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The Dual Functioning Swirl Combined Sewer Overflow Regulator/Concentrator

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THE DUAL FUNCTIONING SWIRL COMBINED SEWER OVERFLOW REGULATOR/CONCENTRATOR

by

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ABSTRACT

A hydraulic laboratory pilot project was run in conjunction with mathematical modeling to refine and demonstrate the swirl flow regulator/solids-liquid separator. The device, of simple annular shape construction, requires no moving parts. It provides a dual function, regulating flow by a central circular weir while simultaneously treating combined wastewater by a 'swirl' action which imparts liquid-solids separation. The low-flow concentrate is diverted via a bottom orifice to the sanitary sewerage system for subsequent treatment at the municipal works, and the relatively clear liquid overflows the weir into a central downshaft and receives further treatment or is discharged to the stream. The device is capable of functioning efficiently over a wide range of combined sewer overflow rates, and can effectively separate suspended matter at a small fraction of the detention time required for conventional sedimentation or flotation. For these reasons, serious thought is being given to the use of swirl units in series and in parallel solely as wet-weather (and domestic sewage) treatment plant systems.

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Introduction

Background

An intensive study(1,2) to develop and design a new type of combined sewer overflow regulator device was fostered by and piloted under the general supervision of the U.S. Environmental Protection Agency's (EPA's) Storm and Combined Sewer Technology Branch, Edison Water Quality Research Laboratory of the National Environmental Research Center - Cincinnati, Edison, New Jersey. The intent was to optimize the initial configuration of a circular combined sewer overflow regulator device referred to as a "vortex" which was originally developed by Smisson (2-6) and installed in Bristol, England in 1964. (Figure 1)

An outstanding team effort carried out the successful model development and optimization endeavor under the technical direction of Mr. Richard H. Sullivan of the American Public Works Association, Research Foundation. Hydraulic modeling to determine swirl concentrator configurations, flow patterns, and solids removal efficiency was performed by the LaSalle Hydraulic Laboratory, Ltd. of LaSalle, Quebec Province. Mathematical modeling by the General Electric Company, Re-entry and Environmental Systems Division was prepared in conjunction with actual hydraulic model results to determine a design basis. As indicated by Figure 2 good correlation was found between the two model studies. Mr. Bernard S. Smisson, responsible for the development of the forerunner vortex device, along with Dr. Morris M. Cohn, Mr. J. Peter Coombes, and Alexander Potter Associates, provided hydraulic model test planning, technical design requirement guidance and translation of findings into practicable application, and project reviews.

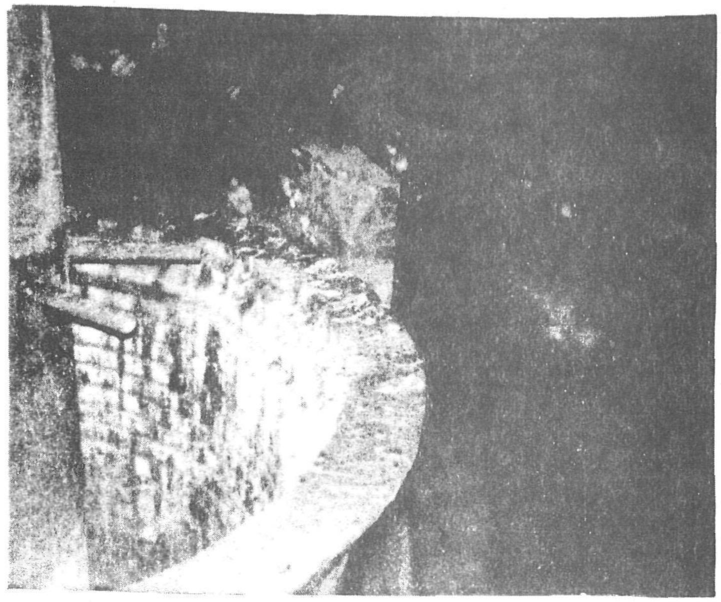


Figure 1

"Vortex" Device Originally Developed by Smisson, Bristol, England.

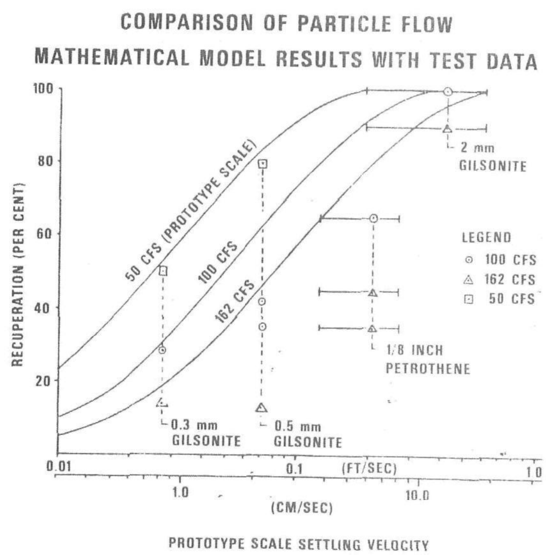


Figure 2

Comparison of Particle Flow Mathematical Model Results with Test Data

Combined Sewer Overflow Problems

The basic difficulty with combined sewers involves their built-in inefficiencies, which are their overflow points (2). Untreated overflows from combined sewers, have proved to be a substantial water pollution source during both wet and dry weather periods. In total nation-wide, there are roughly 15,000 to 18,000 combined sewer overflow points(7). It has been estimated in a study(7) for the EPA that on a national level the expenditure for combined sewer overflow pollution abatement would be 30 billion dollars (at today's cost).

In considering wet and dry-weather water pollution abatement, first attention must be directed to control of the existing combined sewerage system and replacement or stricter maintenance of faulty regulators. Consulting and municipal engineers will agree with the findings(2,4,5,7) that regulator mechanical failures and blockages persist at the overflow or diversion points resulting in unnecessary bypassing especially a problem during dry-weather periods. Malfunctioning overflow structures, both of the static and dynamic varieties, are major contributors to the overall water pollution problem.

The American practice of designing regulators for just flow rate control or diversion for dividing the quantity of combined wastewaters to the treatment plant, and the overflow to receiving waters must be given new consideration. Sewer system management which emphasizes the "dual function" of combined sewer overflow regulator facilities to improve overflow quality by concentrating sewage solids to the sanitary interceptor, as well as conventionally diverting excess storm flow to the outfall, will pay significant dividends(1,2,4,5). A new phrase, the "two Q's" representing both the quantitative and qualitative aspects of overflow regulation has been coined(1,4,5). "Regulators and their appurtenant facilities should be recognized as devices which have the dual responsibility of controling both quantity and quality of overflow to receiving waters, in the interest of more effective pollution control"(1).

"Swirl" Not a "Vortex"

The circular chamber concept which was evolved in England in order to obtain adequate weir length for overflows without the space requirement and expense of constructing a long lateral weir. As a bonus, it was found that this device could concentrate and divert as much as 70 percent of the combined sewage settleable solids along with 30 percent of the flow volume to the treatment works.

The concept of solids removal by rotationally induced forces causing inertial separation other than vertical gravity sedimentation, in relatively small tankage, lies behind the "vortex" principle utilized at Bristol, England. However, this investigation, working with the relatively larger flow diversions of 30 percent as compared to 2-3 percent in American practice, showed that a completely free-surface vortex condition must be avoided. Ackers(8,9) thought he might improve separation by developing a true free-surface vortex and instead concluded that this approach was not feasible. Without a deflector, unimpeded free vortex action as illustrated by Figure 3 is too violent, allowing a significant solids portion to overflow and is not nearly the optimal liquid-solids separation flow field.

Initially in the study(1), a forced vortex or "swirl" action was artifically induced, and the free vortex eliminated, by the manual insertion of a simple flow deflector which prevented flow completing its first revolution from merging with the inlet flow. A condition of rotating motion was established whereby the sewage was caused to follow an even longer spiral path around the circular chamber. Rotary motion at the surface was later further impeded by a vertical baffle (spoiler) arrangement perpendicular to the flow. Some rotational movement remained, but in the form of a gentle swirl, so that liquid entering the chamber from the inlet pipe is slowed down and diffused with very little turbu-

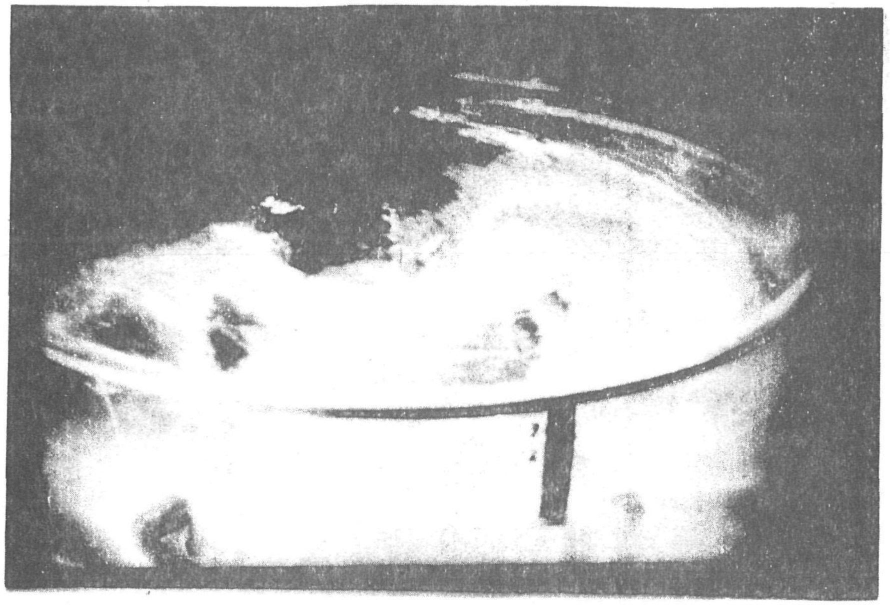


Figure 3

Unimpeded Free-Surface Vortex Action, Pilot Model, LaSalle, P.Q.

lence. The particles entering the basin are thereby induced to spread more easily over the full cross section of the stream tube and settle more rapidly. Solids are entrained along the bottom, around the chamber, and are concentrated at the dry-weather outlet.

Figure 4 illustrates a crude deflector plate inducing a gentle swirling action which encourages a greater inertial separation of solids to take affect. As will be described later, investigations resulted in an optimized device capable of greater separation efficiencies (than the English vortex unit) with a concentrate to the interceptor of only 2% as compared to the 30% (for the British device).

General Description of Swirl Device

The swirl flow regulator/solids-liquid separator is of simple annular-shaped construction and requires no moving parts. An overhead view of the final form of the device in operation is shown in Figure 5. It provides a dual function--regulating flow by a central circular weir-spillway while simultaneously treating combined wastewater by swirl action which imparts liquid-solids separation. Dry-weather flows are diverted through a cunette-like channel in the floor of the chamber into a bottom orifice located near the central standpipe which outlets to the intercepting sewer for subsequent treatment at the municipal plant. Figure 6 depicts another overhead view with the top weir plate arrangement removed and the device dry so that the floor gutters are clearly visible. During higher flow, storm conditions, the low-volume concentrate is diverted via the same bottom orifice leading to the interceptor, and the excess, relatively clear, high-volume supernatant overflows the center circular weir into a downshaft for storage and/or treatment or discharge to the stream. This device is capable of functioning efficiently over a wide range of combined sewer overflow rates having the ability to separate settleable light weight organic matter and floatable solids at a small fraction of the detention time required for primary separation. Figure 7 illustrates an elevation view of the

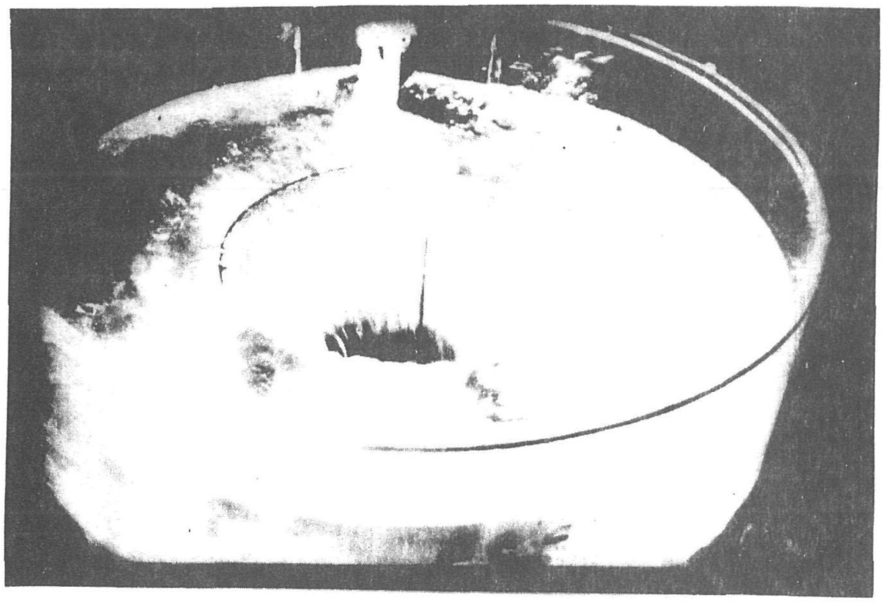


Figure 4

Crude Deflector Plate Inducing Gentle Swirling Action, Pilot Model, LaSalle, P.Q.

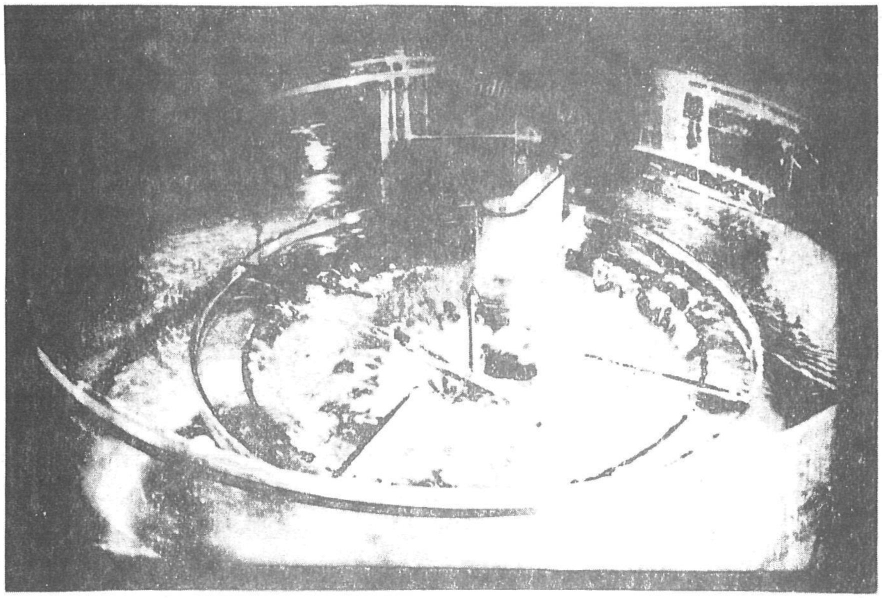


Figure 5
Overhead View of Swirl Flow Regulator/Solids-Liquid Separator in Operation, Pilot Model, LaSalle, P.Q.

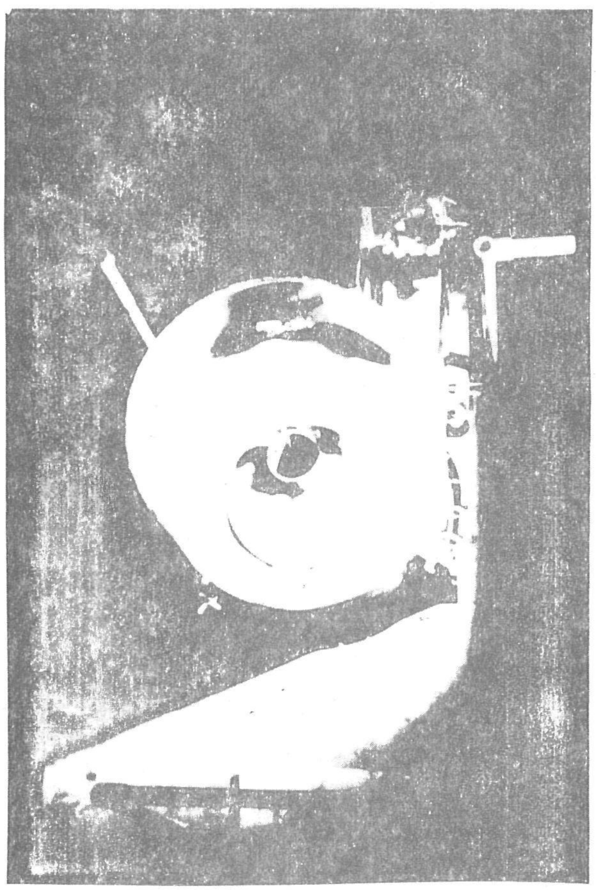


Figure 6

Dry Swirl Device with Floor Gutters Visible, Pilot Model, LaSalle, P.Q.

swirl in operation with solids being separated towards the floor.

Modeling

A prototype chamber was modeled in hydraulic and mathematical studies and specific calculations were performed for both the laboratory model and a proposed prototype unit to be installed at Lancaster, Pennsylvania. Over and above the specificity of the mathematical investigations of Lancaster conditions, the results are applicable to a broad range of chamber sizes, flow rates and particle characteristics.

Hydraulic Model Description

The swirl concentrator model took the form of a vertical cylinder 36 inches in diameter and 40 inches high, made of 1/2-inch plexiglass. The overall model layout is shown in Figure 8 The inlet was a six-inch diameter polyvinyl chloride (PVC) pipe. A vibrating solids injection system was placed on this supply pipe. A movable one-inch diameter tygon tube was placed inside the cylinder, beneath the floor of the test chambers to pick up the concentrated flow. The tube was led out the bottom of the cylinder, and its free end could be raised or lowered to control the discharge drawn off through the concentrate outlet.

The overflow water outlet came up from the base, on the centerline of the cylinder in the form of a six-inch-diameter PVC pipe. Its level and diameter could be changed easily either by adding or removing elements of the same diameter pipe, or with adaptors to provide either larger or smaller diameter downshafts. Similarly, different diameters or configurations of weir could be adjusted and held in place on top of the shaft by a simple threaded brass rod coming up the center of the shaft.

Outflow from this pipe, which in operation represents the major part of the total discharge through the structure, entered a large settling basin equipped with a calibrated V-notch weir. The basin allowed suf-

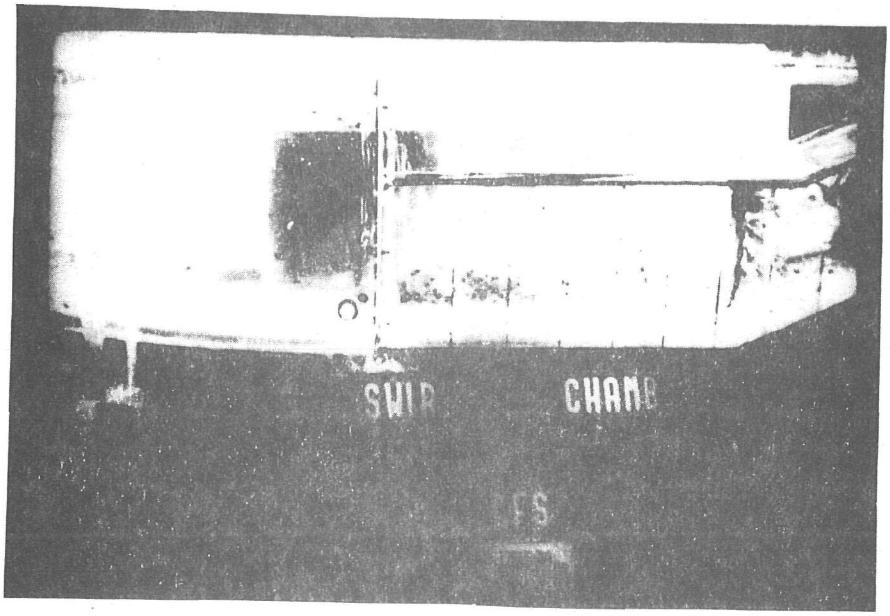


Figure 7

Elevation View of the Swirl in Operation with Solids being Separated Towards the Floor, Pilot Model, LaSalle, P.Q.

SWIRL CONCENTRATOR MODEL LAYOUT

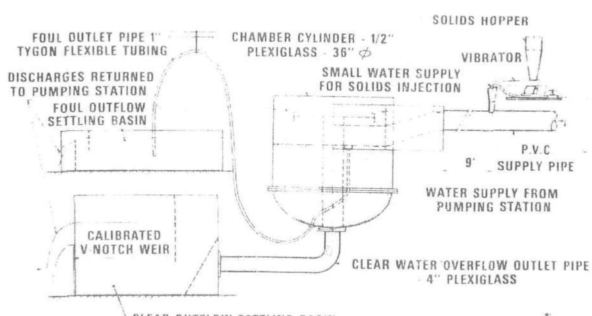


Figure 8

Overall Hydraulic Model Layout, LaSalle, P.Q.

ficient time for most of the solids contained in the clarified overflow to settle out for measurement. The clear discharge over the circular weir in the chamber was determined with the V-notch weir. Underflow and concentrate solids were measured in a like manner by a settling basin-V-notch weir arrangement. Removal effiencies were determined by expressing the total volume of solids separated as a percentage of an original full liter introduced.

Another form of comparison in the optimization process was measurement of rotational velocity. Study of these velocities in the form of detailed contour lines served as an indication of any tendencies to approach ranges found to have reduced removal efficiency.

The swirl chamber floor was moldable to enable easy changes of the bottom shape and its gutters. The entire model structure was designed for the flexibility of a trial and error procedure to optimize its overall configuration.

Normal scaling laws were used to establish the geometry of the hydraulic model and, in turn, of the mathematical model used in verifying the hydraulic findings. A ratio of 1:12 was used for converting the 3 foot diameter chamber laboratory model to an actual 36 foot diameter prototype size for the full-scale application in Lancaster, Pennsylvania. By using these scaling laws, the results calculated for a few special cases can be extended to other flow rates, chamber sizes, particle diameters and specific gravities provided that geometric similarity is maintained. Scaling, therefore, greatly reduces the amount of computation to be performed and extends the usefulness of both the mathematical and physical model results.

The Froude number

$$\frac{V}{\sqrt{gs}}$$

where: V = reference velocity (inlet velocity)

g = acceleration due to gravity

s = reference length (chamber diameter)

is used as a scaling parameter between the model and prototype swirl concentrators because gravitational forces are critical. For a fixed size relationship ($s_{model}/s_{prototype}$), the flow rate in the model must then be adjusted so that

$$\frac{V_{model}}{V_{prototype}} = \frac{s_{model}}{s_{prototype}}$$

Flow rate is proportional to Vs^2. Therefore the laboratory model was operated at a flow rate of

$$Q_m = Q_p \left[\frac{(Vs^2)_m}{(Vs^2)_p} \right]$$

$$= Q_p \left(\frac{s_m}{s_p} \right)^{5/2}$$

For example, to represent the prototype swirl at 100 cfs for a 1:12 size relationship, the scale model flow rate,

$$Q_m = \frac{100}{(12)^{5/2}} = 0.20037 \text{ cfs}$$

At this flow rate, the same Froude number in the model and prototype is maintained, and the fluid motion and the balance between the gravitional and inertial forces will be identical in both concentrators. However, the foul sewer or concentrate flow fraction must be the same in both cases.

The equations of motion also show that the flow velocities at any point in a given concentrator are proportional to the flow rate. At very high flow rates, however, the equations are no longer applicable, due to the increasing importance of non-axisymmetric effects. The proportionality between local velocities and flow rate is only valid below about 250 cfs.

The analysis of the particle flow equations shows that it is not possible to reproduce the three-way balance between inertial, gravitational, and drag forces on a model to prototype basis. However, representation of the full-scale particle flow in the laboratory is possible by preserving only the balance between gravity and drag forces as inertial forces are negligible on particles. To achieve this balance it is only necessary to scale the particle settling velocities according to the Froude number, as for the liquid velocities. The separation efficiency of the concentrator will be the same for all combinations of particle size and specific gravity which give the same settling velocity according to Stoke's equation:

$$V_s = \frac{gd^2\ (\rho s - \rho w)}{18\mu}$$

where: V_s = settling velocity

d = particle diameter

μ = water viscosity

ρw = density of water

ρs = density of solids

g = acceleration due to gravity

This equation is represented by the family of curves on Figure 9.

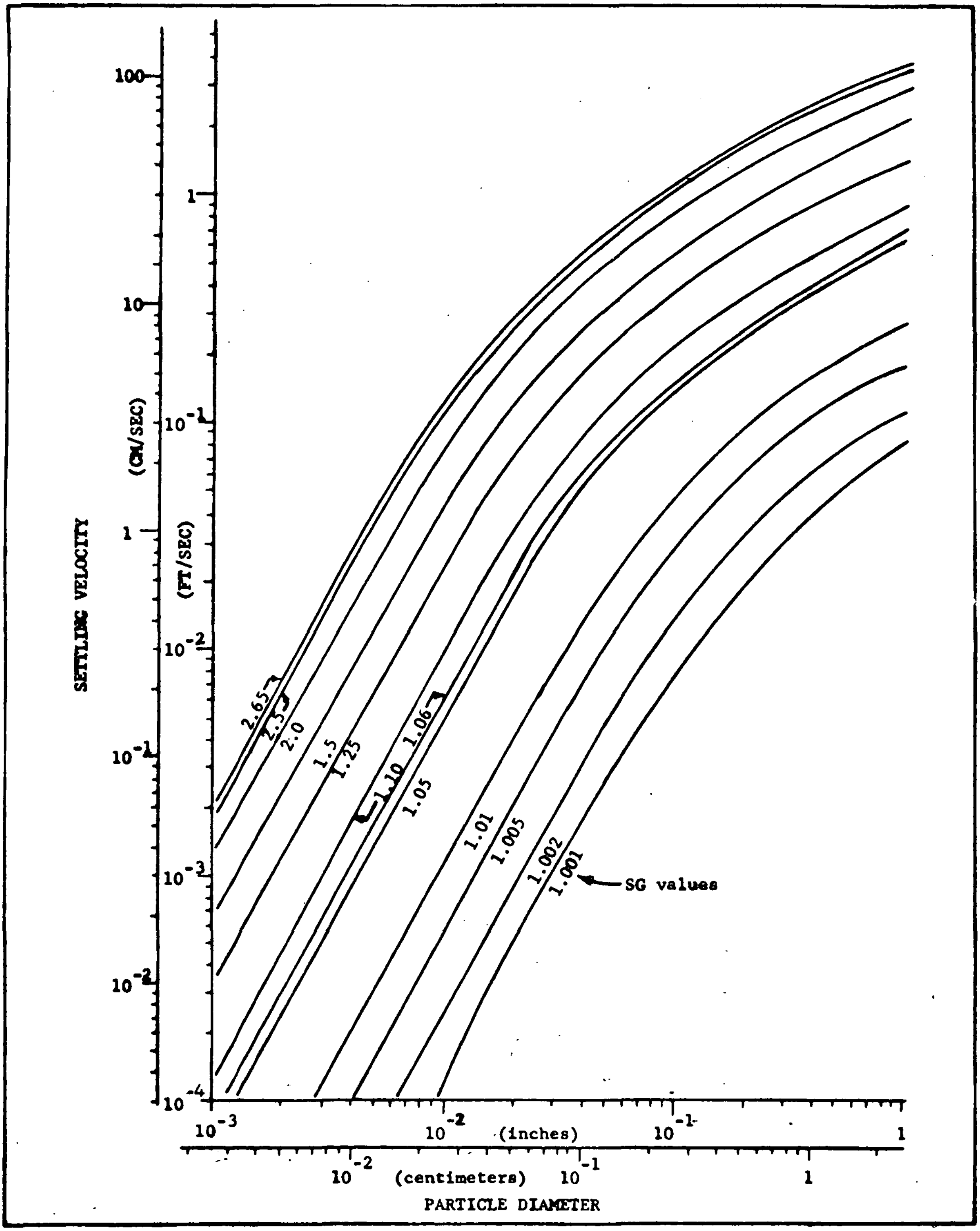


Figure 9
Particle Settling Rates

Suppose it is desired to represent in the scale model the behavior of 01.-in. (0.254mm) particles with a specific gravity of 1.05 moving in the 36-ft. chamber. These particles have a settling rate of 0.146 fps (see Figure 9). They can be represented in the 3-ft. laboratory concentrator by particles with settling velocity, $(V_s)_m$ scaled by the Froude number to equal 0.042 fps:

$$\left(V_s\right)_m = \left(V_s\right)_p \sqrt{\frac{s_m}{s_p}} = (0.146) \sqrt{\frac{3}{36}} = 0.0420 \text{ fps}$$

This scaled settling velocity can be achieved with 0.034-in. particles with a specific gravity 1.05, or 0.080-in. particles with a specific gravity of 1.01, or any other combination of diameter and specific gravity yielding the same settling velocity. The movement and separation efficiency of these scaled particles in the laboratory-scale concentrator will closely duplicate the movement and separation efficiency of the full size particles in the full size concentrator.

In a similar fashion, once the separation efficiency for particles with a settling velocity of 0.0420 fps is measured in the laboratory, the same efficiency applies to all particles with a settling rate of 0.146 fps in the 36-ft.-diameter concentrator. The same measurement can also be applied to other concentrator sizes (say 20 ft.) by scaling the flow rate and settling velocity according to the Froude number.

Elements of the Swirl

The swirl flow regulator/concentrator will be subjected to widely varying flow rates and suspended solids concentrations, characteristic of combined sewer networks. For an essentially static device to perform efficiently under such conditions, special attention must be given to the various pertinent elements within the chamber as learned from the modeling study.

Figure 10--Isometric View of Swirl Regulator/Concentrator, identifies by small letters the various special features which will be discussed.

(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 as possible. The ramp slope chosen in the hydraulic model was 1:2 but greater treatment efficiency can be expected as this slope is decreased, reducing inflow turbulence. Local conditions may govern slope selection as drastic modifications to the combined sewer upstream of the chamber may be necessary to reduce the slope, and the affected section of the collector sewer may become seriously surcharged during overflow periods.

The floor of the inlet ramp should be V-shaped to the center, providing self-cleansing velocity during small storm-flow events and for the dry-weather flow. It is essential that this ramp and its entry port introduce the flow tangentially so that the "long path" maximizing 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, extending to its point of tangency. Its location is important so as to direct 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".

Under the energy conditions normally produced by combined sewer flows, rotational forces in the chamber would quickly form a vortex of relatively low separating efficiency if the flow deflector were not used.

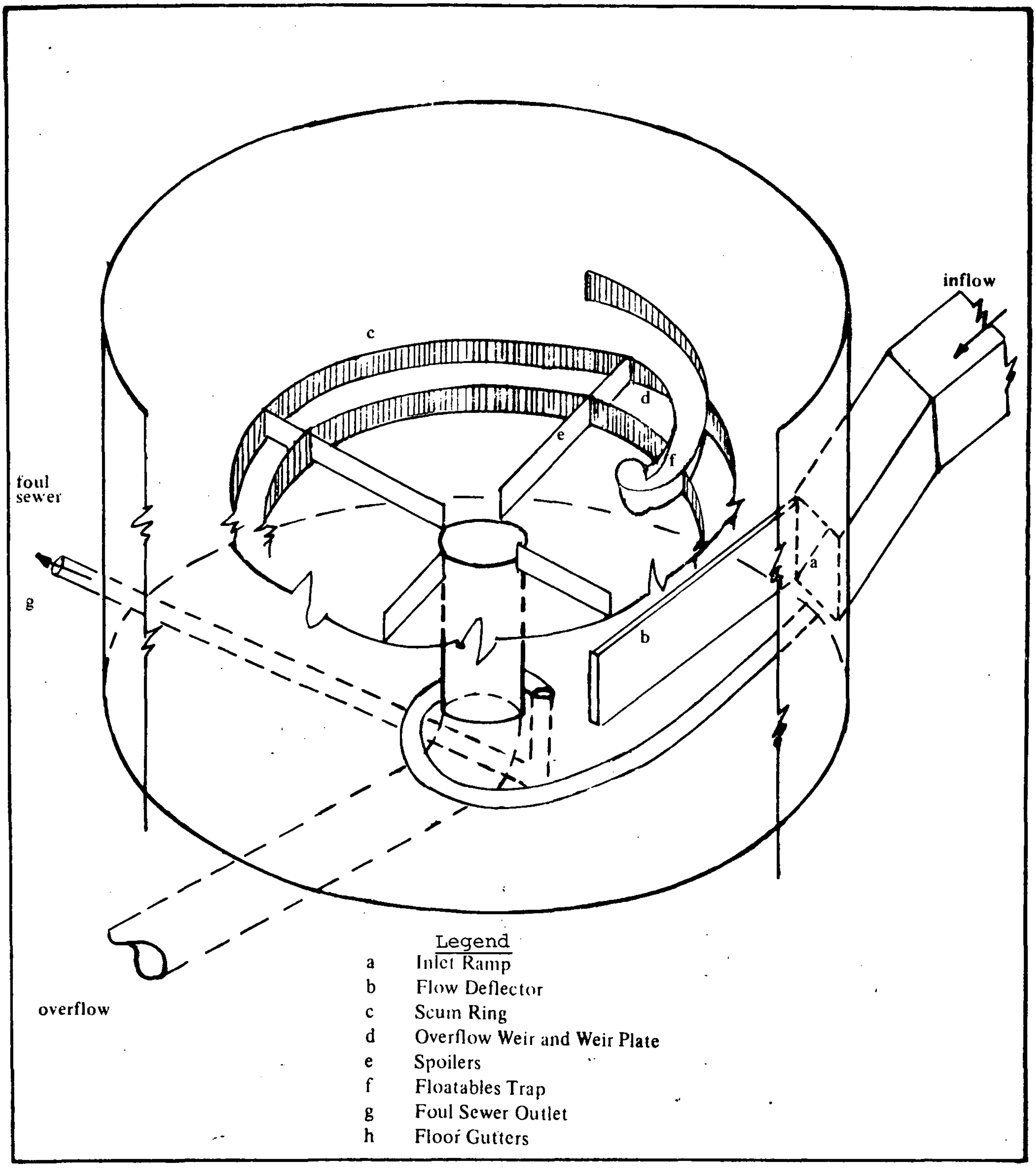


Figure 10

Isometric View of Swirl Regulator/Concentrator

The height of the deflector is equivalent to the height of the inlet port, thus insuring a head above the wall slightly greater than the weir height during overflow events. This head passes over the flow deflector after one revolution in the chamber and acts as a damper on inflow, thus forming incoming solids nearer to the floor and resulting in clearer supernatant at the overflow.

(c) Scum Ring - The purpose of the scum ring is to prevent floating solids from overflowing. It should extend a minimum of six inches below the level of the overflow weir crest, and vertically above the weir crest. Its diameter is such that its edge is located vertically above the flow deflector, thus further establishing a boundary between the outer and inner flow masses. During overflow events, and because of the great difference in volume of liquid overflowing and discharging to the interceptor, the velocities of the outer flow mass are much greater than those of the inner flow mass, allowing solids in the inner zone a greater opportunity to settle.

For large diameter scum rings-weir-configurations, the upward overflow velocity component will be large. Any particles entrained in this flow will be readily swept out with the overflow. As a scum ring diameter is decreased with constant weir diameter the cross section area between the scum ring and weir is decreased and the upward velocity is increased.

(d) Overflow Weir and Weir Plate - The optimum diameter of the overflow weir is not totally dependent on the design overflow. The diameter must be such that an underflow beneath the scum ring will not be created that would allow floating solids to be lost to overflow. Experiments in the hydraulic laboratory indicated that the relation between the weir diameter and the scum ring diameter should be 5:6.

The weir plate is a horizontal circular plane that connects the overflow weir to a central downshaft, carrying 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. The weir skirt should be extended a minimum of eighteen inches below the weir plate, but not lower than the top of the flow deflector.

(e) Spoilers - These are radial flow guides, vertically mounted on the weir plate extending from the center shaft to the scum ring. They are required to 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. Four to eight spoilers should be installed. These spoilers should extend in height from the weir plate to a position, approximately six inches above the crest of the emergency weir, thus assuring efficient and controlled operation of the swirl concentrator well beyond the design flow and preventing formation of a free-surface vortex under all loading conditions.

(f) Floatables Trap - This trap is a surface flow deflector which extends across the outer rotating flow mass and directs floating material into a channel crossing the weir plate to a vertical vortex cylinder located near the wall of the overflow downshaft. Floating material is drawn down beneath the weir plate by the vortex and dispersed under the plate around the downshaft. The trap and its deflector are located at the point of least surface velocity in the outer liquid mass. Locating the device in other positions resulted in floating materials which were collecting at the mouth of the channel being swept under the deflector and scum ring, and then over the weir to overflow. The depth of the deflector should coincide with that of the scum ring. If lower, eddy currents under the deflector will sweep floatables to overflow.

The next two Figures, 11 and 12 show the handling of floatables by the hydraulic model. Figure 11 illustrates floatables emerging under

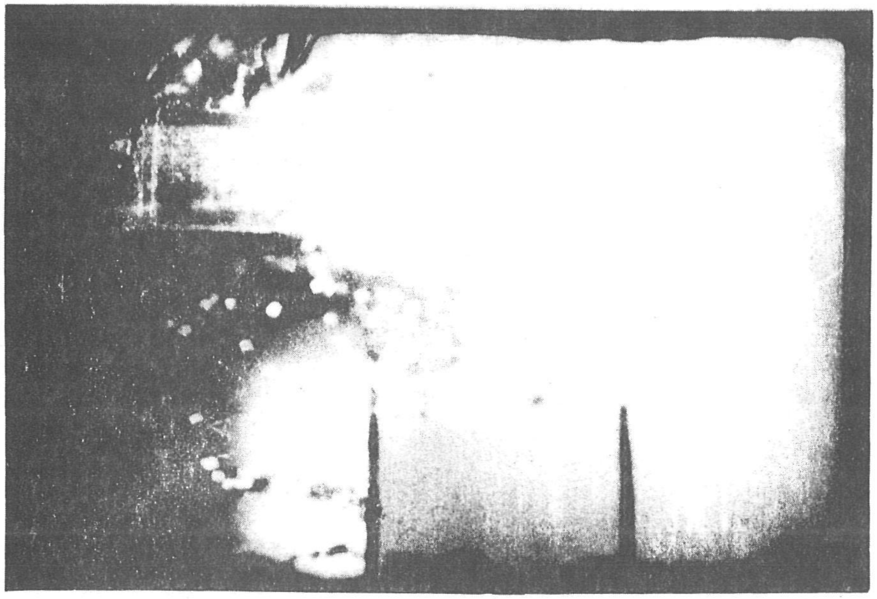


Figure 11
Floatables Emerging Under Weir Plate from Vortex Cylinder, Pilot Model, LaSalle, P.Q.

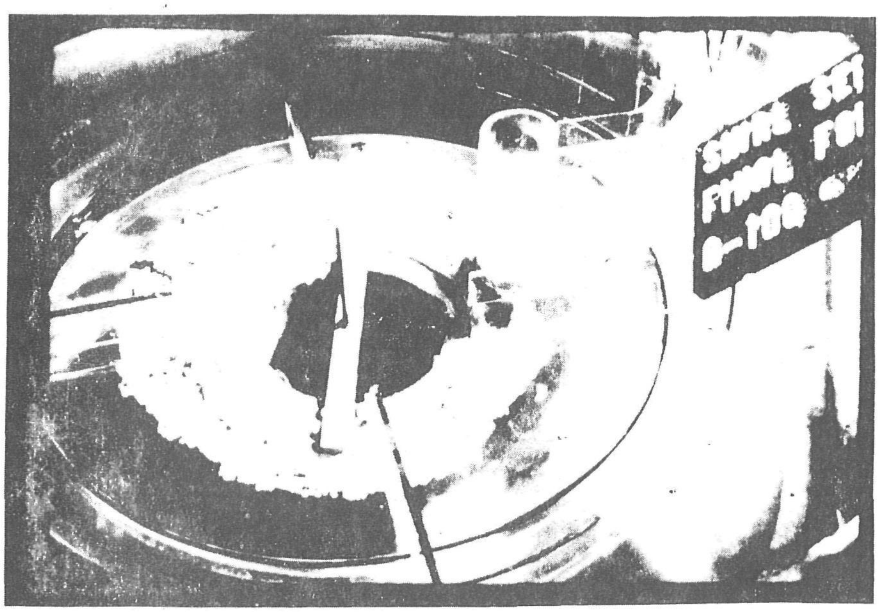


Figure 12
Floatables Trapped Under Weir after Test Operation, Pilot Model, LaSalle, P.Q.

the weir plate from the vortex cylinder. Figure 12 depicts floatables (polythene and alathon) trapped on the underside of the weir plate after a test operation at 103 cfs.

(g) Foul Sewer Outlet - The foul 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. It has been positioned at the point of maximum settlement of solids and is shaped to create a vortex for effective draw down of the surface in dry-weather flow thus improving the efficiency and reducing the clogging problems of a horizontal orifice. Its down draft velocities minimize deposited solids in the vicinity and floatable materials on the surface of the sewage to a depth of one foot.

During the hydraulic investigation, it was determined that the optimum location of the floatables trap and the foul sewer outlet were similar in plan view. Consequently, they have been located in vertical alignment so that these important elements of the swirl concentrator can be readily inspected from above the device.

(h) Floor Gutters - The primary floor gutter is the peak dry-weather flow channel connecting the inlet ramp to the foul sewer outlet to avoid dry-weather solids deposition. Its location has been chosen to eliminate shoaling of settled solids during wet-weather operation. A secondary gutter follows the wall of the overflow downshaft and aids the primary gutter in the minimization of deposits. Although rectangular shaped gutters were used in the laboratory model, a semi-circular section should prove more efficient in minimizing shoaling of solids. Figure 13 shows the empty 3 foot chamber laboratory model with the floor gutters clearly visible.

(i) Floor Shape - Under design flow conditions, flat floors performed very well. However, at low flow conditions and reduced chamber velocities, sedimentation and local shoaling can become a problem.

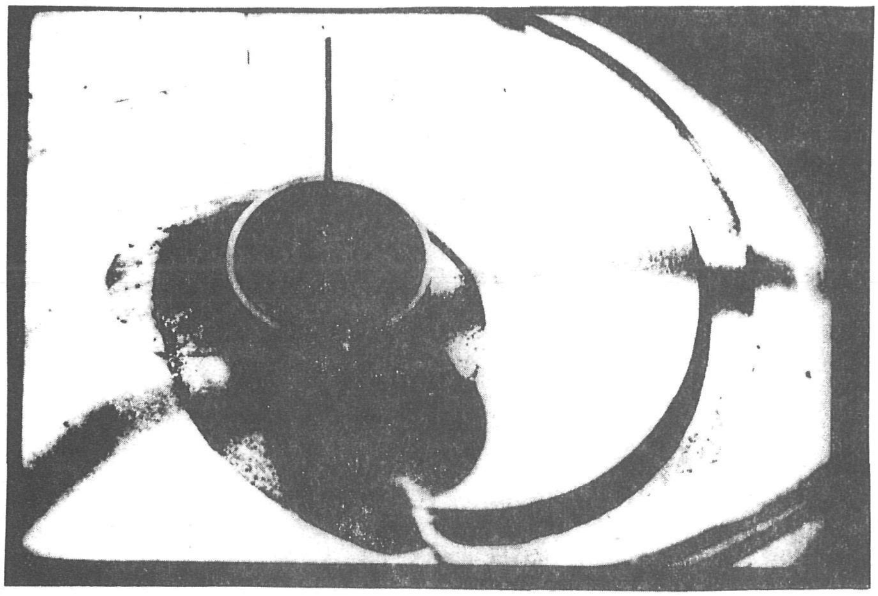


Figure 13

Empty 3-foot Chamber Laboratory Model with Floor Gutters visible, Pilot Model, LaSalle, P.Q.

Therefore, the floor should be sloped a minimum slope of 1/4-in. per foot toward the center to permit the chamber to be flushed out. To facilitate flushing out the chamber, a ring water main should be installed around the outer perimeter wall with radial jets to flush the floor clean following combined sewer overflow events. For greatest efficiency, this flushing action should be activated by level control sensors timed to operate as the water level, on draining, reaches the floor level at the exterior chamber wall. This is discussed in more detail under the section "Special Design Features".

The Prototype at Lancaster, Pennsylvania

Overall Description

This study was performed under EPA's ongoing demonstration grant (No. 11023 GSC) to the City of Lancaster, Pennsylvania entitled "Demonstration of an Underground Storage Silo - Vortex (Swirl) Regulator/ Solids Separator System for Control of Combined Sewer Overflow". Investigations were specifically aimed at optimizing the design of a full-scale unit to be installed at the Lancaster demonstration site. A flow diagram of the proposed Lancaster installation is presented in Figure 14. Figure 15 is a photograph of the installation site. The "two Q" dual purpose ability of the swirl device will be demonstrated at full scale. Aside from the swirl's function as the incoming flow regulator, it will concentrate a solids slurry to the interceptor and sanitary sewage treatment plant. Evaluations will be made of the swirl's ability to minimize solids loading to the storage silo, and to act as a treatment device by itself.

Other full-scale modes of combined sewer overflow control and treatment to be assessed at Lancaster after initial overflow storage in the silo are: pump back to the interceptor during low-flow periods; and microstraining and disinfecting prior to discharge into the Conestoga River.

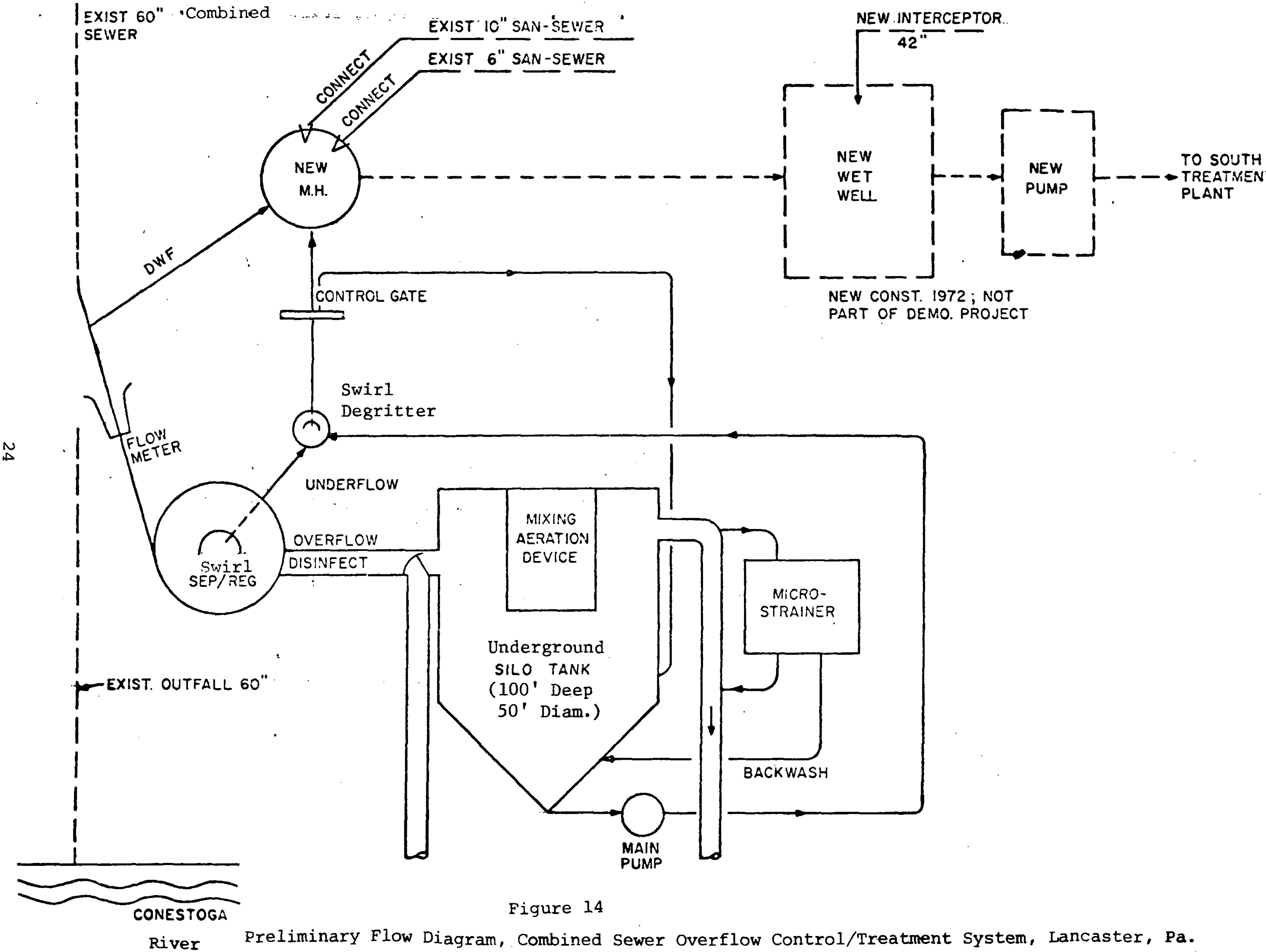


Figure 14

Preliminary Flow Diagram, Combined Sewer Overflow Control/Treatment System, Lancaster, Pa.

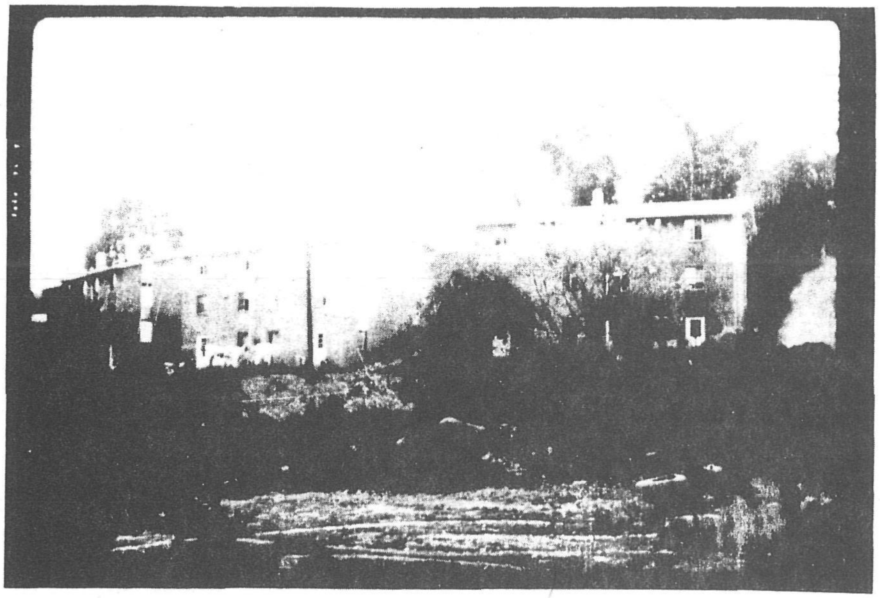


Figure 15

Installation Site, Lancaster, Pa.

Design Flow and Dimensions

The prototype design flow selected for this study was 165 cfs which represents a 5-year frequency storm flow for the 130 acre drainage area. A 3-year storm was estimated to produce 103 cfs. It was decided to evaluate model solids removal efficiencies (in the ranges of grit, settleable suspended solids, and floatables) not only at 165 cfs, but at the 15, 50, and 103 cfs flow levels also. Foul outlet flow was kept constant at 3 cfs, the peak dry-weather flow which is approximately 2 percent of the design flow. The device was hydraulically designed to allow 450 cfs, the peak upstream sewer capacity, without flooding. It was desired to obtain 85 percent of the maximum synthesized settleable solids removal at peak design flow of 165 cfs. On this basis it was found that for the intermediate frequency flow of 103 cfs, optimum settleable solids removal would be provided.

Structural Layout

The recommended primary dimensions of the swirl unit to be installed at the Lancaster site are: a 36 foot diameter chamber, a 20 foot diameter overflow weir with a 1.5 foot weir skirt, a 24 foot diameter scum ring, and a 9 foot vertical distance between the chamber floor and top of the weir. Figures 16 and 17 contain preliminary drawings of the elevation and plan views, respectively for the Lancaster installation.

The cost estimated for the prototype Lancaster installation is $100,000 which is equivalent to $700 per acre; 1972 figures apply. This estimate includes a roof, foul sewer outlet control gate, and a wash-down system.

Figures 18 and 19 depict a 12.5-ft. diameter chamber recently shop-fabricated out of carbon steel for installation in Onondaga County, Syracuse, New York. The cost of this prototype including installation, appurtenances, and pumping is approximately $30,000 and will be demonstrated under the sponsorship of EPA.

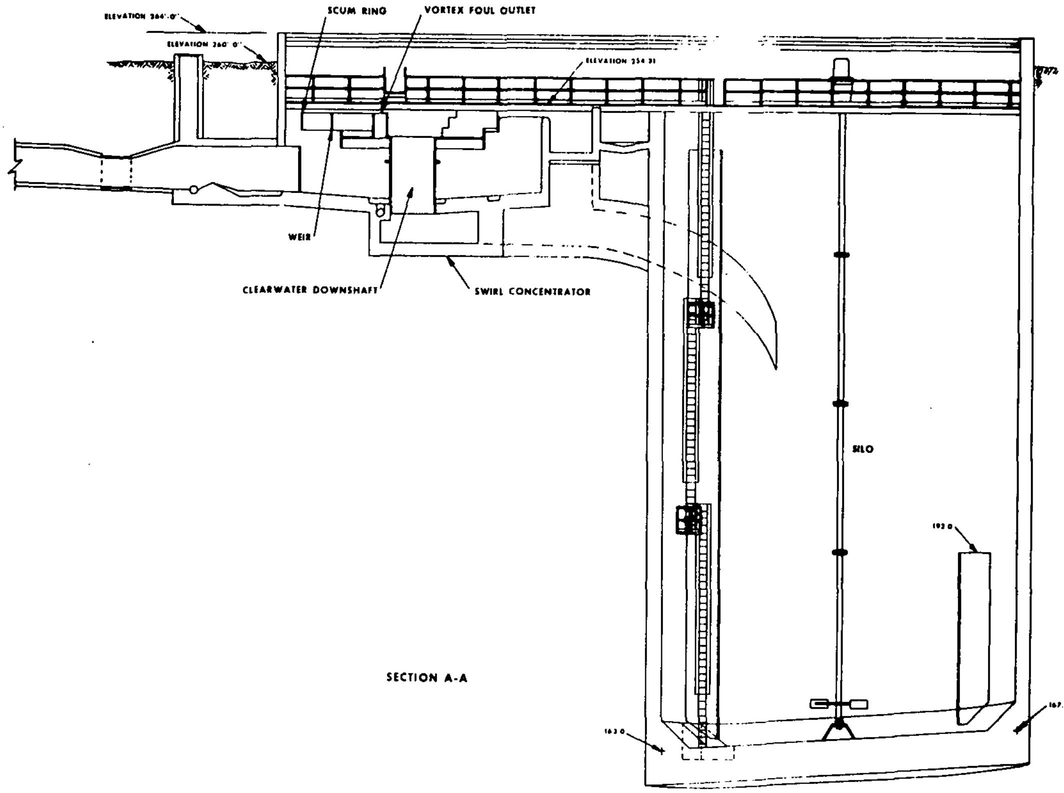


Figure 16

Preliminary Drawing - Elevation View of System, Lancaster, Pa.

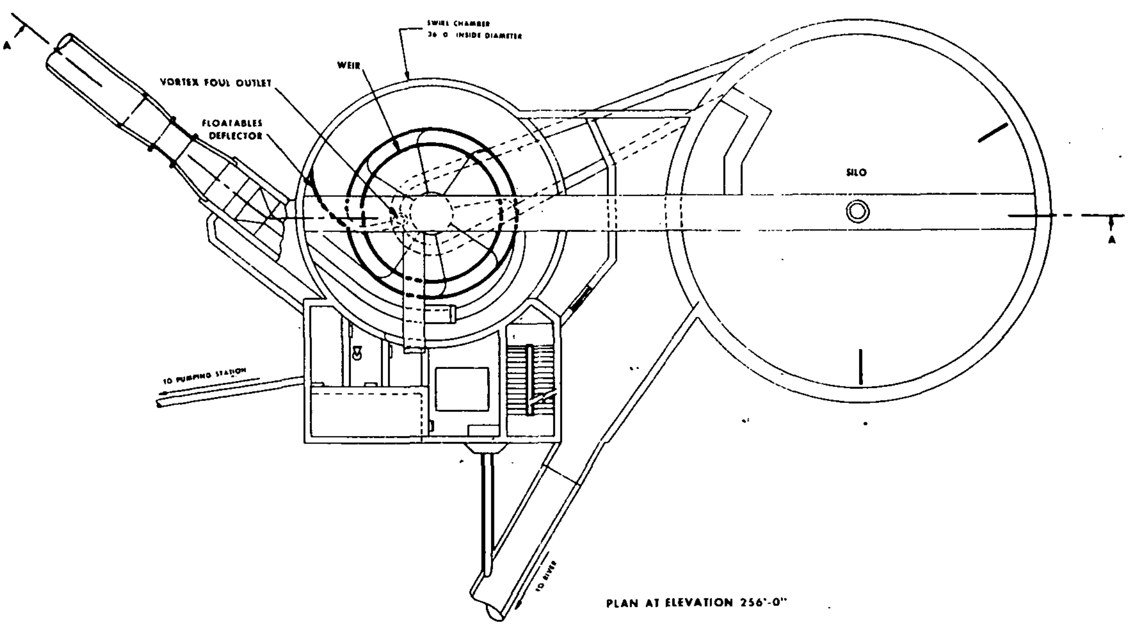


Figure 17

Preliminary Drawing - Plan View of System, Lancaster, Pa.

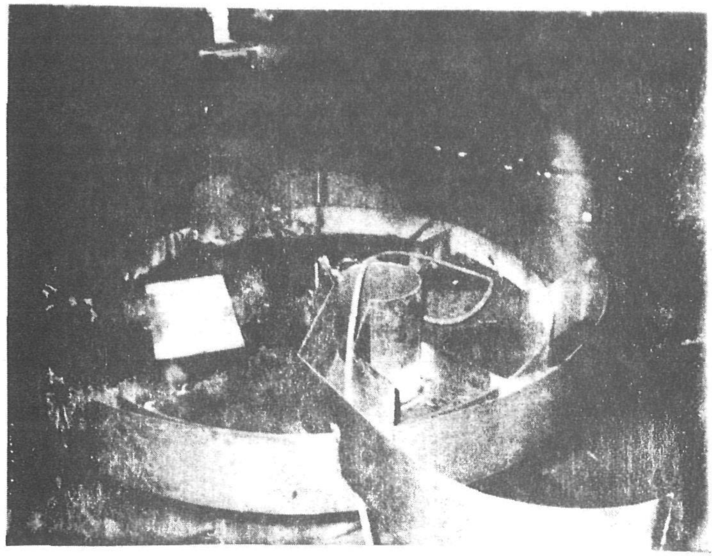


Figure 18
Top View of Weir Assembly
Onondaga County, Syracuse, New York

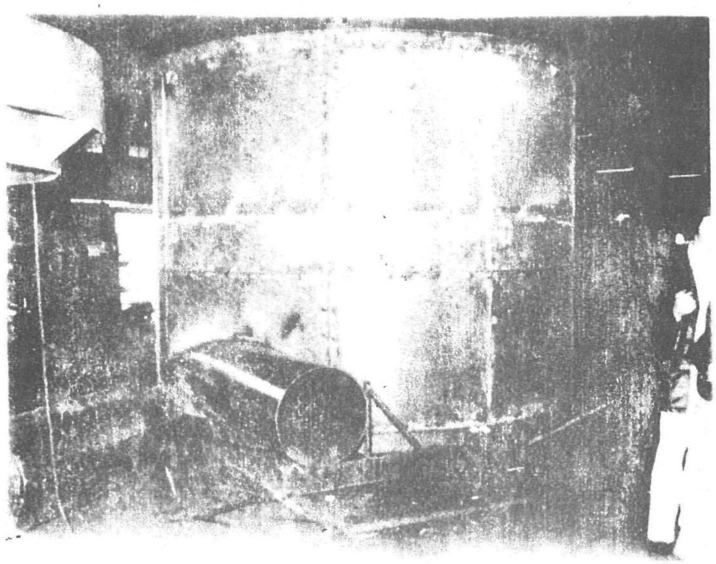


Figure 19
Elevation View of Outside Tank into which Weir Assembly
will be Set, Onondaga County, Syracuse, New York

Solids Separation Efficiencies

Model Particle Materials and Sizes

Since it was not possible to use actual combined wastes in the scaled-down hydraulic model investigations, it was necessary to reproduce ranges of particle sizes and specific gravities with synthetic materials. It was not possible to reproduce the entire spectrum of size and specific gravity, nor was this essential to the accuracy of the model studies because combined sewer flows vary markedly in composition due to geographical and climatic conditions.

After intensive reviews of recorded analytical data(3,9-13) for representative flows from various systems, and consideration of all of the factors outlined above, an acceptable "range" of particle sizes and specific gravities was chosen for the studies. It was necessary to make a basic assumption of the firm analytical data to be used. Table I contains the desired characteristics of grit, settleable solids, and floatable solids to be simulated in the hydraulic laboratory. The characterization on the table includes specific gravity, size, and concentration.

TABLE I

Specific Gravity, Size and Concentration of Settleable Solids

Material	Specific Gravity	Concentration (mg/l)	Particle Size (mm)	Particle Size Distributed (upper line - size mm) (lower line - % by weight)				
Settleable Solids excluding grit	1.2	200-1,500	0.2-5	.2	.5	1.0	2.5	5.0
				10	10	15	25	40
Grit	2.65	20-360	0.2-2	.2	.5	1.0	1.5	2.0
				10	10	15	25	40
Floatable	0.9-.998	10-80	5-25	5	10	15	20	25
				10	10	20	20	40

The material most used in the hydraulic testing program was gilsonite, a natural hydrocarbon with a specific gravity of 1.06 which had a grain size between 1 and 3 mm. Following the Stokes relation at a scale of 1:12 - laboratory test unit to full-sized prototype - this material reproduces grit (with a specific gravity of 2.65) between 0.36 and 1.0 mm and settleable suspended solids (with a specific gravity of 1.2) between 1 and 3 mm. Figures 20 and 21 illustrate the relationships between simulated and actual particles on a size vs. cumulative weight (as a percentage of total weight) basis, for grit and organic settleable solids, respectively.

The grit range leaves a small part of the fines unrepresented, as well as a wide part of the coarser particles. The coarser end of the scale was assumed to be covered, since any larger particles would obviously settle out if those represented in the chosen material had settled. The fines at the lower end of the scale in turn were simulated less often with Petrothene, a compounded plastic with grain sizes between 2 and 4 mm and a specific gravity of 1.01. This also covered prototype settleable solids in the neighborhood of 0.2 mm.

Similar reasoning was utilized in establishing particle characteristics to simulate settleable suspended solids - the larger particles were considered to have been removed if the gilsonite settled. Also at times ground gilsonite having a mean particle diameter of 0.3 mm (45-mesh) was used to approximate the finer organic settleables of 0.2 mm effective diameter.

The rates of settleable solids injection used in the hydraulic pilot unit correspond to the 50-1,550 mg/l range in the prototype flows.

Tests for the removal of floatables were carried out using uniformly sized polythene particles of 4 mm diameter, with a specific gravity of 0.92; and Alathon, another plastic compound with particle size of 3 mm diameter and specific gravity of 0.96. Injection rates for this mater-

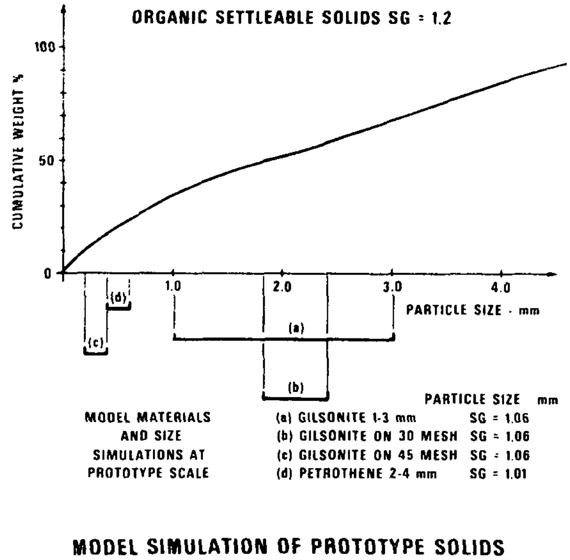


Figure 20

Model Simulation of Prototype Solids - Organic

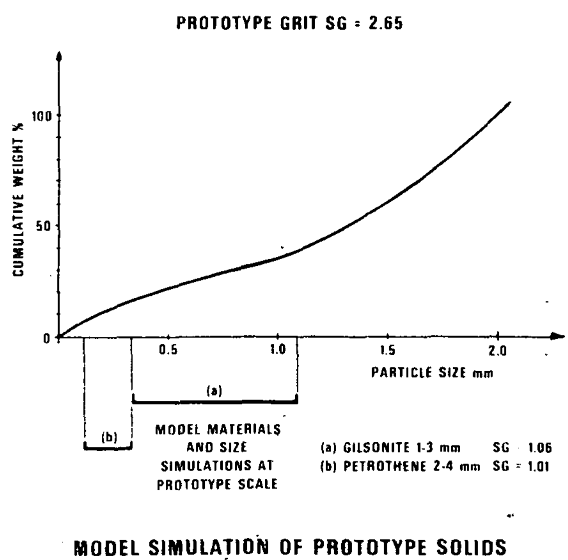


Figure 21

Model Simulation of Prototype Solids - Grit ial varied from 30 to 150 mg/l, at prototype scale.

Removals Expected

Predicted efficiencies based on model testing at 165 cfs are:

For Floatables: with a specific gravity range 0.9 to 0.96, having particles sizes between 5 and 50 mm, the chamber should remove between 65 and 80 percent.

For Grit: with a specific gravity 2.65, having particles larger than 0.3 mm, removal should be 90 to 100 percent. For smaller particles there would be a reduction of efficiency, so that at 0.2 mm it would be about 75 percent, and at 0.1 mm, probably less than 40 percent.

For Settleable Solids: with a specific gravity of 1.2, having particles larger than 1 mm, the efficiency should be between 80 and 100 percent. As shown on Figure 20 this fraction represents 65 percent of the total amount of settleable solids in the design solids concentration. For the finer particles, removal efficiencies decrease so that for 0.5 mm particles it would be about 30 percent and for 0.3 mm, probably less than 20 percent.

The discharge vs. efficiency curves for removal of the larger organic and grit particles greater than 1 mm and 0.36 mm, respectively are shown on Figure 22.

Spot checks were carried out on separation efficiency by using the large gilsonite. The separating flow characteristics in the chamber remained remarkably steady up to about 250 cfs in each case, then they seemed to break up. Note that the separation efficiency curve on Figure 22 begins to decelerate more rapidly after 250 cfs. Figure 23 further indicates a breaking off of the established flow field as the rate of head build up above the weir increases markedly for discharges greater than 250 cfs.

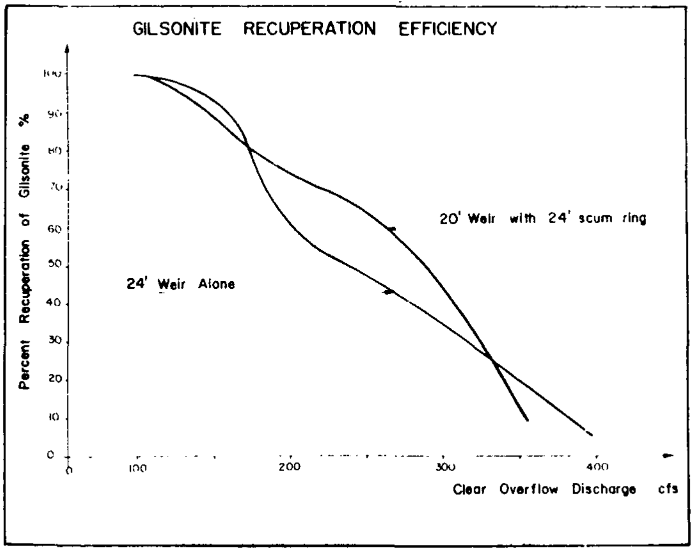


Figure 22

Percent Gilsonite Recuperation vs. Discharge Rate for Grit and Organics

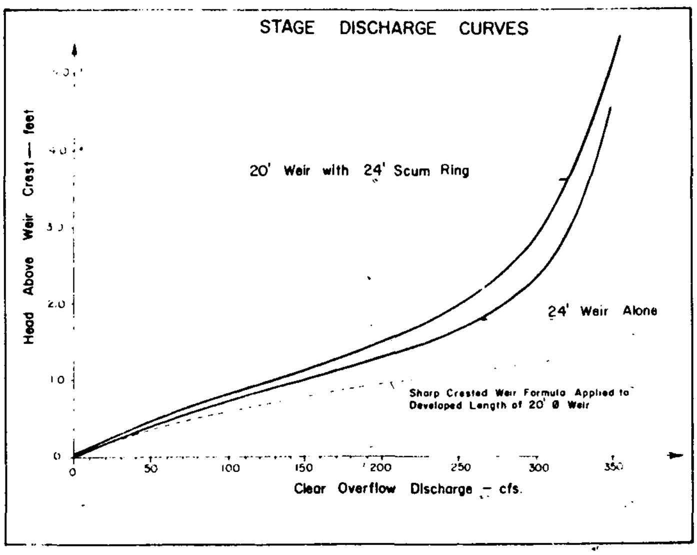


Figure 23

Head Above Weir Crest vs. Discharge Rate

To get a more complete perspective of efficiencies for the entire representative solids concentration range chosen for the model tests, and as depicted by Figure 21 gilsonite removal varies from 65 percent at design flow or 165 cfs, to 87 percent at 103 cfs, up to 97 percent at 50 cfs. It is emphasized that these removals are accomplished at chamber retention times in the order of 5 to 15 seconds.

Design Rationale

Hydraulics

Three flow quantities must be considered in the design: (1) the peak dry-weather flow; (2) the design flow, i.e., the flow for which the optimum desired treatment is established and (3) the maximum flow likely to occur through the chamber.

As the cost of the facility and the hydraulic head loss for dry-weather flows increase with the flow rate, to provide optimum solids removal, choice of the design flow and degree of settleable solids removal is very important. The wisest choice of design flow rate can only be made after analyses of a history of "pollutographs" in the form of dependent curves representing mass emissions of specific pollutants. These analyses may be based on either real-time values or model predictions resulting from rainfall records.

Here it is important to realize that self -leansing efficiency is improved at smaller chamber diameters because of the tendency of the solids to shoal at low rotational velocities.

Head Considerations

The vertical distance between the hydraulic grade lines in the combined sewer and interceptor must be great enough to permit installation of the regulator. There must be sufficient hydraulic head available to allow dry-weather flows to pass through the facility and remain in the channel.

The total head required for wet-weather operation is shown in Figure 24. The total available head should be the differential elevation between the highest point in the combined sewer system that can be tolerated before flooding or undesirable surcharging occurs, and the level in the interceptor.

If sufficient head is not available to operate the foul sewer discharge by gravity, an economic evaluation would be necessary to determine the value of either pumping the foul sewer outflow continuously, or pumping the foul flow during storm conditions and bypassing the swirl concentrator during dry-weather conditions.

Sizing

From the design discharge, Q_d, selected, the diameter of the chamber D_2, may be determined from the curve on Figure 25 which represents the equation of equivalent model and prototype Froude numbers, that is, $D_2 = 3.0\left(\frac{Q_d}{0.322}\right)^{2/5}$. The chamber diameters are 29.5 and 22.5 feet for 103 cfs and 50 cfs design storm discharges, respectively.

The other dimensions of the chamber will have the same ratio to the diameter as those in the model. On this basis the dimensions for design discharges of 50, 103 and 165 cfs are shown in Table II. The location of the various dimensions are shown in Figures 26 and 27.

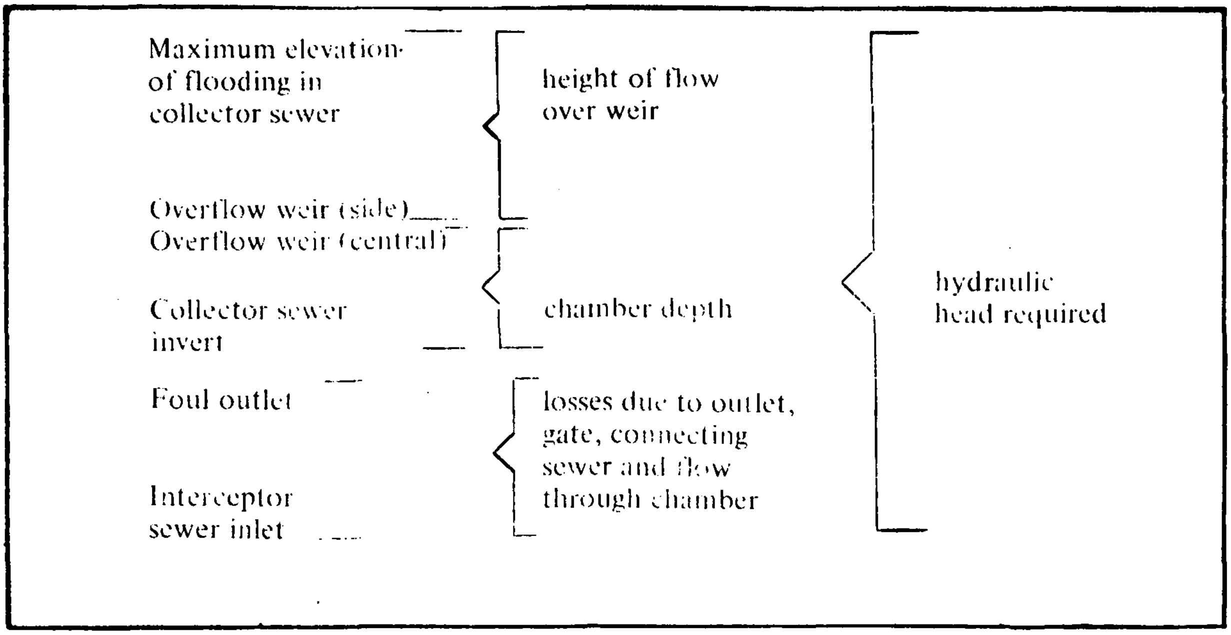
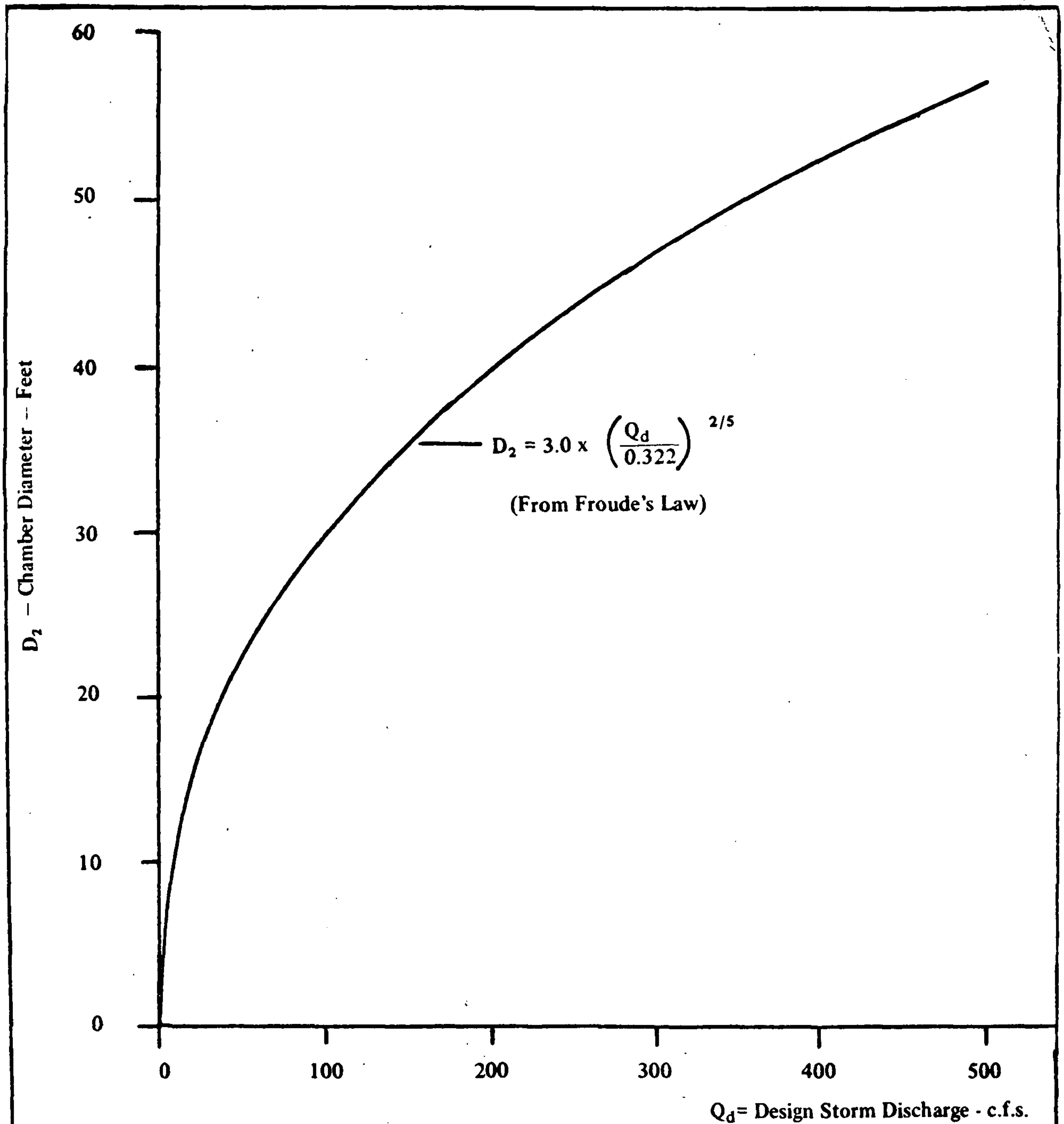


Figure 24

HYDRAULIC HEAD REQUIREMENTS



DESIGN PROCEDURE

1. Select the peak discharge from the desired probability storm hydrograph and use this as the Design Storm Discharge, Q_d.
2. Enter the graph with Q_d, go up to the curve then read the corresponding chamber Diameter, D_2, on the ordinate scale at left.
3. Using this D_2, go to Tab. II to find first D_1, then calculate the dimensions of the other chamber elements.

Figure 25

DESIGN OVERFLOW RATE VS CHAMBER DIAMETER

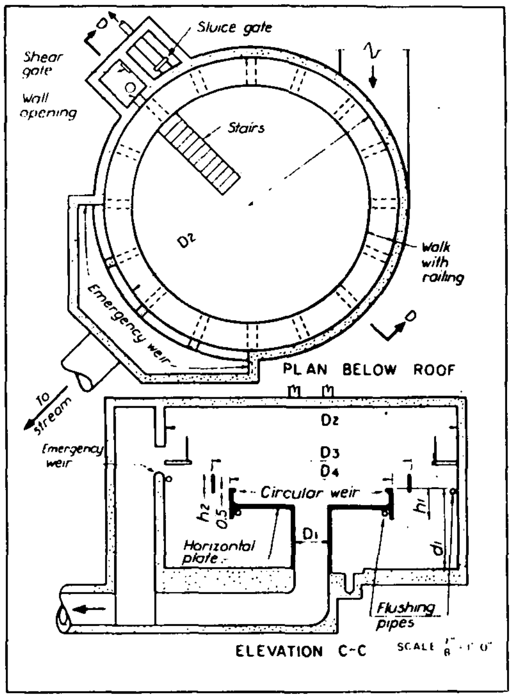


Figure 26

Swirl Plan and Elevation Views - Below Roof

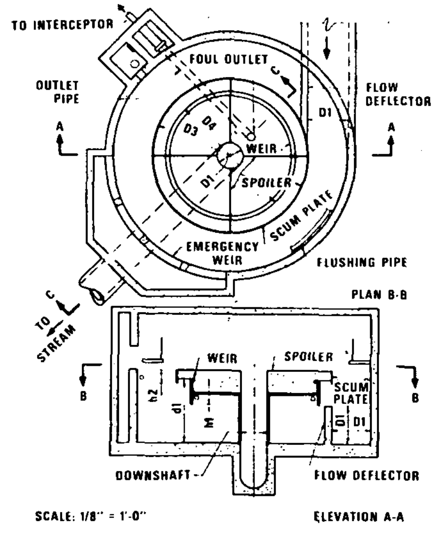


Figure 27

Swirl Plan and Elevation Views - Floor Area

TABLE II

Swirl Chamber Dimensions
(all dimensions in feet)

Design Storm Discharge - cfs		50	100	165
Diameter of Chamber	$= D_2$ (Fig.25)	22.5	29.5	36.0
Diameter of Overflow and Diameter of Inlet	$= D_1 = 1/6\ D_2$	3.75	4.92	6.00
Diameter of Circular Scum Ring	$= D_3 = 4\ D_1$	15.00	19.68	24.00
Diameter of Circular Weir	$= D_4 = 3\ 1/3\ D_1$	12.50	16.40	20.00
Radius of Inlet Gutter (0-90°)	$= R_1 = 2\ 1/3\ D_1$	8.75	11.48	14.00
Radius of Inlet Gutter (90-180°)	$= R_2 = 1\ 1/2\ D_1$	5.62	7.38	9.00
Radius of Secondary Gutter (90-270°)	$= R_3 = 5/8\ D_1$	2.34	3.08	3.75
Radius of Secondary Gutter (0-90°)	$= R_4 = 1\ 1/8\ D_1$	4.22	5.54	6.75
Radius of Secondary Gutter (270-360°)	$= R_5 = 3\ 2/3\ D_1$	13.75	18.04	22.00
Difference in Radius Between Secondary and Circular Weir	$= b_1 = 1/3\ D_1$	1.25	1.64	2.00
Offset Distance for Determining Gutter Radii	$= b_2 = 1/6\ D_1$	0.62	0.82	1.00
Distance Between Floor and Top of Circular Weir	$= d_1 = 1\ 1/2\ D_1$	5.62	7.38	9.00
Depth Invert to Bottom of Chamber	$= d_2 = 5/6\ D_1$	3.12	4.10	5.00
Height of Circular Weir	$= h_1 = 1/2\ D_1$	1.87	2.46	3.00
Height of Scum Ring	$= h_2 = 1/3\ D_1$	1.25	1.64	2.00

The percent of solids diverted to the foul sewer can be obtained from Figure 28 for any given multiple of design discharge. Thus, at design flow the concentrate through the bottom outlet will contain 90 percent of grit larger than 0.35 mm and 90 percent of settleable solids larger than 1.0 mm. Smaller percentages of finer materials would also pass through the foul outlet. Importantly, this curve shows good removal efficiencies are maintained throughout an extremely wide range of overflow rates.

Special Design Features

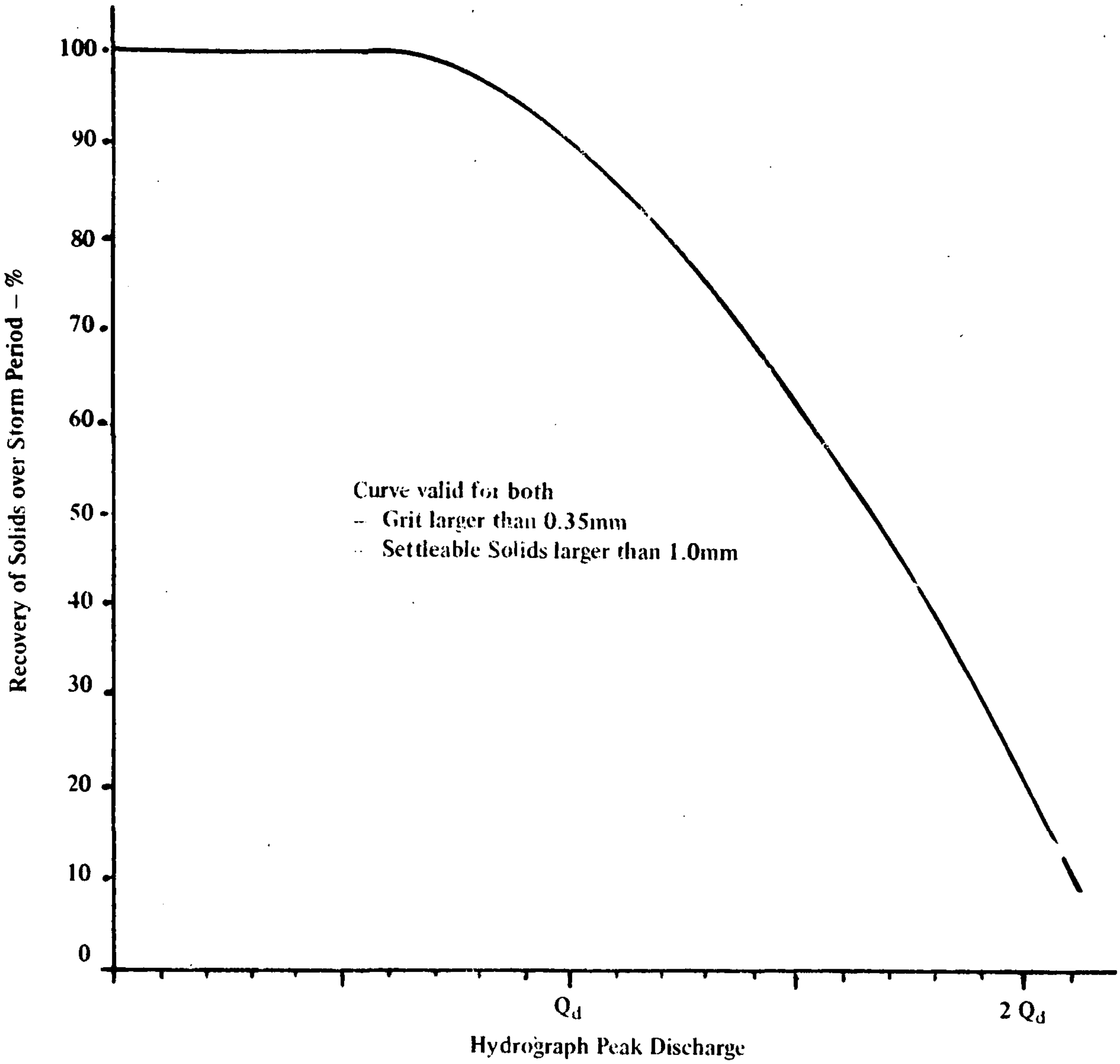
Roof: A roof is considered desirable for safety and aesthetic reasons.

Inspection Walk: A walk should be provided around the chamber periphery and located to allow easy inspection and maintenance of the weir and scum plate.

Automatic Flushing: In order to clear floatables from the under side of the horizontal weir plate it is recommended that a circumferential (4 in. diameter) water pipe be installed below the plate adjacent to the inner side of the skirt. Eight 3/4-in. pipe nozzles should be aimed upward at the bottom of the plate. When the sewage level falls below some point in the chamber under the plate a pump should automatically apply 80 gpm of water at 40 psi.

Another (4-in.) pipe should be anchored to the chamber wall at approximately weir level for cleaning the chamber bottom. Sixteen 3/4-in. nozzles pointed straight downward are recommended which would automatically spray water when the sewage level in the chamber falls below the bottom floor.

Positive Control Gate: At low flow rates, discharge through the foul outlet pipe may occur as gravity flow while at higher flows



NOTE:

1. Solids recovered are only those *larger* than the sizes shown on the curve, i.e., grit larger than 0.35mm, and settleable solids larger than 1.0mm. Smaller percentages of finer material would be removed, but are not defined by this curve.

2. Percentages of solids recoveries calculated as the volume of solids taken out through the foul outlet, with respect to the total volume of solids entering the chamber during the complete storm hydrograph period.

Figure 28

SEPARATION EFFICIENCY CURVE

discharge will occur under varying hydraulic head. It is difficult to size the pipe to act as a "throttle" pipe to pass a specific flow equivalent to dry-weather flow. Therefore, it is recommended that a sluice gate or other flow control devices be installed on the pipe to regulate dynamic flow to the interceptor. The use of a gate will permit adjustment of the opening and the discharge rate. Furthermore, it will allow the use of a larger size pipe with less chance of clogging and, if clogging occurs at the gate, the gate can be opened to clear out the debris.

If the necessity to limit the variation in flow of the foul sewage to a minimum is determined critical, then an automatic motorized gate should be used. Such gates could be controlled by either the level or flow rate in the downstream sewerage system of the stage in the swirl chamber. Remote sensing of interceptor and/or sewage treatment plant flow coupled with remote positive control of the gate affords maximum utilization of these downstream facilities.

To limit clogging potential, the minimum diameter of foul outlet line should be 8 in., but preferably 12 in.

Side Overflow Weir: In many cases a side overflow weir should be provided on the periphery of the chamber to take part of the flow when the flow exceeds an undesirable level above the design flow. This would help to achieve the desired removal of suspended solids. The side weir would tend to alleviate upsetting flowfields; and also increase the hydraulic system capacity.

Enlarged Inlet: In order to maintain low-inflow velocities, in the range of 3 to 5 fps, for minimized turbulence, enlarged inlet pipe sections may be useful.

Grit and Solids Removal: The downstream sewer system and treatment works must provide capacity to handle the increase in grit and settleable solids which will be captured from the combined sewer overflow. This could easily amount to more than a ton of solids from one device in a very short period of time. Additional grit removal and sludge processing equipment may be necessary on the foul sewer prior to the interceptor. Should the concentrated flow be pumped, sumps and pumps should be designed to handle the anticipated high solids content; and the use of hydrocyclones for degritting should be considered.

Potential Applications and Research Needs

Universalization

A further swirl regulator principle requiring development must now be emphasized,, that is, universalization of the device. By enabling interchange of primary dimensions, such as, chamber diameter for height, engineers will have the flexibility of designing a future swirl installation under restrictive structural and hydraulic head limitations imposed at their particular installation site. The Storm and Combined Sewer Technology Program of EPA is now working towards this goal.

Potential Uses

The swirl principle has many potential applications. It may be employed anywhere it is desirable to keep solid particles out of liquid flows. In the field of water pollution control this could relate to the degritting of sanitary and combined sewage, straight urban storm runoff, and silt-laden runoff from eroded land areas; to the primary separation of domestic wastewaters, combined sewer overflows, stormwater, and industrial wastewaters; to the sludge thickening of sanitary stormwater, and various industrial processing concentrates; and to the final clarification process. In potable water purification practices, it may be feasible to apply a form of the swirl for chemical mixing, coagulation, and clarification of raw water. Other uses including industrial processing and pollution control may prove to be realistic.

Each of the above applications in the sanitary engineering spectrum may involve less arduous conditions of operation than the combined sewer regulator application. Both the hydraulic laboratory and the mathematical model investigation have indicated that greater efficiency of solids separation may be experienced if the device operates under steady flow conditions, and if a narrower range of solids size and specific gravity is to be removed.

Similarly, better efficiencies may be achieved with two half-size chambers as opposed to one full-size unit. With two units operating in parallel, one chamber could be used for all flows lower than 103 cfs... (at the site of the proposed prototype regulator where 165 cfs was the design flow)...and the second would be required if the storm flow exceeded that value. This would provide better separation at both higher and lower flow rates.

The possibility also exists of operating units in series to improve solids removal by breaking a wide range of particle characteristics into narrower grain size/specific gravity bands.

The EPA has recently awarded a supplemental grant to the City of Lancaster, Pennsylvania for the development of a swirl degritter for treatment of the swirl regulator/separator concentrate before entering the interceptor system.

The Storm and Combined Sewer Program of EPA is also actively pursuing a project which includes optimization of a swirl concentrator as a primary separator for combined sewer overflow, sanitary sewage, stormwater runoff, and erosion runoff along with universalization of regulator. More effective removals should result at the more confined diameter and specific gravity ranges as compared to the broad ranges of this regulator study. Also chamber detention times will be in the order of 5 to 15 min., whereas those times in the swirl regulator were in the range of 10 to 20 seconds.

Conclusions

The dual functioning swirl unit is the first regulator device of its kind in this country offering the basic advantage of controlling the "two Q's", that is, quantity and quality of combined sewer overflows, simultaneously. It is a practical and simple facility which can effectively reduce significant portions of grit, settleable solids, and floatables over a wide range of varying overflow rates.

The swirl principle employes an innovative approach to the clarification and concentration of solid-liquid mixtures which does not require moving or mechanical parts and their associated power requirements. Studies have confirmed that the kinetic energy produced by swirl flow action can be harnessed to accelerate the solids separation process. Deposited solids are self-cleansed by its own flow patterns. This is in contrast with standard grit and sedimentation facilities which require some form of collection and removal mechanisms to perform this function. Density and thermal current short circuiting can be overcome by the swirl action.

Conventional static and dynamic regulators have a known history of chronic failures due to clogged orifices and malfunctioning moving parts. The absense of moving parts overcomes the mechanical breakdowns problem and the need for standby equipment. Corrosion of metallic parts could be avoided by construction of a swirl chamber with relatively inert materials such as, concrete, stainless steel, or plastic.

Relative detention times are extraordinarily short, being only seconds. It is further envisioned that swirl concentrators can be constructed to take the place of primary settling tanks which could have as little as 1/8 of the two hour retention time of these conventional units. Tankage requirements and costs would be greatly reduced by substituting swirl units for primary separation in future construction.

Although the study was performed as part of an EPA demonstration grant for the City of Lancaster, Pennsylvania, with design and developmental criteria defined by a specific site for installation, all work was accomplished in a manner which readily allows translation of results to many conditions which exist at other locations and possibly for other types of flow treatment purposes. The device is simple to design - a procedure has been established as part of the final report(1) for the study. The report can be considered a "cookbook" manual for rapid design of the swirl facility at various rates of flow and site requirements.

Before using the swirl concentrator as a combined sewer overflow regulator for a given application, the following must be evaluated:

1. Hydraulic head differential between the collector and interceptor sewers taking maximum advantage of the head available in the collector sewer to allow in-system storage;
2. Hydraulic capacity of collector sewer;
3. Design flow;
4. Dry-weather flow and capacity of interceptor sewer; and
5. Amount of character of settleable solids.

Small changes in the design of the concentrator and its appurtenant elements may produce wide variations in its operation efficiency. In this regard, particular care must be taken during design and construction to avoid irregularities or intrusions in the walls, floors, and elements of the device.

Solids separation efficiencies noted in this paper relate to specific gravities, sizes, and concentrations selected for the model studies. Such conditions of size and specific gravity may not reflect local conditions. An examination of the mathematical modeling design methods in Appendix 2 of the more complete final report(1) will indicate necessary adjustments for greater removal efficiency of specific particle types. If, for example, grit is a problem in a particular design area, scaling down of concentrator dimensions established by the hydraulic design should be considered.

We are at the stage now where we feel confident with what can be done with the device. The swirl flow regulator/solids separator will be very useful to communities as a tool for combatting the combined sewer overflow problem. In addition, as a primary treatment device for domestic wastewaters it should allow facilities to be constructed and operated more efficiently and at less cost.

As combined sewer systems are upgraded and improved regulators constructed to reduce the pollutional impact of overflows on receiving waters, the swirl concentrator must be considered.

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