Environmental Protection Technology Series

RELATIONSHIP BETWEEN DIAMETER AND HEIGHT FOR THE DESIGN OF A SWIRL CONCENTRATOR AS A COMBINED SEWER OVERFLOW REGULATOR

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RELATIONSHIP BETWEEN DIAMETER AND HEIGHT FOR THE DESIGN OF A SWIRL CONCENTRATOR AS A COMBINED SEWER OVERFLOW REGULATOR

A Supplement to the Swirl Concentrator as a Combined Sewer Overflow Facility

EPA-R2-72-008, September 1972

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FOREWORD

Man and his environment must be protected from the adverse effects of pesticides, radiation, noise and other forms of pollution, and the unwise management of solid waste. Efforts to protect the environment require a focus that recognizes the interplay between the components of our physical environment – air, water, and land. The National Environmental Research Centers provide this multidisciplinary focus through programs engaged in

- studies on the effects of environmental contaminants on man and the biosphere, and
- search for ways to prevent contamination and to recycle valuable resources.

The continued investigation of the swirl concentrator concept represented in the following report reflects the latter of these roles. It also points up a meaningful research and development effort around a new technology that may influence the treatment of water pollution from combined sewer overflows for years to come.

The swirl concentrator traces its origins to the work performed by the American Public Works Association Research Foundation in 1972 sponsored by the City of Lancaster, Pennsylvania and the U.S. Environmental Protection Agency, reported in *The Swirl Concentrator as a Combined Sewer Overflow Regulator Facility,* EPA R2-72-008. This effort demonstrated the capacity of this nonmechanical device to effect excellent removals of settleable and floatable solids contained in combined sewer overflow.

This publication reports the results of further research and development to establish the most efficient and economical geometry for the swirl device. It also provides a better method for design based upon the percentage removal of organic and inorganic solids. As such, it brings the most up-to-date information available on this new technology to the wastewater quality manager to assist in the handling of combined sewer overflows in a more efficient way. This research effort of an important new development demonstrates the best use of the technology transfer process and a way to better assure the quality of the nation's water resources.

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ABSTRACT

This report is a supplement to the report, *The Swirl Concentrator as a Combined Sewer Overflow Regulator Facility*, EPA-R2-72-008, September, 1972. The work described by this report allows flexibility for the designer faced with structural, head or land area constraints by enabling interchange of basic heights and diameter dimensions.

Studies of *The Swirl Concentrator as a Combined Sewer Overflow Regulator Facility*, conducted in 1972 by the American Public Works Association Research Foundation for the City of Lancaster, Pennsylvania, and the U.S. Environmental Protection Agency, demonstrated that this type of dynamic flow, non-mechanical device could effect excellent removals of suspended and floatable solids contained in admixtures of sanitary sewage and storm water. This improvement in the quality of storm flow discharges to receiving waters, or to treatment or storage facilities could reduce the pollutional impact on the nation's water resources.

The 1972 studies established a suitable relationship between swirl chamber depth and diameter and their effect on the liquid flowfield and particle removal efficiencies. It was deemed advisable to augment the 1972 studies by investigating this depth-to-width ratio and to define the dimensions which will provide optimum construction economy and operating efficiency in terms of solids separation. This report presents an account of these supplemental studies of a hydraulic model of the swirl concentrator at the LaSalle Hydraulics Laboratory at Montreal.

The report translates the model study findings into a design basis that can be used for any rational flow rate in universal service for the treatment of combined sewer flows. It establishes the basic principle that variations in overflow weir height, or chamber depth, do not materially influence solids particle removals and that the most definitive design parameters are size of inlet sewer and swirl chamber diameter. While the model studies showed that a ratio of weir height to chamber diameter of 1 : 4 was the most convenient to use as a design aid, the data have been extrapolated to produce geometry modification curves that cover swirl chamber diameters and depths. This information will be of value in the design of facilities which are the most economical and efficient.

The report provides design curves for various influent flow rates, covering chamber diameters and inlet sewer sizes which will produce settleable solids removal efficiencies of 70, 80 and 90 percent. It presents design details for floatable solids traps to retain these components, and for essential details of swirl chamber geometrics. Procedures are outlined on how the model study curves can be used in the design of prototype swirl concentrator units of various capacities and dimensional relationships.

The report of the hydraulics laboratory model studies is included as an appendix to the project report.

This report was submitted in partial fulfillment of Contract 68-03-0283 between the U.S. Environmental Protection Agency and the American Public Works Association.

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PREAMBLE

The study was performed with synthetic solid particles. Designers should carefully evaluate the size and density distribution of sewage in their areas before setting individual criteria.

SECTION I
CONCLUSIONS, RECOMMENDATIONS AND OVERVIEW

This study of the relationship between the diameter of a swirl concentrator and the height of the overflow weir, in terms of size of inlet conduit and efficiency of removal of settleable and floatable solids contained in combined sewer flows, is an extension of original studies in 1972 on the application of the swirl flow principle as a combined sewer overflow regulator facility. The study provides design parameters which will give the greatest solids removal efficiencies under specific conditions in full-scale prototype installations.

The need for reduction in the amount of hydraulic head loss needed to achieve the desired chamber depth can make it necessary to determine if increasing the diameter of the chamber could reduce the height, thus making it possible to use the swirl separation principle in a greater number of locations. Similarly, vertical or horizontal limitations at the construction site would be made relatively flexible, again expanding the potential use of the swirl concentrator regulator. The hydraulic model studies undertaken at the LaSalle Hydraulics Laboratory, and as reported here, make it possible to draw the following conclusions:

1. Design parameters can be definitively established, covering swirl concentrator chamber diameter, inlet pipe dimensions, and internal chamber facilities, to provide specific solids removal efficiencies for prototype combined sewer overflow systems.

2. For chambers having a ratio of chamber diameter to chamber depth of 4 : 1 it was found that the depth had little effect on recovery rate. The same condition was found when the ratio of chamber diameter to inlet dimension was in the range of 6 : 1 or 7.2 : 1. When the ratio of chamber diameter to inlet dimension was increased to 9 : 1 or 12 : 1 the depth or weir height had more influence on recovery rates.

For any given discharge the use of a smaller ratio of chamber diameter to inlet dimension results in lower inlet velocity and lower chamber area and volume. Hence for economy reasons the designer should attempt to reduce this ratio as close to six as is possible with the use of the design curves given in this report.

3. Where circumstances are not favorable for the standard design with a ratio of chamber diameter to depth of 4 : 1 it is possible to decrease the chamber depth to a value equal to the inlet dimension. This also results in an increase in the chamber diameter and chamber area. The chamber volume may also be somewhat affected either up or down by this change.

These conclusions are translatable into the following recommendations:

- It is recommended that the swirl concentrator principle be utilized more extensively for the removal of solids pollutants of both inorganic and organic nature which are contained in combined sewer overflow wastes. These concentrators offer a rapid and relatively economical means for the improvement of the quality of such overflows and a reduction in the pollutional impact on receiving waters, or on overflow holding and treatment facilities.
- The use of such quality control facilities, over and above the prototype installation at Onondaga County, New York, will demonstrate in full-scale operation the validity and applicability of the model studies which have been conducted in the APWA report *The Swirl Concentrator as a Combined Sewer Overflow Regulator Facility* (EPA R2–72–008, Sept., 1972), and as presented in this report on supplementary investigations of the relationship between diameter and height in terms of design parameters.

OVERVIEW OF STUDY

A study of *Combined Sewer Regulator Overflow Facilities,* 11022 DMU 07/70 carried out by the APWA Research Foundation for the U. S. Environmental Protection Agency, disclosed the need for more effective design, installation, operation and maintenance of regulator devices. Too many installations failed to regulate the flows of stormwater-sanitary sewage admixtures intercepted for transmission to treatment works and the volumes discharged "overboard" to receiving streams, lakes and coastal waters.

Of significance to the water pollution problem in areas served by combined sewers in this country was the finding that overflow regulators were not designed to entrain the most concentrated and polluted increments of flow during storm flow periods in order to discharge such concentrations to interceptors leading to treatment works, and thereby reduce the pollutional impacts of overflow volumes on receiving waters. Greater emphasis on improvement in overflow wastewater quality in overflow regulator facilities was found in European practice.

The report on the study of regulator facilities, issued in 1970 as a result of the studies, emphasized the fact that a regulator must be charged with two responsible functions: effective reduction in the volume, time, frequency and duration of overflows; and effective control of the quality of the overflow wastewaters. This dual function of regulator devices was referred to as the "2 Q" principle of regulation of *quantity* and *quality*. The use of vortex-type chambers as regulator devices in Bristol, England, led to the proposal that such facilities could serve the "2 Q" purposes in American practice and that further study of the applicability of this principle to combined sewer regulator service should be undertaken.

Subsequently, a study of *The Swirl Concentrator as a Combined Sewer Overflow Regulator Facility* (EPA-R2-72-008, Sept. 1972) was undertaken by the APWA Research Foundation in 1971 for the U.S. EPA and the City of Lancaster, Pennsylvania, where a prototype installation of such a device is proposed. The report on this project was completed in July 1972. This investigation involved the development and study of a hydraulic model at the LaSalle Hydraulic Laboratory, LaSalle, Quebec, and an evaluation of a mathematical model of such a system and its flow patterns and performances by the General Electric Company, Philadelphia, Pennsylvania.

The studies established the dimensions and configurations of a swirl regulator that would perform the quality improvement function proposed in the earlier combined sewer regulator investigation. The scale model, based on a proposed 1 : 12 (based on Froude number) enlargement for the Lancaster installation, provided an efficient structure that clarified the synthesized solids-liquids admixture injected into the swirl flow pattern, the device produced relatively clear overflow for discharge to receiving waters or holding-treatment facilities; and a concentrated portion of the flow that contained the major amount of settleable contaminant solids which could be collected in the bottom of the swirl concentrator and discharged through a so-called foul sewer line for transmission via the interceptor to a wastewater works. Thus, in addition to serving as a *quantity* regulator, the swirl concentrator performed the *quality* control function envisioned in the "2 Q" principle.

The hydraulic model used in the original swirl concentrator to handle combined sewer wastewaters provided a fixed set of geometric proportions to achieve these results for given flow conditions. Further analysis of the data developed with the combined sewer swirl concentrator-regulator indicated the desirability of extending the hydraulic investigations to obtain information on how such a facility would perform with different depth-to-width ratios.

The effect of swirl concentrator depth-to-width ratio, in the initial study, on the liquid flow field and solids particle removal efficiency was determined by operating the mathematical model for two different chamber depths, with all other parameters held constant. This mathematical model study of depth-to-width ratios served to augment and validate the hydraulic studies carried out by the LaSalle Laboratory. The mathematical model investigation demonstrated little change in liquid flow characteristics resulting from changes in chamber depth but the model predicted a marginal improvement in solid particle removals for greater depths – 67.1 percent from 63.4 percent with particle settling velocity of 2.2 cm/sec (0.0717 fps); and 96.0 percent from 93.2 percent with settling velocities of 6.4 cm/sec (0.212 fps): this was not verified by testing with hydraulics laboratory configurations. However, laboratory tests utilizing earlier concentrator configurations indicated that "marginal, even questionable" increases in performance were observed at a depth of up to 4.56 m (15 ft).

The economic feasibility of providing increased depth of swirl concentrator construction to achieve such minimal, and even questionable, improvements in solids separation performance remains doubtful. In the case of so-called conventional gravity solids separation settling chambers, the depth factor is empirically chosen. The design criteria for such basins are "locked in" in many cases by the specific flow rate to be handled and by regulatory agency standards which establish surface settling rate parameters.

The swirl concentrator principle, on the other hand, is not based on velocity of flows or any surface area parameter, but, rather, on long-path geometric liquid flow patterns which create the dynamic solids-liquid separation with minimal turbulence. Thus, the optimum depth of a swirl concentrator is that depth that will give effective solids deposition in the proper place in the chamber floor and removal of concentrated solids via a foul sewer bottom outlet (orifice) properly located. Any depth that will provide the flow patterns to separate solids and not permit turbulences of flow to cause an upsweep of solids out over the clear liquor outlet weir will assure the desired chamber efficiency.

The diameter of the wier was not varied due to the conclusion after the first laboratory and mathematical modeling that an optimum relationship had been established.

Further analysis of the data obtained in the swirl hydraulic studies indicated the desirability of extending studies to provide information on its performance capabilities with different width-depth ratios in order to reduce the hydraulic head requirements. The current series of tests were carried out to augment earlier findings, and to determine the solids recovery rates when the chamber diameter (width) and weir height (depth), are varied and the inlet pipe size held constant relative to each other.

SECTION II
THE STUDY

The supplemental studies of the relationship between swirl chamber width, or diameter, inlet size, and height of clear liquid weir, or depth of the chamber, were based on the concentrator configurations utilized in the original 1972 investigation of the solids-liquid separation performance. The principle of chamber design to provide a controlled combination of solids settling and rotational flow to concentrate the deposited solids at the center of the chamber floor (and to provide a surface trap facility to entrain and retain floatable solids) was the basic guideline for the supplemental laboratory studies reported herein.

It was deemed impracticable to vary the swirl chamber diameter from the hydraulic investigative device used in the earlier configuration and performance studies. The model diameter, thus, remained at 91.4 cm (36 in.), with a 50.8 cm (20 in.) diameter clear liquid overflow weir and the 61 cm (24 in.) diameter scum ring.

The variable factors chosen to provide the chamber depth-to-width relationships were: weir height, and the inlet pipe diameter. Figure 1, Model Layout, portrays the facilities utilized in the study. Details are shown in Figure 2, Chamber Internal Details. Figure 3, Details of Weir, Scum Ring and Spoiler Assembly, shows the details of the other major components.

The study covered five rates of discharge, including the rational ranges that would be imposed on a full-scale unit. This enabled the study to encompass operational capacities that would result in findings that would make possible the "universalization of the swirl concentrator as a combined sewer regulator facility." These flow rates, on a 1 : 12 scale of laboratory model to prototype, were: 1.42; 2.83; 4.25; 5.66; and 8.49 cm/sec (50; 100; 150; 200; and 300 cfs). Four inlet pipe diameters were studied: 0.91; 1.22; 1.52; and 1.83 meters (3; 4; 5; and 6 ft).

At least three weir heights, or chamber depths, were tested for each inlet pipe diameter. The range selected for the hydraulic study was: 1.83; 2.14; 2.74; 3.36; and 3.97 meters (6; 7; 9; 11; and 13 ft). Some of the lower weir heights could not be tested because they would interfere, or be interfered with, by the weir and the scum ring assembly. The dimensions listed, and the test operations with these configurations, were deemed to cover all of the parameters required for the depth-width relationships to be studied. The full details of the model portrayed in Figure 2 are described in the LaSalle Hydraulic Laboratory, report contained in Appendix A.

The model used for the supplemental studies was the same unit utilized in the first studies in 1972. The separation chamber was a vertical cylinder made of 13 mm (1/2 in.) Plexiglas®, 91.4 cm (36 in.) in diameter and 102 cm (40 in.) high. The inlet synthetic wastewater line was made of polyvinyl chloride pipe, varying in size of 7.6; 10.2; 12.7; or 15.2 cm (3; 4; 5; or 6 in.), set at a slope of 1 : 1,000 to provide tangential flow of the incoming liquid in the swirl concentrator chamber. The incoming flow was composed of water supply from a constant level tank in the laboratory, and solids of proper composition injected into the inflow stream by a vibrating feed unit.

The clear water outlet from the swirl concentrator was through a polyvinyl chloride pipe 15.2 cm (6 in.) in diameter which was installed upward through the bottom of the model centerline. The height could be varied at will by adding or removing segments to or from the top of the pipe. The foul flow (concentrate) was discharged from the bottom of the chamber through a flexible 5.1 cm (2 in.) tube, leading to a solids settling tower fitted with an adjustable level outlet pipe which could be raised or lowered to regulate the rate of discharge of the foul flow (concentrate).

The solids introduced into the inlet flow were synthesized to simulate the physical character of combined sewer flows which would be handled in actual practice by a prototype swirl concentrator. This involved synthesizing grit material, organic material and floatable materials of representative sizes, specific gravities and quantities. Appendix A

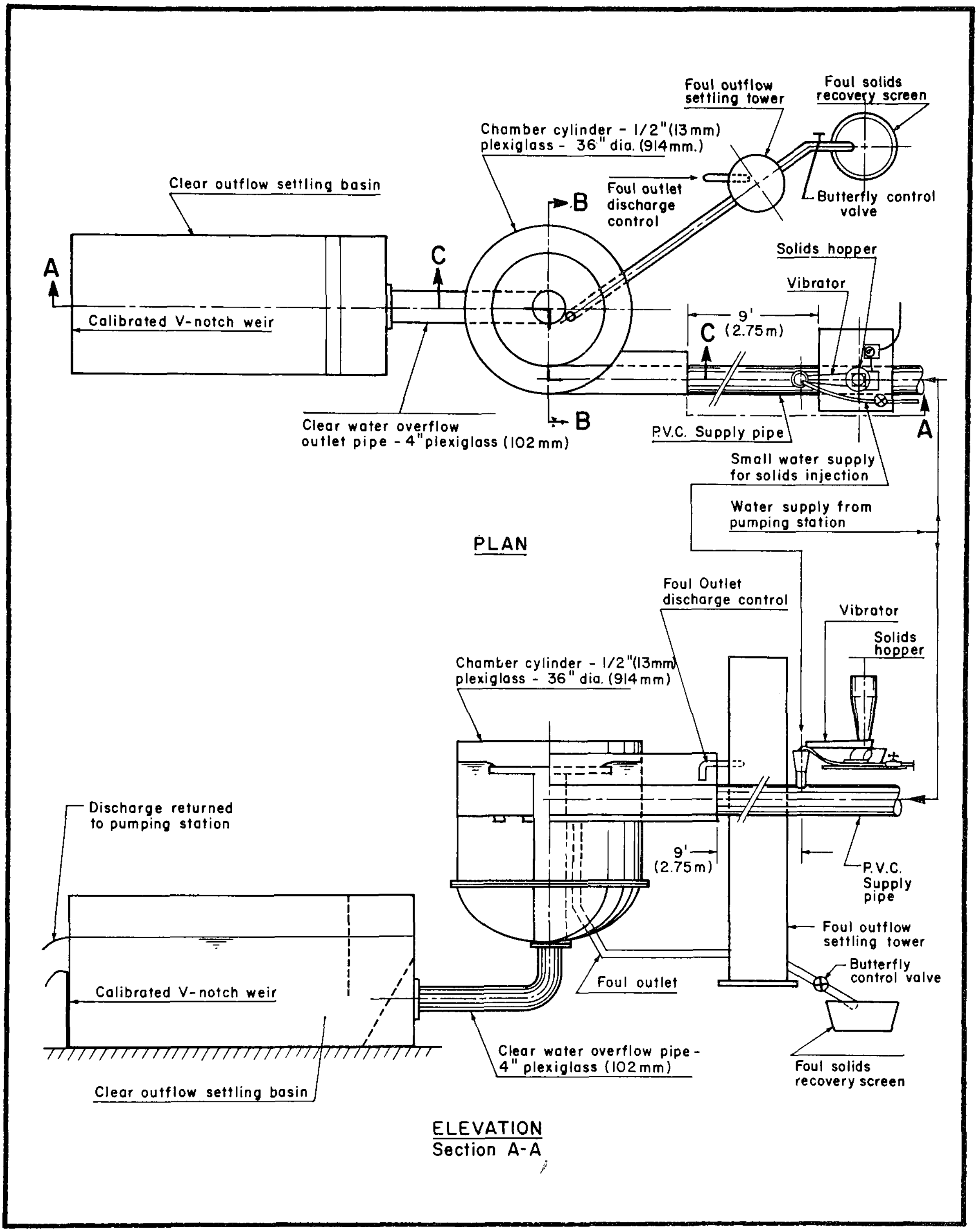


FIGURE 1
MODEL LAYOUT

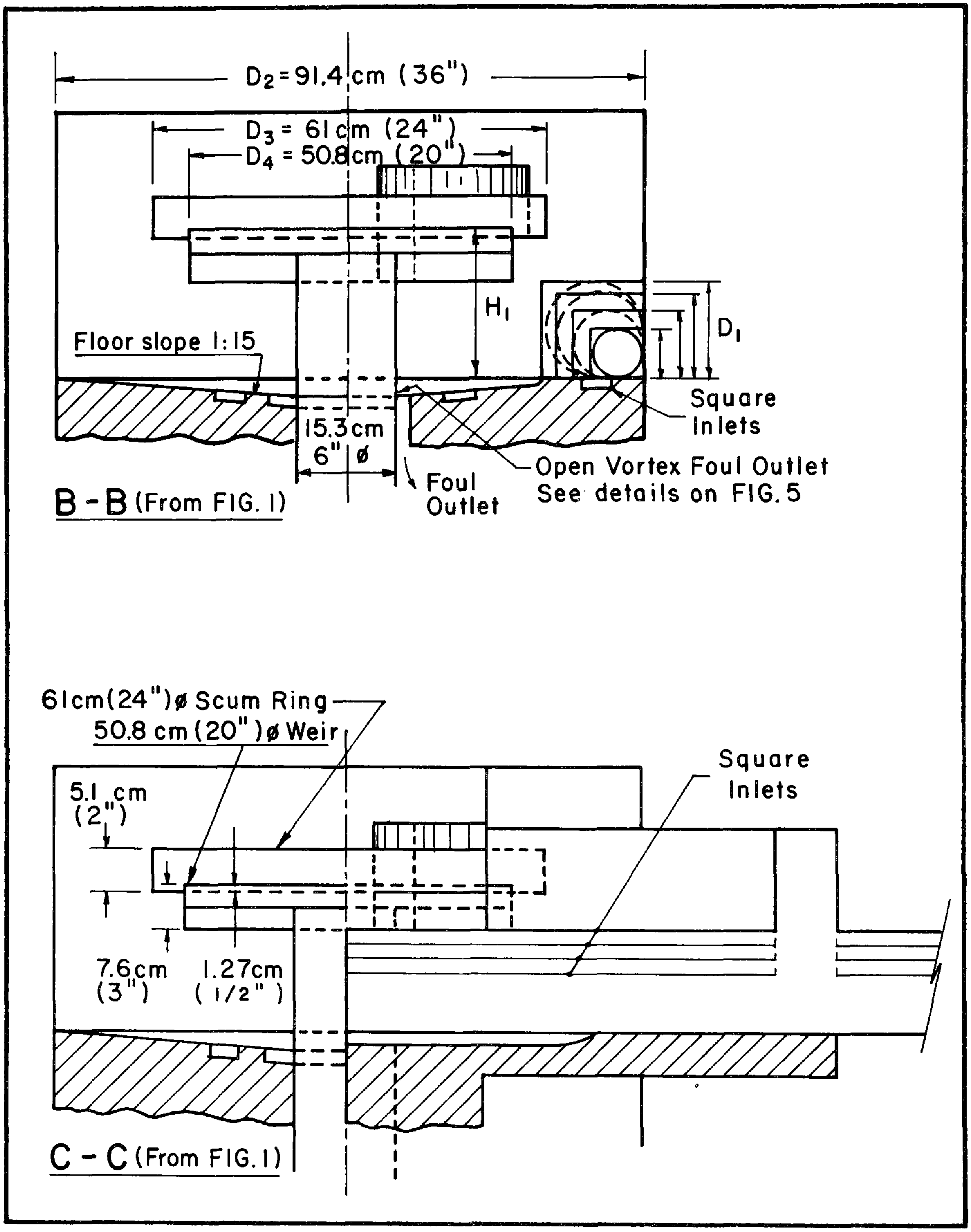


FIGURE 2
CHAMBER INTERNAL DETAILS
(Sections are from Figure 1)

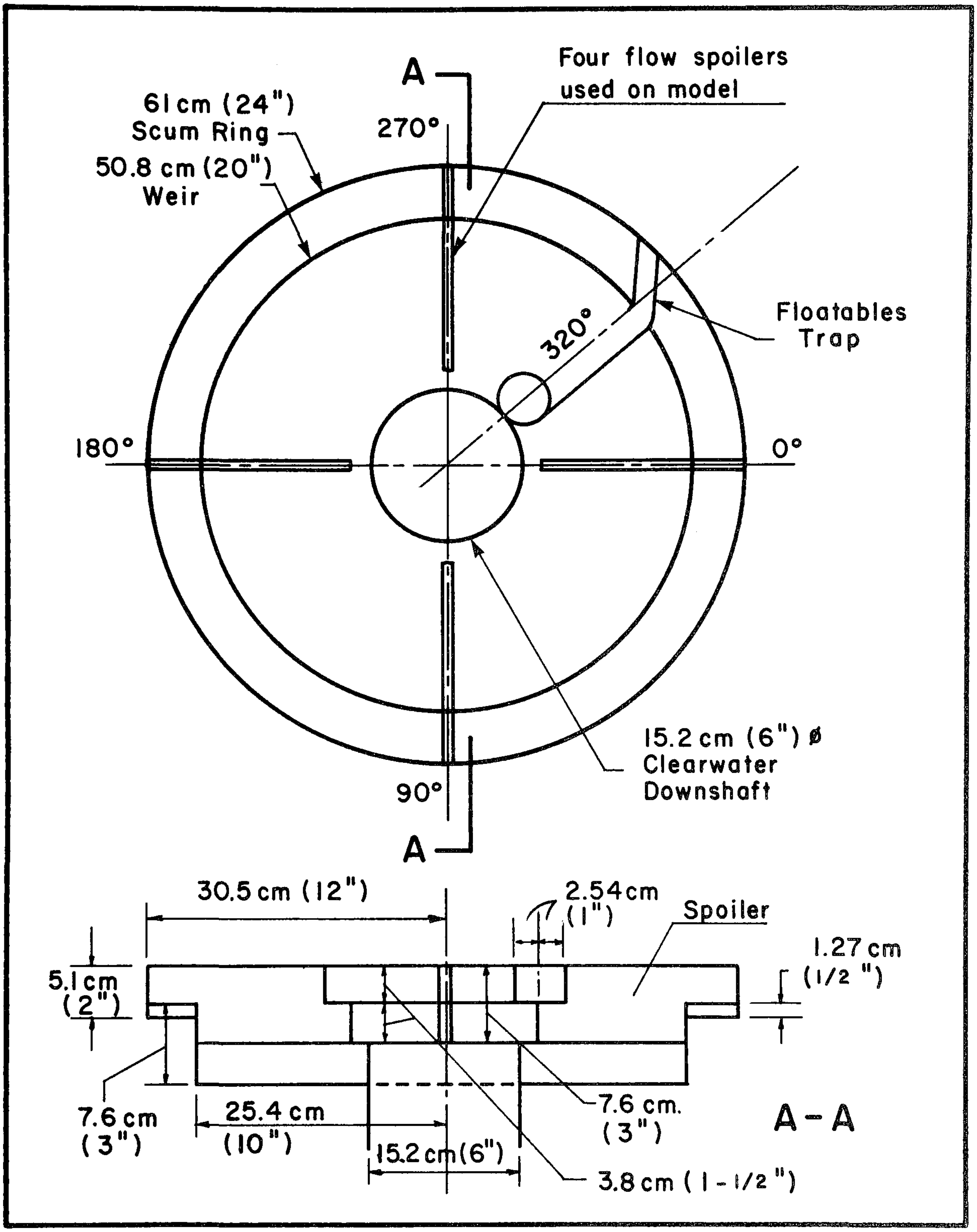


FIGURE 3
DETAILS OF WEIR, SCUM RING AND SPOILER ASSEMBLY

describes in detail the materials utilized for these purposes.

The grit increment of the solids injected into the stream flow to the swirl, to stimulate combined sewage flows, was assumed to have a specific gravity of 2.65 and a straight line grain size distribution was selected as a representative average of samples taken from existing combined sewer systems – from 0.2 to 2.0 mm (No. 70 to 10 sieve sizes). The concentration range was 20 to 360 mg/l. Figure 4, Prototype Gradation for Grit and Organic Material, represents the prototype gradations for grit and organic material that the synthetic solids scale up to.

Particle sizes greater than 1 mm move along in a flowing liquid stream according to equations deduced by Meyer-Peter and Muller[1] or Einstein[2]. Particles between 1 mm and 0.2 mm are considered to be in a transition zone between the Meyer-Peter, Muller or Einstein equation and the Stokes relation. It was necessary to deduce curves of particle settling velocities for grit, organics and Gilsonite material, as shown in Appendix A, utilizing the Froude law of similitude.

Gilsonite components of the simulated combined sewage solids material were deduced as described in Appendix A. While the Gilsonite did not adequately cover the larger prototype particle sizes, it was assumed that the larger size particles not represented by the Gilsonite material used in the studies would have settled at least as effectively as the recovery rates shown for the other material. Thus, the estimates of removal efficiencies through the swirl concentrator would be on the conservative side. Even if all the lighter materials not covered by the Gilsonite were assumed to be lost over the clear outlet weir, they would represent only 10 percent of the prototype grit, at most.

The organic material contained in combined sewage to be removed from the flow in a prototype swirl concentrator, was defined as having a specific gravity of 1.2 and a grain size distribution from less than 0.1 to 5 mm. The Gilsonite utilized in the laboratory studies adequately simulated the upper limits of the range but the lower range left a significant zone of finer solids or particles not simulated across the scales considered in the studies. However, the Gilsonite represented the major portion of the prototype organics and its use was deemed suitable for the investigations.

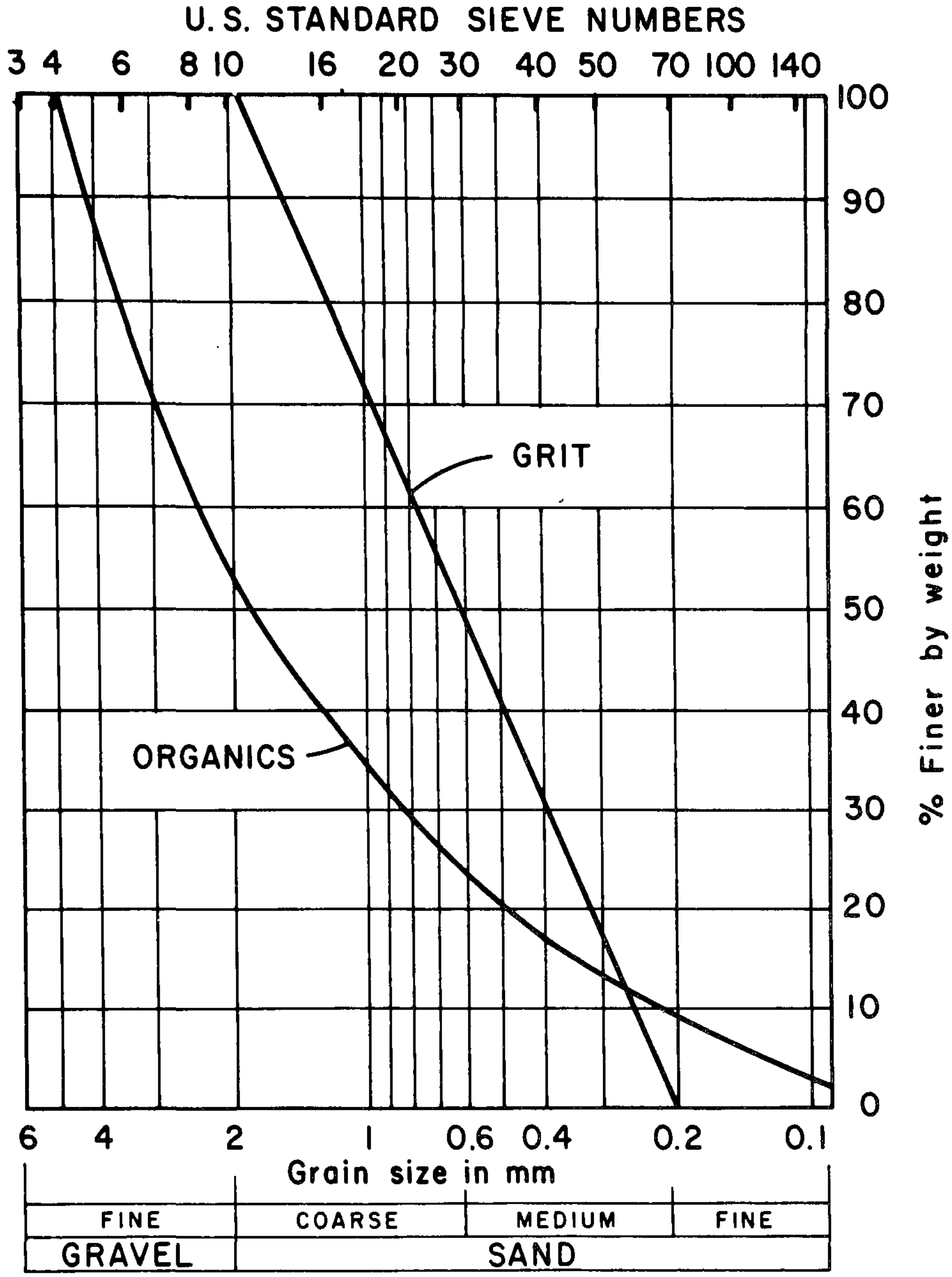
The floatable increment injected in the flow had a specific gravity of 0.9 to 0.998 and a size range from 5 to 25 mm. The concentration range was 10 to 80 mg/l. The simulated floatables material used was polythene particles 4 mm in diameter having a specific gravity of 0.92.

It is obvious that the hydraulic model studies could not duplicate the variations in inflow rates and in combined wastewater solids concentration, which normally occur in sewer system operations. Steady-state flows were investigated in the swirl chamber rotational flow pattern and steady-state discharges were established. Similarly, a specific grit-organics-floatables solids concentration was utilized in the studies, by means of injecting one liter of Gilsonite and polythene into the steady-state flow rates.

Removal efficiency was based on the amounts of synthesized solids introduced into the swirl concentrator, the amount discharged through the foul sewer (concentrate line), the amount spilled over the clear overflow weir with the supernatant liquor, the amount retained on the floor of the chamber after each flow pattern had been studied, and the lighter-than-water materials entrained in the floatables trap. The Gilsonite material used was considered to represent both the grit and organic components of the simulated combined wastewater.

As stated, solids recovery, or removal, was evaluated for four sizes of pipe inlets and various weir heights. For an inlet size of 15.2 cm (6 in.), increasing or reducing the weir height produced little impact on recovery rates. Likewise, the 12.7 cm (5 in.) inlet demonstrated similar recovery rates for the weir heights (or chamber depths) tested; the depth range investigated varied from 22.8 cm to 33 cm (9 to 13 in.). However, a smaller inlet size than 12.7 cm (5 in.) produced differences in recovery rates when the weir height was varied.

The basic finding that weir height has minimal effect on solids recovery made it possible to develop fundamental design curves which relate recovery rates to inlet size (as it relates to chamber diameter) and discharge



U.S. SIEVE SIZE	SIZE mm	% FINER BY WEIGHT	
		GRIT	ORGANICS
4	5.0	100	100
10	2.0	100	53
20	0.84	63	31
40	0.42	31	17
50	0.30	18	14
70	0.20	0	10

FIGURE 4
PROTOTYPE GRADATION FOR GRIT AND ORGANIC MATERIAL

rates. This eliminates the weir height parameter, within a broad range, as a factor in design decisions, making it possible for the designer to choose the solids recovery efficiency he hopes to achieve and, thus, determine the ratio between the chamber diameter and inlet dimension for the discharge rate upon which his design will be based.

The practical value of the scale-up curves developed from the hydraulic laboratory studies will be obvious to designers. They translate discharge rates and theoretical settleable solids recovery efficiencies to various inlet dimensions and chambers of different sizes.

Of even greater value to the designer are extrapolated curves which relate discharge flows to swirl chamber diameters for desired settleable solids removal efficiencies ranging from 90 percent to 70 percent.

Section III provides a step-by-step explanation of how these hydraulic data can be utilized in design procedures. Based on the known criteria of design flow rates to be handled and the solids removals, the inlet dimension, the chamber diameter and other general design details can be determined. This information is invaluable; it converts the model studies to the realities of utilizing the swirl principle for the improvement of combined sewer overflow quality by concentrating solids pollutants for discharge to municipal treatment facilities and by discharging clarified supernatant liquors to receiving streams, retention facilities or storm-water treatment systems.

SECTION III
ALTERNATIVE DESIGN OF SWIRL CONCENTRATION FACILITIES

The initial report, *The Swirl Concentrator as a Combined Sewer Overflow Regulator Facility,* recommended specific dimensional relationships.

D_1 = inlet dimension.

D_2 = diameter of chamber = $6D_1$.

d_1 = height of weir = 1 1/2 D_1

Therefore $D_2 = 4d_1$

(Note: d_1 is designated as H_1 in this supplemental study of alternative design factors.)

The purpose of this supplemental study was to determine the effect of varying ratios of swirl chamber diameter to height, or D_2 to H_1. The results indicated that the optimum weir height had the same relationship as in the original study, i.e., $H_1/D_2 = 0.25$. This study indicated that the ratio of the diameter of the chamber to the dimension of the inlet has considerable effect on the recovery of settleable solids. The resultant design dimensions indicate a range of the ratio of D_2 to D_1 of from 6-12. In the original study the ratio of D_2 to D_1 was reported as six.

In the original report, Figure 5, Storm Discharge vs. Chamber Diameter, and Figure 6, General Design Details, were to be used in determining the chamber diameter. At the design discharge it was found that the design configuration would result in removal of 90 percent of grit larger than 0.35 mm, and of settleable organics larger than 1.0 mm.

The supplemental study reported herein used Gilsonite in a range of sizes which simulated grit over 0.2 mm size and organics over 0.4 mm size with model scale of 1 : 4 and grit over 0.25 mm size and organics over 0.7 mm size in the model with model scale of 1 : 24. Hence the supplemental design charts are based on removing particles of smaller size than in the original study report. This report presents design figures for removing either 90, 80 or 70 percent of the grit and organics. *These design figures should be used in preference to Figures 5 and 6.*

Three sets of curves for sizing the swirl concentrator were developed from the hydraulic model studies, based upon the desired degree of efficiency of settleable solids removal at the design discharge. Figures 7, 8 and 9, Chamber Diameters for 90%, 80% and 70% Recovery, respectively, are used to determine the chamber diameter for various inlet dimensions.

Where it is desired to modify the chamber dimensions to minimize the weir height, Figure 10, Geometry Modification Curves, may be used. Use of these curves presumes that the inlet dimension will be retained and that the weir height and chamber diameter will be modified.

In order to determine the percent recovery of settleable solids for various inlet diameters, Figures 12, 13, 14, 15, 16, 17, and 18, Settleable Solids Recovery for 30.5 cm (1 ft); 45.8 cm (1.5 ft); 61 cm (2 ft); 91.5 cm (3 ft); 122 cm (4 ft); 152.5 cm (5 ft); and 183 cm (6 ft). Inlet and Different Sized Chambers, respectively, should be used. Use of these figures allows a rapid check of anticipated efficiency of settleable solids removal.

Design Procedure

The design procedure, utilizing Figures 7-10:

1. **Select Design Discharge**

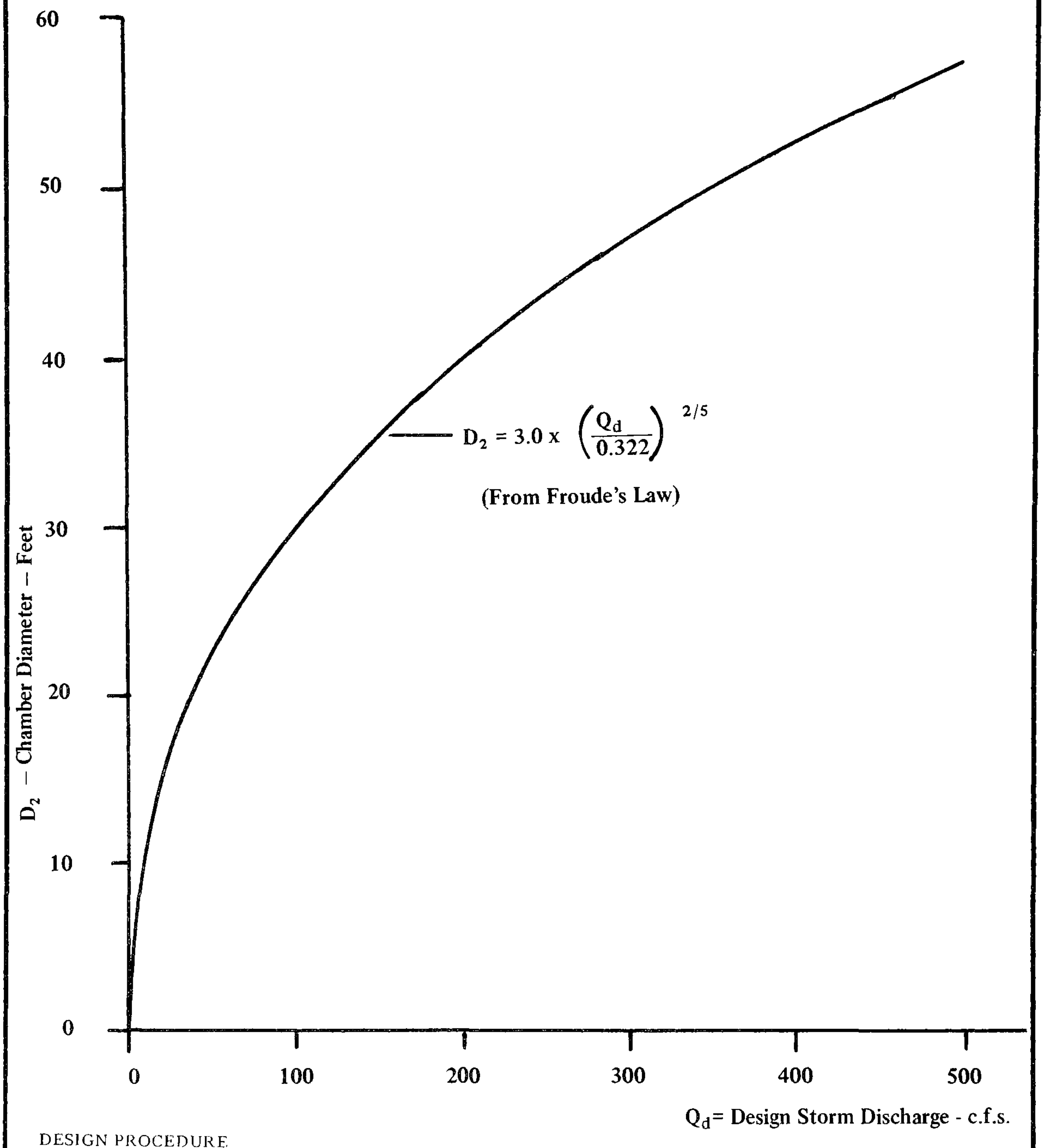
The design engineer must select the design discharge appropriate to each project, based on the design criteria for the project.

2. **Select the Recovery Efficiency Desired**

One of three performance efficiencies can be chosen – either 90, 80 or 70 percent recovery of settleable solids. It is suggested that 90 percent settleable solids recovery be taken for peak storm discharges. Only in cases where low probability peak flows are being considered would it be reasonable to design on the basis of 80 percent or 70 percent recovery.

3. **Find the Inlet Dimension – D_1**

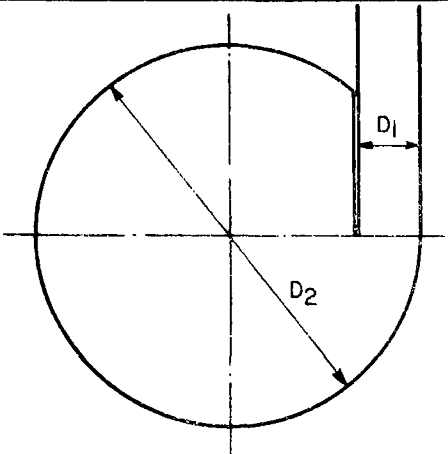
Having selected the desired recovery rate and the design discharge, use the corresponding chart in the series of Figures 7, 8 and 9 for determining D_1. Using the proper chart with the design discharge, follow this vertically upward to the broken D_1 line which most nearly corresponds to the inlet sewer diameter. (Note: It might be advantageous to select a larger or smaller D_1 to coincide exactly with the inlet sewer size.) In the



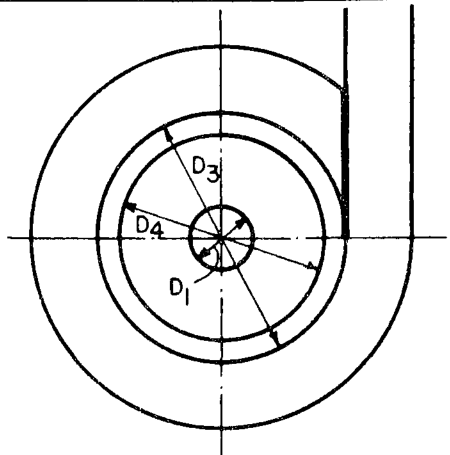
DESIGN PROCEDURE

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 Fig. 18 to find first D_1, then calculate the dimensions of the other chamber elements.

FIGURE 5
STORM DISCHARGE VS. CHAMBER DIAMETER
Note: From original APWA study, do not use

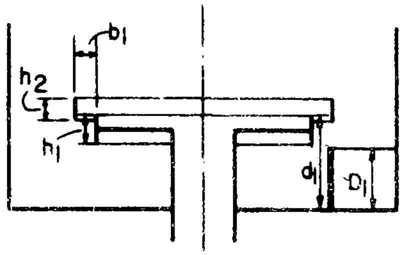


Inlet, Chamber Diameters

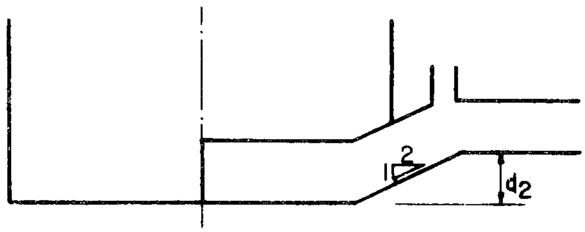


Weir, Scum Ring Diameters

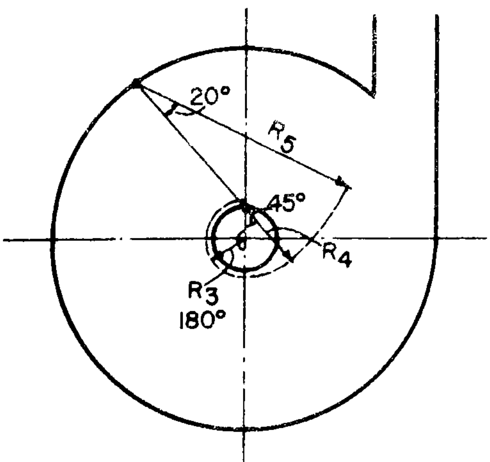
D_1	=	unit	D_2	=	$6D_1$	D_3	=	$4D_1$	D_4	=	$3\ 1/3\ D_1$
h_1	=	$D_1/2$	h_2	=	$D_1/3$	b_1	=	$D_1/3$	d_1	=	$1\ 1/2\ D_1$
d_2	=	$5/6\ D_1$	R_1	=	$2\ 1/3\ D_1$	R_2	=	$1\ 1/2\ D_1$	R_3	=	$5/8\ D_1$
R_4	=	$1\ 1/8\ D_1$	R_5	=	$3\ 2/3\ D_1$	b_2	=	$D_1/6$			



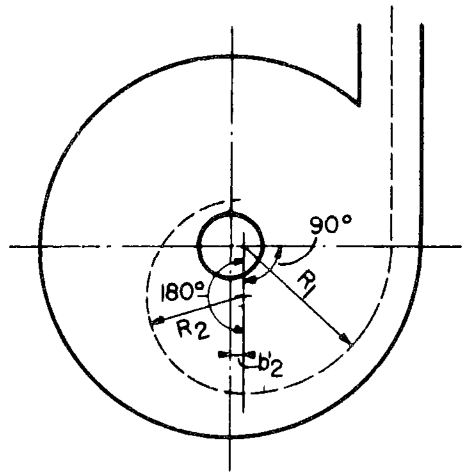
Weir, Scum Ring Details



Inlet Detail



Centerline Secondary Gutter



Centerline Primary Gutter

FIGURE 6
GENERAL DESIGN DETAILS
Note: From original APWA study, do not use

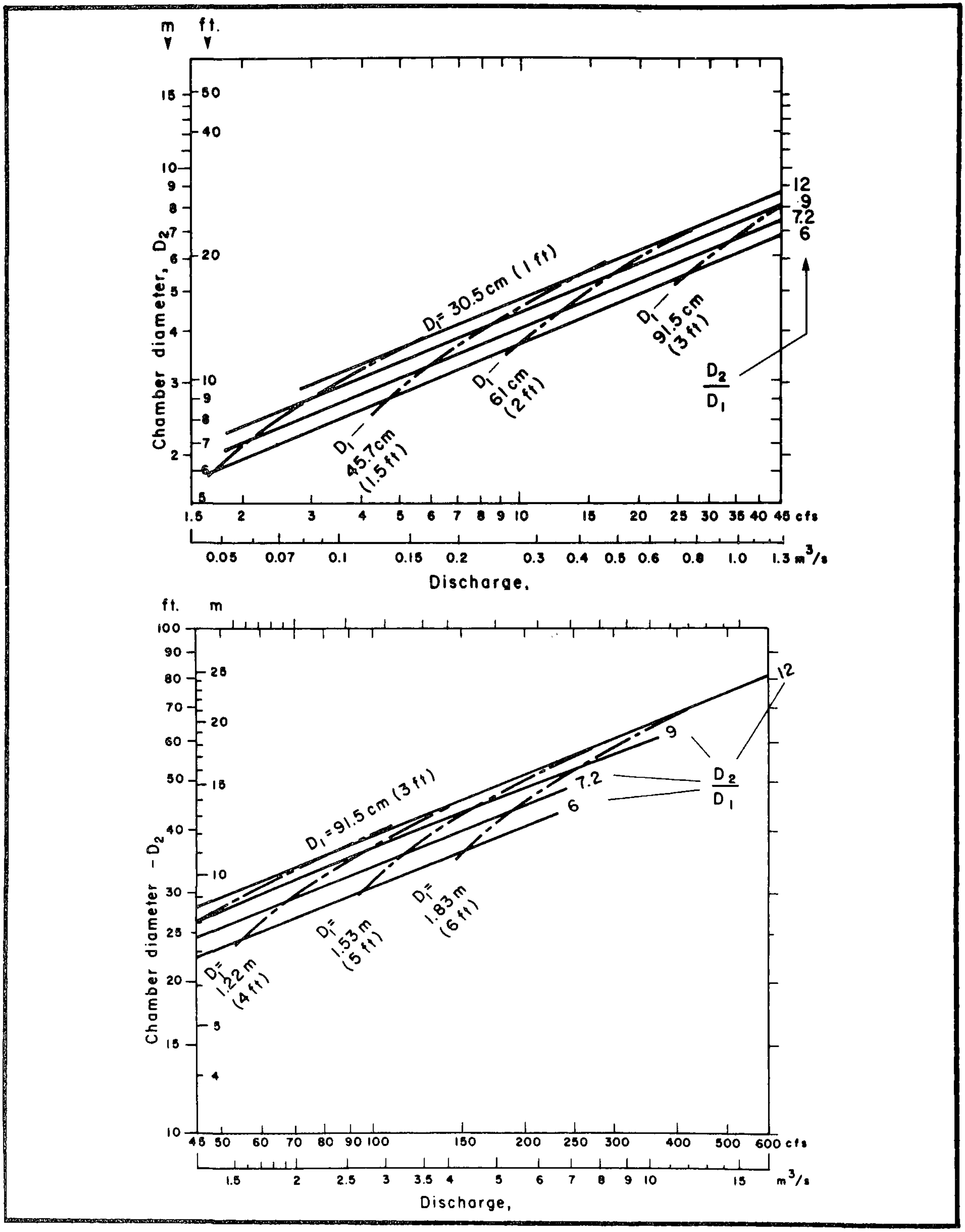


FIGURE 7
$H_1 : D_2 = 0.25$
CHAMBER DIAMETERS FOR 90% RECOVERY

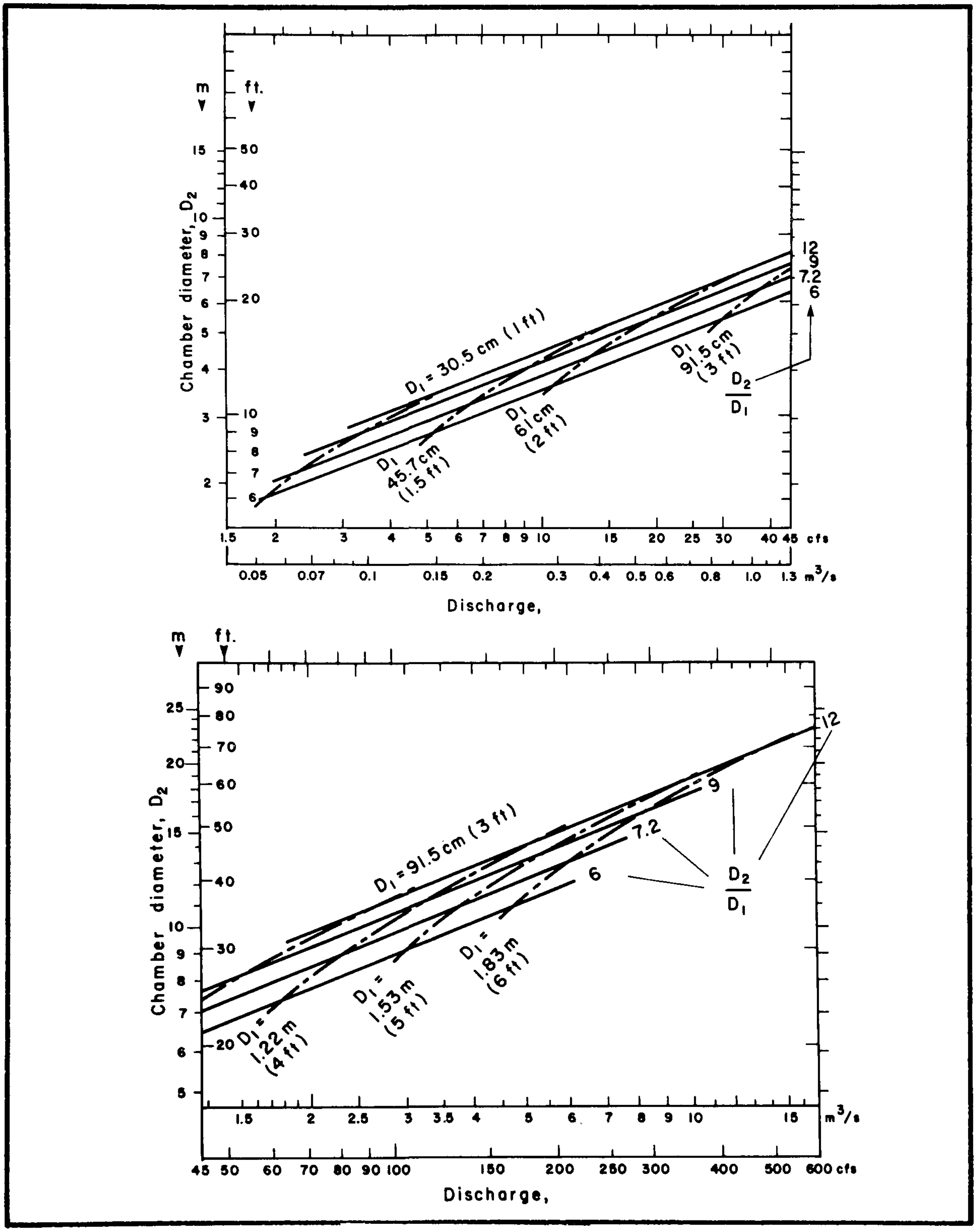


FIGURE 8

$H_1 : D_2 = 0.25$

CHAMBER DIAMETER FOR 80% RECOVERY

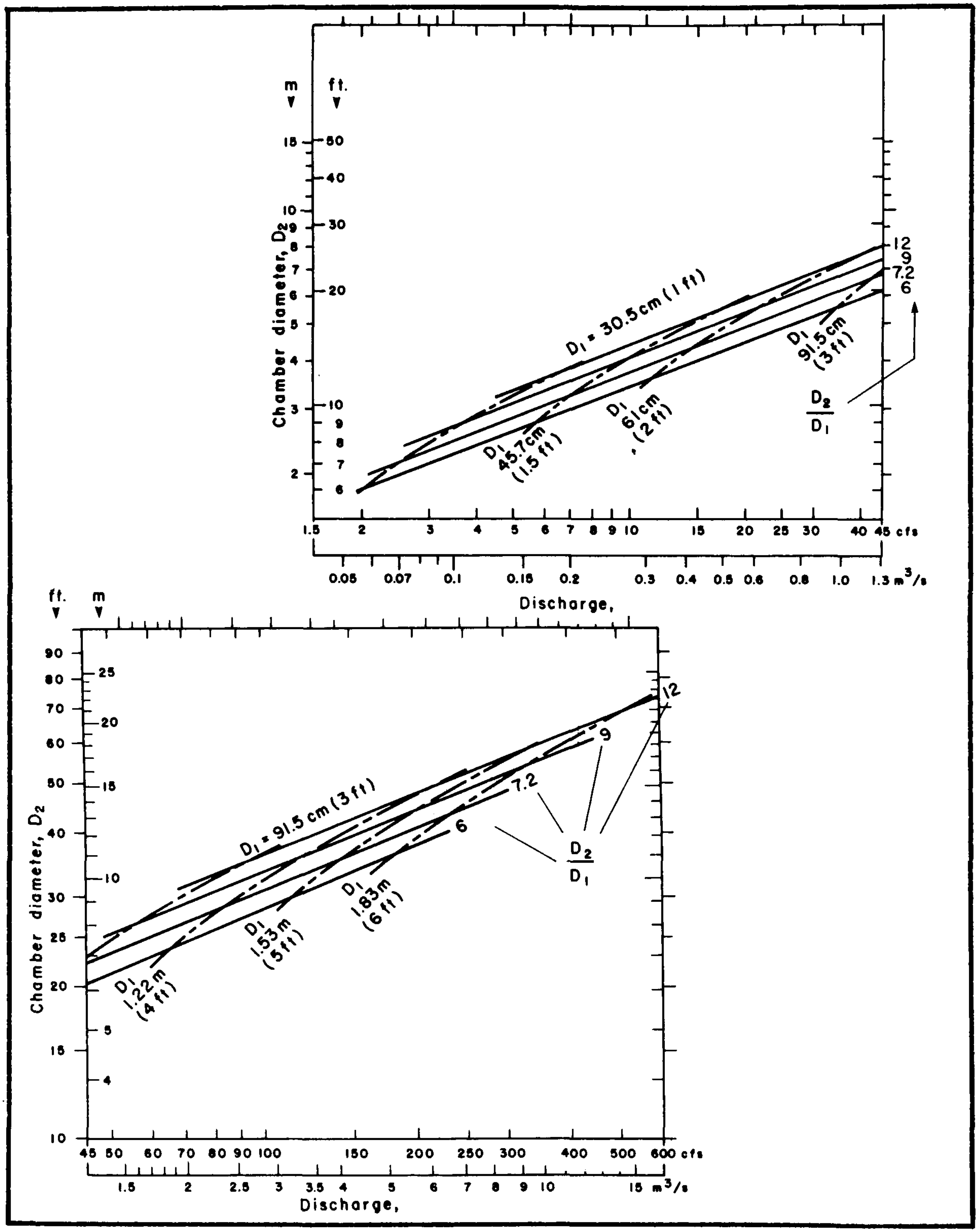


FIGURE 9

$H_1 : D_2 = 0.25$

CHAMBER DIAMETER FOR 70% RECOVERY

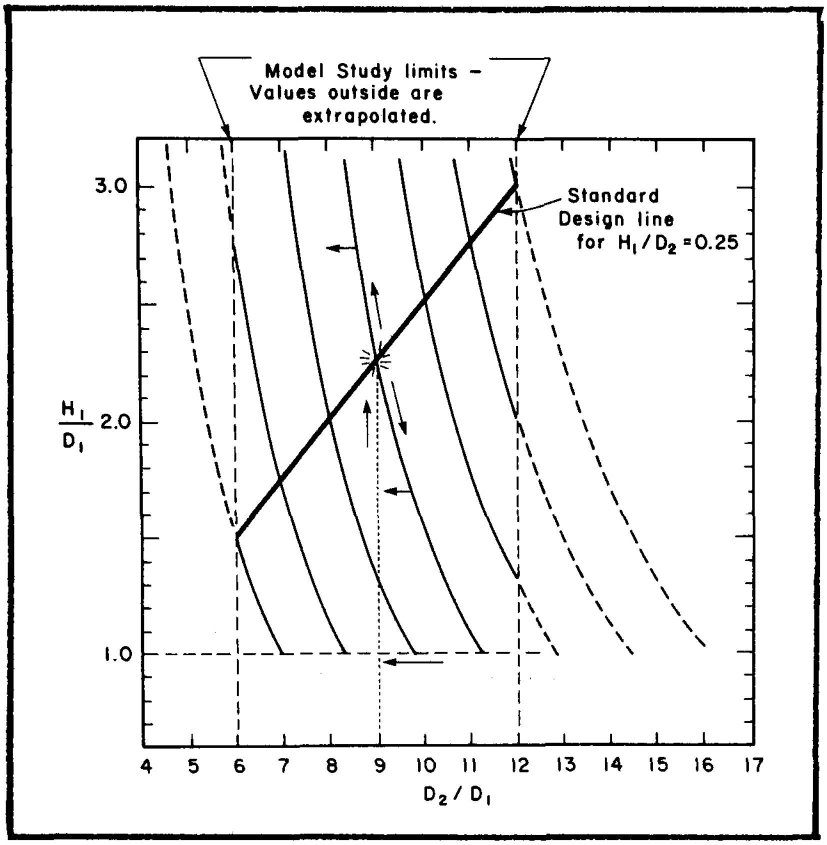


FIGURE 10
GEOMETRY MODIFICATION CURVES

model tests, the square inlet dimension was the same as the inlet sewer diameter, an ideal condition for this unit.

In cases where the square inlet dimension cannot conveniently be made the same as the inlet sewer, a reducing or expanding adapter or conversion section would be necessary to ensure obtaining the efficiencies given in the curves. If the inlet sewer is concentrically aligned with the swirl chamber inlet, the transition section should have a length of at least three times D_1 (i.e. $3D_1$). Another possibility would be to provide for the inlet sewer to discharge into an inspection manhole. From the manhole, a conduit with a square cross section would be provided to the swirl chamber. The distance from this conversion manhole to the square inlet discharge into the chamber should also be a minimum of three times (D_1 (i.e. $3D_1$). This manhole arrangement could be used to provide for change in the alignment, elevation or size between the inlet sewer and the square inlet into the swirl chamber.

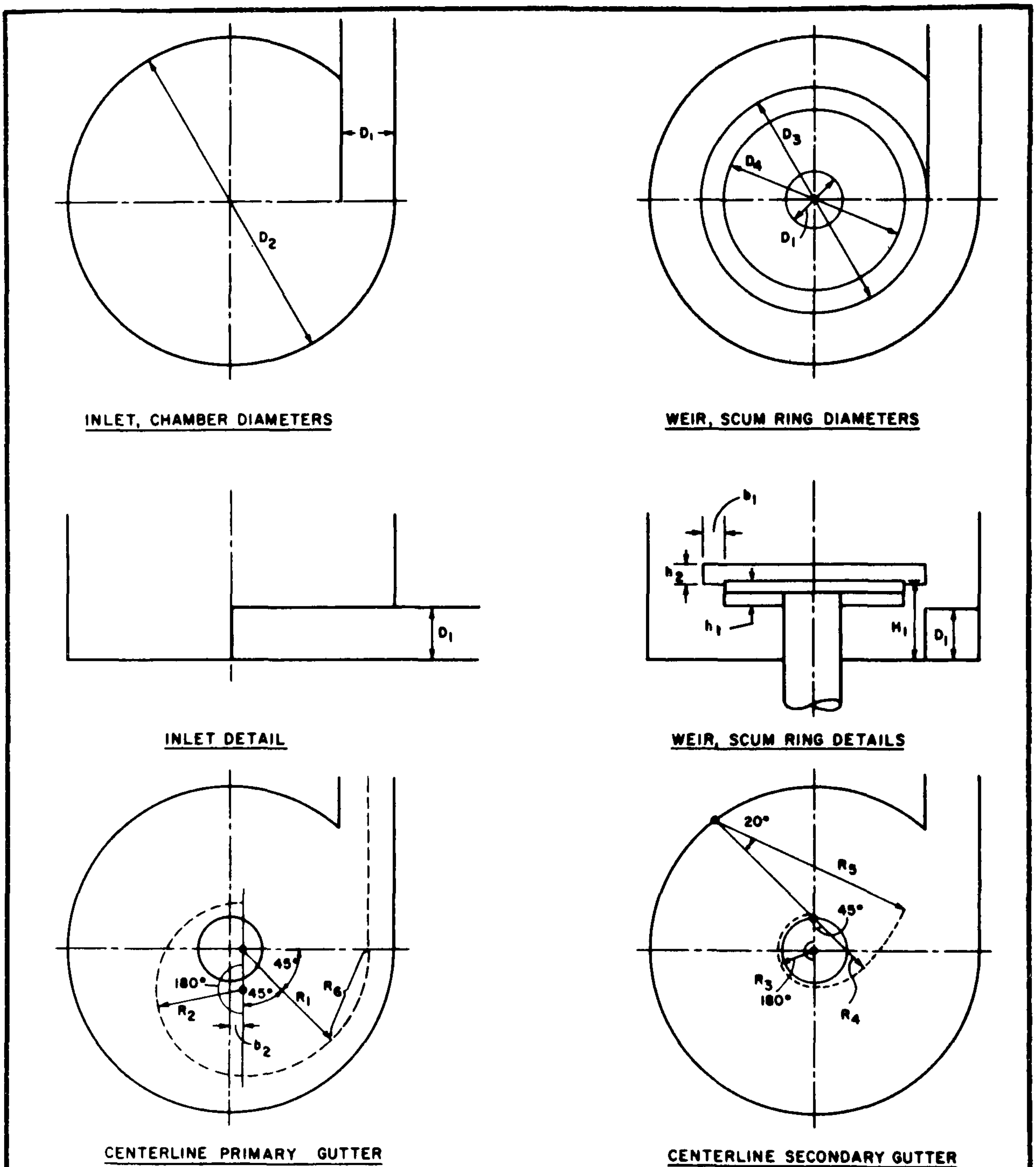
4. Find Chamber Diameter – D_2

The intersection point found in 3, above, defines the chamber diameter, D_2, on the ordinate scale of the chart. In choosing D_1, it might be a valuable aid to check the D_2 size, as well. Using a smaller D_1 will make a larger D_2 necessary; the designer can determine the optimum relation between the two dimensions.

5. Check Discharge Range Covered

The anticipated efficiency at various flow rates can be determined for different sized inlets and chambers by using Figures 12-18. If the selected D_2 curve is not shown in the figure, its recovery line can be interpolated and drawn between the given curves.

The recovery rates over the range of discharges represented by the sewer hydrograph should be checked, including the design discharge. The designing engineer must



D_1 = FROM FIGURE 7, 8, 9, OR 10

D_2 = FROM FIGURE 7, 8, 9, OR 10

H_1 = $D_2/4$ OR FROM FIGURE 10

D_3 = $2/3\ D_2$

D_4 = $5/9\ D_2$

h_1 $D_1/2$

h_2 = $D_1/3$

b_1 = $D_2/18$

R_1 = $7/18\ D_2$

R_2 = $D_2/4$

R_3 = $5/48\ D_2$

R_4 = $3/16\ D_2$

R_5 = $11/18\ D_2$

R_6 = Curve smoothed in to meet inlet centerline

FIGURE 11
GENERAL DESIGN DETAILS

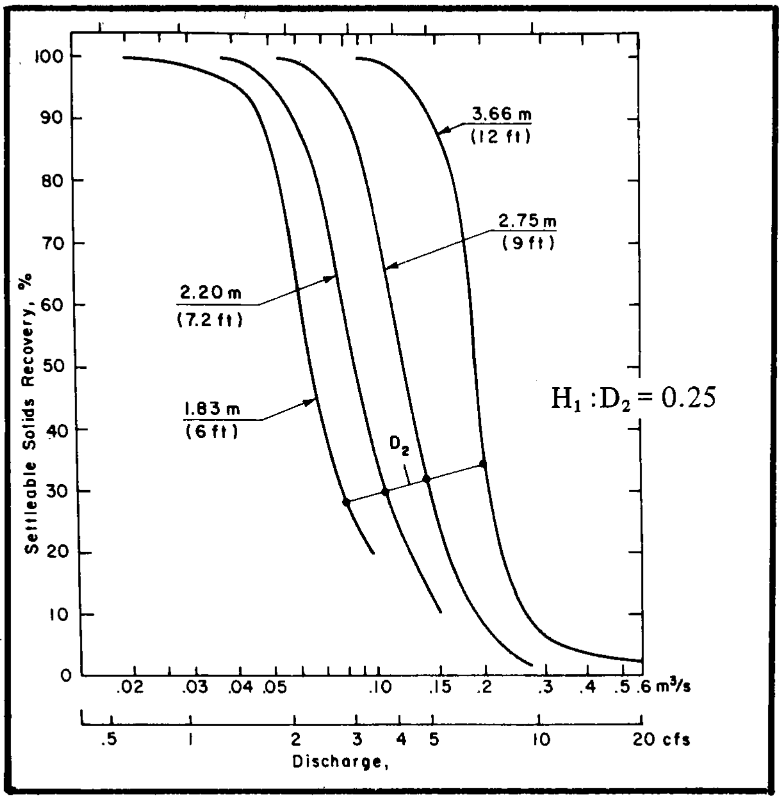


FIGURE 12
SETTLEABLE SOLIDS RECOVERY FOR 30.5 cm (1 ft)

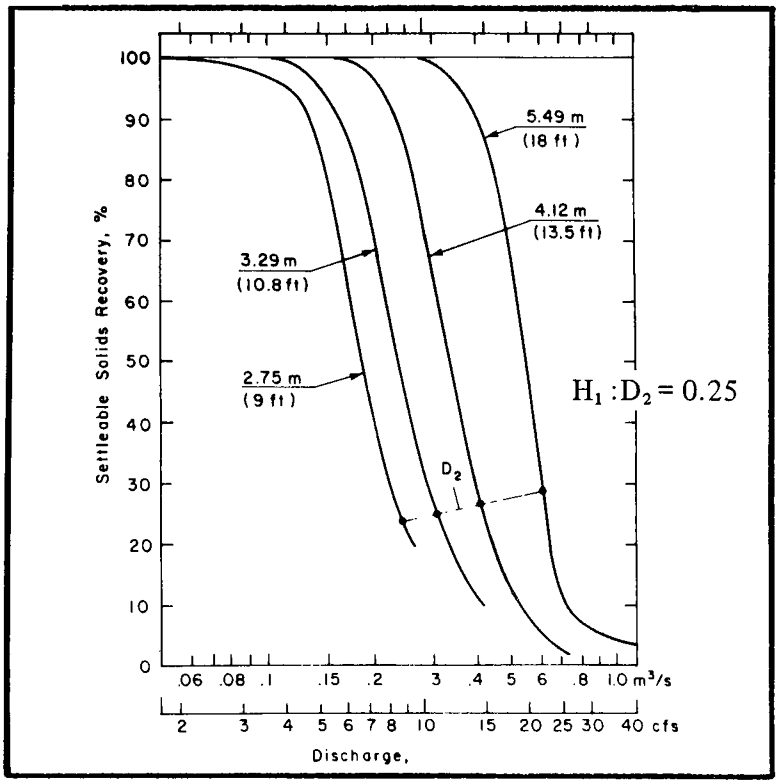


FIGURE 13
SETTLEABLE SOLIDS RECOVERY FOR 45.8 cm (1.5 ft)

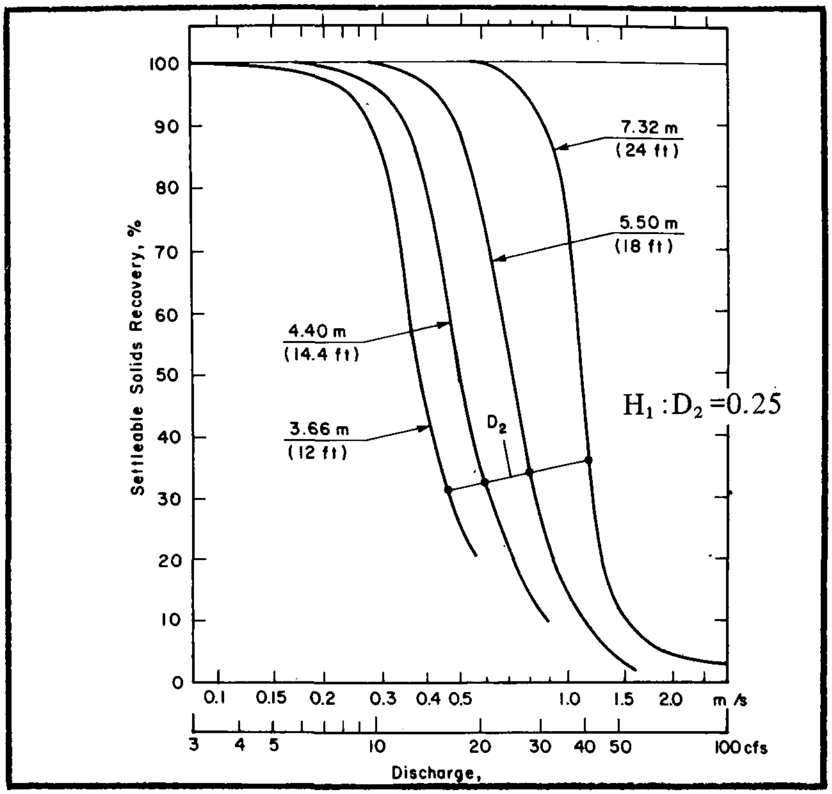


FIGURE 14
SETTLEABLE SOLIDS RECOVERY FOR 61 cm (2 ft)

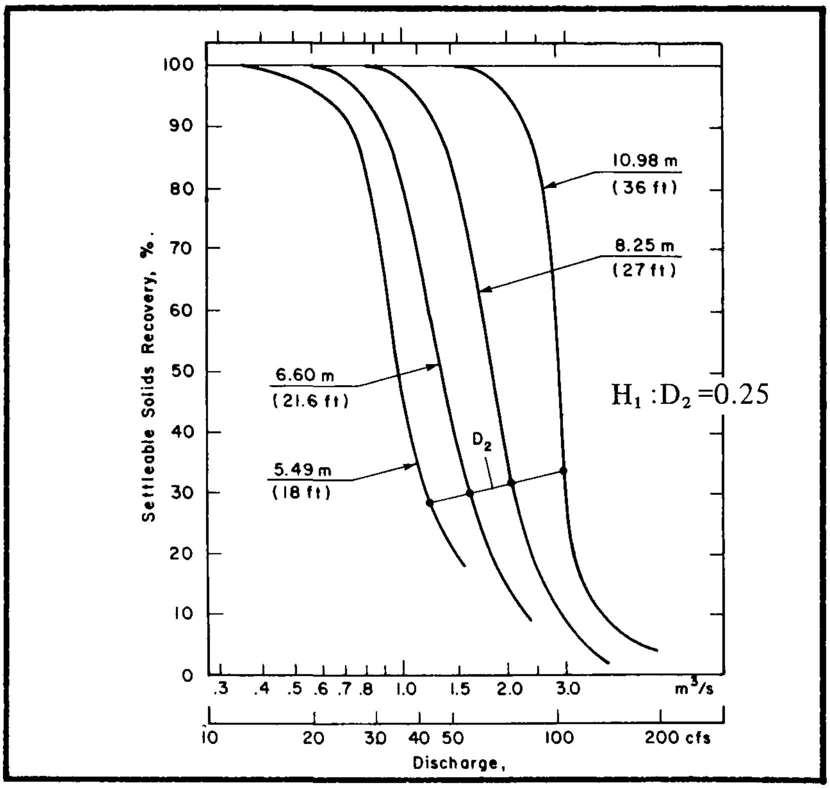


FIGURE 15
SETTLEABLE SOLIDS RECOVER FOR 91.5 cm (3 ft)

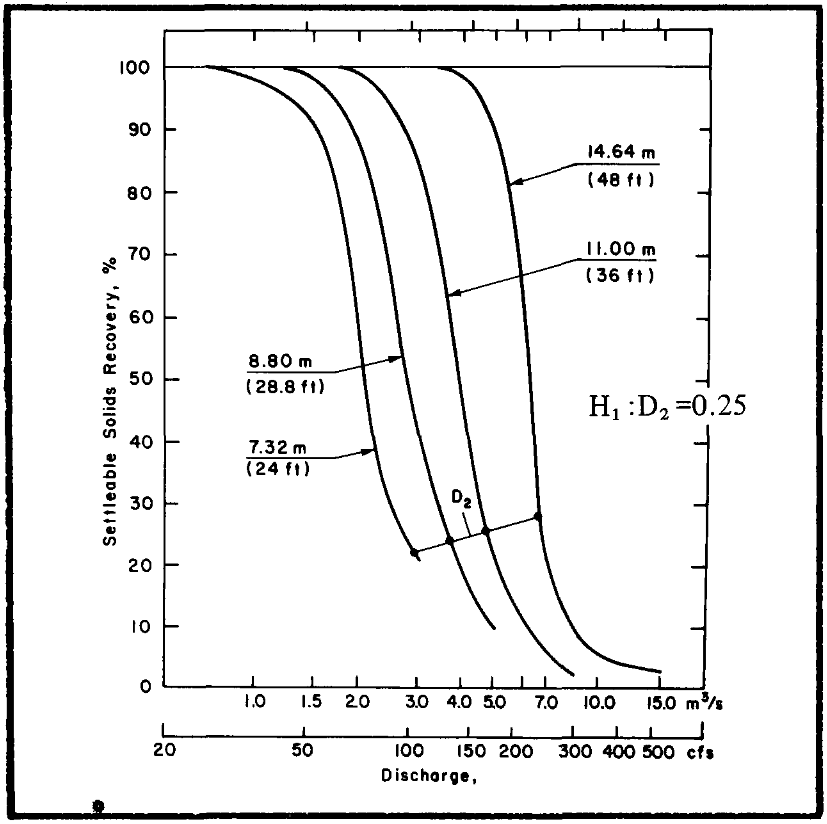


FIGURE 16
SETTLEABLE SOLIDS RECOVERY FOR 122 cm (4 ft)

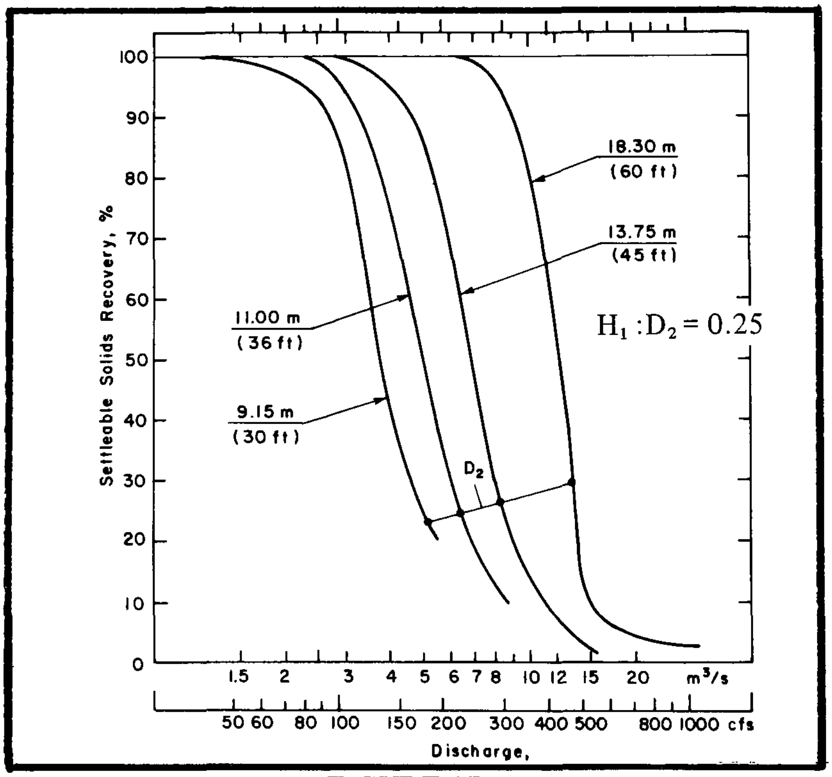


FIGURE 17
SETTLEABLE SOLIDS RECOVERY FOR 152.5 cm (5 ft)

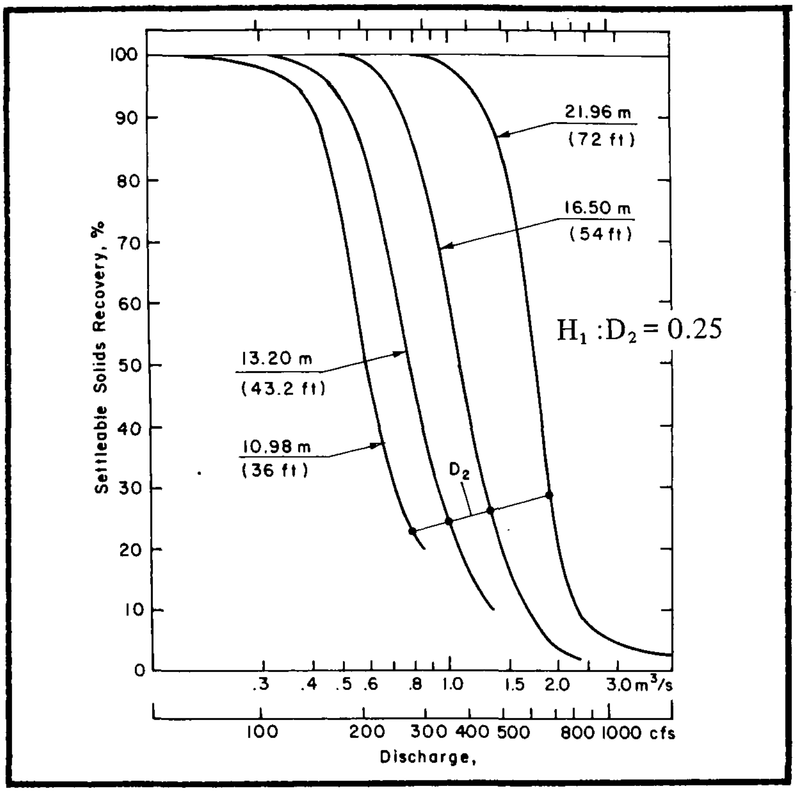


FIGURE 18
SETTLEABLE SOLIDS RECOVERY FOR 183 cm (6 ft)

determine at this stage that the discharge range and recovery rates are adequate, or carry out further adjustments in D_1 and D_2 dimensions through steps 3, 4 and 5 until they are adequate.

6. Find Dimensions for the Whole Structure

Having made decisions on acceptable D_1 and D_2 values, these can be applied to Figure 11, General Design Details. to determine the necessary dimensions for all the features of the entire swirl chamber.

7. Geometry Modifications

The above steps have provided the structural configurations to meet the design hydraulic conditions. However, at this stage other considerations such as available space, depth or head, or economic factors, might make it desirable to modify the general proportions of the chamber. The same operating conditions can be obtained if the geometry is modified according to Figure 10. This procedure assumes that the inlet dimension, D_1, is retained from the above procedures, and that the chamber diameter and weir height would be modified.

Using the $D_2 : D_1$ abscissa chosen for the standard design above, move vertically to the intersection with the bold standard design line to locate the working point. Constant operating conditions for the specific design then lie on the geometry modification curve passing through the working point. Moving down to the right corresponds to increasing the chamber diameter or width and lowering the weir height or chamber depth. Moving up to the left reduces the chamber diameter and increases the weir height.

Any choice of $D_2 : D_1$ or $H_1 : D_1$ relationship can then be made, and the corresponding values found. It will then be necessary to re-dimension the other elements of the structure, based on the general design details in Figure 11.

Table 1, Design Procedure for Swirl Concentrator as a Combined Sewer Overflow Regulator, illustrates the design procedure. Item 1 is the design discharge. Item 2 is the design settleable solids recovery efficiency. Item 3 is the possible inlet diameters selected from Figure 7. Item 4 is the chamber

TABLE 1
DESIGN PROCEDURE FOR SWIRL CONCENTRATOR AS A COMBINED SEWER OVERFLOW REGULATOR

1.	Design Discharge	m^3/s	1.416		2.832			4.673	
		cfs	50		100			165	
2.	Operating Efficiency	%	90	90	90	90	90	90	90
3.	Inlet D_1 (Fig. 7)	m	0.9	1.5	1.2	0.9	1.8	1.5	1.2
		ft	3	5	4	3	6	5	4
4.	Diameter D_2 (Fig. 7)	m	7.9	9.8	11.3	11.9	12.1	13.7	14.6
		ft	26	32	37	39	40	45	48
5.	Recovery (Fig. 12)	%	75			90			
	(Fig. 13)	%			92				90
	(Fig. 14)	%		90				90	
	(Fig. 15)	%					90		
6.	Revised D_2 (Fig. 12)	m							
		ft	28						
7.	Design Diameter D_2	m	8.5	9.8	11.3	11.9	12.1	13.7	14.6
		ft	28	32	37	39	40	45	48
8.	Depth H_1	m	2.1	2.4	2.8	3.0	3.0	3.4	3.6
		ft	7	8	9.25	9.75	10	11.25	12
9.	Inlet Velocity	cm/s	170	122	189	338	140	201	314
		fps	5.6	4.0	6.2	11.1	4.6	6.6	10.3
10.	D_2/D_1 (Line 7 / Line 3)		9.35	6.4	9.25	13	6.7	9.0	12.0
11.	Design Modifications								
	(Min. H_1) D_1	m	0.9	1.5	1.2	0.9	1.8	1.5	1.2
		ft	3	5	4	3	6	5	4
	Revised H_1/D_1 (Fig. 10)		1.0	1.0	1.0	1.1	1.0	1.0	1.0
	Revised D_2/D_1 (Fig. 10)		11.5	7.5	11.4	17	7.9	11.2	16.0
	H_1	m	0.9	1.5	1.2	1.0	1.8	1.5	1.2
		ft	3.0	5.0	4.0	3.3	6.0	5.0	4.0
	D_2	m	10.5	11.4	13.9	17.1	14.5	16.8	19.5
		ft	34.5	37.5	45.5	56.0	47.5	55.0	64.0

diameters selected from Figure 7. Item 5 indicates the actual recovery rates selected from Figures 12-15. One recovery rate is below 90 percent, therefore a greater diameter (D_2) must be selected from Figure 15 to conform with 90 percent recovery (Items 6 and 7). The final diameters (D_2) are shown in Item 7. The chamber depth or height of weir (H_1) in Item 8 is equal to 0.25 D_2.

The inlet velocity is shown in Item 9. It is obvious that, where there is a choice of inlet sizes, the largest inlet size will result in the lowest inlet velocity, and the smallest and most economical structure. Hence, the designer should select the largest inlet size shown on the design figures as being suitable for the design discharge with the hydraulic head available and the hydraulic constraint of the inlet sewer.

The resultant depth (H_1) is equal to the inlet dimension (D_1) and the chamber diameter (D_2) is larger than the diameter selected in Item 7 of the standard design.

The foregoing design is based on a ratio of chamber diameter to depth of 4 : 1.

This ratio can be modified by use of the geometry modification curves in Figure 10. Assume it is desirable to reduce the depth to its minimum value. Determine the ratio of D_2/D_1 as shown in Item 10 of Table 1. Then, with the use of Figure 10, proceed as shown in Item 11. Enter Figure 10 with D_2/D_1, extend line vertically to standard design line, to working point. Move down parallel to modification curves to horizontal line where ratio of H_1/D_1 is 1.0. Then proceed down vertically to obtain revised ratio of D_2/D_1. diameter (D_2) is larger than the diameter selected in Item 7 of the standard design.

For informational purpose, Table 2, Data from Design by Earlier Experimentation, reviews the major design elements for the flows investigated in Table 1 as obtained from the original experimentation.

Table 3, Comparison of Variations in Design Elements, indicates the difference in the major factors of inlet diameter, diameter and height, comparing the results of the 1972 study (original) which did not consider percent of settleable solids removed, the present study (revised), based upon 90 percent settleable solids removal, and dimensions with minimum H_1 (min H_1). The table indicates that a change from the standard design to one with a minimum depth for a discharge of 4.673 m^3/s (165 cfs) results in a decrease of the depth from 3.0 to 1.8 meters or a decrease of 1.2 meters and an increase in the chamber diameter from 12.1 to 14.5 meters or an increase of 2.4 meters.

Table 4, Comparison of Variations in Area and Volume between Standard Design and Design with Minimum Depth, lists the areas and volumes for the structures shown in Table 1 for 2.832 m^3/s (100 cfs) and 4.673 m^3/s (165 cfs). For the standard design it is obvious that the largest inlet size results in the minimum area and volume. The areas and volumes of the modified design with minimum depth are compared with the areas and volumes of the smallest chamber in standard design. For the two sizes shown the design with minimum depth compared to the smallest standard design show an increase in area of 38 to 42 percent and a decrease in volume of 14 to 15 percent. This table indicates that for any given situation the designer has several choices and must weigh the advantages of each before reaching a final decision.

TABLE 2
DATA FROM DESIGN BY EARLIER EXPERIMENTATION

Design Discharge	m^3/s	1.416	2.832	4.673
	cfs	50	100	165
Diameter D_2	m	6.8	9.0	11.0
	ft	11.5	19.5	36
Inlet D_1	m	1.1	1.5	1.8
	ft	3.75	4.92	6
Depth H_1	m	1.7	2.2	2.7
	ft	5.62	7.38	9

TABLE 3
COMPARISON OF VARIATIONS IN DESIGN ELEMENTS

	Depth H_1 (m)	**Inlet D_1 (m)**	**Diameter (width) D_2 (m)**
50 cfs – 1.416 m^3/s			
Original(1972)	1.7	1.1	6.8
Standard Design	2.1	0.9	8.5
Min. H_1	0.9	0.9	10.5
100 cfs – 2.832 m^3/s			
Original (1972)	2.2	1.5	9.0
Standard Design	2.4	1.5	9.8
Min. H_1	1.5	1.5	11.4
165 cfs – 4.673 m^3/s			
Original (1972	2.7	1.8	11.0
Standard Design	3.0	1.8	12.1
Min. H_1	1.8	1.8	14.5

TABLE 4
COMPARISON OF VARIATIONS IN AREA AND VOLUME BETWEEN STANDARD DESIGN AND DESIGN WITH MINIMUM DEPTH

1. Design Discharge	m^3/s		2.832			4.673	
	cfs		100			165	
2. Inlet D_1	m	1.5	1.2	0.9	1.8	1.5	1.2
	ft	5	4	3	6	5	4
Standard Design							
3. Area	m^2	74	97	111	116	148	168
	sf	800	1040	1200	1250	1590	1810
4. Volume	m^3	181	280	328	354	504	617
	cf	6400	9900	11600	12500	17800	21800
5. Area change from smallest	%	0	+30	+50	0	+27	+45
6. Volume change from smallest	%	0	+55	+82	0	+43	+66
Modified Design – Min. H_1							
7. Area	m^2	102	150	228	164	220	299
	sf	1100	1620	2450	1770	2370	3220
8. Volume	m^3	156	184	229	300	337	365
	cf	5500	6500	8100	10600	11900	12900
9. Area change from smallest standard	%	+38	+102	+206	+42	+90	+158
10. Volume change from smallest standard	%	-14	+2	+27	-15	- 5	+3

Note: Area and volume are based on dimensions given in Table 1

SECTION IV
REFERENCES

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2. *The Bed Load Function for Sediment Transportation in Open Channel Flows.* H.A. Einstein, U.S. Department of Agriculture, Technical Bulletin No. 1026, September 1950.

3. *Swirl Concentrator as a Combined Sewer Overflow Regulator Facility,* EPA – R2-72-008, September, 1972. PB-214 687.

4. *Combined Sewer Regulator Overflow Facilities.* 11022DMU 07/70. PB-215 902.

SECTION V
GLOSSARY OF PERTINENT TERMS

Combined Sewer — A pipe or conduit which collects and transports sanitary sewage, with its component commercial and industrial wastes and infiltration and inflow during dry-weather conditions, and which, in addition, serves as the collector and conveyor of stormwater runoff flows from streets and other sources during precipitation and thaw periods, thus handling all of these types of wastewaters in a "combined" facility.

Concentrate – The portion of the inflow directed to the interseptor sewer which carries the bulk of the settleable solids.

Concentrate Outlet – The outlet in the floor of the chamber in which the concentrates enter the foul sewer.

Depth of Chamber – The vertical distance between the floor level of the swirl concentrator and the crest of the overflow weir at the central downdraft structure, or at any other location.

Diameter of Swirl Chamber – The internal diameter of the concentrator chamber, a circular device which induces the swirl flow pattern.

Floatable Solids – Lighter-than-water solids and congealed floating materials which rise to the surface of the liquid in the swirl concentrator and must be intercepted to prevent discharge with the liquid passing over the overflow weir crest with the clarified effluent.

Floatable Trap – A structural configuration or device in a swirl concentrator which intercepts or entrains floatable solids and prevents them from being discharged over the weir crest with the overflow clarified liquid by retaining this material until it is removed and disposed of by predetermined means.

Foul Sewer – The sewer which carries a predetermined portion of swirl chamber liquid and the concentrated settleable solids deposited in the bottom of the chamber, discharged from the bottom gutter through an outlet located at a predetermined location.

Grit – Solids, predominantly mineral in character, in the combined sewer flow which are heavier and larger in weight and size and, thereby, settle readily to the floor of the swirl chamber by gravimetric classification.

Gutter – A structural configuration in the floor of the swirl concentrator, which provides a channel for the desired flow of sanitary wastewater during dry-weather conditions from the chamber inlet to the foul sewer (concentrate) outlet, and for conducting the foul slurry (concentrate) to the bottom outlet when the chamber is serving as a solids concentrator.

Inlet Size – The diameter or square dimensions of the sewer which enters the swirl concentrator at its floor level and, thereby, serves to create the flow pattern which produces the solids-liquid separation which the chamber is intended to induce.

Long-Flow Flow Pattern – The path of the swirl flow pattern through the swirl concentrator, induced by proper baffling which causes the liquid to traverse the circular chamber more than once, and prevents the incoming flow from being diverted or short-circuited directly to the overflow weir, thereby inducing the solids to discharge into the foul sewer channel and outlet.

Organic Solids – Solids of a non-grit, or lighter weight, contained in the combined sewer flow, which can decompose and become oxygen-demanding in receiving waters, which therefore, must be removed from the overflow liquid to prevent pollutional impacts on water sources into which these overflows are discharged, or on holding and treatment devices in which overflows are handled.

Overflow Weir – The structural member of the swirl concentrator which is intended to serve as the circular overflow crest for the clarified or supernatant liquid in the chamber, thus serving to establish the effective operating depth of the chamber.

Scum Ring – A circular plate of baffle encircling the overflow weir, located at a predetermined distance from the weir and at a depth that will cause it to retain floatables and scum and prevent them from passing over the weir crest with the clarified liquid.

SECTION VI
APPENDIX A
REPORT BY LA SALLE HYDRAULICS LABORATORY ON HYDRAULIC MODEL STUDY OF THE SWIRL CONCENTRATOR AS A COMBINED SEWER OVERFLOW REGULATOR FACILITY – DEPTH-WIDTH TESTS

The studies described in this report of hydraulic laboratory studies were undertaken as an extension of the work covered in the American Public Works Association Research Foundation Report, *The Swirl Concentrator as a Combined Sewer Overflow Regulator Facility,* EPA-R2-72-008 September, 1972.

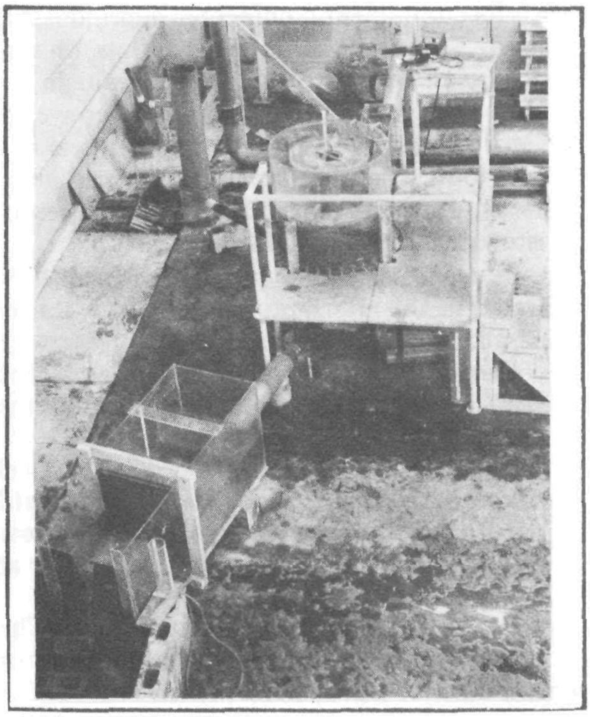
The hydraulic model studies carried out in the earlier work were performed to the point where they had developed an efficient swirl chamber structure with a fixed set of geometric proportions for given flow conditions. Further analysis of these data showed the desirability of extending the study to provide information on the performance of the swirl chamber with different depth-width ratios.

The present series of tests was undertaken to define the recovery rates when the chamber diameter, weir height and inlet pipe size were varied relative to each other.

As described in the earlier study, the principle involved in these structures is a controlled combination of solids settling and rotational flow which tends to concentrate the heavier particles at the inner part on the chamber floor. Furthermore, the structure which had been developed also included a floatables trap set into the overflow weir.

It was decided to retain the basic structural configuration that had been developed for the 1972 studies, and to vary the weir height and the pipe diameter with respect to the fixed chamber diameter. The model layout was shown in Figure 1. Photograph 1, General View of Model, shows the laboratory test structure.

Figure 2 gave the chamber internal details, and Photograph 2, Interior of Chamber Showing Submerged Inlet Floor Gutters, Foul and Clear Water Outlets, portrays the basic model chamber geometry. Figure 19, Details of Gutter Centerline Layouts, shows the locations of the gutters in the chamber floor. It will be noted here that the main gutter position was varied in the 0° to 45° section. These minor modifications

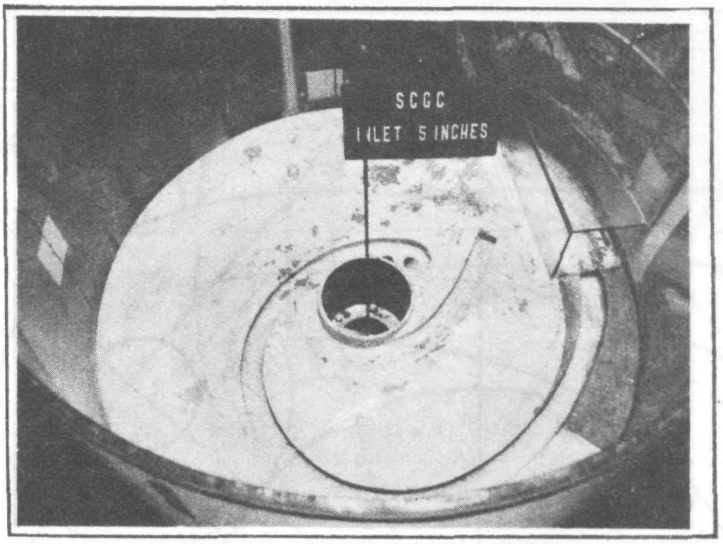


PHOTOGRAPH 1
GENERAL VIEW OF MODEL

were required so the gutter centerlines would coincide with those of the successively smaller inlet pipes which were installed in the model.

Figure 20, Details of the Open Vortex Foul Outlet, shows the opening through which the heavier pollutants were drawn off from the floor of the chamber. Figure 21, Details of Floatables Trap, presents the arrangement which had been developed on the overflow weir to trap the floatables and retain them under the weir.

In order to establish practical prototype values for the study, the model was considered first at 1/12 scale. On this basis, the prototype chamber diameter, D_2, would be 10.96 m (36 ft). Five discharges were selected which would cover any likely limits: 1.42, 2.83, 4.25, 5.66 and 8.49 m^3/s (50, 100, 250, 200 and 300 cfs). Four inlet pipe dimensions, D_1, were chosen as being practical with such a chamber: 0.91, 1.22,



PHOTOGRAPH 2
INTERIOR OF CHAMBER SHOWING SUBMERGED INLET FLOOR GUTTERS, FOUL AND CLEAR WATER OUTLETS

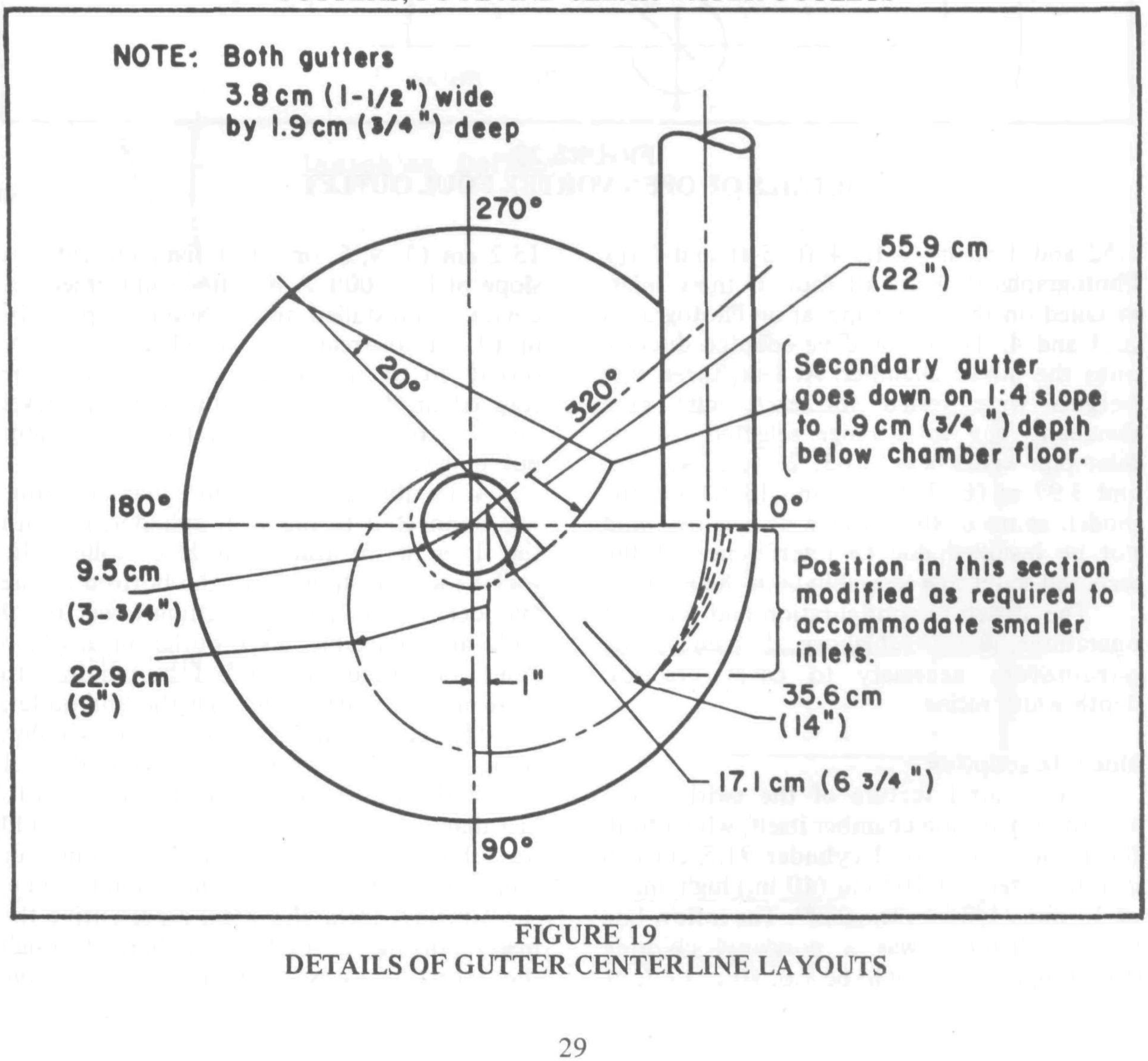


FIGURE 19
DETAILS OF GUTTER CENTERLINE LAYOUTS

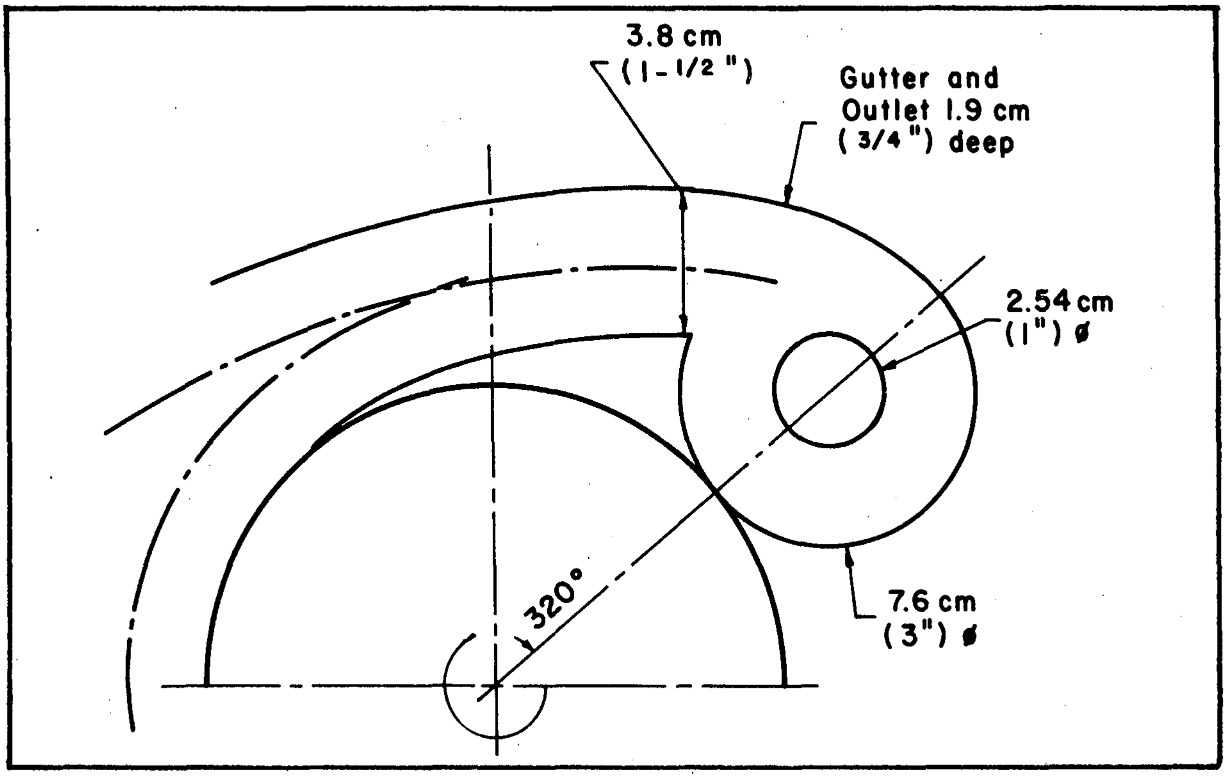


FIGURE 20
DETAILS OF OPEN VORTEX FOUL OUTLET

1.52 and 1.83 m (3 ft, 4 ft, 5 ft and 6 ft). Photographs showing all four of these inlets installed on the model appear on Photographs 2, 3 and 4. These could be adapted directly onto the model chamber. At least three weir heights were tested for each inlet pipe diameter. The total range selected for the inlet pipe series was: 1.83, 2.14, 2.74, 3.36, and 3.97 m (6, 7, 9, 11, and 13 ft). On the model. some of the lower weir heights could not be installed due to interference of the weir and scum ring assembly with the inlet.

The structure configuration and range of operations, as set out above, defined all the parameters necessary to cover practical depth-width ratios.

Model Description

The central feature of the swirl model was the separation chamber itself, which took the form of a vertical cylinder 91.5 cm (36 in.) diameter and 102 cm (40 in.) high, made of 13 mm (1/2 in. Plexiglas®. The inflow line to the chamber was a polyvinyl chloride (PVC) pipe which could be 7.6, 10.2, 12.7, or 15.2 cm (3, 4, 5, or 6 in.) diameter, set at a slope of 1 : 1000. A vibrating solids injection device was installed on this supply pipe, 2.14 m (9 ft) upstream of the chamber. Water supply to the model through the inlet pipe was taken directly from the constant level tank in one of the laboratory permanent pumping stations.

A flexible 5.1 cm (2 in.) diameter tube was connected to the swirl cylinder, beneath the floor of the test chamber to collect the foul flow. The tube from the bottom of the cylinder, led to a solids settling tower fitted with an adjustable level outlet pipe which could be raised or lowered as required to control the discharge through the foul outlet.

The clear water outlet was a cylinder, rising from the chamber on the centerline of the swirl basin in the form of a 15.2 cm (6 in.) diameter PVC pipe. Its crest level could be changed easily either by adding or removing sections of the same diameter pipe.

Outflow from this pipe, representing the major portion of the total discharge through the structure, was discharged into a large

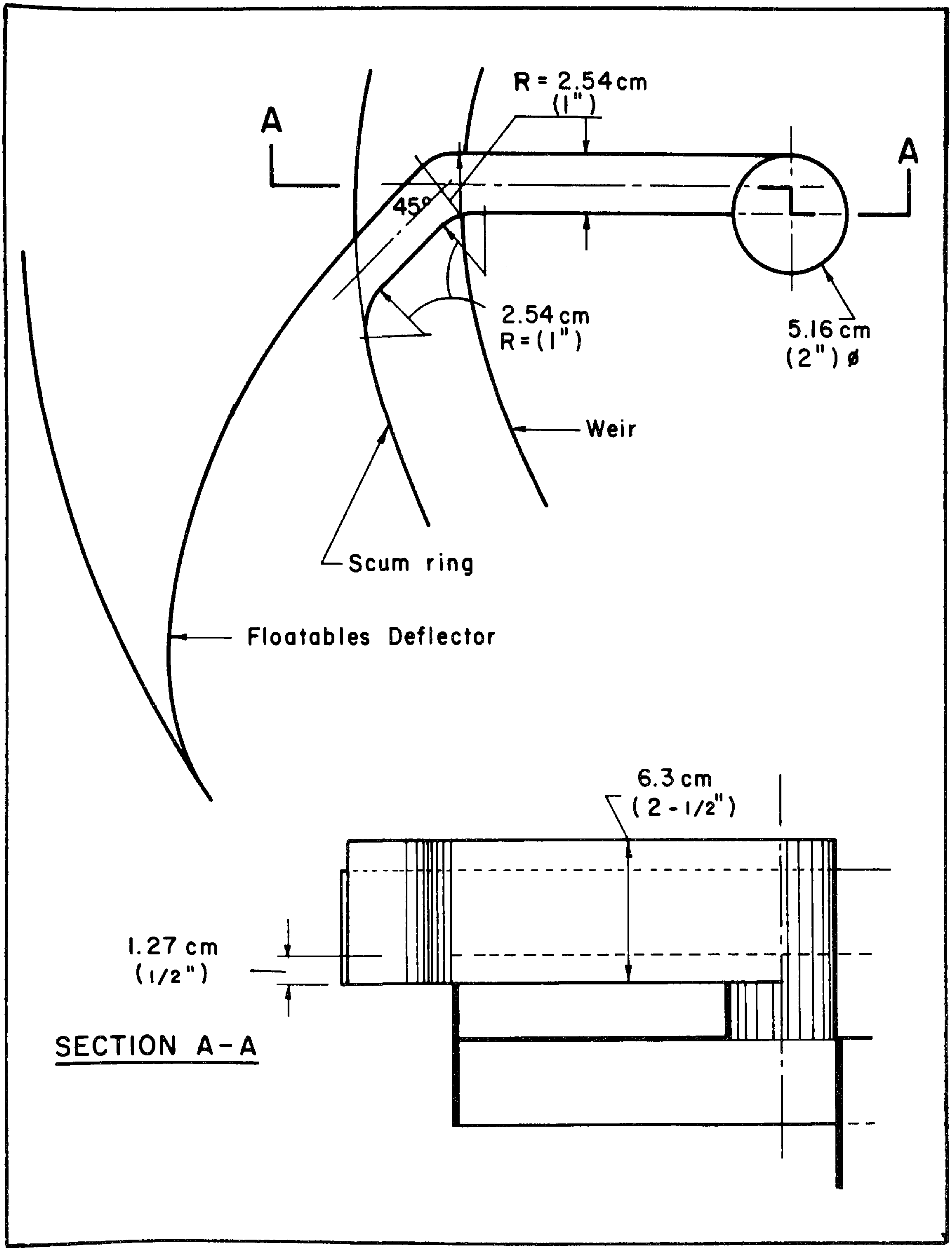


FIGURE 21
DETAILS OF FLOATABLES TRAP

settling basin equipped with a calibrated V-notch weir. The basin provided sufficient time for most of the solids contained in the clarified swirl chamber overflow to settle out. A point gauge on a manometer pot read the level within the basin which determined the discharge going over the V-notch weir, or the clear discharge over the circular weir in the swirl chamber.

In the model at the outset of this study, the circular inlet pipe entered an enlarged rectangular Plexiglas® enclosure fixed to the cylindrical chamber wall. The different sized square entrance forms could be fitted into this enclosure to correspond to the inlet pipes, as shown in Figure 16.

The floor of the chamber was constructed with a thin cement mortar crust, supported on a gravel base which filled the lower portion of the chamber. The features shaped into the floor included the slope, gutters and foul outlet shown in Figures 2, 19 and 20.

Solids Simulation

Grit

The prototype gradation of the grit material in sewage which is to be removed in the swirl structure was chosen as shown in Figure 4. The outside grain size limits of 0.2 and 2.0 mm (No. 70 and No. 10 sieve) represent the standard soil mechanics definition of medium and fine sand. The specific gravity of the grit was assumed as 2.65, and the straight-line grain size distribution was selected as a representative average of grit size data reported for existing sewage and treatment plants. Concentration was considered as being from 20 to 360 mg/l.

Particle sizes larger than about 1 mm (No. 18 sieve) are known to remain suspended and be transported in flowing water according to equations of the type reported bv Meyer-Peter and Muller[1], or H.A. Einstein[2]. Between 1 mm and 0.2 mm (No. 18 and No. 70 sieve) the particles are in the transition zone between the above equations and the Stokes relation. Since the particles involved in both prototype and model extended into both ranges, across the transition zone, the above equations could not adequately describe the scale relations.

It was necessary, therefore, to use curves of particle settling velocities as shown in Figure 22, Particle Settling Velocities for Grit, Organic Material and Gilsonite in Still Water. For a given grit size with S.G. 2.65 in prototype, the settling velocity was determined from Figure 22. Based on Froude's law of similitude, this was divided by the square root of the scale being considered to find the required model settling velocity. By referring to Figure 22 with this model settling velocity, the model particle sizes were found for the simulating material, Gilsonite.

The physical relations used here can be expressed as follows:

Model scale = $\lambda = L_p/L_m$

where L_p and L_m are corresponding lengths in the prototype and the model respectively.

From Froudes Law, the velocity simulation is expressed by the equation:

$$\frac{V_p}{V_m} = \frac{L_p}{L_m} = \lambda$$

and
$$V_m = \frac{V_p}{\lambda}$$

For example, if the scale ratio of prototype to model is 4 : 1, the settling velocity in the prototype should be divided by the square root of 4 or 2. From Figure 22, the settling velocity of prototype grit of 0.2 mm size is 2.6 cm/sec. The model settling velocity is then 1.3 cm/sec. Thus, in the model the grit of 0.2 mm size can be simulated by 0.80 mm Gilsonite.

The Gilsonite available for test work in the laboratory had the grain size distribution shown in Figure 23, Gradation Curve for Gilsonite Used in Model. Practical limits represented on this curve were chosen between 0.5 and 3.0 mm (No. 35 and No. 6 sieves), and the corresponding prototype grit sizes simulated were calculated. The results are shown in Figure 24, Prototype Grit Sizes Simulated by Gilsonite on Model.

This figure shows that for smaller scales, up to about 1/16, the Gilsonite did not cover the larger prototype particle sizes. However, it was reasoned that if the structure under study showed a particular recovery rate for these scales, the larger particles not simulated would have settled equally as well. Therefore,

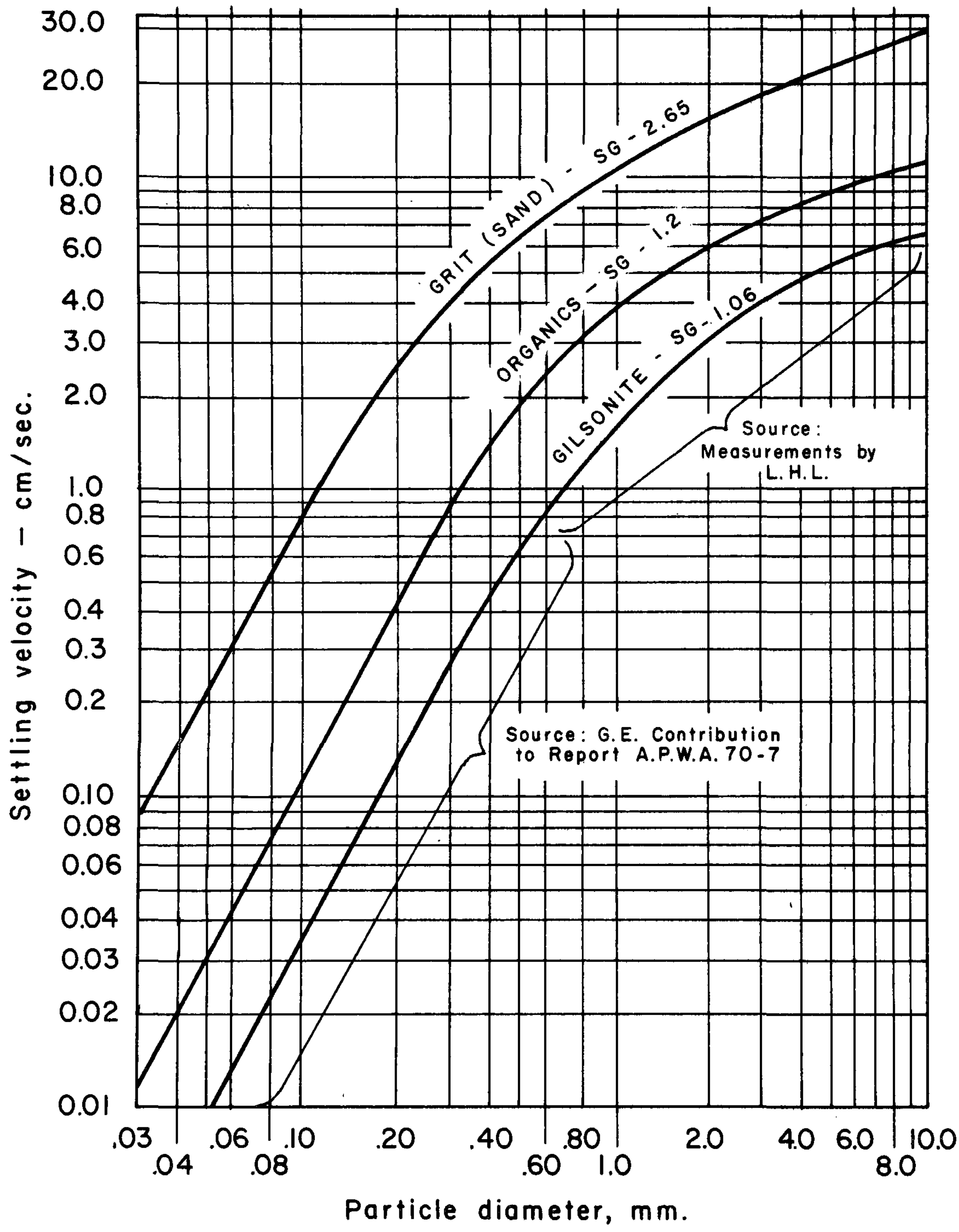


FIGURE 22
PARTICLE SETTLING VELOCITIES FOR GRIT, ORGANIC MATERIAL AND GILSONITE IN STILL WATER

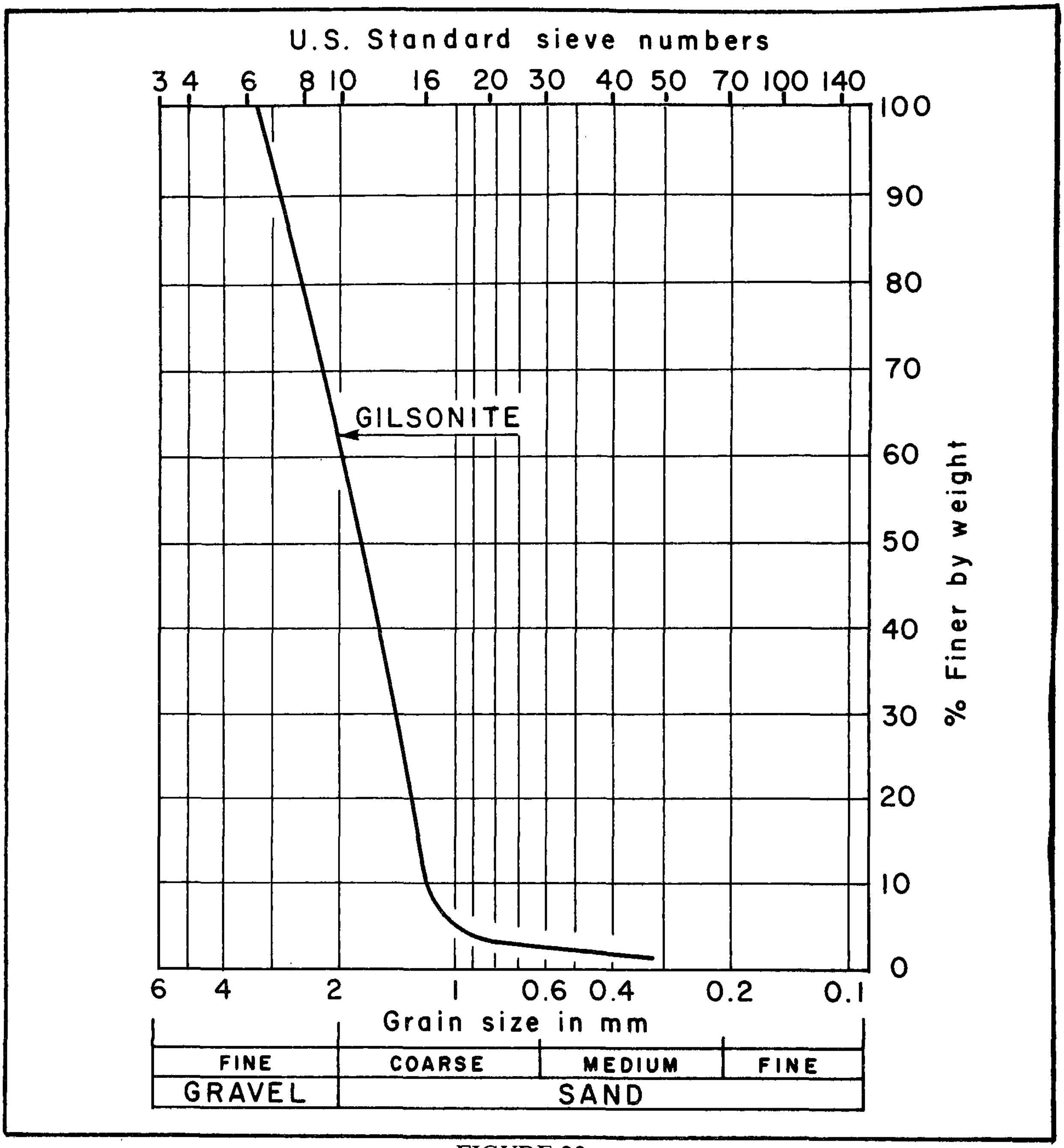


FIGURE 23
GRADATION CURVE FOR GILSONITE USED IN MODEL

the recovery rate quoted would be conservative.

Conversely, for scales larger than 1/16, the lower model limit left a small zone of fine grit not simulated. This portion might be considered as lost, but at most, it actually represents only 10 percent of the prototype grit.

Organics

The organic material that it was desired to remove from the flow in the prototype was assumed to have a specific gravity of 1.2, and a grain size distribution as shown in Figure 4. The same Froude model scale-up procedure was followed, and the limits simulated by the Gilsonite were calculated as shown in Figure

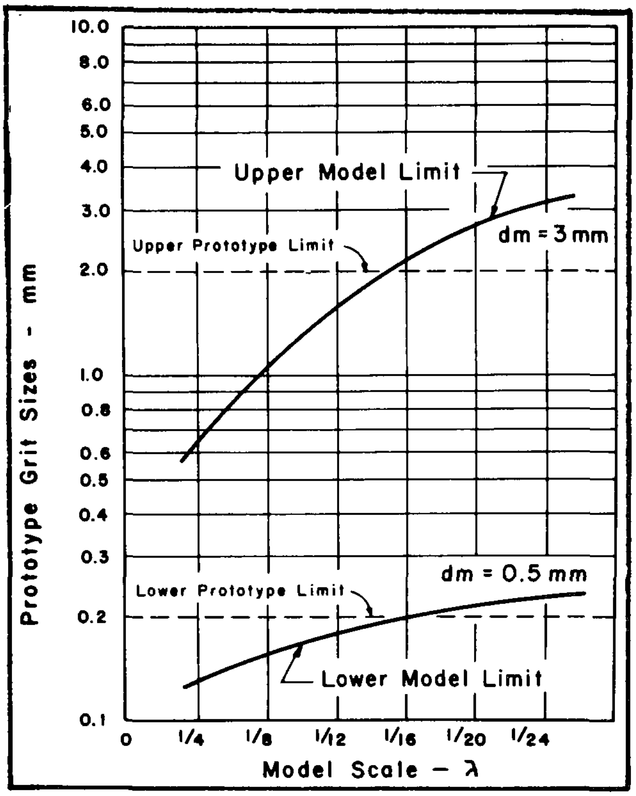


FIGURE 24
PROTOTYPE GRIT SIZES SIMULATED BY GILSONITE ON MODEL

25, Prototype Organic Material Sizes Simulated by Gilsonite on Model.

The upper limits offer no difficulty; all the larger sizes were very easily covered by the Gilsonite. However, the lower model limit left a significant zone of finer particles not simulated throughout the scales being considered. At 1/4 scale, particle sizes below 0.35 mm were not covered. Figure 4 shows that this represents 15 percent of the total sample. At 1/24 scale, particles smaller than 0.7 mm would not be included; Figure 4 shows that this represents 27 percent of the sample. Although it would have been preferable to provide model particles which more adequately covered these smaller sizes, the Gilsonite was retained due to its ease of use in the laboratory, and on the basis that it would at least give a consistent evaluation for the major part of the prototype organics.

Floatables

Floating particles were assumed to have a specific gravity between 0.9 and 0.998, and a size range between 5 and 25 mm. Concentrations of 10 to 80 mg/l were assumed. In the model studies, uniformly sized polythene particles 4 mm in diameter and a specific gravity of 0.92 were used.

Testing Procedure

Although use of the swirl concentrator as a stormwater regulator would normally involve a continuously varying discharge over a storm hydrograph, for testing purposes in the current depth-to-width investigation, steady state discharges were used. For each individual test run, the steady state discharge was instituted in the model, and equilibrium conditions were established. A mixture containing one litre each of Gilsonite and polythene was injected into the water supply line entering the swirl chamber, using the same vibrating rate for all tests; the full two litres were added over a period of five minutes.

As soon as all the Gilsonite and polythene had entered the chamber and their flow

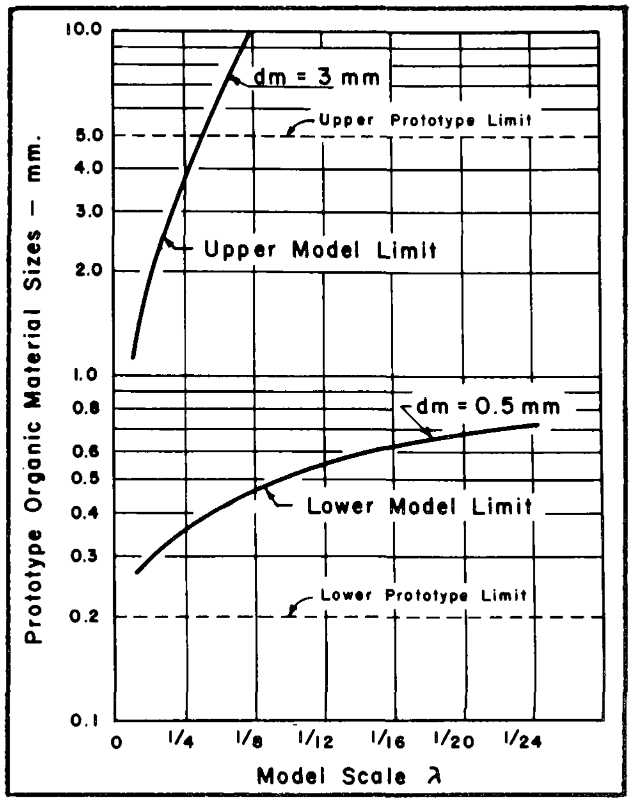


FIGURE 25
PROTOTYPE ORGANIC MATERIAL SIZES SIMULATED BY GILSONITE ON MODEL

pattern was firmly established, the influent flow was stopped. The amounts of Gilsonite that was entrained on the bottom of the chamber or had passed out the foul outlet and had gone over the weir were measured. Similarly for the polythene, the amount retained as floatables under the weir was measured as well as that which had gone over the weir.

The recovery, or removal, rate for the Gilsonite was expressed as the percentage represented by the amount measured on the floor and which had gone out the foul outlet as compared to the original full litre injected. For the polythene, the percentage recovery was expressed in terms of the amount retained under the weir, with respect to the full litre injected.

Settleable Solids Recovery Results

In discussing settleable solids for the purpose of this report, reference is made to the recovery rates for the Gilsonite only. As described in the section on solids simulation, the Gilsonite was assumed to represent grit and organic materials over the ranges as defined.

The recovery rates for the four sizes of pipe inlets are shown in Figures 26, 27, 28 and 29, Gilsonite Recovery on Model for 15.2, 12.7, 10.2 and 7.6 cm (6, 5, 4 and 3 in.) Inlets and Various Weir Heights.

Figure 26 shows that for the 15.2 cm (6 in.) inlet pipe, changes in the weir height had very little effect on the Gilsonite recovery rate. The same was true for the 12.7 cm (5 in.) inlet, although there appeared to be a tendency for the curves to spread, as seen on Figure 28. This spread, or variation, was more distinct for the 10.2 cm (4 in.) pipe; Figure 29 and Figure 30 indicate that the different weir heights did start showing significantly different recovery rates for a given discharge.

In order to be able to convert the model data into a useful design procedure, a mean curve for anticipated settleable solids (Gilsonite) recovery was selected for each of the inlet sizes, covering a range of discharge rates. These curves are portrayed in Figure 30, Average Gilsonite Recovery Curves Used for Design Curve Analysis. In fact, these average curves result in the elimination of the effects of the weir height changes, as the mean curves all corresponded to a standard weir height of

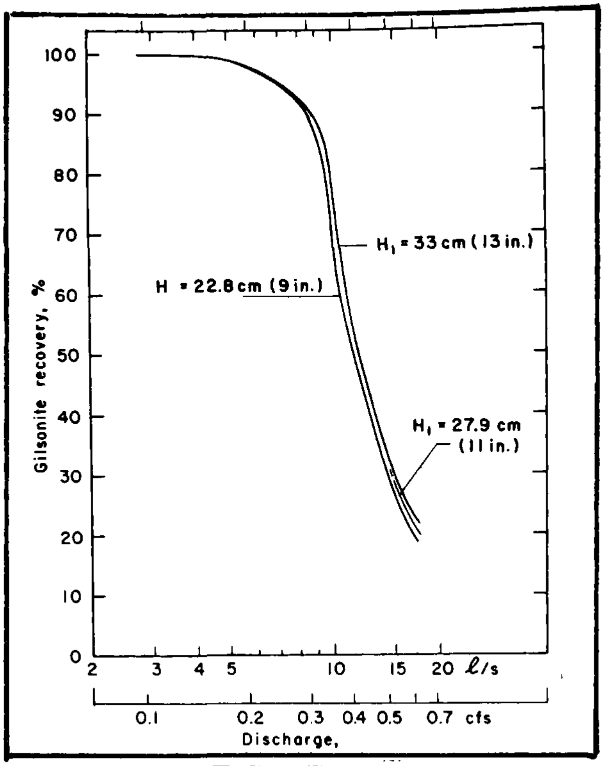


FIGURE 26
GILSONITE RECOVERY ON MODEL FOR 15.2 cm (6 in.)

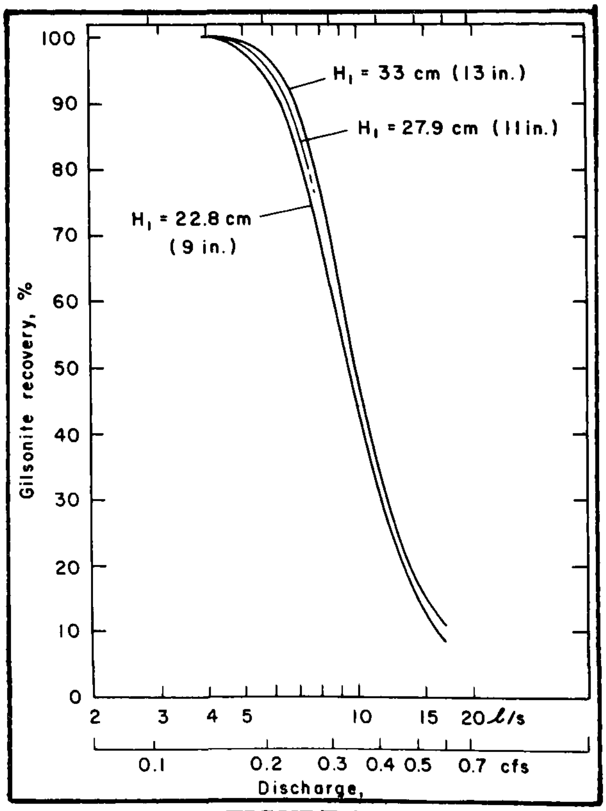


FIGURE 27
GILSONITE RECOVERY ON MODEL FOR 12.7 cm (5 in.)

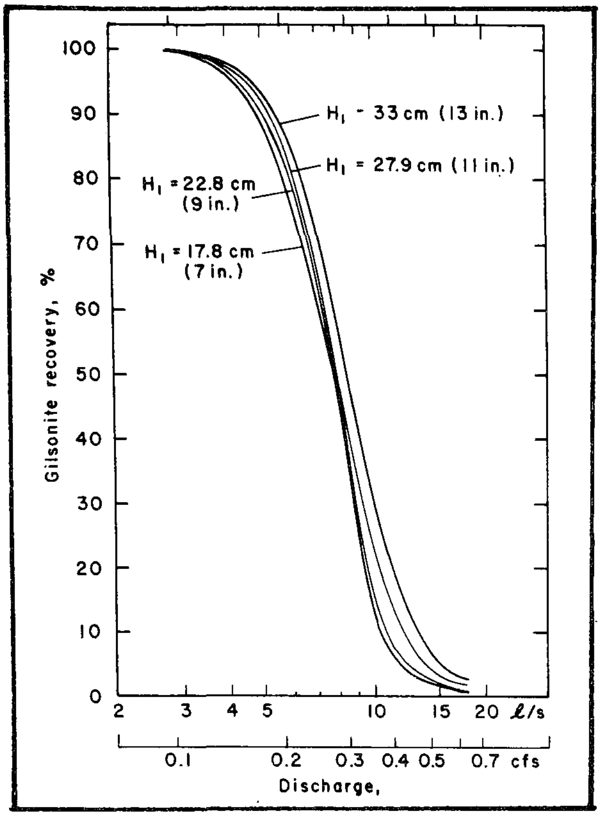


FIGURE 28
GILSONITE RECOVERY
ON MODEL FOR 10.2 cm (4 in.)

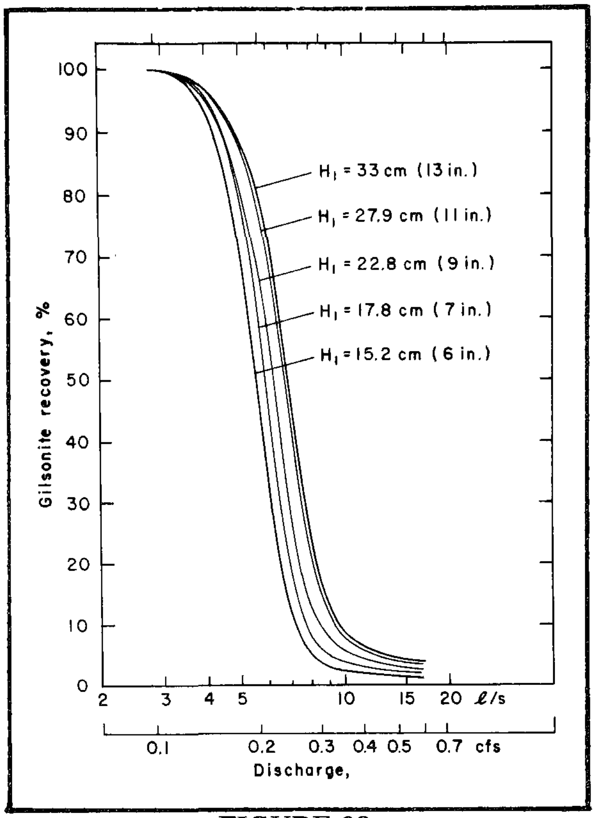


FIGURE 29
GILSONITE RECOVERY
ON MODEL FOR 7.6 cm (3 in.)

22.9 cm (9 in.), or a H_1/D_2 ratio of 0.25. The rationale in support of this approach is that the ratio of inlet dimension to chamber width produces a far greater effect on the recovery rates than weir height and therefore, should be retained as the variable parameter.

Performance and Design Curve Development

Working from the average recovery values established in Figure 23, these data were scaled up to prototype structures having inlet sewer sizes between 30.5 cm (1 ft) and 1.83 m (6 ft). The resulting performance curves were presented as Figures 12 through 18.

The data presented in Figures 12 through 18 cover the complete range of performance included in the model study, as applicable to full-scale prototype installations. It would be possible to use these curves to select pertinent dimensions for swirl chamber structures, but this is not a straightforward procedure. Therefore, a set of design curves was prepared for three recovery rates: 90, 80, and 70 percent.

By selecting particular recovery rates as stated above, it was possible to choose from Figures 12 through 18 the corresponding values for the discharge, inlet dimension and chamber diameter over the complete range of performance. The data resulting from this analysis were plotted in Figures 7 through 10.

As stated earlier, the data application steps required selection of a fixed weir height to chamber diameter ratio – i.e., $H_1 : D_2 = 0.25$. This dimensional relationship will be retained as the so-called Standard Design.

However, it is obvious that for specific design case, with a given discharge and inlet size, if the chamber diameter can be increased, it will be possible to reduce the weir height, or depth of the swirl chamber. Similarly, if the chamber diameter is reduced, the required weir height or chamber depth will be increased. The following procedure was followed to modify the test data to allow changes in the Standard Design geometry to fit other depth-width ($H_1 : D_2$) ratios.

Based on 90 percent recoveries on the average Gilsonite curves in Figure 30, the values were scaled up to provide a nominal 30.5 cm (1 ft) inlet. The ratios of the chamber volumes to inlet energies were

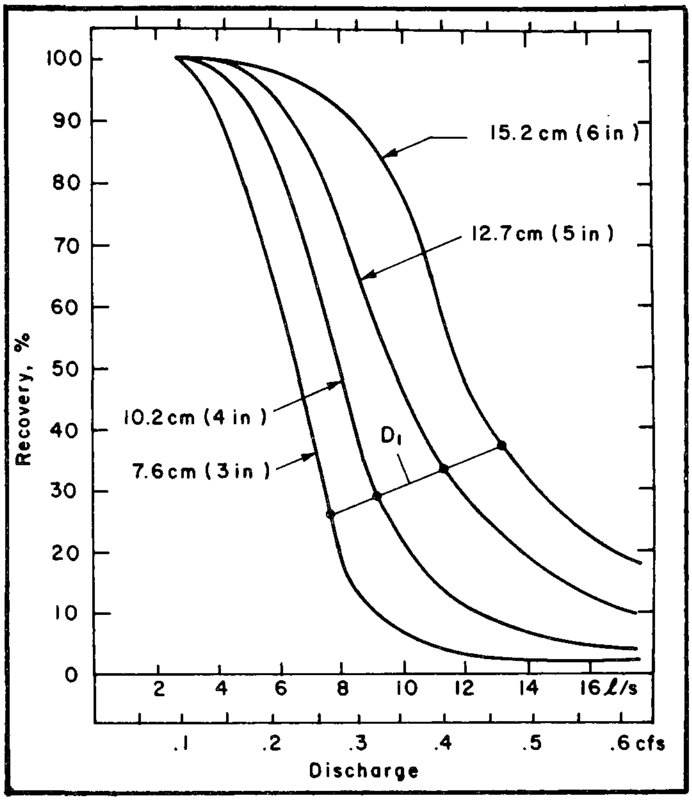


FIGURE 30
AVERAGE GILSONITE RECOVERY CURVES USED FOR DESIGN CURVE ANALYSIS

computed as a function of the $D_2 : D_1$ ratio and presented graphically. For the four given cases, with $H_1 : D_2 = 0.25$, progressively larger and smaller chamber diameters were selected, varying the $D_2 : D_1$ ratio. For each new $D_2 : D_1$, a value for the volume-energy ratio was found; this value was then divided by the constant energy for the fixed inlet size and discharge, to provide a corresponding new chamber volume. The new weir height or chamber depth was then computed as a function of the chamber diameter.

The final results for $H_1 : D_1$ and $D_2 : D_1$ ratios were expressed in non-dimensional form, as shown on Figure 11. This provides information upon which to base design of optimum swirl chambers to meet individual project needs.

The design procedure utilizing these figures is explained in Chapter III.

Floatables Recovery Results

Results of the tests with the polythene, representing floatable material, were not as uniform as for Gilsonite. The interpreted average results for the four sizes of inlets tested are shown on Figure 31, Average Model Results – Polythene Recovery.

Following the same procedures as for Gilsonite, the average curves were scaled up over the selected prototype range as shown on Figures 32 to 38, Polythene (Floatables) Recovery for 30.5, 45.7, 61, 91.5, 122, 152.5, 183 cm (1, 1.5, 2, 3, 4, 5, 6 ft) Inlet Sewers and Different Sized Chambers.

Figure 38 portrays the curve for the 15.2 cm (6 in.) inlet, showing a polythene recovery rate of only 10 percent for 9 l/s (0.33 cfs). In the 1972 original tests a recovery of 65 percent was obtained. The only difference between the 1972 tests and the current studies was the inlet configuration. The present inlet consisted of a square cross section which advanced tangentially into the chamber to the 0° position. In the earlier work, the square cross section was terminated at the chamber perimeter, and a baffle then continued its inside wall to the 0° position.

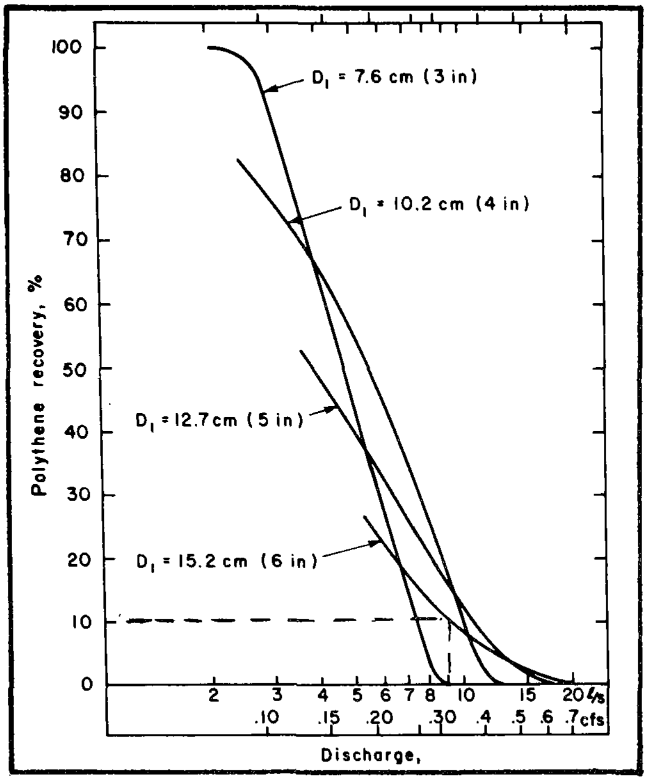


FIGURE 31
AVERAGE MODEL RESULTS – POLYTHENE RECOVERY

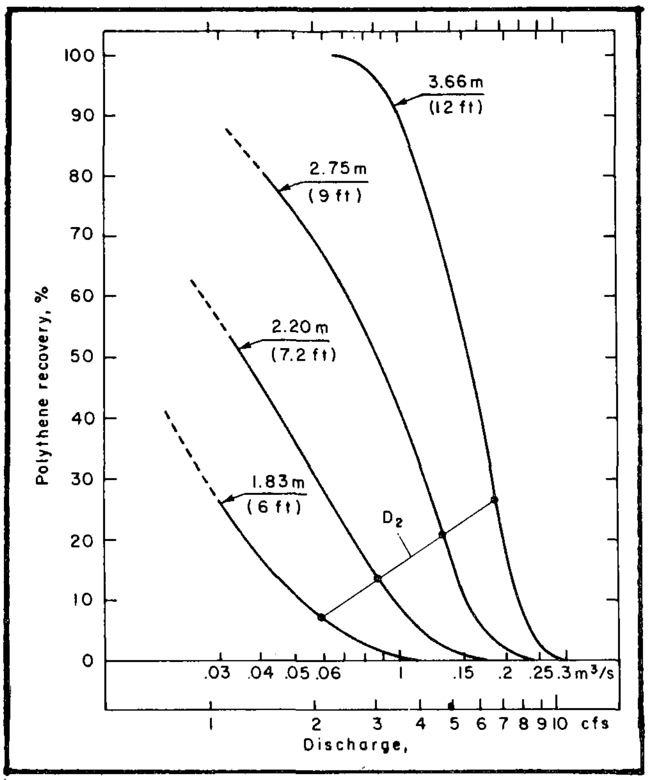


FIGURE 32
POLYTHENE (FLOATABLES) RECOVERY FOR 30.5 cm (1 ft)

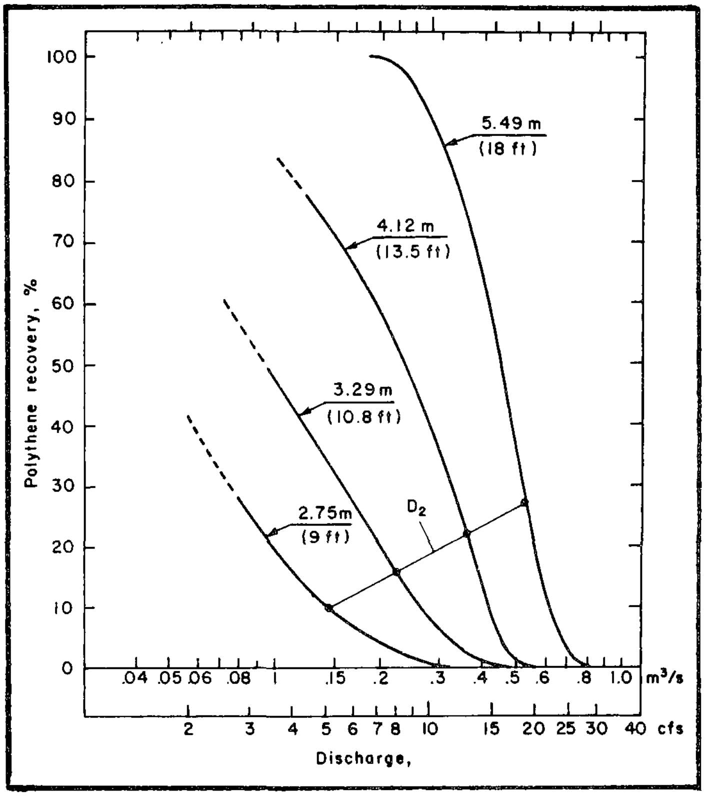


FIGURE 33
POLYTHENE (FLOATABLES) RECOVERY FOR 45.7 cm (1.5 ft)

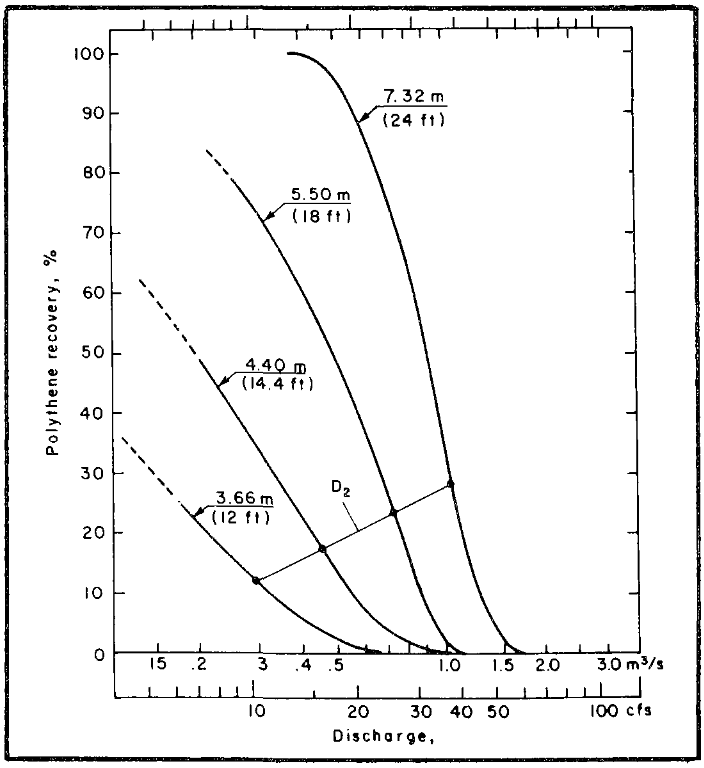


FIGURE 34
POLYTHENE (FLOATABLES) RECOVERY FOR 61 cm (2 ft)

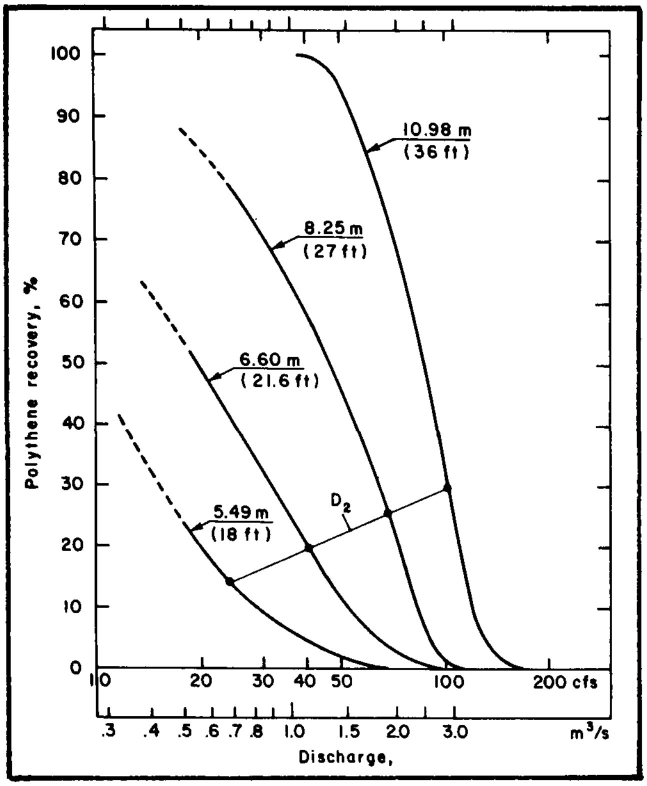


FIGURE 35
POLYTHENE (FLOATABLES) RECOVERY FOR 91.5 cm (3 ft)

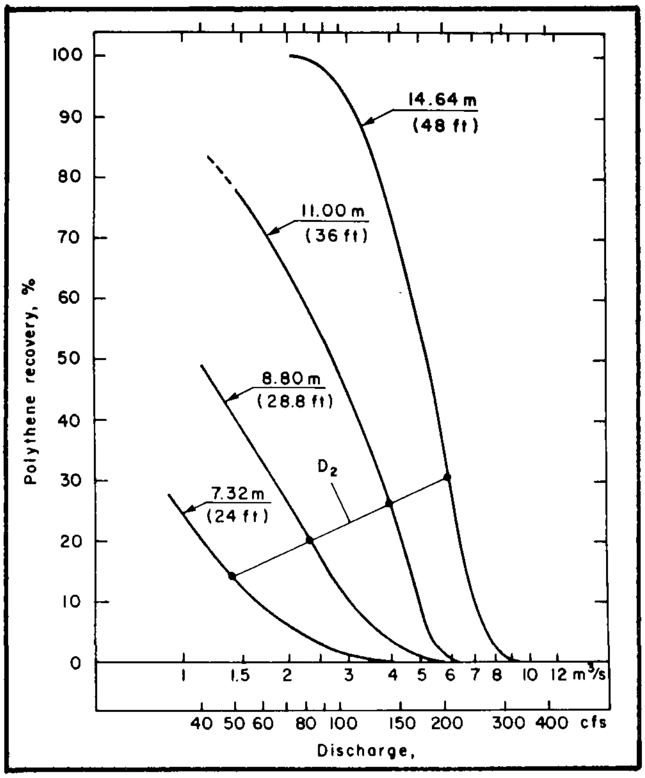


FIGURE 36
POLYTHENE (FLOATABLES) RECOVERY FOR 122 cm (4 ft)

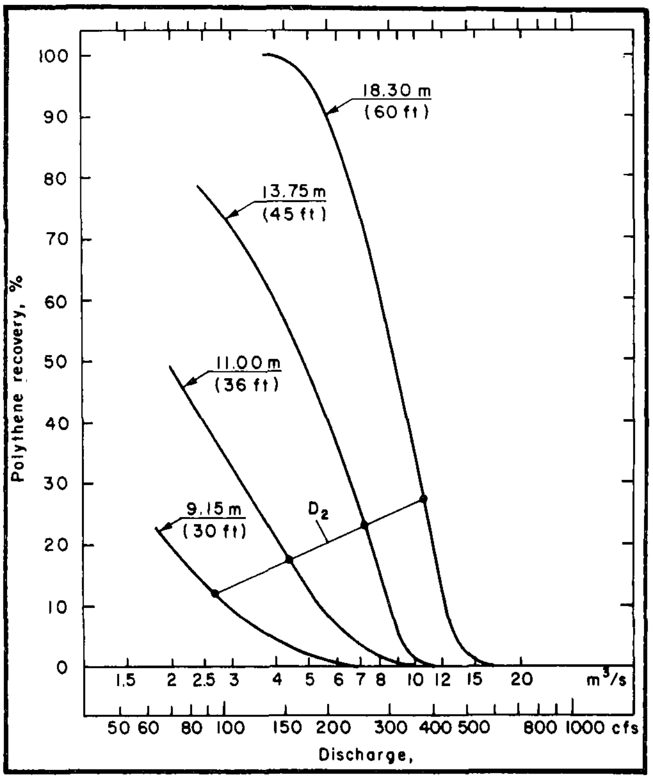


FIGURE 37
POLYTHENE (FLOATABLES) RECOVERY FOR 152.5 cm (5 ft)

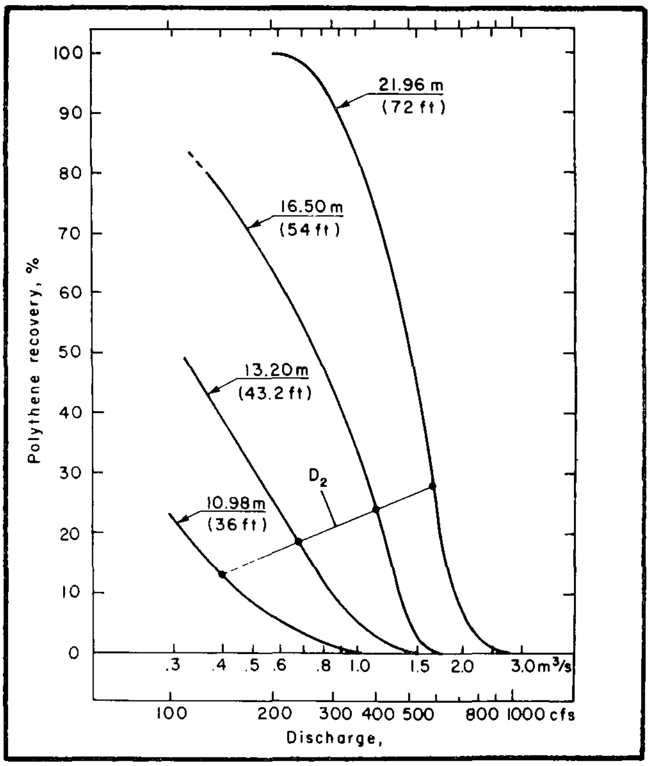


FIGURE 38
POLYTHENE (FLOATABLES) RECOVERY FOR 183 cm (6 ft)

This baffle extended up to the same elevation as the underside of the scum ring.

It appeared that the square inlet, being lower, allowed a higher velocity to build up in the top layers of the outside annular ring, which later were transmitted to the area under the weir disc. Although all the polythene was captured by the floatables trap and forced down under the weir disc, the higher velocities carried it further and gradually drew it out under the skirt and over the weir.

The results of these tests, therefore, provide a sound argument in favor of retaining the baffle inlet developed in the 1972 project for $D_1 : D_2$ ratios of say 1 : 6 to 1 : 9. From $D_1 : D_2$ = 1.9 to 1 : 12, the square inlet would give acceptable floatables recovery.

Conclusions

1. With larger inlet lines entering the chamber, say with a $D_1 : D_2$ relationships of 1 : 6 to 1 : 72 variation of the weir height, or chamber depth, had very little effect on settleable solids recovery.

2. With smaller inlets, for $D_1 : D_2$ of 1 : 9 or 1 : 12, the weir heights began to show varying Gilsonite recoveries as they were changed. However, a fixed ratio with the weir height being one quarter the chamber diameter, $H_1 : D_2 = 0.25$, was retained for the data analysis.

3. A set of Standard Design curves and a design procedure were developed on the basis of the Gilsonite (settleable solids) recovery for $H_1 : D_2 = 0.25$.

4. A procedure was developed to modify the depth-width ratio for any Standard Design case, making it possible to select weir heights and chamber diameters which might better conform with other project requirements.

5. Floatables recovery, as represented by polythene in the model, was less than satisfactory for the larger square inlets, with $D_1 : D_2$ = 1 : 6 to 1 : 9. In this range, the use of a baffle inlet is recommended.

6. For $D_1 : D_2$ of 1 : 9 to 1 : 12, the square inlet concept could provide acceptable floatables recovery.

TECHNICAL REPORT DATA

(Please read Instructions on the reverse before completing)

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		6. PERFORMING ORGANIZATION CODE
7. AUTHOR(S) Richard H. Sullivan, Morris M. Cohn, James E. Ure, Fred E. Parkinson, and George Galiana		8. PERFORMING ORGANIZATION REPORT NO.
9. PERFORMING ORGANIZATION NAME AND ADDRESS AMERICAN PUBLIC WORKS ASSOCIATION 1313 East 60th Street Chicago, Illinois 60637		10. PROGRAM ELEMENT NO. 1BB034/ROAP 21ATA/TASK 31
		11. CONTRACT/GRANT NO. 68-03-0283
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		14. SPONSORING AGENCY CODE

15. SUPPLEMENTARY NOTES

Supplement to "The Swirl Concentrator as a Combined Sewer Overflow Regulator Facility," EPA-R2-72-008, September 1972 (PB-214 687)

16. ABSTRACT

This report is a supplement to the report, *The Swirl Concentrator as a Combined Sewer Overflow Regulator Facility*, EPA-R2-72-008, September, 1972. The work described by this report allows flexibility for the designer faced with structural, head or land area constraints by enabling interchange of basic heights and diameter dimensions.

Studies of *The Swirl Concentrator as a Combined Sewer Overflow Regulator Facility*, conducted in 1972 by the American Public Works Association Research Foundation for the City of Lancaster, Pennsylvania, and the U.S. Environmental Protection Agency, demonstrated that this type of dynamic flow, non-mechanical device could effect excellent removals of suspended and floatable solids contained in admixtures of sanitary sewage and storm water. This improvement in the quality of storm flow discharges to receiving waters, or to treatment or storage facilities could reduce the pollutional impact on the nation's water resources.

The 1972 studies established a suitable relationship between swirl chamber depth and diameter and their effect on the liquid flowfield and particle removal efficiencies. It was deemed advisable to augment the 1972 studies by investigating this depth-to-width ratio and to define the dimensions which will provide optimum construction economy and operating efficiency in terms of solids separation. This report presents an account of these supplemental studies of a hydraulic model of the swirl concentrator at the LaSalle Hydraulics Laboratory at Montreal.

The report translates the model study findings into a design basis that can be used for any rational flow rate in universal service for the treatment of combined sewer flows. It establishes the basic principle that variations in overflow weir height, or chamber depth, do not materially influence solids particle removals and that the most definitive design parameters are size of inlet sewer and swirl chamber diameter. While the model studies showed that a ratio of weir height to chamber diameter of 1 : 4 was the most convenient to use as a design aid, the data have been extrapolated to produce geometry modification curves that cover swirl chamber diameters and depths. This information will be of value in the design of facilities which are the most economical and efficient.

The report provides design curves for various influent flow rates, covering chamber diameters and inlet sewer sizes which will produce settleable solids removal efficiencies of 70, 80 and 90 percent. It presents design details for floatable solids traps to retain these components, and for essential details of swirl chamber geometrics. Procedures are outlined on how the model study curves can be used in the design of prototype swirl concentrator units of various capacities and dimensional relationships.

The report was submitted in partial fulfillment of Contract 68-03-0283 between the U.S. Environmental Protection Agency and the American Public Works Association.

17. KEY WORDS AND DOCUMENT ANALYSIS

a. DESCRIPTORS	b. IDENTIFIERS/OPEN ENDED TERMS	c. COSATI Field/Group
*Overflows, Design, *Combined sewers, *Flow control, *Flow regulators, Flow rate, *Swirling--separation, *Water treatment, *Waste treatment	*Solids separation, *Swirl concentrator, Overflow quantity, Overflow quality	13B

18. DISTRIBUTION STATEMENT RELEASE TO PUBLIC	19. SECURITY CLASS *(This Report)* UNCLASSIFIED	21. NO. OF PAGES 54
	20. SECURITY CLASS *(This page)* UNCLASSIFIED	22. PRICE

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