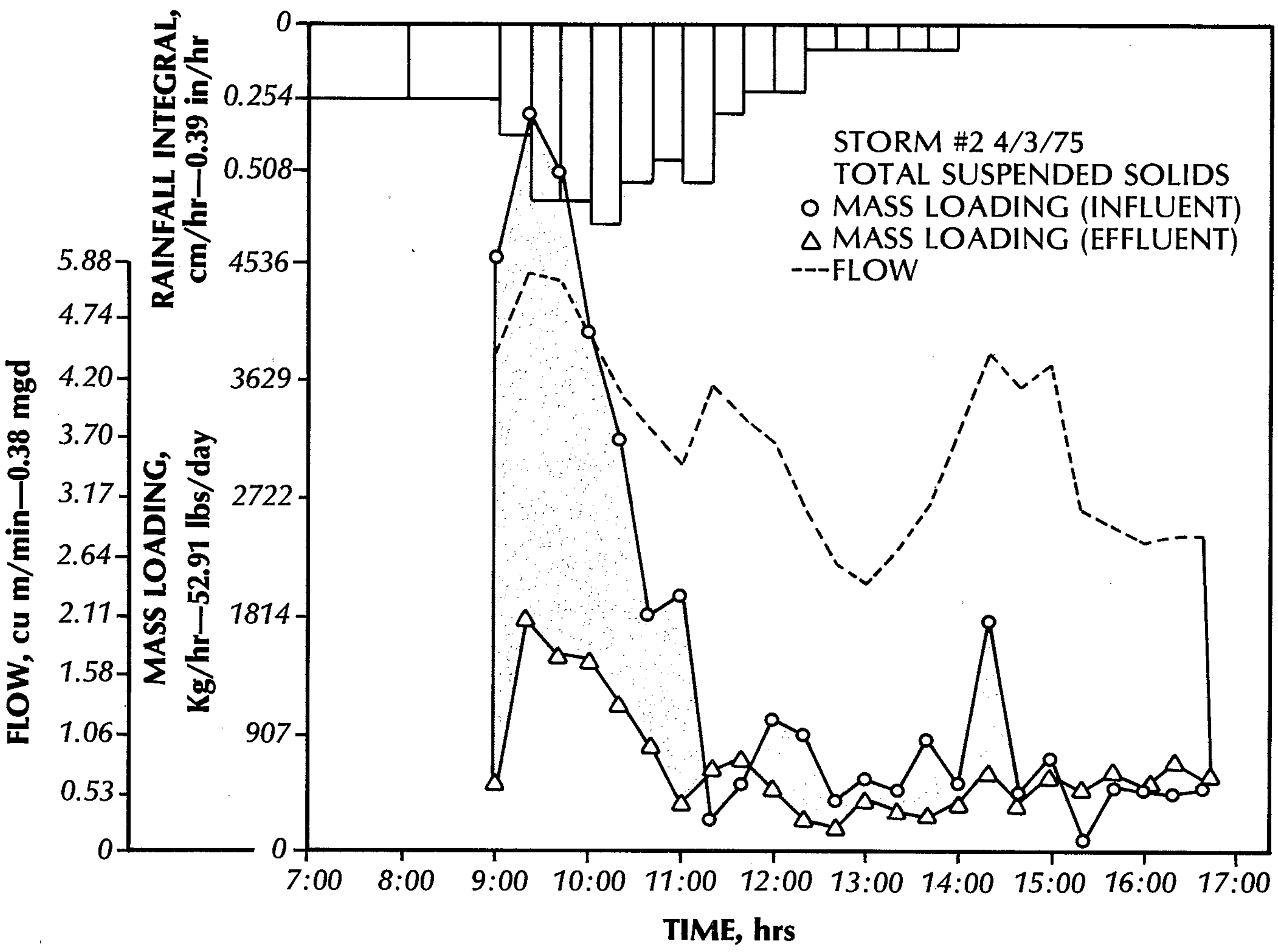


Figure 2. Swirl Regulator Suspended Solids Removal, Syracuse, N.Y., Storm #2.

Figure 3 further reveals the trend of greater SS mass loading reduction as the SS influent concentrations increase. Suspended solids influent concentrations greater than 250 mg/l generally resulted in removals of better than 50 percent of the total mass loading to the swirl.

Care must be taken in evaluating swirl solids treatability since under dry-weather flow conditions, all regulators are designed to divert the entire flow volume and associated solids to the intercepting sewer until a predetermined overflow rate is reached. This diversion to the interceptor continues at a maximum throughout the storm. However, the swirl has the added advantage of concentrating solids as well as conventionally diverting flow during overflow events. This concentrating effect is evidenced by removal efficiencies in terms of SS concentrations varying from 18 to 55 percent (Table 1), as previously stated; whereas conventional regulators are assumed not to concentrate solids at all (zero percent removal) (Table 1, footnote a).

If the swirl regulator was replaced by a conventional flow regulator, the net mass loading reductions (attributable to the SS conventionally going to the intercepted underflow) would have ranged from 17 to 64 percent (Table 1) as compared to a more effective range of 33 to 82 percent (Table 1) for the swirl. This may be a better way to compare the effectiveness of the swirl to conventional combined sewer overflow regulators since conventional devices will remove the solids associated with the flow diverted for treatment.

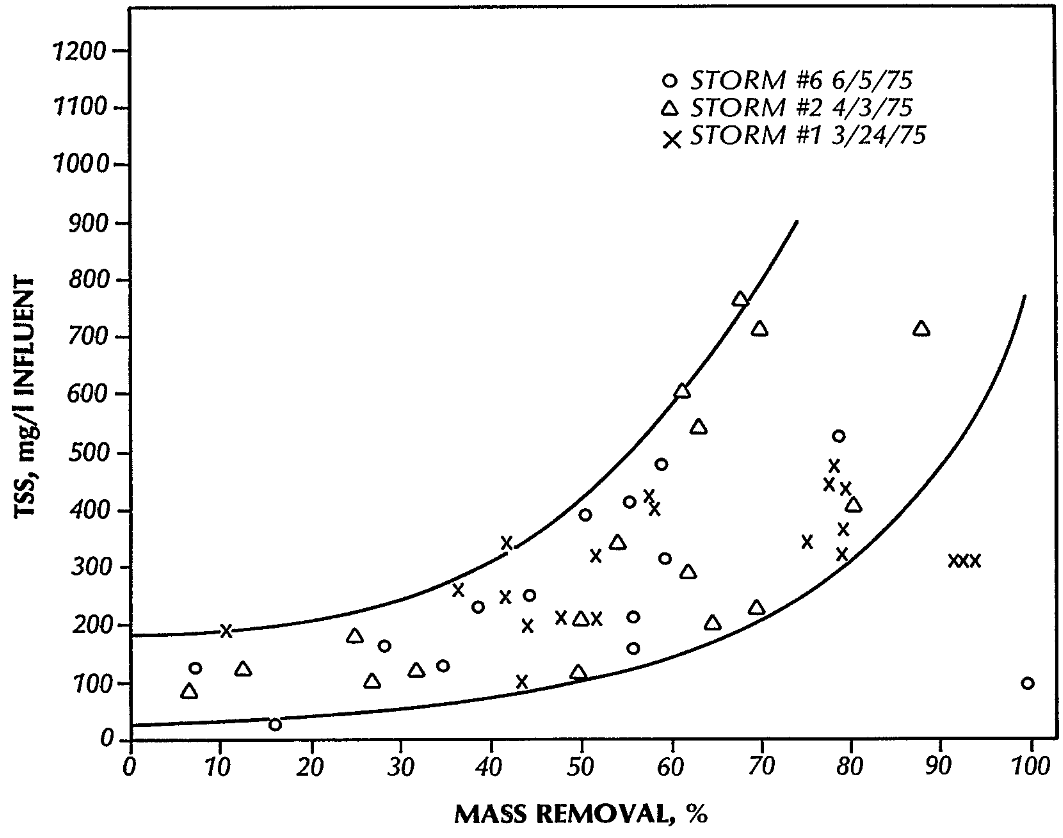


Figure 3. Swirl Regulator Suspended Solids Influent Concentration vs Percent Mass Loading Removal, Syracuse, N.Y.

For low-flow storms, approaching the maximum dry-weather capacity of the interceptor, the advantages of swirl concentration are reduced as would be expected based on the physical principle of mass balance involved. In other words, as the ratios of "inflow to foul outlet underflow" or "weir overflow to foul outlet underflow" decrease, the SS removal advantage from swirl concentrating also decreases. This is because the intercepted hydraulic loading to underflow becomes more significant in the net mass loading calculation of the hypothetical conventional regulator. This phenomenon is exemplified by the SS total (of the swirl) compared to SS net (of the conventional regulator) mass loading removals of Storm No. 1-1975 (Table 1), where the hydraulic loadings to the swirl were low, approaching dry-weather conditions.

Many outfalls are designed to pass 20, 100 and even 1,000 times average dry-weather flow as opposed to West Newell Street which, at best, passes only 10 times average dry-weather flow. For these cases, the swirl concentrating effect will exhibit distinct advantages over conventional regulators for SS removal.

BOD REMOVAL

Prototype analyses indicated BOD_5 removals of 50 to 82 percent for mass loading, and 29 to 79 percent in terms of concentration (Table 2). Figures 4 and 5 indicate the trend for BOD_5 total mass loadings removal for the swirl prototype. Figure 6 indicates higher removals at higher BOD_5 influent concentrations.

Table 2
BOD_5 REMOVAL

	Mass Loading, kg			Average BOD_5 per storm, mg/l		
Storm #	Influent	Effluent	Rem. (%)	Influent	Effluent	Rem. (%)
7-1974	26,545	4,644	82	314	65	79
1-1975	3,565	1,040	71	165	112	32
2-1975	12,329	6,164	50	99	70	29

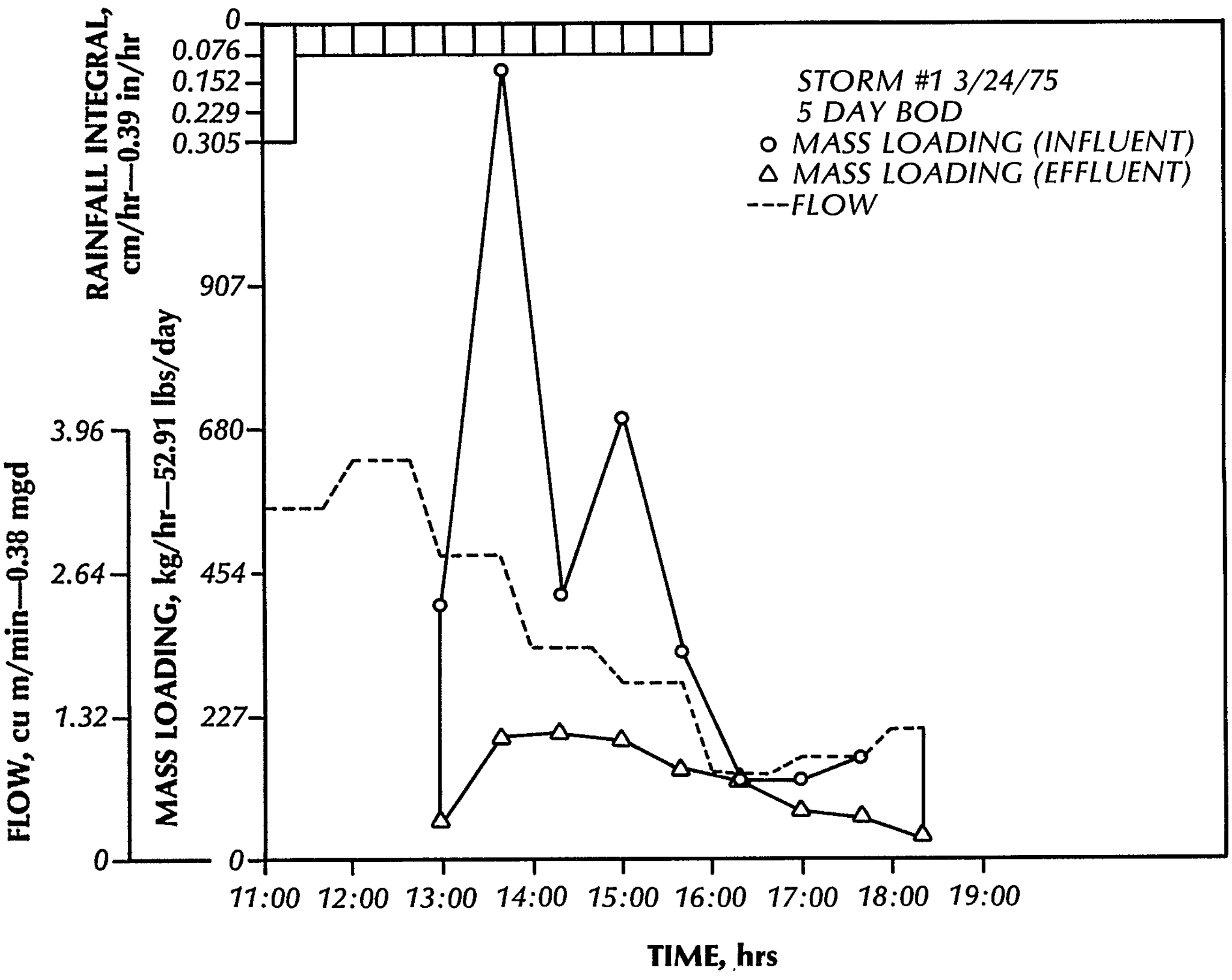


Figure 4. BOD_5 Removals, Syracuse, N.Y., Storm #1.

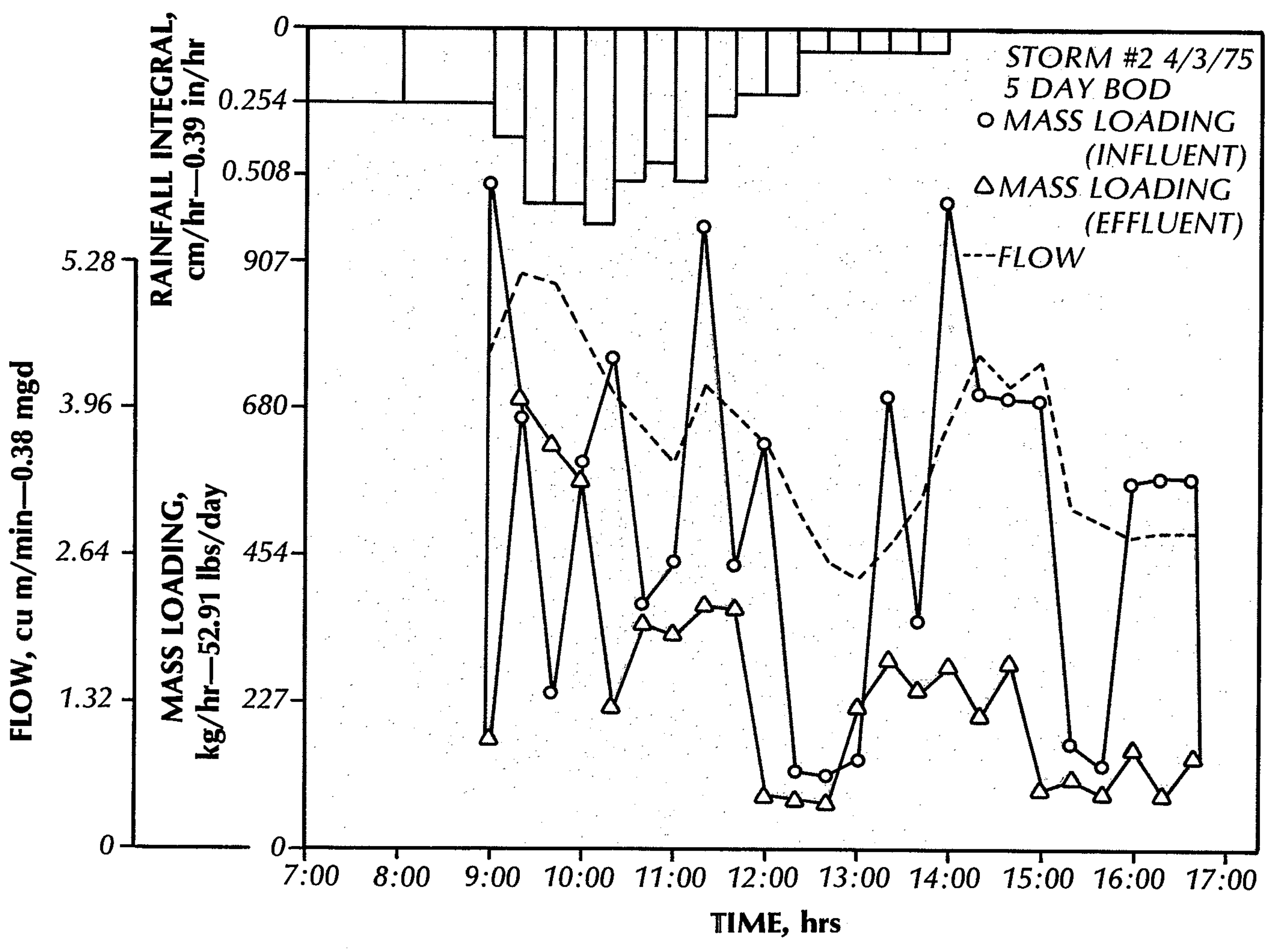


Figure 5. BOD_5 Removals, Syracuse, N.Y., Storm #2.

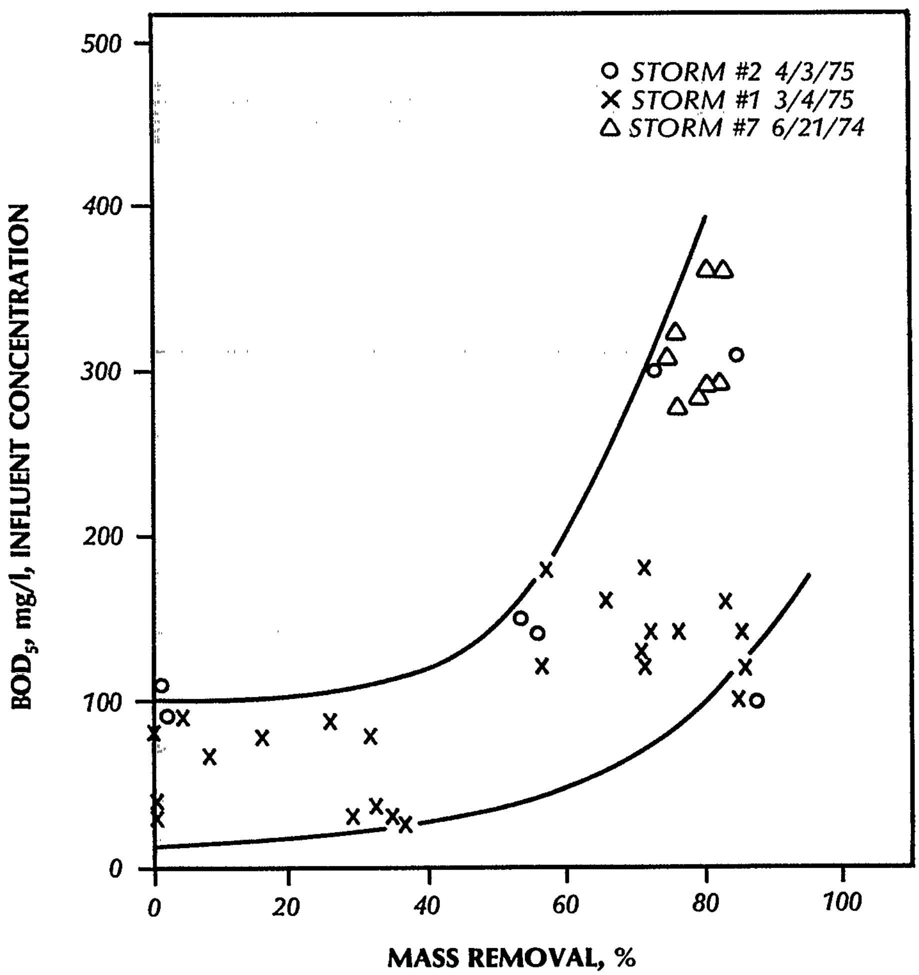


Figure 6. Swirl Regulator BOD_5 Influent Concentrations vs. Percent Mass Loading Removal, Syracuse, N.Y.

4. THE ECONOMICS

Costs for the swirl prototype at West Newell Street (designed to remove 90 percent grit, without pumping) were $55,000 capital ($8,100/mgd or $1,000/acre) and $2,000/yr operation and maintenance. In addition, $13,000 in capital costs were incurred for pumping. If an automatic pipe and nozzle washdown were installed, it would cost an additional $3,500 (estimated).

Swirl cost curves (Figure 7) were developed on the basis of capital costs experienced at Syracuse and full-scale costs estimated for another study. It is assumed that swirl regulator maintenance requirements are independent of size and that the person-hour requirements and associated costs will be 88 hr/yr and $1,800/yr, respectively, as previously stated.

The West Newell Street design closely matches full-pipe flood conditions which could be overly safe for pollution control, especially for larger outfalls. It is entirely possible to reduce capital costs to $2,000/mgd and to $200-500/acre.

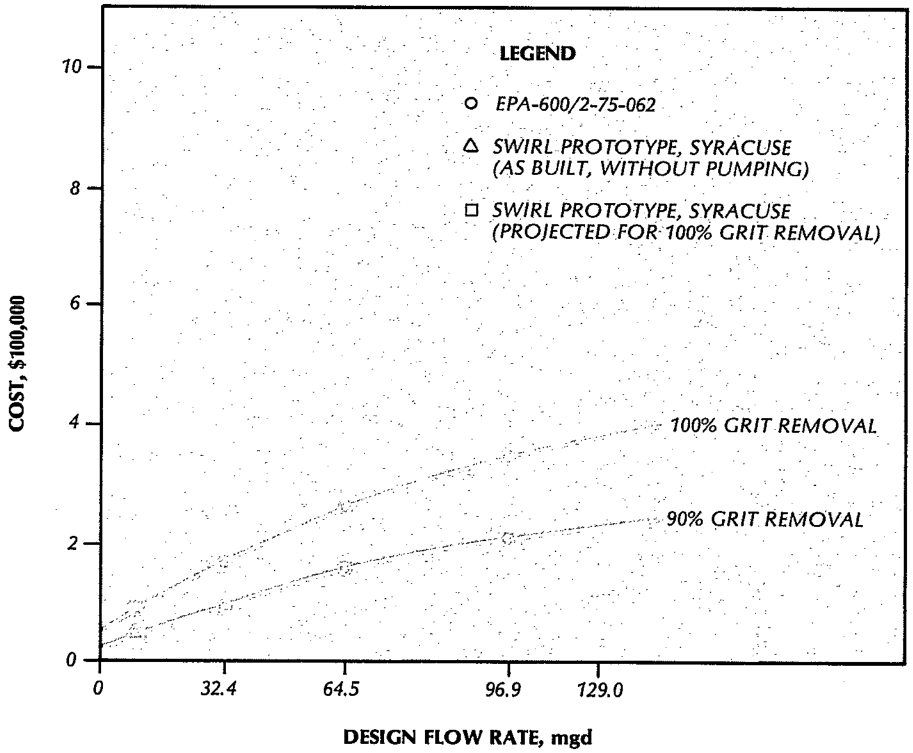


Figure 7. Estimated Construction Cost Curves — Swirl Regulator

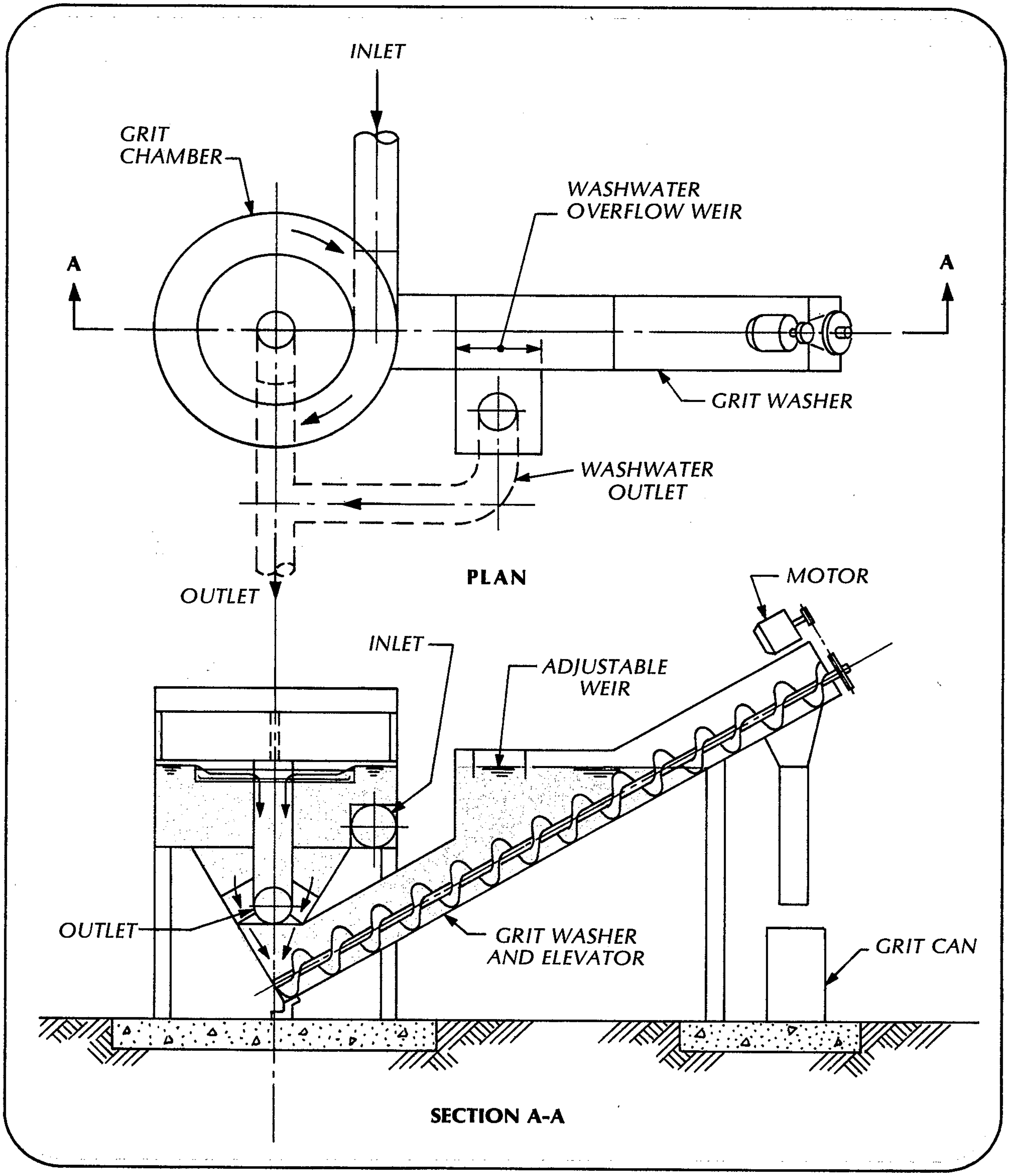
5. OTHER AREAS OF SWIRL APPLICATION

Aside from their use as flow regulator/separators, modified swirl devices have been considered, developed or demonstrated for grit removal and primary treatment of combined sewer overflows and municipal wastewater as well as for erosion control and separate urban stormwater pollution abatement.

THE SWIRL CONCENTRATOR AS A GRIT SEPARATOR DEVICE

The ability of the swirl flow pattern to effectively remove solids of particular sizes or specific gravities was noted during previous studies as discussed earlier. A swirl configuration and associated flow pattern was developed and adapted to effectively remove grit from either the underflow from the swirl combined sewer overflow regulator or from domestic sanitary sewage under EPA Grant No. S-802219 with the city of Lancaster, Pennsylvania. Hydraulic model development was performed by LaSalle Hydraulic Laboratory, Ltd., LaSalle, Quebec, Canada.

Recently a large pilot swirl concentrator designed as a grit removal facility was tested by the Metropolitan Denver Sanitary District No. 1 under EPA Grant No. S-803157. It was found that under the physical arrangements in Denver and testing with domestic sanitary wastewater ("spiked" with 0.25 mm dry blasting sand to simulate wet-weather flow concentrations), the swirl unit performed well. The efficiency of removing grit particles with specific gravity of 2.65 and sizes greater than 0.2 mm was equal to that of conventional grit removal devices. The small size, high efficiency, and absence of mechanical equipment in a swirl grit chamber facility offers economic advantages over conventional systems.



Grit Chamber Above Ground With Inclined Screw Conveyor — General Layout Plan

THE SWIRL CONCENTRATOR AS A PRIMARY SEPARATOR

In the interest of removing a greater fraction of suspended solids than the swirl regulator/separator does, a study was conducted to determine if the basic swirl concentrator principle could be used to provide primary treatment to combined sewer overflows and municipal wastewaters comparable to conventional sedimentation. Again, a hydraulic model with synthetic wastewater was used to arrive at an optimized configuration and a design basis. The design was then tested under actual wet- and dry-weather flow conditions using a large scale, 0.79 cu m/min (0.3 mgd) pilot constructed in Toronto, Canada under EPA Grant No. S-803157. These studies indicated that the device closely matched the treatment efficiency of conventional primary sedimentation at an overflow rate of 65.2 m^3/m^2 day (1600 gpd/sq ft) which is 2.67 times conventional design. Figure 8 gives a comparison of time to achieve treatment between the swirl and the conventional system at Toronto. Its height and diameter are equal, thus providing a relatively deep structure which enhances sludge thickening.

The relatively high overflow rates or lower detention times used with swirl concentrator design at various levels of suspended solids removal make the device potentially less costly to construct with less space required, thus enhancing its use in wastewater plant expansion and combined sewer overflow treatment. Its static sludge and scum collection system enhances appeal because of lower operation and maintenance costs.

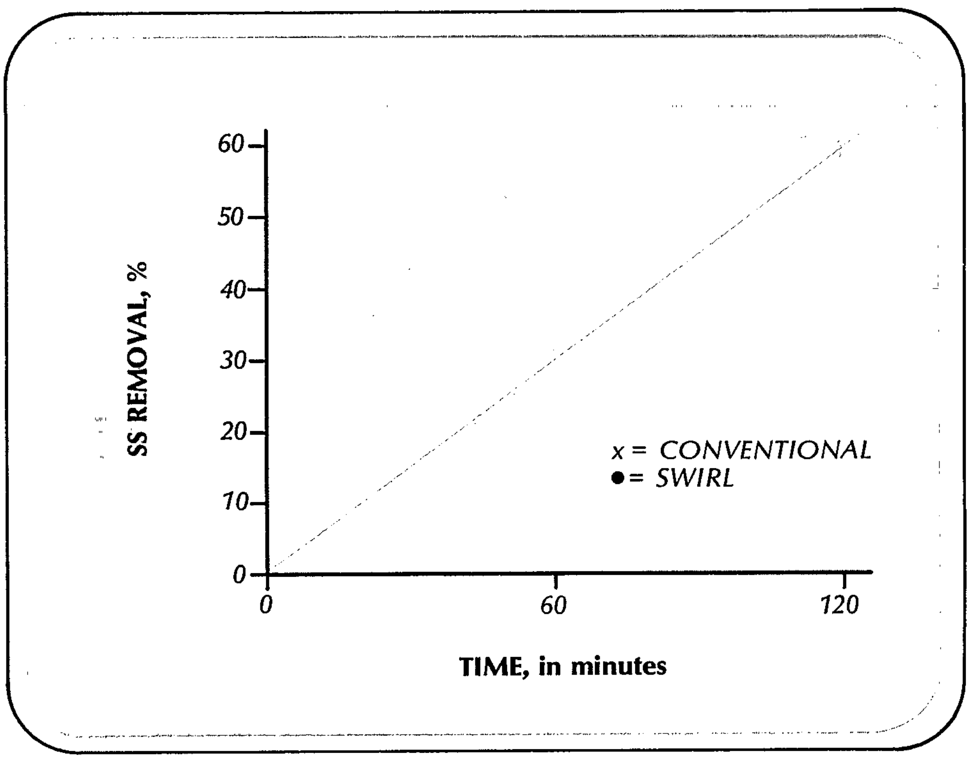
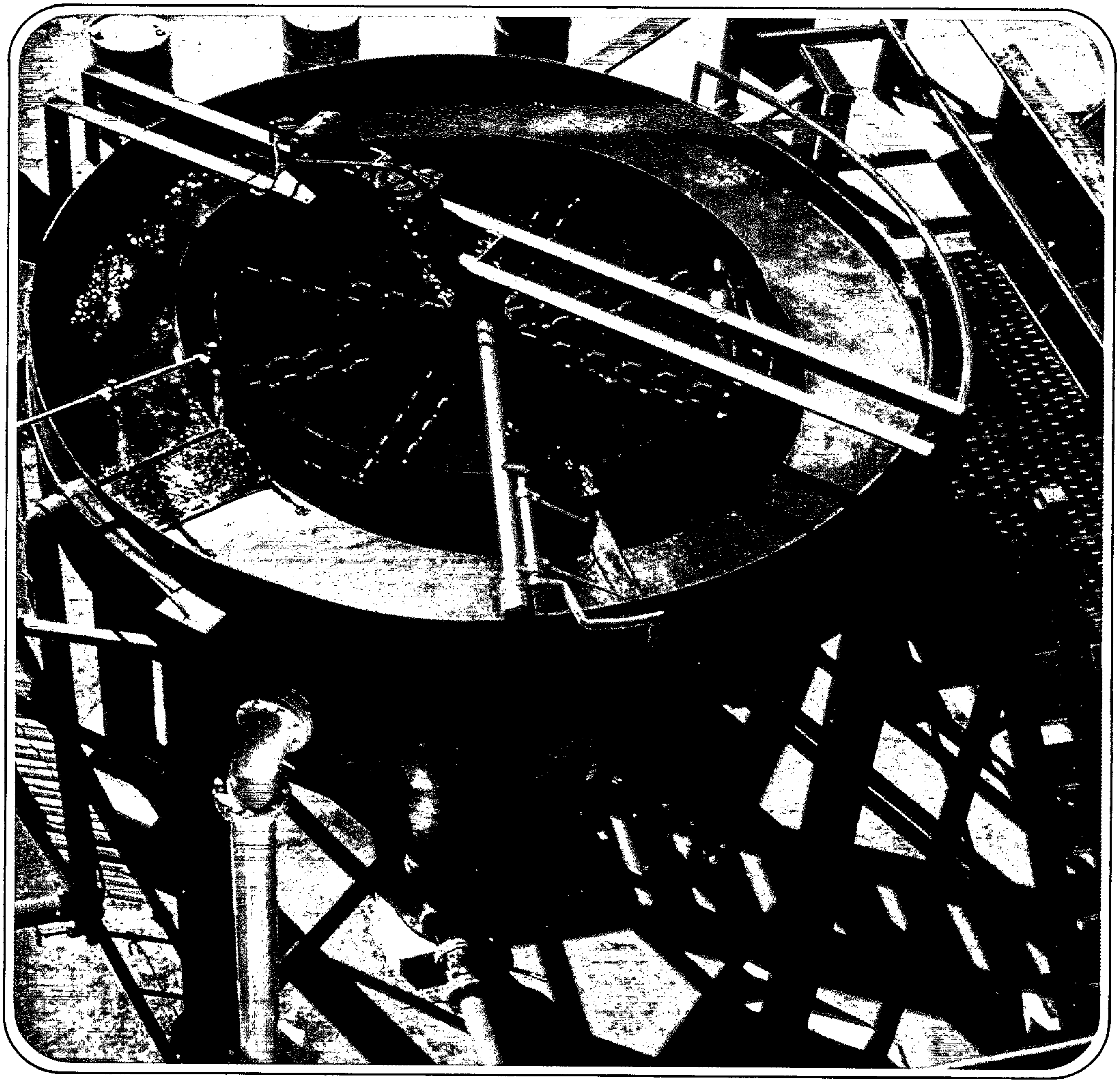


Figure 8. Comparison of Time to Achieve Primary Treatment — Swirl vs. Conventional Sedimentation — Toronto, Canada



Swirl Prototype Primary Separator, Toronto, Canada

THE SWIRL CONCENTRATOR AS AN EROSION CONTROL DEVICE

Soil erosion and resulting sediment are major problems. A properly designed and proportioned swirl concentrator chamber as developed under EPA Contract No. 68-03-0272 with the American Public Works Association, Chicago, Illinois, and LaSalle Hydraulic Laboratory, Ltd., LaSalle, Quebec, Canada, can perform an effective job of removing soil erosion particles from stormwater runoff at construction or other vulnerable sites. This swirl device can be rapidly and economically installed at points of erosion runoff by use of a conventional cattle watering tank having a 3.66 m (12 ft) diameter and a 0.9 m (3 ft) depth, fitted and equipped with a suitable inlet line, a circular overflow weir, a foul sewer outlet, and necessary interior appurtenances. Such a chamber could be readily disassembled, moved to another site, and reinstalled for the treatment of erosion runoff flows. If a permanent structure is desired, it can be fabricated out of concrete.

The de-silted or clarified effluent could be discharged to drainage facilities and disposed of into receiving waters or other points of disposal or use. The collected solids could be discharged through the foul sewer outlet and entrained or collected at suitable points for return to the point or points of erosion for use for other predetermined purposes. See Figure 9.

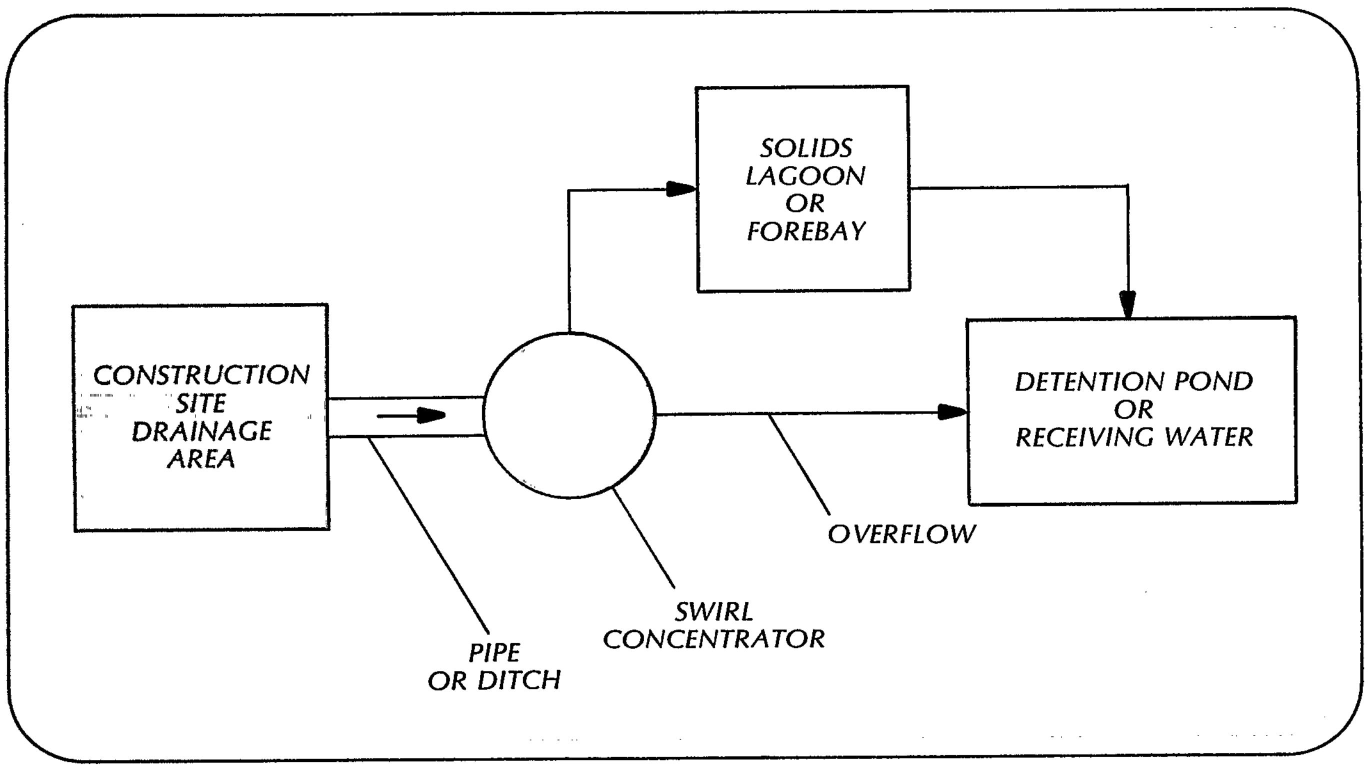


Figure 9. Swirl Erosion Control Device—Schematic.

THE SWIRL CONCENTRATOR AS URBAN STORMWATER RUNOFF POLLUTION CONTROL DEVICE

Swirls similar to the combined sewer overflow regulator variety can be installed on separate storm drains before discharge and the resultant concentrate can be stored in relatively small tanks since concentrate flow is only a few percent of total flow. Stored concentrate can later be directed to the sanitary sewer for subsequent treatment during low-flow or dry-weather periods, or if capacity is available in the sanitary system, the concentrate may be diverted to it without storage (see Figure 10). This method of stormwater control would be cheaper in many instances than building huge holding reservoirs and it offers a feasible approach to the treatment of separately sewered urban stormwater.

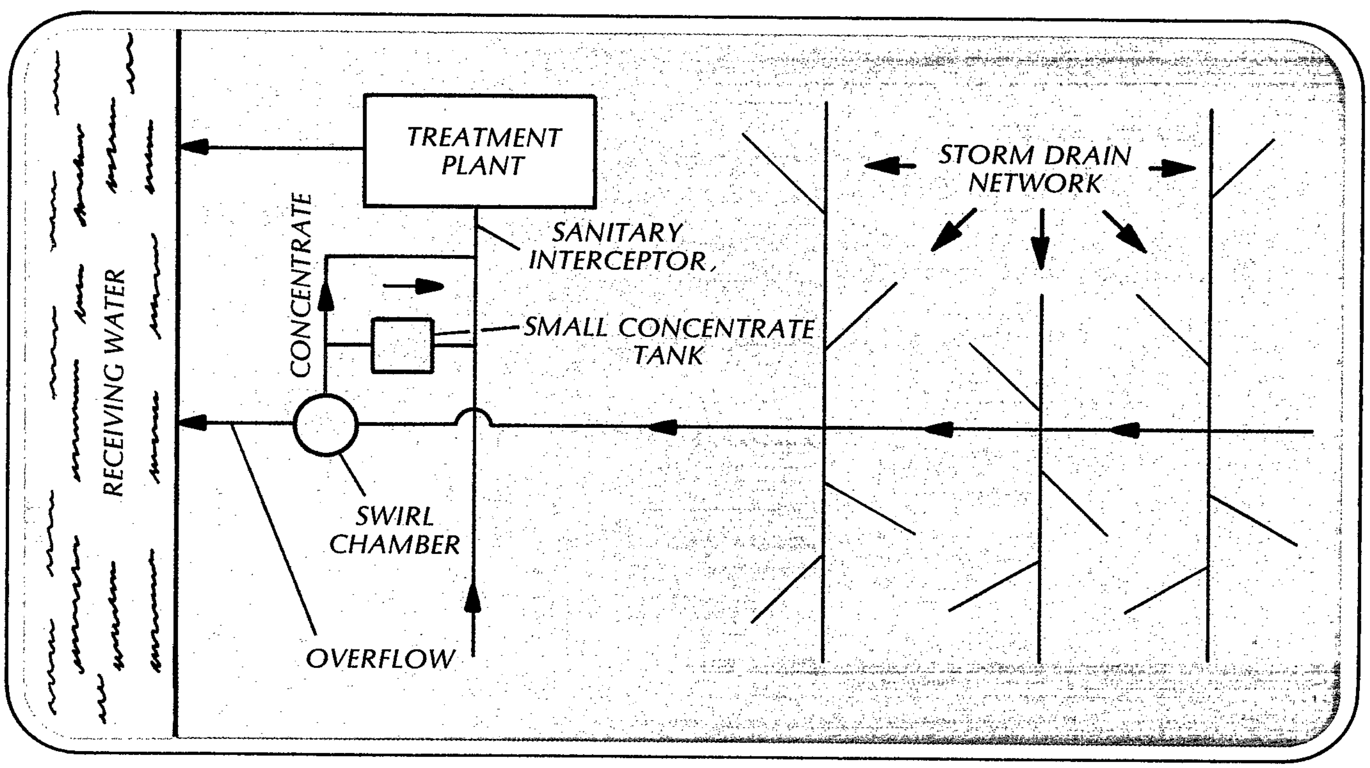


Figure 10. Swirl Urban Stormwater Run-Off Pollution Control Device—Schematic.

For further information:

The following detailed project reports are available from the National Technical Information Service, Springfield, Virginia 22151.

EPA-600/2-75-062, "The Helical Bend Combined Sewer Overflow Regulator."

EPA-670/2-74-026, "The Swirl Concentrator as a Grit Separator Device."

EPA-670/2-74-039, "Relationship Between Diameter and Heights for the Design of a Swirl Concentrator as a Combined Sewer Overflow Regulator."

This capsule report was prepared by Richard Field and Hugh Masters, U.S. Environmental Protection Agency, Storm and Combined Sewer Section, Edison, New Jersey.

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