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CATCHBASIN TECHNOLOGY OVERVIEW AND ASSESSMENT

Municipal Environmental Research Laboratory
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CATCHBASIN TECHNOLOGY OVERVIEW AND ASSESSMENT

by

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FOREWORD

The Environmental Protection Agency was created because of increasing public and government concern about the dangers of pollution to the health and welfare of the American people. Noxious air, foul water, and spoiled land are tragic testimony to the deterioration of our natural environment. The complexity of that environment and the interplay between its components require a concentrated and integrated attack on the problem.

Research and development is that necessary first step in problem solution and it involves defining the problem, measuring its impact, and searching for solutions. The Municipal Environmental Research Laboratory develops new and improved technology and systems for the prevention, treatment, and management of wastewater and solid and hazardous waste pollutant discharges from municipal and community sources, for the preservation and treatment of public drinking water supplies and to minimize the adverse economic, social, health, and aesthetic effects of pollution. This publication is one of the products of that research, a most vital communications link between the researcher and the user community.

The deleterious effects of storm sewer discharges and combined sewer overflows upon the nation's waterways have become of increasing concern in recent times. Efforts to alleviate the problem depend in part upon the development of improved flow attenuation and treatment devices.

This report describes the overview and assessment of current catchbasin technology, the performance of catchbasin hydraulic modeling analyses, an economic evaluation of alternative storm and combined sewer designs, recent developments and continuing program needs, and a recommended catchbasin design configuration.

Francis T. Mayo
Director
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ABSTRACT

An overview and assessment of current catchbasin technology has been prepared to provide engineers and municipal managers with technical and economic information on catchbasins and some alternatives so that they can make intelligent, informed decisions on runoff collection systems in light of pollution control legislation, the municipality's financial status, and its particular stormwater runoff characteristics.

Various catchbasin configurations and sizes were evaluated for hydraulic and pollutant removal efficiencies using hydraulic modeling analyses.

Detailed study findings are presented in sections dealing with (1) a state-of-the-art review, (2) a review of variables affecting catchbasin efficiency, (3) hydraulic modeling analyses, (4) an assessment of the role of catchbasins, (5) an economic evaluation of alternative storm and combined sewer designs, and (6) a review of recent developments and continuing program needs. Detailed example problems of the evaluation of catchbasin performance and economics are included.

A recommended catchbasin design configuration based upon hydraulic performance and sediment capture efficiency is presented.

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LIST OF ABBREVIATIONS AND SYMBOLS

ORGANIZATIONS

APWA -- American Public Works Association
EPA -- Environmental Protection Agency

ABBREVIATIONS

avg -- average
BOD_5 -- biochemical oxygen demand (5-day)
cfs -- cubic feet per second
cm -- centimetre(s)
cm/h -- centimetres per hour
cm/s -- centimetres per second
COD -- chemical oxygen demand
curb mi -- curb mile
d -- day(s)
diam -- diameter
ENRCC -- Engineering News Record Construction Cost Index
ft -- foot (feet)
ft^2 -- square foot (feet)
ft^3 -- cubic foot (feet)
ft/s -- feet per second
g -- gram(s)
gal -- gallon(s)
gal/d -- gallons per day
h -- hour(s)
ha -- hectare
in. -- inch(es)
in./h -- inches per hour
kg -- kilogram(s)
kg/curb km -- kilograms per curb kilometre
$kg/km^2 \cdot yr$ -- kilograms per square kilometre per year
km -- kilometre(s)
km^2 -- square kilometre(s)
L -- litre
lb -- pound(s)
lb/curb mi -- pounds per curb mile
lin ft -- linear foot (feet)
L/s -- litres per second
m -- metre(s)
m^3 -- cubic metre

Mgal	--	million gallon(s)
Mgal/d	--	million gallons per day
mg/L	--	milligrams per litre
mi	--	mile(s)
mi^2	--	square mile
min	--	minute
mm	--	millimetre(s)
RRL	--	Road Research Laboratory
S.G.	--	specific gravity
tons/$mi^2 \cdot yr$	--	tons per square mile per year
yd	--	yard(s)
yd^2	--	square yard
yd^3	--	cubic yard

SYMBOLS

D_1	--	barrel diameter
D_2	--	outlet pipe diameter
H_1	--	barrel height
H_2	--	barrel storage height
H_3	--	height from crown of outlet pipe to top of inlet grating
H_w	--	discharge head (headwater) above invert under discharge Q
M_g	--	geometric mean
σ_g	--	standard deviation
µ	--	micron
%	--	percent
°	--	degree
#	--	number
>	--	greater than
<	--	less than
≥	--	greater than or equal to
≤	--	equal to or less than
/	--	per

ACKNOWLEDGMENTS

The successful completion of this study was dependent on the cooperation and assistance of a number of individuals and organizations. We are indebted particularly to Richard Field, Chief of the Storm and Combined Sewer Section, Municipal Environmental Research Laboratory--Cincinnati, EPA, Edison, New Jersey, and Anthony N. Tafuri, Project Officer, for their guidance and review of the work.

The hydraulic modeling was conducted under subcontract by Hydro-Research-Science, Santa Clara, California, under the direction of Dr. Alexander B. Rudavsky who also provided valuable consultation during the course of the work. Section 6 of this report, including the figures and tables, is based upon a report prepared by Dr. Rudavsky describing and providing an interpretation of the hydraulic modeling and analyses.

The excellent case history and "real world" experience was contributed by Harold C. Coffee, Jr., Senior Engineer, Division of Sanitary Engineering, City and County of San Francisco, Department of Public Works, and the several cooperating staffs of the Bay Area communities.

This project was conducted under the supervision and direction of John A. Lager, Project Director, and William G. Smith, Project Manager. Portions of the report were written by Michael K. Mullis and George B. Otte. Project assistance, report review, and example problem development were provided by Dr. George Tchobanoglous, Professor, University of California at Davis. Marcella S. Tennant served as technical editor.

SECTION 1

INTRODUCTION

Control of stormwater runoff is a problem of increasing importance in the field of water quality management. Over the past 70 years, there has been some extensive use of catchbasins for coarse material removal from stormwater runoff. Yet catchbasin effectiveness and economics have never been evaluated in depth, even though the installation, operation, and maintenance costs of a catchbasin system may be extremely high relative to alternative methods. An informed decision cannot be made about the need for a catchbasin system by a municipal manager without the aid of such information.

PURPOSE OF STUDY

The purpose of this study is to provide municipal managers with technical and economic information on catchbasins and some alternatives so that they can make intelligent, informed decisions on runoff collection systems in light of pollution control legislation, the municipality's financial status, and its particular stormwater runoff characteristics. An additional purpose is to evaluate possible new devices to replace catchbasins and to identify the need for additional study of catchbasin performance.

REPORT FORMAT

In evaluating the use of catchbasins, consideration was given to their hydraulic characteristics; performance with respect to the removal of pollutants, street cleaning frequency, and catchbasin cleaning programs; comparison with inlets and other alternatives; and costs.

The detailed findings derived from this study are presented in the six sections that follow, which deal with a state-of-the-art review (Section 4); a review of variables affecting catchbasin efficiency (Section 5); hydraulic modeling analyses (Section 6); an assessment of the role of catchbasins (Section 7); an economic evaluation of alternative storm and combined sewer designs (Section 8); and a review of recent developments and continuing program needs (Section 9). A glossary of terms is presented in Appendix A. The analysis of catchbasin survey data reviewed during this study is presented in Appendix B.

DATA AND INFORMATION SOURCES

The data and information for this study were derived principally from five sources: (1) a 1973 municipal survey of catchbasin maintenance practices conducted by the American Public Works Association (APWA) [102]; (2) an Environmental Protection Agency (EPA) report, "Water Pollution Aspects of Street Surface Contaminants," November 1972, by URS Research Company, San Mateo, California [66]; (3) a comprehensive literature review of both United States and European practice; (4) a series of hydraulic modeling runs conducted specifically for this study by Dr. A. B. Rudavsky, Hydro-Research-Science Company (HRS), Santa Clara, California; and (5) interviews with selected municipalities, equipment suppliers, and contractors.

Cited reports, studies, and other pertinent literature are listed at the end of this report, following Section 9. Where reference is made to this information in the text, the appropriate numbers are enclosed in brackets. A brief foreign language bibliography is presented in Appendix C.

SECTION 2

CONCLUSIONS

Conclusions derived from this investigation are as follows:

STATE-OF-THE-ART

1. Historically, the purpose of catchbasins was to prevent sewer clogging by trapping coarse debris and to prevent emanantion of odors from the sewer by providing a water seal. The retention of solids is achieved by providing a combination settling basin-sump below the catchbasin outlet. A universal standard design for catchbasins has not been developed.

2. In U.S. regions with heavy winter snowfall, the area drained by a single catchbasin generally is between 0.6 and 1.3 ha (1.55 and 3.75 acres). For all regions in the United States, the typical drainage area varies from 0.85 to 2.05 ha (2.15 to 5.05 acres).

3. There are four categories of catchbasin cleaning methods: manual, eductor, bucket, and vacuum. Less than 45 percent of the U.S. cities presently use mechanical cleaning methods while more than 60 percent of Canadian cities do.

4. Many of the problems presently associated with catchbasins--blockage, odors, pollution source--are directly related to inadequacies of the cleaning program.

5. The required catchbasin cleaning frequency is a function of several local parameters, such as sump capacity, quantity of accumulated street solids, antecedent dry period, meteorological conditions, street cleaning methods and practices, surrounding land use, topography, and the erodability of the soils subject to washoff. While many of these factors are subject to controls to optimize catchbasin system efficiency, all too often the cleaning of catchbasins is given a low priority until a major interruption in service occurs.

6. The median catchbasin cleaning frequency, as taken from comprehensive national survey responses, was reported as once per year in 1973 and twice per year in 1956. Without comparing on a city-by-city basis (especially the change, if any, in both street and catchbasin cleaning practices), it appears that the cleaning frequency has decreased on a nationwide basis, even though the need, with rare exception, has not abated.

HYDRAULIC MODELING ANALYSIS

1. Properly designed and maintained catchbasins can be very efficient in removing medium to very coarse sands (>1.0 mm diameter) from stormwater runoff. Further, the removals remain high (65 to 90 percent) over a wide range of flows and reduce to approximately 35 percent at maximum design inflow.

2. Removal efficiencies, as expected, are very sensitive to particle size and specific gravity. Under the test conditions examined, the removal of fine sands (0.25-0.125 mm diameter) ranged from fair to poor with increasing flow. Removals of very fine sand (<0.125 mm diameter, S.G. of 2.65) and low specific gravity material (gilsonite, S.G. of 1.06) were negligible at 40 percent of maximum flow.

3. Storage basin depth is the primary control for performance; efficiencies improve with increasing depth.

4. The accumulation of sediment in catchbasins does not appear to impair solids removal efficiencies until 40 to 50 percent of the storage depth is filled. Beyond this depth, removals drop rapidly, even to the point of negative values (washout exceeds sedimentation).

5. Of the standard modifications tested, hoods or traps were found to increase the discharge head requirements significantly. In the higher flow ranges, increased scour currents were observed as the flow was diverted downward by the obstruction of the outlet. By comparison, curb openings or protrusions had negligible effect.

ASSESSMENT

1. On the basis of a recent survey, there are approximately 900,000 catchbasins in the United States in cities with populations exceeding 100,000 and an estimated 850,000 additional catchbasins in sewered areas of smaller communities.

2. The practice of using catchbasins rather than inlets in new construction continues to be strong (4:1); however, there is a growing trend by the minority to move positively away from using catchbasins.

3. Existing catchbasins exhibit mixed performance with respect to pollution control. The trapped liquid purged from catchbasins to the sewers during each storm generally has a high pollution content that contributes to the intensification of first-flush loadings. Countering this negative impact is the removal of pollutants associated with the solids retained in, and subsequently cleaned from, the basin.

4. The collection of conclusive field data is hindered by the prevailing poor conditions found in most basins resulting from underfinanced and poorly monitored cleaning programs.

5. Approximately 95 to 98 percent of the BOD_5 load in the liquid contained in a catchbasin prior to a storm will be displaced to the sewer by a rainfall of as little as 0.05 cm/h (0.02 in./h) lasting 4 hours. This is approximately equivalent to the waste discharged by one person in one day.

6. On an annual basis, the amount of material that would be retained in a catchbasin is given in the following tabulation:

Percentage of material retained in catchbasin for individual storm

Constituent	Probable % retained Worst	Probable % retained Best
Total solids	42.1	75.0
Volatile solids	15.2	25.5
BOD_5	15.5	26.6
COD	7.5	14.1
Kjeldahl nitrogen	14.6	27.4
Nitrates	9.5	17.1
Phosphates	2.3	6.0
Total heavy metals	37.4	64.4
Total pesticides	13.6	29.7

7. From a pollution abatement standpoint, the benefits of catchbasins appear limited at this preliminary level of analysis. For example, the net removal of BOD_5 from a well-designed and maintained system of catchbasins based on conformance to observed data is expected to be in the range of 5 to 10 percent of the

applied load. A potential exception may be the removal of heavy metals which, as tabulated above, could be significant.

8. Catchbasin cleaning frequency should be adjusted to limit the sediment buildup to 40 to 50 percent of the sump capacity.

9. Decisions on the use or nonuse of catchbasins must be viewed and implemented with a total system perspective. The effectiveness of solids control and removal practices impact each downstream element until final removal of discharge is attained.

10. The principal alternatives to the use of catchbasins involve replacement with inlets, sewer cleaning, street cleaning, and the use of flow-attenuation devices and off-line storage.

11. Catchbasins should be used only where there is a solids transporting deficiency in the downstream sewers or at specific sites where surface solids are unusually abundant.

12. The advantages of converting existing catchbasins to inlets, where solids transport is not a problem, include (1) a probable reduction of the first-flush pollutant load, (2) a reduction in required level of maintenance, and (3) the opportunity to reallocate the conserved labor.

ECONOMICS

1. The cost and required frequency of cleaning existing sewers is the dominating economic consideration with respect to converting catchbasins to inlets.

2. On the basis of annual cost, it is generally more economical to install inlets rather than catchbasins in new developments in which separate storm drains are to be used, provided that the required sewer cleaning frequency when inlets are used is not less than one-half that when catchbasins are used.

SECTION 3

RECOMMENDATIONS

Recommendations derived from this investigation are as follows:

1. Studies should be undertaken to determine the impact of best management practices in reducing solids and other pollutant loads in surface runoff that must be collected from urban areas and introduced to the sewer through catchbasins.

2. Studies should be performed to evaluate the effectiveness, through field scale demonstration, of closely monitored catchbasin cleaning programs with respect to impacts of cleaning frequency and techniques on solids carryover, general pollution abatement, and associated costs.

3. Studies should be conducted to determine the magnitude of the problem of solids deposition within real sewer systems and the extent to which this problem is mitigated by properly designed and functioning catchbasins. It should also be determined whether or not the prime source of the deposited materials is the surface runoff introduced through catchbasins.

4. The cost effectiveness of converting catchbasins to inlets should be evaluated in a major prototype demonstration study.

5. The field demonstration studies recommended above should be carried out in a minimum of three to five regionally representative urban areas. Regions recommended are northeast, midwest, southern, and western because of their differences in climate, hydrology, and system characteristics. Selected catchments should range from 40 to 405 ha (100 to 1,000 acres).

6. Municipalities should keep systematic records of solids buildup experience (rate and location) and removal costs in both catchbasins and sewers. Long-term documentation of the behavior of the real system is the most valuable input to cost-effective decision making.

SECTION 4

STATE-OF-THE-ART REVIEW

In this state-of-the-art review of catchbasins, information is presented on their historical development and function, design (both American and European practices), and operation and maintenance practices.

BACKGROUND

Definition

A catchbasin is defined as a chamber or well, usually built at the curbline of a street, for the admission of surface water to a sewer or subdrain, having at its base a sediment sump designed to retain grit and detritus below the point of overflow. Because some communities call any device that receives stormwater a catchbasin, the distinction is made between those devices that intentionally trap sediment and those that do not. In this report, the device that traps sediment is called a catchbasin and the device that does not is called an inlet.

The entrance to either the catchbasin or the inlet is through a grate and/or a curb opening; or, in the case of a catchbasin not connected directly to the street but supplied from one or more inlets, the entrance is through an inlet pipe.

History and Function

Stormwater runoff in urban areas normally flows for a short period of time in the gutter and is diverted by an inlet structure leading to an underground conduit or open channel for transportation to a receiving body of water. The underground conduit, either a storm sewer or combined sewer, may be protected from clogging by catchbasins built in conjunction with the inlets.

Historically, the purpose of catchbasins was to prevent sewer clogging by trapping coarse debris and to prevent odor emanations from the sewers by providing a water seal. The prevention of sewer clogging was especially important prior to the existence of good quality street pavements. In areas where streets were partially or wholly unpaved, significant quantities of stone, sand, manure, and other materials were washed into the sewer system during periods of rainfall. Also, during the earlier years of sewer construction, little attempt was made to maintain self-cleaning velocities in sewers of at least 61 cm/s (2 ft/s) [42].

The usefulness of catchbasins was considered marginal as far back as 1900 [33]. Most modern texts generally agree and only provide short disclaimers regarding the value of catchbasins, except where deposition of large amounts of grit is expected in the sewer without them [15, 87].

Despite the purported reduced need for catchbasins, they are still used widely in many jurisdictions in many parts of the country [102]. Thus, it appears that the continued use of catchbasins is a matter of custom rather than a well-defined technical requirement.

Little investigation has been conducted on the hydraulic characteristics of flow within a catchbasin. The University of Illinois conducted some investigations and concluded that catchbasins are hydraulically inefficient [41]. In another study of hydraulic characteristics by the APWA, it was found that for all practical purposes complete mixing occurs within a catchbasin [42]. This seems to fit in with the University of Illinois studies which indicated that a catchbasin is a poor sedimentation device because of its tendency to resuspend the solids in the sludge deposits even at moderate inflow rates.

Attempts by the University of Illinois group to improve settling by baffling showed additional adverse effects. However, a more recent study of catchbasins with large antecedent debris contents indicated that only about 1 percent of the antecedent content washed out [66]. It was concluded, however, that the material flushed out as the initial slug would have a substantial pollutional impact on the receiving waters. In the APWA study, it was also concluded that catchbasins may be one of the most important single sources of pollution from stormwater flows [42]. All of the studies concluded that catchbasins cannot efficiently satisfy the competing objectives of good hydraulic characteristics and solids retention.

CATCHBASIN DESIGN

Catchbasins serve two main purposes: to prevent sewer gases from escaping through the inlet gratings and to prevent solid matter from the street from entering the sewers. The trapping of sewer gases is accomplished by water seals of different types. The retention of solids is achieved by providing a sump or settling basin in which the heavy solids settle to the bottom while the light solids float on top. The water drains to the sewers through the inlet of a trap, which is generally a few inches below the water surface. These basins are normally built under the inlet gratings or openings, either under the gutter or just back of the curb. Occasionally, one catchbasin will serve two or more standard inlets.

American Practice

In American practice, a standard catchbasin appears to be nonexistent. There is some uniformity attempted within individual cities which shows varying degrees of success. The best source of catchbasin geometry yet located appeared in the July 1928 issue of The American City [51]. Ninety-six American cities in 28 states and the District of Columbia, and 4 cities in Canada, provided data on catchbasin and inlet geometry, including the number of units in use, average size, outlet location, and storage capacity below the outlet. The data reflected a very wide range overall, as shown in Table 1.

TABLE 1. CATCHBASIN AND INLET CONSTRUCTION STANDARDS, 1928 [51]

	Inlets	Catchbasin[a]
Equivalent diameter, cm (in.)		
Average	76.2 (30)	115.6 (45.5)
Range	15.2-137.2 (6-54)	40.6-160 (16-63)
Depth, cm (in.)		
Average	121.9 (48)	182.9 (72)
Range	45.7-182.9 (18-72)	91.4-304.8 (36-120)
Outlet location above bottom, cm (in.)		
Average	....	99 (39)
Range	....	45.7-213.4 (18-84)
Storage capacity, m^3 (yd^3)		
Average	....	1.11 (1.45)
Range	....	0.21-3.8 (0.28-5.0)

a. Median values: diameter, 121.9 cm (48 in.); depth, 198.1 cm (78 in.); outlet above bottom, 76.2 cm (30 in.); capacity, 0.89 m^3 (1.16 yd^3).

From data derived in the 1973 APWA survey [102], it is interesting to note that the storage capacity given in Table 2 is essentially equal to that given in Table 1.

TABLE 2. CATCHBASIN VOLUMES, 1973 [102]

	Value
No. of cities in sample[a]	43
No. of catchbasins	270,950
Catchbasin storage capacity, m^3 (yd^3)	
Range	0.08-2.21 (0.11-2.96)
Average	1.07 (1.44)
Median	0.97 (1.30)

a. Random cities using catchbasins exclusively.

In American practice, the effectiveness of the water seal gas trap is directly proportional to the antecedent dry period and the corresponding evaporation rate. In addition, organics in the catchbasin itself will decompose with time and contribute odors similar to sewer gas even if the water seal has not evaporated. In climates supporting their existence, mosquitos will use the trapped water as a breeding ground, creating an additional nuisance.

American design standards for the interconnecting pipe between the catchbasin and the combined or storm sewer are a minimum flowing-full velocity of 91.4 cm/s (3 ft/s) and usually a maximum surcharge in the catchbasin corresponding to a water surface of 30.5 to 45.7 cm (1 to 1.5 ft) below the top of the gutter curb. Usually, the pipe is 30.5 to 38.1 cm (12 to 15 in.) in diameter, depending on topography and design flow requirements. Representative catchbasin designs in America are shown in Figure 1.

European Practice

In Europe, where catchbasins are used, their sizes vary, except in Germany where they have been standardized. Two types of catchbasins are used: a simple depository type and another type generally called a "selective" catchbasin in which a bucket sieve or some other means is used to select and separate various solid materials. The latter type varies greatly in different countries and various cities. The buckets provide an easy and rapid method for cleaning by street crews.

European catchbasins tend to be smaller in size, reflecting closer spacing, i.e., smaller drainage areas per unit. Most European cities are located on a relatively flat terrain with long-duration, low-intensity, high-frequency rain patterns, and

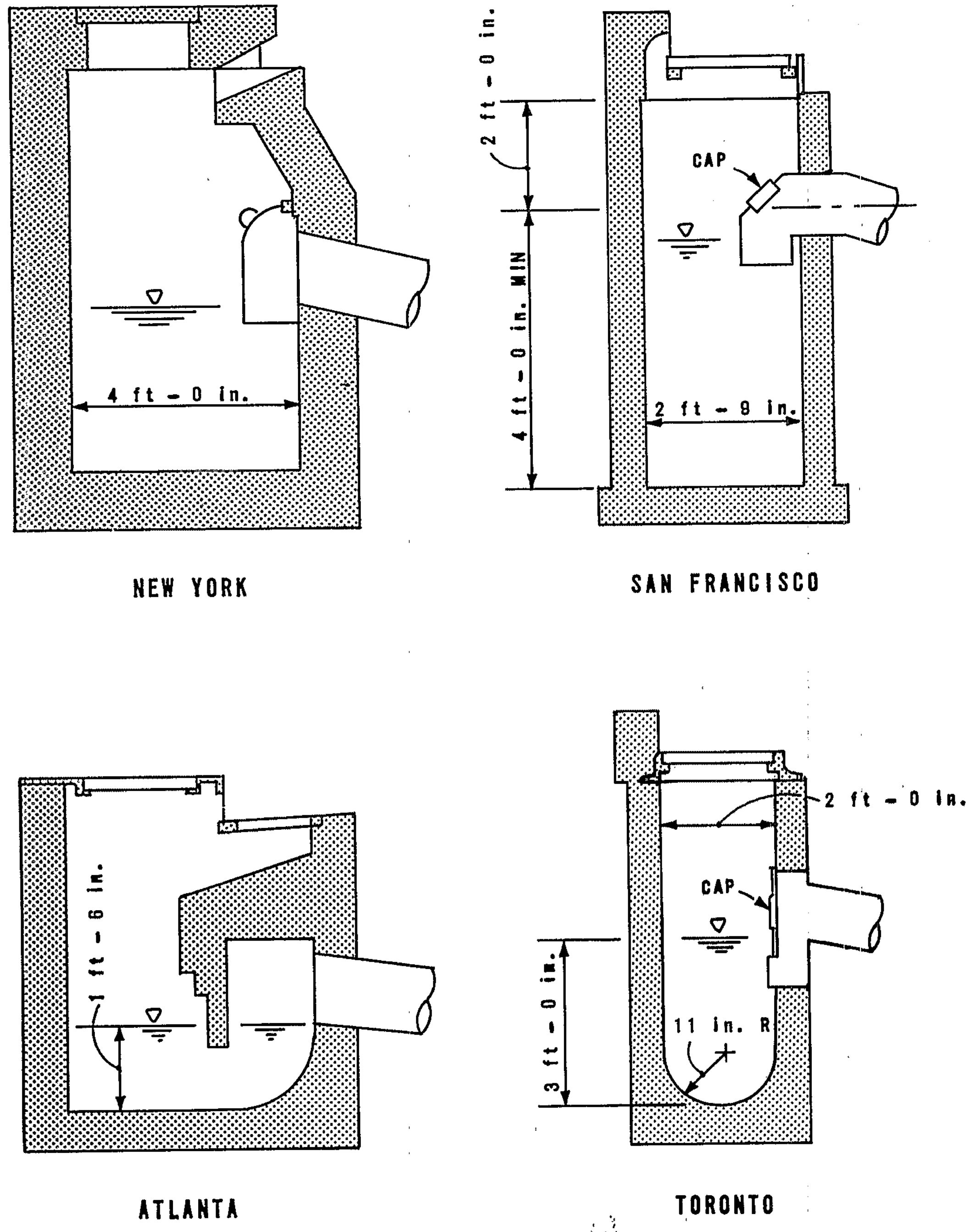


Figure 1. Representative catchbasin designs in United States and Canada.

most catchbasins do not include gas traps because of the frequent flushing by storm runoff. Catchbasins are usually circular in shape. A perforated removable bucket is used to catch large objects, and the runoff flow is relied on to carry the smaller material on into the sewer.

A grill is generally used for a top cover for every catchbasin and various configurations are prevalent. Vertical openings in the curb are used, but horizontal gratings are also prevalent. At the present time, the recommendation is to use a "New York-type" grating, where the grating is horizontal and overflow openings are mounted into the curb. The vertical grating and the vertical openings have the disadvantage of not being able to catch the flow on steep sloping streets. On the other hand, the horizontal grating very often gets obstructed by large pieces of trash.

There is a definite tendency in most of the textbooks in Europe to discount, or not recommend, depository type catchbasins, because the material that accumulates with the water is subject to fermentation odors and other problems of stagnation. When depository type basins are required, a siphon modification, in which a separation baffle is installed, is often used. The solid material is left in one compartment, and the flow is basically drained through the siphon and underneath the baffle.

In general, catchbasins are not used in Europe when a steep pipe gradient is provided, but they are used where extremely flat gradients prevail. Cleaning is generally accomplished by pumping based on a suction arrangement. The most prevalent volumetric capacity for a catchbasin sump is approximately 1.5 m^3 (2 yd^3). Catchbasins that are representative of European practice are shown in Figure 2.

Catchbasin Placement

Generally, the same spacing is used for catchbasins and inlets, which means that wherever an inlet is placed, it could be replaced with a catchbasin or the reverse. Frequently, it is more economical to use fewer catchbasins and to let one or more inlets connect to a single catchbasin. Typical data on the areal distribution of catchbasins in the United States are presented in Table 3.

In the design of a storm drainage system, the designer initially positions catchbasins or inlets at street intersections to intercept the pavement runoff before it spreads across the street and at the low points of vertical curves. After the initial positioning, the drainage system is designed and the spacing of intermediate catchbasins is determined. The general procedure for intermediate spacing is as follows: (1) establish the allowable spread of water onto the roadway for the design storm;

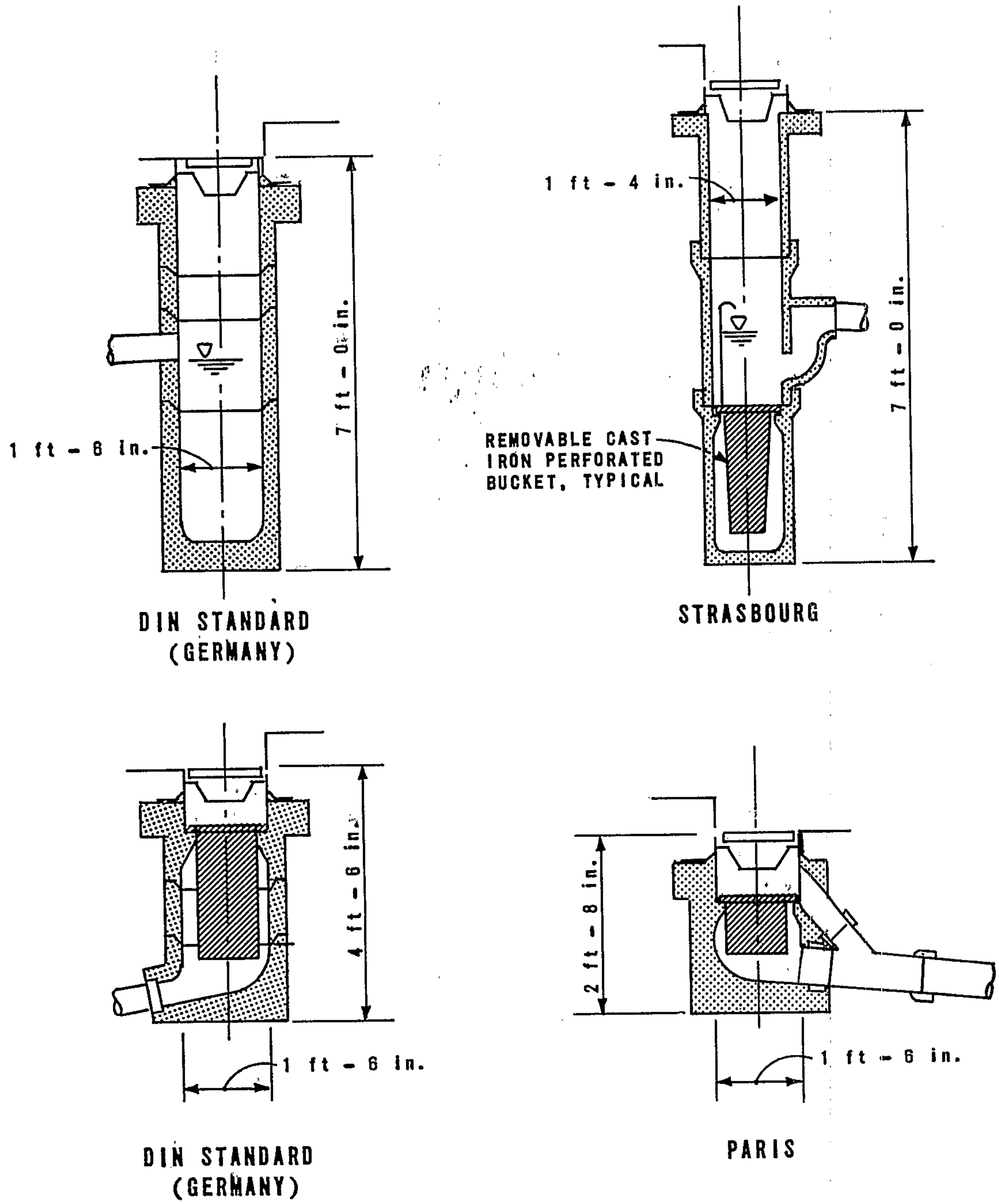


Figure 2. Representative catchbasin designs in Europe.

TABLE 3. AREAL DISTRIBUTION OF CATCHBASINS, 1973 [102]

Statistical measure[a]	ha (acres)/catchbasin
States with heavy winter snowfall	
Geometric mean (M_g)	0.63 (1.56)
Standard deviation (σ_g)	0.69 (1.71)
All states	
Geometric mean	0.88 (2.17)
Standard deviation	1.17 (2.88)

a. See Appendix B.

(2) using the design storm and one of several methods for computing runoff, such as the Rational Formula or the RRL Method, establish the maximum spacing based on the allowable spread of water, gutter and street cross-section, roughness of gutter surface, and longitudinal slope; (3) using the flow calculated for the maximum spacing, determine whether or not the inlet grate and/or curb opening inlet is capable of intercepting this flow. If it will not intercept this design flow, reduce the spacing of the next inlet so that the amount of flow passing the first inlet plus the flow accumulated between the first and second inlet does not exceed the allowable gutter flow requirement.

OPERATION AND MAINTENANCE

Because the primary purpose of a catchbasin is to trap solids that would otherwise enter the sewer and form deposits that would cause stoppages or otherwise impede the flow, it is obvious that the material that has been trapped must be removed if the catchbasin is to perform in its designed manner. Gratings, openings, traps, and outlets must also be kept free so that they will not interfere with, or prevent, the flow of stormwater. When catchbasins or inlets become clogged, stormwater backs up and spreads over the pavement and adjacent areas, and serious property damage frequently results. The expenses and hazards involved in cleaning clogged catchbasins during storm conditions make a regular cleaning program an attractive alternative.

The following information is based primarily on the APWA text, "Street Cleaning Practice," published in 1959 [9].

The agency responsible for cleaning catchbasins and inlets clearly should be the public works department. However, assignment within the public works department varies from city to city. Some cities consider catchbasins and inlets as appurtenances to the sewer system and thus assign the cleaning duty to the sewer maintenance division. Others consider catchbasins and inlets as part of the street system and assign the cleaning to the street maintenance division. Still others assign the cleaning to the street cleaning division. In theory, where cooperation among municipal officials exists, it makes little difference which divisions perform the cleaning operation. However, it is usually desirable for the street cleaning division to also be responsible for the cleaning of catchbasins and inlets.

The following discussion presents details on catchbasin and inlet cleaning methods and procedures, debris disposal, oiling, and cleaning frequency.

Catchbasin Cleaning

There are four categories of cleaning methods: manual cleaning, bucket cleaning, eductor cleaning, and vacuum cleaning. Many cities use one or more of the methods. Data on the number of cities using mechanical means for cleaning catchbasins are reported in Table 4. Manual cleaning will always be required for certain situations, but the major cleaning effort of any catchbasin cleaning program should be based on modern, economical, and efficient methods and machines. It is interesting to note from Table 4 that 44 percent of the U.S. cities and 62 percent of the Canadian cities use mechanical cleaning methods. Apparently the United States, more so than Canada, is just beginning to use mechanical cleaning methods, while in Europe they have been used almost exclusively for many years.

TABLE 4. NUMBER OF CITIES USING MECHANICAL MEANS FOR CLEANING CATCHBASINS, 1973 [102]

	No. of cities	
	United States	Canada
Total cities responding to survey	443	43
Cities using catchbasins	322	42
Cities using mechanical means for cleaning catchbasins	142[a]	26[b]

a. Of this total, 113 were vacuum, 20 were eductor, and 9 were bucket machines.

b. Of this total, 17 were vacuum and 9 were eductor.

Equipment and Crew Size--

Several different pieces of equipment and techniques are commonly used to clean catchbasins. A representative listing is shown in Table 5.

TABLE 5. REPRESENTATIVE EQUIPMENT USED

Manual cleaning
Dump truck, 1 or 1-1/2 tons
Clamshell shovel, two different lengths
Scoop shovel
Brooms
Grating lifter
Self-priming solids pump
Hoist on truck (hand operated)
Eductor cleaning
Eductor truck
Rake
Scoop shovel
Broom
Grating lifter
Vacuum cleaning
Vacuum truck
Extensions for vacuum line
Flushing water
Pole for cleaning corners
Grating lifter

The number of persons required to clean catchbasins varies depending on the type of equipment being used, union regulations, and city policy. Typically, a crew to clean catchbasins manually consists of two persons. When equipment is used, such as a vacuum truck or eductors, the crew often consists of three persons. The third person may be required to be part of the crew to act as a driver and/or equipment operator.

Manual Cleaning--

The most common manual cleaning method is to bail out the water and dip out the material accumulated in the sump using long-handled right-angle spoons or dippers, and then pile it on the street for subsequent removal by trucks after draining on the street. A fire hose is then used to refill the basin with clean water. When the dirty water has not been removed first, the fire hose stream may be applied near the bottom of the catchbasin to flush the remaining silt along with the dirty water into the sewer.

This method of manual cleaning is undesirable because the pile of removed material on the pavement is usually unsightly and odorous, it leaves the pavement dirty and unsanitary, and the method itself is relatively slow and expensive (though low in capital costs).

Another method commonly used for large sumps is pumping or bailing out the water and then having men enter the catchbasin to shovel the contents into a bucket. This method eliminates the messy step of piling the debris on the pavement and probably results in better cleaning, but it requires the men to work in a rather foul environment, is relatively expensive, and requires the trucks to be absolutely watertight.

Some cities use hose flushing alone to clean catchbasins. A high-pressure water jet breaks up the catchbasin contents and flushes all the debris to the sewer. The method is relatively easy and inexpensive, but it defeats the purpose of the catchbasin, i.e., prevention of solids entering the sewer system. If inlets are used in place of catchbasins, the flushing step could be eliminated, for the most part, especially in the case of sewers sloped enough to provide self-scouring velocities.

In summary, manual cleaning should be limited to special cases and to catchbasins too small for mechanical cleaning. It is relatively expensive, inefficient, unsanitary (both for the cleaning crew and the public), and in the case of hose flushing, self-defeating.

Bucket Cleaning--

Bucket cleaning consists of lowering a standard or specially designed orange peel or clamshell bucket into the catchbasin, lifting the full bucket to the surface, and then discharging the contents into a dump truck or hopper attached to the bucket and crane machine. This method is effective for removing most of the basin contents, but leaves behind material that cannot be reached by the bucket. Also, much basin water is spilled on the street surface and causes a nuisance of odor and aesthetics, as in manual cleaning. By using special fabricated buckets, the bucket method has been adapted to many basins that ordinarily would require manual cleaning. A drawback to this method, as with manual cleaning, is the large manpower requirement which limits the frequency and quality of the cleaning.

Eductor Cleaning--

In the eductor method, the vacuum effect of an eductor is used to draw up the catchbasin contents. The solids-water mixture is then separated by settling in the tank compartment of this unit. The water is recycled to operate the eductor. This method can be accompanied by a flushing procedure to facilitate solids removal by breaking up the solids mass. The eductor usually will not pass large debris, which may require manual cleaning for removal. Though relatively high in capital costs, the eductor cleaning method is a sound approach to catchbasin cleaning and should be considered for new catchbasin designs or for modifications of existing basins.

Vacuum Cleaning--

The vacuum cleaning method operates essentially the same as the eductor method, except that an air blower is used to create the vacuum, and air-solids-liquid separation is accomplished in the unit by gravity separation and baffles. The air is exhausted to the atmosphere. Usually, larger pieces of debris can be removed from the catchbasin with a vacuum unit than with an eductor unit. As with the eductor, the vacuum method is economical, efficient, and does not create nuisances. It should be considered one of the major catchbasin cleaning methods and should be incorporated in concepts for new catchbasin designs and for modification of existing catchbasins.

Inlet Cleaning

Inlet cleaning is very similar to catchbasin cleaning, but there are some small differences in cleaning frequency, crew size, and equipment. Inlets are usually cleaned with the same frequency as catchbasins (about once per year), but occasionally they are cleaned as frequently as every 2 months. Inlet cleaning is usually quite rapid and often is little more than a visual inspection for large materials that could block the flow.

Typically, inlet cleaning requires only a two-man crew. The work in most cases is performed manually. Occasionally, a vacuum truck is used, but the time required to assemble and disassemble the extension segments of the vacuum unit reduces the time saving.

Summary of Specific Cleaning Procedures

The following step-by-step procedures for cleaning catchbasins and inlets are typical of those used by the municipalities that were interviewed.

Manual Cleaning

Catchbasins (approximate total time, 30 to 90 minutes)

1. Remove grating using grating lifter (Illustration 1, Figure 3).
2. Pump out excess water.

3. Use shovels and clamshell shovels to remove accumulated solids (Illustration 2, Figure 3). Solids can be placed directly in truck or on pavement and then shoveled into truck.

4. Wash deposited solids not placed in truck off street.

5. Refill catchbasin with water if desired to maintain effective operation of trap.

6. Replace grating.

Inlets (approximate total time, 10 to 30 minutes)

Steps 1, 3, and 6 above.

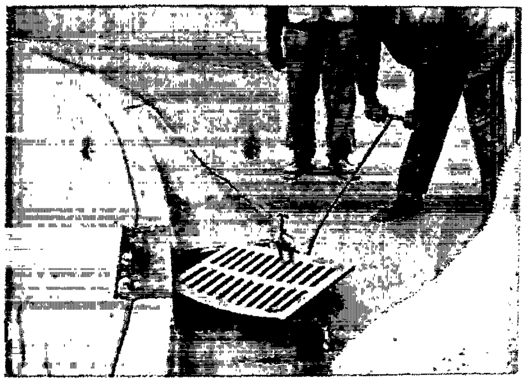


Illustration 1
City of Santa Clara, California. Removing inlet grating with grating lifter.

Illustration 2
Removing debris with clamshell shovel.

Figure 3. Manual cleaning.

Eductor Cleaning

Catchbasins (approximate total time, 15 to 45 minutes). Before using truck or after dumping trash, eductor must be filled with water (Illustration 1, Figure 4).

1. Place truck in position so that catchbasin can be reached by eductor hose.
2. Place safety cones.
3. Open grating.
4. Lift out floating debris and garbage onto pavement with rake.
5. Place eductor hose into catchbasin.
6. Turn on eductor, protecting nozzle with rake to assure that no solids (cans or bottles) are sucked into hose (Illustration 2, Figure 4).

7. Use pressure nozzle on pipe extension to clean corners and loosen sludge for removal by eductor.
8. Stop eductor for removal of tin cans or bottles stuck in sediment.
9. Restart eductor to finish cleaning basin.
10. Stop eductor and allow water to flow into catchbasin to form water seal on trap.
11. Remove eductor hose from catchbasin.
12. Load debris from pavement into truck.
13. Sweep or flush pavement clean.
14. Replace grating.

Inlets - Eductors were not used for inlet cleaning.

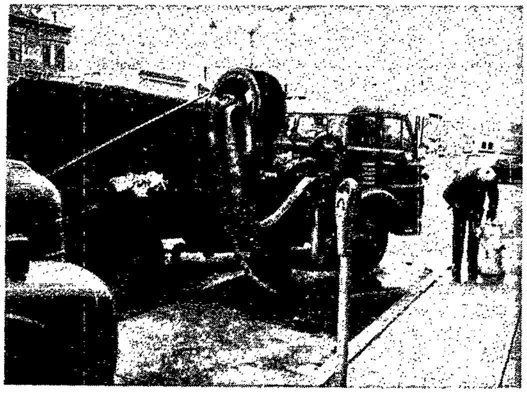


Illustration 1
City of San Francisco, California. Overall view of unit about to be filled with water.

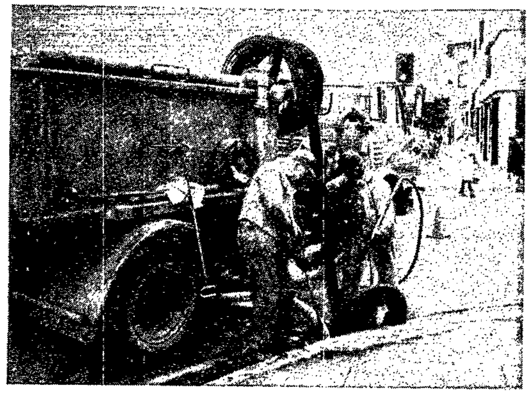


Illustration 2
Eduction nozzle in catchbasin with man at left holding rake to keep nozzle protected and man on right using pressure jet to wash sides and break up solids.

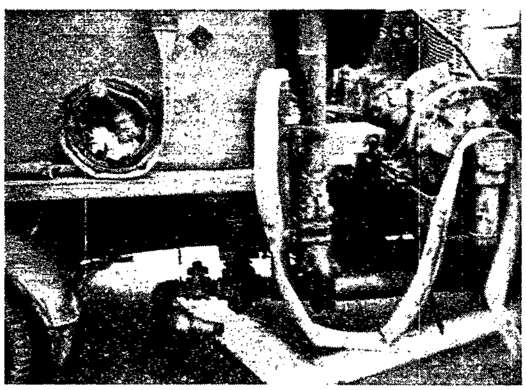


Illustration 3
Closer view of eduction nozzle in bracket on truck (partially concealed by main water supply hose).

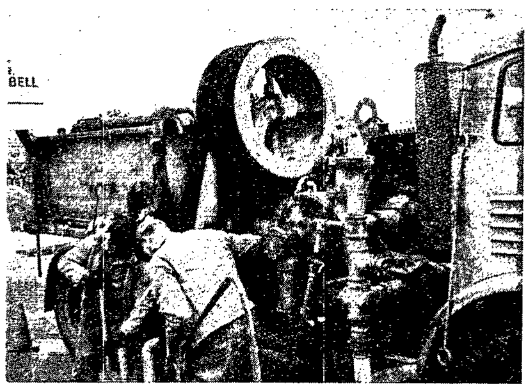


Illustration 4
Closer view of eduction pump and hose reel.

Figure 4. Eductor cleaning.

Vacuum Cleaning

Catchbasins (approximate total time, 15 to 30 minutes).

1. Place vacuum truck in position so that catchbasin can be reached with vacuum hose.
2. Place safety cones and block wheel of truck.
3. Open grating. (Occasionally, pick used to open grating is placed in position to counterbalance grate and prevent accidents).
4. Set vacuum extension into catchbasin and connect hose (Illustration 1, Figure 5).
5. Turn on vacuum unit and remove water and accumulated solids (Illustrations 2 and 3, Figure 5).
6. Use bar to break up grit and scrape grit from corners (scraping end of bar in foreground of Illustration 1, Figure 5).
7. Wash down excess solids with pressure hose.
8. Disassemble vacuum extension unit.
9. Refill catchbasin with water if desired to maintain effectiveness of trap.
10. Replace grating.

Inlets (approximate total time, 15 minutes). Same procedures as above, except omit Step 9.

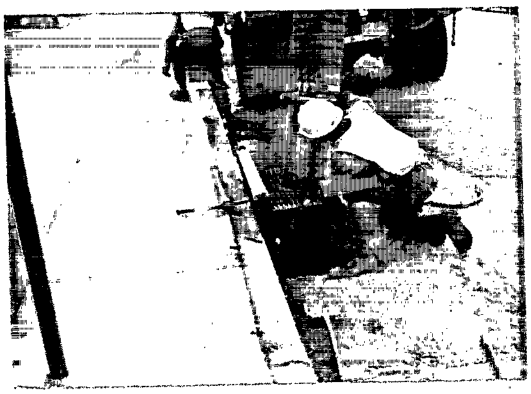


Illustration 1
City of Berkeley, California. Connecting 6 ft extension to flexible hose. Hand scraper in foreground.

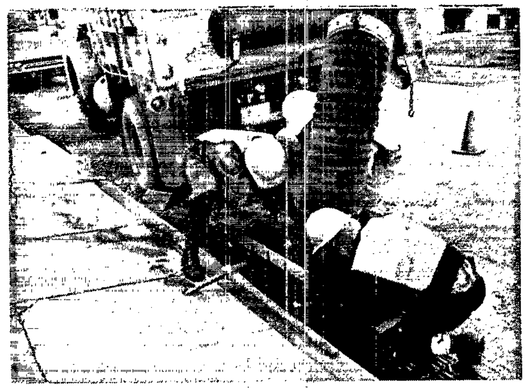


Illustration 2
Cleaning the catchbasin.

Illustration 3
Overall view of operation in progress.

Figure 5. Vacuum cleaning.

Debris Disposal

Catchbasin debris usually contains appreciable amounts of water and offensive organic material. Depositing it on the pavement is therefore objectionable aesthetically and sometimes creates a traffic hazard (due to slippery pavement).

The debris is low in organic content on a mass basis, which eliminates burning as a disposal method. Unless it is immediately covered by a layer of soil, it is unusable for fill material. This need for immediate removal from the pavement and immediate use as fill material can present difficult coordination problems. Consequently, the usual method of disposal is sanitary landfill in spite of the appreciable water content. The widespread use of sanitary landfill disposal is indicated by results of the 1973 APWA survey [102] summarized in Table 6.

TABLE 6. CATCHBASIN DEBRIS DISPOSAL METHODS [102]

	No. of cities	
	United States	Canada
Total cities responding to survey	443	43
Disposal method		
Landfill	338	38
Fill unimproved streets	11	0
Fill private property	26	1
Other	23	2
Not stated	45	2

Many cities have experienced difficulties, such as rapid slope degradation or fill instability, when large amounts of the muck are being disposed of in the sanitary landfill [9]. For these reasons some municipalities have set aside separate sanitary landfill sites for catchbasin debris. An important consideration by administrators in evaluating the continued use of catchbasins must be the availability of suitable disposal sites. Because of the large quantities of material involved, up to a ton or more per basin, long haul requirements may dominate the economics.

Oiling

The stagnant water in a trapped catchbasin is an ideal breeding ground for mosquitos. Prevention measures are necessary, particularly in warm climates, and usually consist of spraying the water surface with fuel oil or larvacides. The frequency of application would logically be within 7 days (the normal incubation cycle of mosquitos [103]) after each catchbasin flushing event (either intentional or natural). Colder weather, of course, lengthens the incubation cycle and thus the period allowed between sprayings.

In the 1973 APWA survey, the annual frequency of oil or larvacides spraying catchbasins for mosquito control was reported as follows[102]:

No. of cities responding	Annual frequency of spraying
9	1
9	2
4	3
2	4
1	6
1	12
26	

The median frequency was 2 times per year. The two high annual frequencies of 6 and 12 times per year occurred in two high-income residential areas. Oiling of catchbasins was not reported to be a widespread practice; 276 of 356 cities stated that they do not spray their catchbasins [102]. Excessive use of oil or larvacides is, of course, an indirect source of pollution to the receiving waters and must be avoided.

Cleaning Frequency

As a minimum requirement, catchbasins must be cleaned often enough to prevent debris from accumulating to such a depth that the outlet to the sewer might become blocked, and this only prevents plugging and subsequent street and basement flooding. To achieve gross solids removal, the sump itself must be kept clean so that storage capacity is provided. Otherwise, almost all of the solids may be forced through the trap into the sewer, or the trap itself may become plugged, preventing the passage of the stormwater.

The required frequency of catchbasin cleaning is a function of several local parameters, such as sump capacity, quantity of accumulated street solids, antecedent dry period, meteorological conditions, street cleaning methods and practices, surrounding land use, topography, and to some extent, the type of surface soil adjacent to the street. Many of these parameters are subject to optimization to maximize catchbasin system efficiency, because they are physical parameters. Unfortunately, in reality, the most influential parameter in some cities is the human element; i.e., many of the deficiencies of existing catchbasin systems are the result of public apathy either through ignorance or lack of concern on the part of citizens, responsible public officials, cleaning crews, or a combination thereof. All too often, the cleaning of catchbasins is given a low priority until a major disaster occurs. A good example of this is the subway flooding attributed to clogged catchbasins that occurred in New York City on July 3, 1969, when the New York City Transit Authority was forced to abandon service on its Pelham Line north of 139th Street [108].

Another example of the low priority of catchbasin cleaning are the data returns from the 1973 APWA survey [102]. The catchbasin cleaning frequencies reported by 299 cities are summarized in Table 7.

TABLE 7. FREQUENCY OF CATCHBASIN CLEANING IN VARIOUS NORTH AMERICAN CITIES

Frequency	No. of cities	
	1973[a]	1956[b]
As needed	...	11
Once in 4 years	3	...
Once in 3 years	7	2
Once in 2 years	13	7
Twice in 3 years	1	...
1 time per year	142	37
1.5 times per year	1	4
2 times per year	81	68
2.5 times per year	...	4
3 times per year	21	15
3.5 times per year	...	2
4 times per year	13	14
5 times per year	2	1
6 times per year	5	6
7-8 times per year	1	1
9 times per year	3	1
10-15 times per year	2	3
20-26 times per year	1	3
31 times per year	1	...
45 times per year	1	...
52 times per year	1	1
Total	299	180
Median annual frequency	1	2
Mean annual frequency	2.3	...
Mean of middle 80% of cities	1.5	...

a. Reference [102].

b. Reference [9].

The results of the 1973 survey are similar to results of a much earlier survey (1956), also by the APWA [9]. The reported frequencies for this earlier survey are also summarized in the table. The median cleaning frequency was reported as once per year for 1973 and twice per year for 1956. Without comparing on a city-by-city basis (especially the change, if any, in both street and catchbasin cleaning practices), it appears that the cleaning frequency has decreased on a nationwide basis, even though the need, with rare exception, has not abated.

The data illustrate a crucial point about catchbasins--that many of the problems associated are probably due to the inadequacies of the cleaning programs. In the following sections, performance effectiveness will be related to design and maintenance practices.

SECTION 5

REVIEW OF VARIABLES AFFECTING CATCHBASIN EFFICIENCY

The principal variables that affect the performance of catchbasins in removing pollutants found in stormwater are reviewed in this section. These variables deal with (1) catchbasin hydrology, (2) catchbasin hydraulics, (3) pollutant characteristics, and (4) solids washoff.

CATCHBASIN HYDROLOGY

The hydrology of the drainage area tributary to the catchbasin is important because the area contributes runoff water to the catchbasin and thus affects the solids loading of the catchbasin. The amount of runoff is controlled by the terrain and street slopes, drainage area size and shape, distance to the catchbasin, runoff coefficients, distribution of pervious and impervious surfaces, lag time, storm intensity and duration, depression and gutter storage, flow routing, and infiltration capacity.

Defining a typical runoff area hyetograph and hydrograph for universal application as an evaluation criterion for catchbasins may be unrealistic. To illustrate this, the variation of localized rainfall intensity extrapolated from the 1963 U.S. Weather Bureau Rainfall-Frequency Atlas for various design storms for three U.S. cities is reported in Table 8. It is apparent that, to be realistic, evaluation should be based on known hydrological data in a known runoff area.

TABLE 8. TYPICAL 5-MINUTE RAINFALL INTENSITIES [106]

Recurrence interval, yr	Intensity, in./h		
	San Francisco	Chicago	Washington, D.C.
10	4.29 (3.1)	8.15 (7.1)	9.94 (7.34)
5	3.48 (2.6)	6.63 (6.1)	8.07 (6.4)
2	2.68 (2.0)	5.10 (4.6)	6.21 (5.25)
1	2.01 (0.9)	3.83 (...)	4.66 (....)

Note: Figures in parenthesis represent official gage data.

cm/h = in./h x 2.54

The area tributary to an inlet is usually dependent on the inlet spacing. For a given rainfall intensity, inlet spacing is dependent primarily on the longitudinal slope of the gutter and the allowable spread of water on the traveled way. Using the typical city street cross-section shown in Figure 6 and assuming a maximum allowable water spread of 182.9 cm (6 ft), excluding 33.5 cm (1.1 ft) of gutter width, the depth of flow at the curb would be 8.2 cm (0.27 ft). Based on the curb depth of 8.2 cm, the maximum flows and corresponding velocities for various longitudinal gutter slopes are shown in Table 9, as computed by using a modified form of Manning's equation [68]:

$$Q = 0.56\ (Z/n)\ S_o^{1/2}\ d^{8/3} \qquad (1)$$

where Q = rate of discharge, cfs
Z = reciprocal of the gutter cross slope (T/d)
n = Manning's coefficient of channel roughness
S_o = longitudinal slope, ft/ft
T = top width of water surface, ft
d = depth of channel at deepest point, ft

The true Manning equation cannot be used without modification to compute flow in triangular gutter sections because the hydraulic radius does not adequately describe the gutter cross-section, particularly when the top width T of water surface may be more than 40 times the depth d at the curb. To compute gutter flow, the Manning equation for an increment of width is integrated across the width T using Equation 1. Equation 1 ignores the resistance of the curb face, but this resistance is negligible from a practical viewpoint, provided that the width of flow is at least 10 times the depth at the curb face. Equation 1 gives a discharge about 19 percent greater than the incorrect solution, obtained by computing the discharge by the true Manning equation.

TABLE 9. TYPICAL MAXIMUM GUTTER FLOWS ON OLDER CITY STREETS

Longitudinal gutter slope, m/m	Q, L/s (cfs)	V, cm/s (ft/s)
0.002	25.2 (0.89)	36.6 (1.20)
0.004 (practical minimum)	35.7 (1.26)	51.8 (1.70)
0.010	56.6 (2.0)	82.3 (2.70)
0.060	138.8 (4.9)	201.8 (6.62)
0.100 (practical maximum)	179.0 (6.32)	260.3 (8.54)

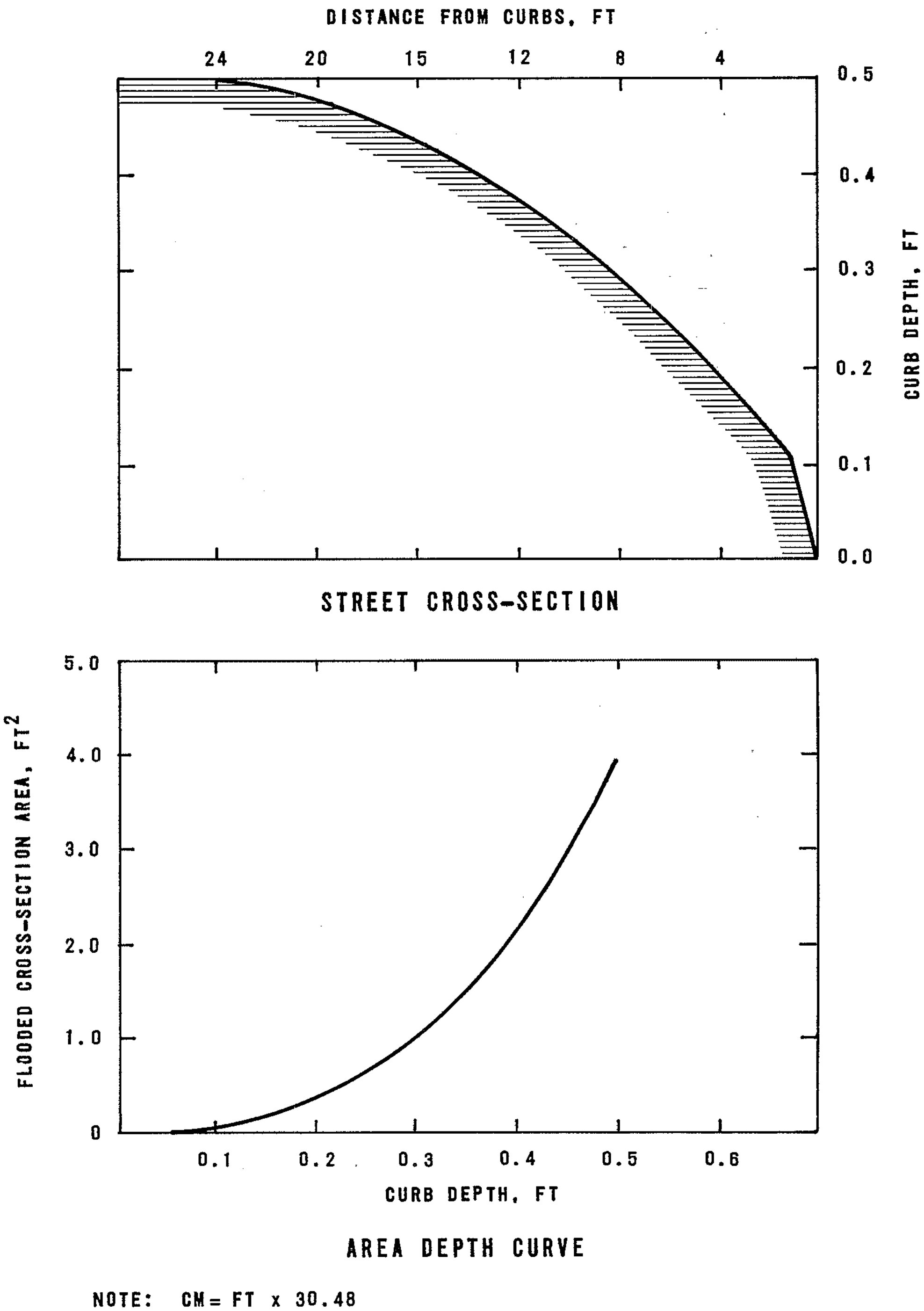


Figure 6. Typical old street cross-section [68].

The corresponding tributary paved areas for the cities in Table 8 can be determined using the Rational formula,

$$Q = CiA \tag{2}$$

where Q = maximum rate of runoff, cfs
C = runoff coefficient = 0.8 to 0.9 for common pavements
i = rainfall intensity corresponding to time of concentration, generally taken as 5 minutes
A = area tributary to inlet, acres

Assuming a 5-year 5-minute storm intensity and a C value of 0.9, tributary paved areas are as given in Table 10. The importance of knowing the tributary area is that the pollutant load entering a catchbasin is directly related. The nature of this relationship is considered in a subsequent subsection.

TABLE 10. TYPICAL TRIBUTARY PAVED AREAS TO CATCHBASINS

Longitudinal gutter slope, m/m	Area, acres		
	San Francisco	Chicago	Washington, D.C.
0.002	0.28 (0.74)	0.15 (0.77)	0.13 (0.41)
0.004	0.40 (1.05)	0.21 (1.08)	0.17 (0.53)
0.010	0.64 (1.68)	0.34 (1.74)	0.28 (0.88)
0.060	1.56 (4.11)	0.82 (4.20)	0.67 (2.09)
0.100	2.02 (5.31)	1.06 (5.44)	0.87 (2.72)

Note: Figures in parenthesis indicate approximate total tributary area, both paved and unpaved, to a catchbasin [84, 42, 80].

ha = acres x 0.40

CATCHBASIN HYDRAULICS

The hydraulics of a catchbasin are defined and determined by the geometric configuration. The standard basin is basically a barrel 182.9 cm (6 ft) deep and 121.9 cm (4 ft) in diameter with an open top covered by a grating and an outlet pipe mounted at the side approximately 107 cm (3-1/2 ft) above the bottom. The hydraulics of such a system are best defined by following the flow from the top entrance through the intermittent storage in the barrel to the outflow through the pipe outlet.

The entrance flow conditions vary from a simple drop inlet condition to free surface, peripheral, weir-type overflow to orifice flow entering a barrel. Obviously, the inflow pattern is modified by the grating, which tends to spread the flow over the top and to direct the flow in the form of jets falling between the grating bars. The approach flow conditions also play an important role, especially if there is a considerable approach velocity. With a diminishing velocity of approach, the inflow into the catchbasin is more uniform, and the discharge into the catchbasin is more uniform and more concentrated around the periphery. Comparative data on the intake capacities of various inlets are given in Figure 7.

The flow in the barrel of the catchbasin consists first of filling the basin until the water surface reaches the invert of the outlet pipe, at which time a control of outflow is established. Depending on the slope of the pipe and entrance geometry, a discharge control is effected. Under these conditions, two controls exist, and the flow through the basin presents a miniature flood-routing phenomenon of inflow from the top, temporary storage in the basin, and controlled outflow into the outlet pipe.

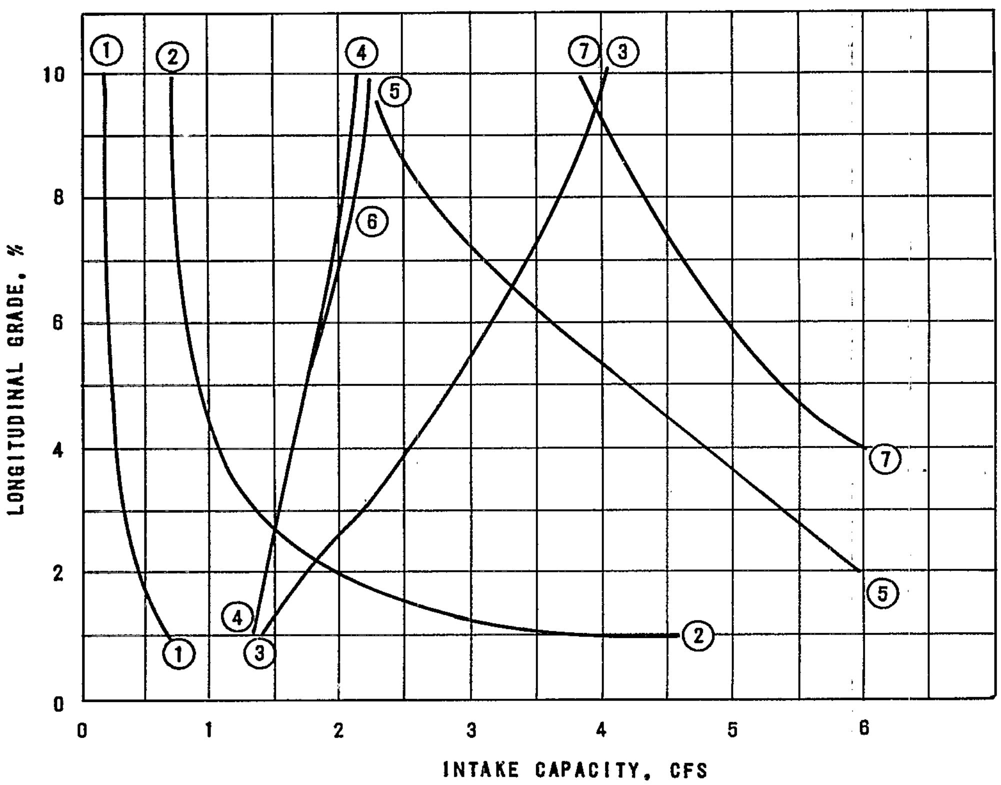
The control at the outlet pipe is typical of discharge characteristics through a closed conduit, generally defined in hydraulics as culvert flow. Different regimes can be established for such a flow, beginning with weir control, proceeding to orifice control, and finally reaching full pipe flow. Once the opening becomes submerged, the discharge capacity diminishes (discharge to square root of head relationship for pressure flow, as contrasted to discharges to headwater to 3/2 power relationship for open channel flow). If the outlet end is submerged, the capacity will depend on the hydraulic gradient between the head in the barrel and the head at the end of the outlet pipe.

When the flow in the outlet pipe becomes pressure flow and the catchbasin is full, the head differential between the surface on the street and pressure gradient in the main sewer conduit determines the flow conveyance and discharge. The two controls merge into one, and the geometric configurations of the barrel and the entrance into the pipe outlet become important only in terms of the coefficient for minor losses.

Influence of Various Parameters on Hydraulics

The key parameters in controlling the flow through the basin are the geometric configuration of the top entrance (see Figure 7), the volumetric capacity of the catchbasin, and the elevation, slope, and entrance geometry of the outlet conduit. By properly changing these variables, the catchbasin system can be optimized to make it hydraulically most efficient for whatever purposes are intended.

CURVE ① CURB OPENING, NO DEPRESSION, GRATE LENGTH, L = 10 FT
CURVE ② CURB OPENING, 2½-IN. DEPRESSION, L=10 FT
CURVE ③ CURB OPENING, 3-FT WIDE DEFLECTOR, L=8.33 FT
CURVE ④ GRATE, NO DEPRESSION, W=2.5 FT, L=2.5 FT
CURVE ⑤ GRATE, 2½-IN. DEPRESSION, W=2.5 FT, L=2.5 FT
CURVE ⑥ COMBINATION, NO DEPRESSION
CURVE ⑦ COMBINATION, 2½-IN. DEPRESSION



NOTE: CM = FT x 30.48

Figure 7. Comparison of inlets: intake capacity at 95% capture of gutter flow: Manning's n = 0.013; cross slope = 0.0417 ft/ft [76].

Control of the Flow of Solids

Control of the solids flow by an intentional retention or sluicing of solid material through the catchbasin can be effected by modifications in catchbasin geometry. Establishing a controlled conveyance and detention of flow, such a design can be developed by experimental means. By use of baffles, separate compartments, or flow-controlled devices (like weirs, orifices, or side weirs), a flow conveyance can be established so that the flow pattern is effective for whatever action is intended in the movement of solid material. The consideration of turbulence, flow agitation, and other conditions plays an important part in proper development of the necessary geometry.

Other methods for the conveyance or separation of solid material include swirl chambers, spiral flow, flow around bends, and other ways of exploiting some definite hydraulic characteristics.

POLLUTANT CHARACTERISTICS

Pollutants in stormwater can be divided into the four general categories of floatable, dissolved, suspended, and settleable material. Each category can be further subdivided into organic and inorganic components.

Because this report is concerned primarily with catchbasin performance, the pollutant sources of interest are limited to street accumulations and to those pollutants generated in catchbasins. Stormwater pollutants are of concern only for gross comparisons, because collected stormwater contains pollutants from other sources as well as catchbasins. Unfortunately, these limitations also greatly reduce the amount of available data. Although many studies have been performed on stormwater after collection (for example, in combined or storm sewers), few studies have been performed on catchbasin pollutants.

From a recent study that dealt principally with street surface contaminants on a nationwide basis, the following applicable conclusions were formed [66].

1. Runoff from street surfaces is generally highly contaminated.

2. The major constituent of street surface contaminants is inorganic, mineral-like matter, similar to common sand and silt.

3. A great portion of the overall pollutional potential is associated with the fine solids fraction of the street surface contaminants.

4. On the basis of specially conducted field studies, catchbasins (as they are normally used) are reasonably effective in removing coarse inorganic solids from storm runoff (coarse sand and gravel) but ineffective in removing fine solids and most organic matter.

Little information is available on the floatable portion or the dissolved portion of street contaminants. However, the suspended and settleable solids portion of street surface contaminants has been studied with respect to particle size and distribution and the distribution of organic, inorganic, and specific pollutants [66]. The following qualifications justify consideration of the suspended solids portion only:

1. The dissolved portion of runoff passes on into the storm or combined sewer regardless of the type of intermediate device, whether it is a catchbasin or inlet. The relationship that may exist between dissolved solids generated by street cleaning practices and those occurring naturally has not been studied.

2. The floatable portion is almost impossible to characterize, as it varies from oil droplets to small beach balls and does not seem to be a function of land use classification. The only apparent quantity trait for large floatables deposited on the street surface is their proportionality to street cleaning practices.

3. In one study it was found that an average of 92 percent (by weight) of the *in situ* street litter collected in the sampling program passed through a 2,000 micron screen (10 mesh) and was composed mainly of dust, dirt, sand, and gravel [66].

Particle Size and Distribution

In a recently completed nationwide study of street surface contaminants [66], the contaminants usually found on typical American streets were characterized with respect to particle size; distributions for five cities are reported in Table 11. Street solids loading by land use and as a function of the distance from the curb are given in Table 12.

Using the data derived in this study, a street surface particle size distribution simulant was developed for use in experimental studies, as shown in Table 13.

TABLE 11. PARTICLE SIZE DISTRIBUTION OF SOLIDS, SELECTED CITY COMPOSITES [66]

Particle size ranges	Milwaukee	Bucyrus	Baltimore	Atlanta	Tulsa
Distribution, %[a]					
>4,800 μ	12.0	....	17.4	....	.....
2,000-4,800 μ	12.1	10.1	4.6	14.8	37.1
840-2,000 μ	40.8	7.3	6.0	6.6	9.4
246-840 μ	20.4	20.9	22.3	30.9	16.7
104-246 μ	5.5	15.5	20.3	29.5	17.1
43-104 μ	1.3	20.3	11.5	10.1	12.0
30-43 μ	4.2	13.3	10.1	5.1	3.7
14-30 μ	2.0	7.9	4.4	1.8	3.0
4-14 μ	1.2	4.7	2.6	0.9	0.9
<4 μ	0.5	....	0.9	0.3	0.1
Sand, %					
43-4,800 μ	92.1	74.1	82.1	91.9	92.3
Silt, %					
4-43 μ	7.4	25.9	17.1	7.8	7.6
Clay, %					
<4 μ	0.5	....	0.9	0.3	0.1
Sand, kg/curb km (lb/curb mi)	699 (2,480)	288 (1,020)	238 (845)	111 (394)	85 (300)
Silt, kg/curb km (lb/curb mi)	56 (200)	100 (356)	50 (176)	9.5 (33.5)	8.5 (30)
Clay, kg/curb km (lb/curb mi)	3.8 (13.5)	....	2.6 (9.3)	0.4 (1.3)	0.1 (0.3)

Note: μ = microns.

a. By weight unless otherwise noted.

TABLE 12. STREET SOLIDS LOADING BY LAND USE [66]

Use	Quantity, kg/curb km (lb/curb mi)	Range, kg/curb km (lb/curb mi)
Residential	338 (1,200)	9-1,946 (31-6,900)
Industrial	790 (2,800)	68-3,384 (240-12,000)
Commercial	102 (360)	17-338 (60-1,200)
Mean value	395 (1,400)	....

Street location, distance from curb, cm (in.)	Solids loading intensity, % of total
0-15.2 (0-6)	78
15.2-30.5 (6-12)	10
30.5-101.6 (12-40)	9
101.6-243.8 (40-96)	1
243.8 (96) to centerline	2

TABLE 13. STREET SURFACE SIMULANT [66]

Particle size, μ	Composition, % by weight	Description[a]
2,000	8	Very coarse sand
840-2,000	20	Coarse sand
246-840	30	Medium sand
104-246	20	Fine sand
43-104	16	Very fine sand
43	6	Coarse silt

a. Handbook of Applied Hydrology.

Organic and Inorganic Pollutants

The quantities of various pollutants found on street surfaces are summarized on a weighted mean basis in Table 14. The distribution of various pollutants associated with a particle size range is presented in Table 15. As can be seen, the very fine silt-like material (less than 43 microns) accounts for only 5.9 percent of the total solids, but it accounts for about 25 percent of the oxygen demand and from 30 to 50 percent of the algal nutrients. This concentration of pollutants in the very fine material is important because the catchbasin does not efficiently trap particles in this size range and thus allows a large percentage of these pollutants to pass through.

TABLE 14. CONTAMINANT CHARACTERISTICS AND QUANTITY SUMMARY [66]

Measured constituents	Weighted mean for all samples, kg/curb km (lb/curb mi)
Total solids	395 (1,400)
Oxygen demand	
BOD_5	3.8 (13.5)
COD	27 (95)
Volatile solids	28 (100)
Algal nutrients	
Phosphates	0.3 (1.1)
Nitrates	0.026 (0.094)
Kjeldahl nitrogen	0.62 (2.2)
Bacteriological	
Total coliforms, org/curb mi[a]	99×10^9
Fecal coliforms, org/curb mi	9.6×10^9
Heavy metals	
Zinc	0.18 (0.65)
Copper	0.06 (0.20)
Lead	0.16 (0.57)
Nickel	0.01 (0.05)
Mercury	0.02 (0.073)
Chromium	0.03 (0.11)
Pesticides	
p, p-DDD	$19 (67) \times 10^{-6}$
p, p-DDT	$17 (61) \times 10^{-6}$
Dieldrin	$6.8 (24) \times 10^{-6}$
Polychlorinated biphenyls	$310 (1,100) \times 10^{-6}$

a. The term "org" refers to the number of coliform organisms observed.

TABLE 15. FRACTION OF POLLUTANT ASSOCIATED WITH EACH PARTICLE SIZE RANGE, PERCENT BY WEIGHT [66]

Constituent	Particle size, μ					
	>2,000	840-2,000	246-840	104-246	43-104	<43
Total solids	24.4	7.6	24.6	27.8	9.7	5.9
Volatile solids	11.0	17.4	12.0	16.1	17.9	25.6
BOD_5	7.4	20.1	15.7	15.2	17.3	24.3
COD	2.4	4.5	13.0	12.4	45.0	22.7
Kjeldahl nitrogen	9.9	11.6	20.0	20.2	19.6	18.7
Nitrates	8.6	6.5	7.9	16.7	28.4	31.9
Phosphates	0	0.9	6.9	6.4	29.6	56.2
Total heavy metals	16.3	17.5	14.9	23.5	----27.8----	
Total pesticides	0	16.0	26.5	25.8	----31.7----	

Catchbasin Loading Intensity

The principal factors affecting the loading intensity at any given site include the following: surrounding land use, the elapsed time since streets were last cleaned (either intentionally or by rainfall), local traffic volume and character, street surface type and condition, public works practices, and season of the year [66].

In addition to the street surface contaminants, other materials, such as crankcase drainings, leaves, and grass clippings, are frequently discarded into catchbasins. This additional loading is highly variable, highly polluting, and difficult to estimate. A survey of San Francisco catchbasins, which illustrates the wide range of pollutant loading, is shown in Table 16.

Sediment Pollution

Although the sedimentation problem is primarily related to the runoff that enters streams directly rather than the runoff that flows through the storm drainage system, it is obvious that self-cleaning storm drains could contribute large quantities of sediment to waterways. These sediments can damage biological structures, bury organisms, and clog respiratory, feeding, and digestive organs [66]. In addition, sediment can contribute to flooding problems by raising stream beds and clogging drainage structures. Increased water treatment costs are associated with increased turbidity of the water. Decreased reservoir capacity caused by sedimentation is an expense that can be quite large.

TABLE 16. ANALYSIS OF CATCHBASIN CONTENTS, CITY OF SAN FRANCISCO, 1970 [65]

Catchbasin location	First sampling series, mg/L				Second sampling series, mg/L			
	COD	BOD_5	Total N	Total P	COD	BOD_5	Total N	Total P
Plymouth and Sadowa	3,860	190	10.9	<0.2	8,610	122	2.8	0.3
7th and Hooper	15,000	430	33.2	<0.2	2,570	170	2.0	<0.2
Yosemite	739	11	1.8	<0.2	21,400	120	4.6	<0.2
40th and Moraga	9,060	40	16.1	<0.2	51,000	130	12.0	<0.2
Mason and O'Farrell	8,100	130	29.7	<0.2	7,720	85	16.5	<0.2
32nd and Taraval	153	5	0.5	<0.2	708	15	1.4	<0.2
Haight and Ashbury	37,700	1,500	1.4	<0.2	143,000	420	14.6	<0.2
Marina area	701	100	7.0	<0.2	8,600	40	0.5	<0.2
Montgomery Street	6,440	390	18.8	<0.2	8,160	300	3.9	<0.2
Webster and Turk	1,440	44	14.0	<0.2	....	...	....	...
Lower Selby	288	6	1.4	<0.2	....	...	....	...
Upper Mission	5,590	50	12.0	0.2	....	...	....	...

Note: Both sampling series were conducted in winter 1970. All values based on an analysis of total basin contents after complete mixing.

Increased sediment pollution is associated with construction and urbanization; the pollution usually decreases after the construction phase is completed. Predevelopment background sediment yields generally range from 7.0×10^4 to 17.5×10^4 $kg/km^2 \cdot yr$ (200 to 500 $tons/mi^2 \cdot yr$) [105]. Sediment yields for various locations and conditions of land use are shown in Table 17.

SOLIDS WASHOFF

Solids movement phenomena from the surface of the street to the gutter, and then along the gutter to the inlet and into a catchbasin, are mainly a function of the following factors: rainfall intensity, longitudinal slope of street, cross slope of street, antecedent dry period, land use, size and shape of drainage area, type and condition of street surface, season of year, street sweeping program, size distribution and availability of solids, and possibly others.

TABLE 17. REPRESENTATIVE DATA ON SEDIMENT YIELD [105]

Location	Drainage area, km^2 (mi^2)	Sediment yield, $kg/km^2 \cdot yr$ ($tons/mi^2 \cdot yr$)	Condition
Johns Hopkins University, Baltimore, Md.	0.0065 (0.0025)	48.9×10^6 (140,000)	Construction site
Tributary Mineback Run, Towson, Md.	0.081 (0.031)	27.9×10^6 (80,000)	Commercial
Tributary, Kensington, Md	0.24 (0.091)	8.38×10^6 (24,000)	Housing subdivision
Oregon Branch, Cockeysville, Md.	0.61 (0.236)	25.1×10^6 (72,000)	Industrial park

On the basis of experimental studies, it has been concluded that:

1. The soluble fractions go into solution. The impacting raindrops and the horizontal sheetflow provide good mixing turbulence and a continuously replenished clean "solvent."

2. Particulate matter (from sand size to colloidal size) is dislodged from its resting place by the impact of falling drops. Once dislodged, even reasonably heavy particles will be maintained in a state of pseudo-suspension by the repeated impact of adjacent drops, creating a reasonably high general level of turbulence [66].

Various equations have been developed to represent the solids washoff phenomenon. Perhaps the most utilized is that developed for the Storm Water Management Model [81].

At the start of the rain, the amount of a particular pollutant on surfaces which produce runoff (both impervious and pervious) will be P_o , pounds per subarea. Assuming that the pounds of pollutant washed off in any time interval, dt , are proportional to the pounds remaining on the ground, P , the first order differential equation is:

$$\frac{-dP}{dt} = kP \qquad (3)$$

which integrates to

$$P_o - P = P_o(1-e^{-kt}) \qquad (4)$$

in which $P_o - P$ equals the pounds washed away in the time, t .

In order to determine k, it was assumed that k would vary in direct proportion to the rate of runoff, r, or $k = br$. To determine b it was assumed that a uniform runoff of 0.5 inch per hour would wash away 90 percent of the pollutant in one hour. This leads to the equation:

$$P_o - P = P_o(1-e^{-4.6rt}) \qquad (5)$$

where r = Runoff rate (in./hr)
t = Time interval (hr)

The use of Equation 5 is illustrated in Section 7. Modifications to this equation by the University of Cincinnati [64] and URS Research Company [109] provide for use of alternate units and site specific data. In the Storm Water Management Model version, an availability factor "A" of pollutants available for washoff is used for site specific calibration.

SECTION 6

HYDRAULIC MODELING ANALYSES

In the preceding sections, the functions of catchbasins and design and maintenance practices were identified, and the principal variables believed to affect performance were reviewed with respect to the removal of pollutants found in stormwater. Through these studies it was observed that virtually no basic documentation exists on the operational characteristics of catchbasins. Specifically, no data were found relating performance to basin geometry, flow, influent solids gradation, and accumulated sediment within the basins. To fill this data gap, controlled hydraulic modeling analyses were performed and the results are presented in this section.

The following presentation is extracted and adapted from Hydro-Research-Science Project Report No. HRS-039-75 "Catchbasin Hydraulic Model Studies of Flow Conveyance and Pollution Control" by Dr. Alexander B. Rudavsky, November 1975, performed under subcontract to this study.

OBJECTIVES

The flow-through pattern in catchbasins involves a three-dimensional flow, the configuration and complexity of which depend on the shape of the structure and the peripheral flow conditions. Such flows are complex and not subject to computational analysis. To analyze the flow patterns in existing catchbasins and to develop a design for future units, modeling techniques are imperative. Also, an experimental approach through model studies is required to assess the efficiency of solids capture quantitatively.

The objectives of the adopted modeling program were to test and document the following:

- Flow-through variations from 5.7 to 175.6 L/s (0.2 to 6.2 cfs), approximately 4 to 100 percent of maximum expected basin inflows
- Basin geometry variations in barrel diameter, outlet pipe diameter, barrel height, and barrel storage height (defined as height of outlet pipe invert above base)

- Outlet discharge controls, both open and trapped, for conditions from free flow to complete submergence

- Sediment capture as a function of gradation and accumulated sediment

- Performance associated with a recommended design configuration

EXPERIMENTAL SETUP

The setup for the catchbasin experimental program, as shown in Figure 8, consisted of three main components: (1) the catchbasin model, (2) the peripheral simulation of inlet and outlet conditions, and (3) the auxiliary appurtenances, including supportive machinery and storage basins. Model to prototype dimensions were fixed at undistorted linear scale ratios of 1:2.72 or 1:3.40, depending on the prototype barrel diameter simulated.

Components

The catchbasin model consisted of a multisectioned barrel with a movable bottom and two interchangeable outlet pipes, as shown in Figure 9. Bolted and pressure-tight connections provided the flexibility of substituting and removing sections to meet the full range of geometric configurations required. Each component was constructed of transparent plastic, permitting direct observation of the flow when illuminated.

The peripheral flow conditions were simulated by a partial representation of the street, the inlet opening with a grating, and the outlet pipe section, as shown in Figure 10. The street inflow conditions were simulated simply by inclining the surface platform 10 percent longitudinally and 20 percent transversely. The square grating was movable so that the bars could run parallel to, or across, the gutter flow. The outlet pipe was set at an angle of 5.4° below horizontal to force a critical control section at its entry.

Auxiliary equipment included (1) upstream and downstream tanks, (2) a sump to store water, (3) a centrifugal circulating water pump, (4) a system of discharge valves and butterfly regulating valves, (5) a solids feed system and a trap basin to avoid recirculating solids with the water, and (6) a metering system for measuring elevations, velocities, and discharges. In the sediment capture portions of the testing, commercial grade sands and ground sands, as well as a synthesized graded sand mixture, were used.

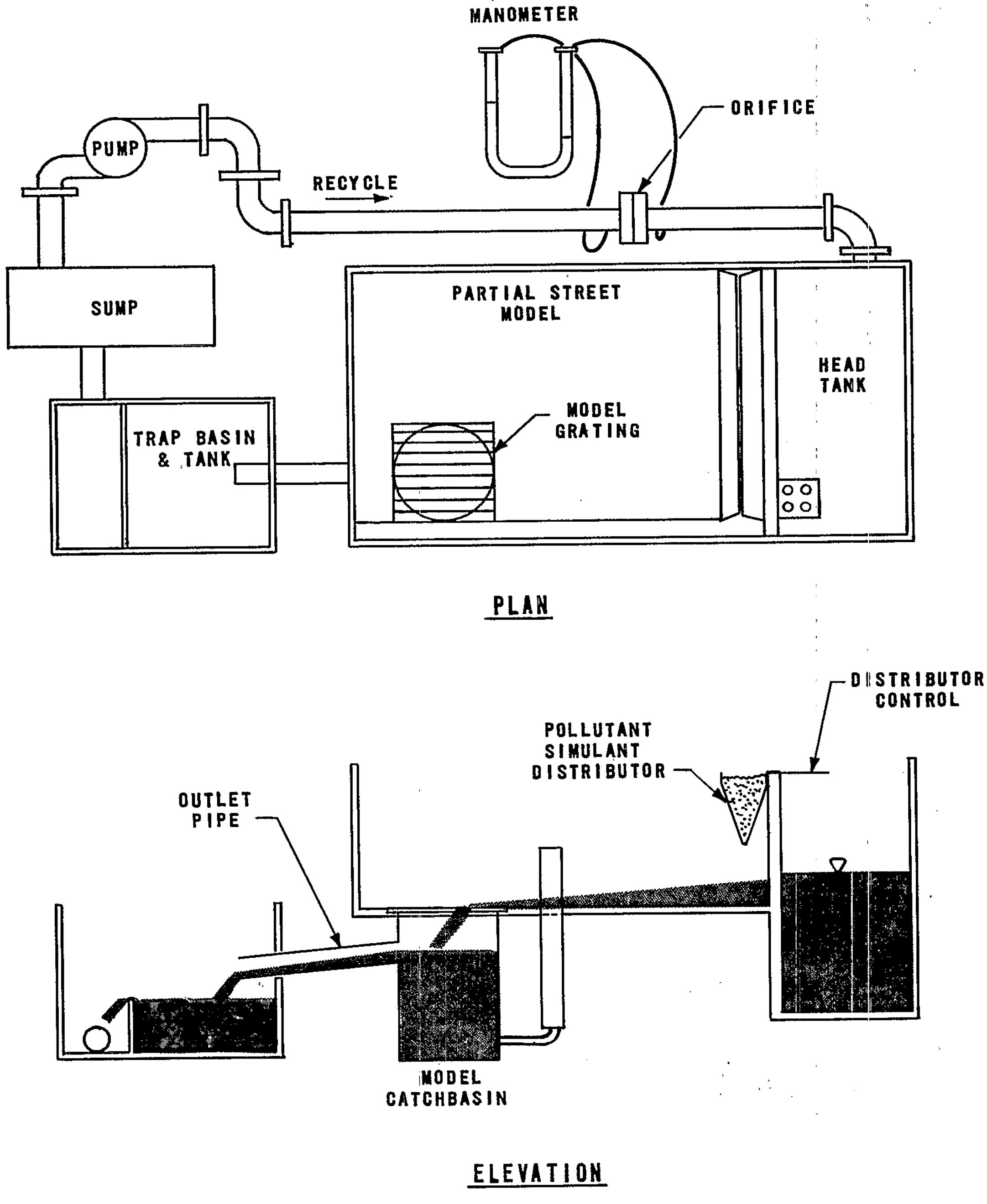


Figure 8. Experimental setup.

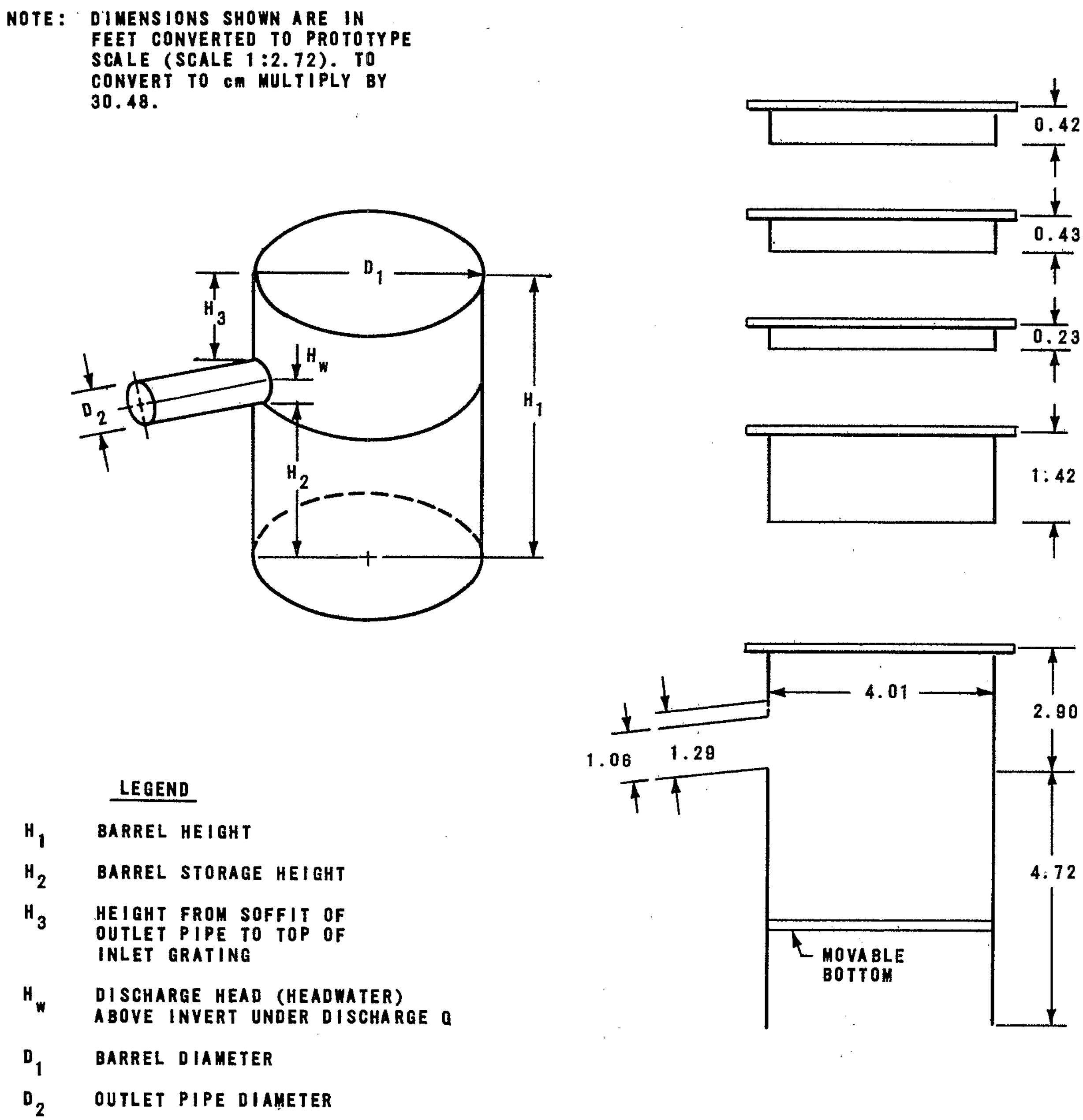
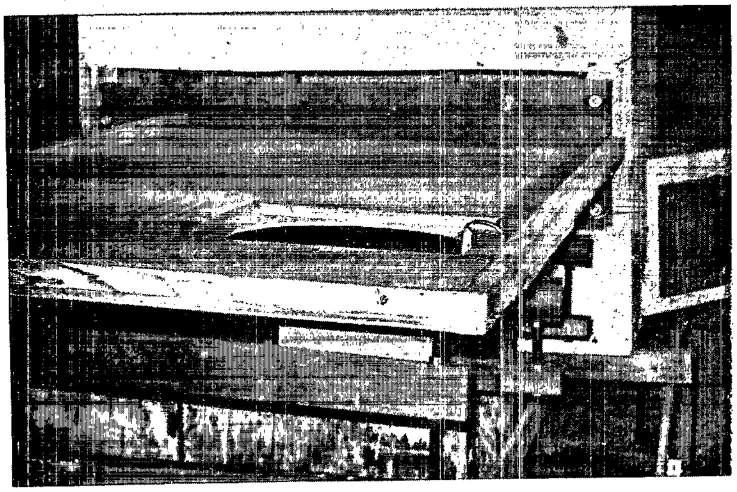


Figure 9. Model catchbasin.

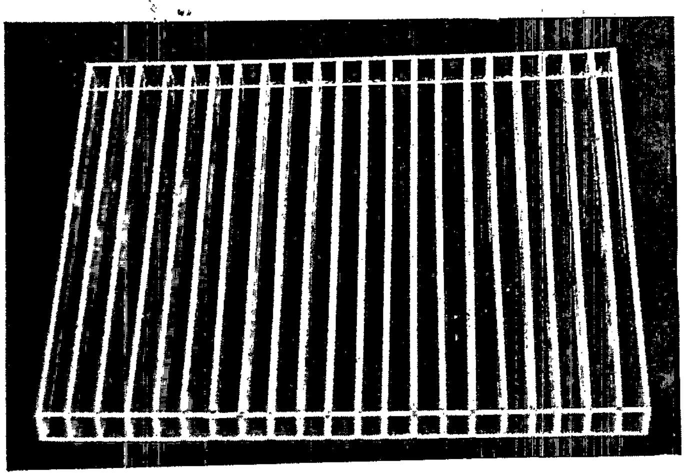
Photograph 1

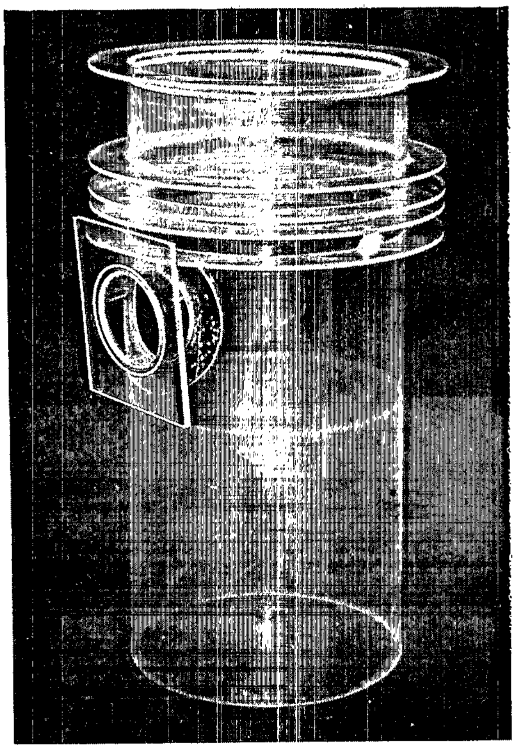
Upstream view of partial street model with the view of head basin and the opening for grating insert.



Photograph 2

Close-up view of model grating.





Photograph 3

Overall view of catch basin barrel assembled.

Figure 10. Model components prior to assembly.

Model Laws and Dimensional Analysis

The mathematical relationships between the model and the prototype, based on the Froude law, are summarized in Table 18. These scale relationships were used to transfer quantitatively the discharge, depth of flow, and velocities from the model to the prototype. Unless otherwise designated or self-evident, only prototype equivalents are presented.

TABLE 18. MODEL TO PROTOTYPE RELATIONSHIPS

Dimension	Ratio of model to prototype	Scale relationships	
Length	$L_r = \frac{L_m}{L_p}$	1:2.72	1:3.40
Area	$A_r = (L_r)^2$	1:7.40	1:11.56
Time	$T_r = (L_r)^{1/2}$	1:1.65	1:1.84
Velocity	$V_r = (L_r)^{1/2}$	1:1.65	1:1.84
Discharge	$Q_r = (L_r)^{5/2}$	1:12.20	1:31.32
Roughness	$n_r = (L_r)^{1/6}$	1:1.18	1:1.23

Note: m = model; p = prototype; r = ratio of model to prototype

Since complete dynamic similarity and accurate reproduction of some prototype properties are not possible, some limitations must be imposed on the model results:

- Measurements of discharge elevations and velocity can be transferred without reservation.
- Since it is not feasible to reproduce the roughness of a concrete surface in a plexiglass model of this scale, some differences in conveyance efficiencies can result. In this case, the differences are considered negligible.
- Air entrainment cannot be modeled by the Froude law alone, and there is now no acceptable method of correlating air entrainment between the model and prototype.
- Grain size dimensioning is based on settlement velocities and subject to many practical limitations. Thus, capture efficiencies are presented as a design guide and not as precise research data.

Dimensional analysis techniques were used to identify and group the significant variables.

EXECUTION

The hydraulic modeling was carried out in four phases:

- Phase 1. An experimental analysis of flow conditions in catchbasins representing current practice
- Phase 2. A selective repetition of Phase 1 tests with standard inlet and outlet modifications
- Phase 3. A series of runs to evaluate sediment capture
- Phase 4. The development and verification of flow conditions in the recommended catchbasin design

Prototype equivalents of variables used in the experimentation are listed in Table 19. Complete tests were run in four physical groupings (based on the ratio of barrel diameter to outlet diameter), three barrel heights (long, medium, and short), and two storage depths (deep and shallow), for a total of 24 discrete configurations.

TABLE 19. PRINCIPAL VARIABLES TESTED

Variable	Range
Discharge, L/s (cfs)	Q_{max} = 178.4 (6.3) Q_{des} = 35.4 (1.25) also Q_{small} = 14.2 (0.5) Q_{min} = 7.1 (0.25)
Barrel diameter, cm (ft)	$(D_1)_{max}$ = 152.4 (5.0) $(D_1)_{min}$ = 121.9 (4.0)
Barrel height, cm (ft)	$(H_1)_{max}$ = 243.8 (8.0) $(H_1)_{medium}$ = 182.9 (6.0) $(H_1)_{min}$ = 121.9 (4.0)
Barrel storage height, cm (ft)	$(H_2)_{max}$ = 121.9 (4.0) (50% of H_1 max) $(H_2)_{max}$ = 30.5 (1.0) (25% of H_1 min)
Exit pipe diameter, cm (ft)	$(D_2)_{max}$ = 38.1 (1.25) $(D_2)_{max}$ = 30.5 (1.0)

Typically, the test procedure was as follows:

1. Set up components in selected configuration.
2. Apply maximum flow and observe approach conditions, flow over grating, and flow conditions in the basin and outlet.
3. Record headwater height (above the invert D_2) and flow patterns, including extensive photography.

4. Trim to next lower flow and repeat until all desired flows are covered.

5. Drain, change to next configuration, and repeat full sequence.

In Phase 3, where solids were applied, only a minimum of experimental setups were used because of the added long drying and weight checking periods required. The range of materials used was chosen from commercially available sand mixtures, defined by their commercial designations as No. 20, No. 30, No. 2, No. 57, and No. 84. Their respective sieve analyses are shown in Figure 11 along with the prototype gradation used by Sartor and Boyd [66].

A limited supportive program was executed to establish the significance of discharge, pollutant load concentration, and test duration to sediment capture results. Commercial No. 20 and No. 30 sands were discharged with different concentrations through a wide range of test durations. For example, No. 20 sand was run separately at a constant feed rate for 25.5, 10.3, and 5.8 minutes for a single discharge. In all of these studies, the retention characteristics appeared to be independent of the concentration, and the deposition was directly proportional to the length of run. Similar results were obtained using No. 2 sand, and it was concluded that the test durations could be uniformly fixed at a nominal 5 minutes for the Phase 3 and Phase 4 studies.

Note that in a typical 5-minute test under maximum flow conditions, over 53,000 L (14,000 gal.) of water was circulated through the test unit carrying approximately 7,100 g (16 lb) of simulant for a mean concentration of 133 mg/L. This is within the typical range expected in surface runoff from streets.

RESULTS

In expressing the experimental results, somewhat detailed descriptions are given for what may appear to the reader to be rather obvious conclusions. The intent is to maximize the benefits of this experimentation for potential future investigations as well as to satisfy the immediate study objectives.

Phase 1 - Hydraulics

In Phase 1, all 24 configurations were tested, and a discharge rating curve was constructed for each configuration. A preliminary assessment was made as to which basins were satisfactory, unsatisfactory, or marginal for sediment capture on the basis of observed turbulence and flow patterns.

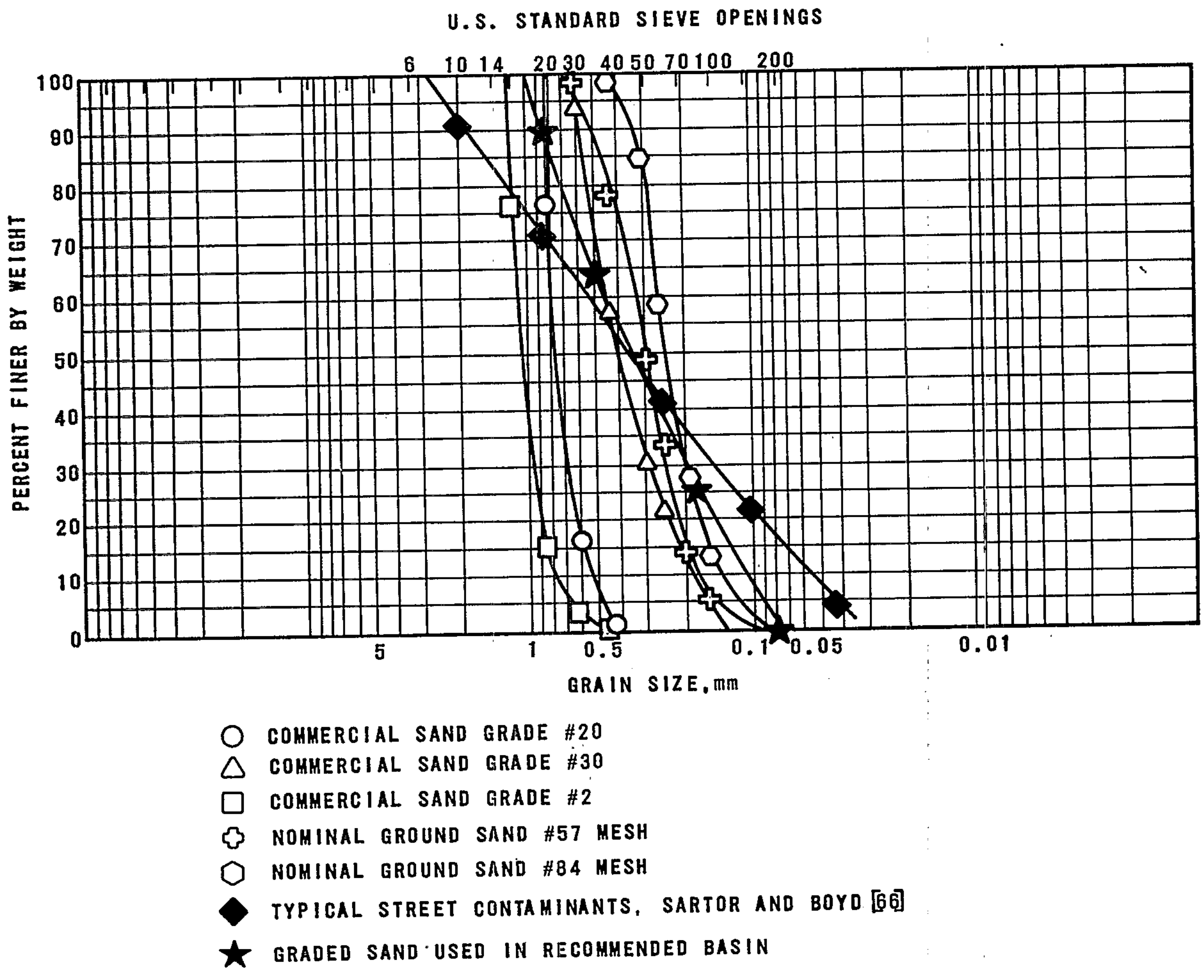


Figure 11. Sieve analyses of test simulants.

Two flow pattern groupings were evident: those influenced by the exit conditions and those generated in the storage basin.

Exit Conditions --

As shown in Figure 12, the outlet pipe controlled the flow through the following ranges, presented in the order of increasing flow: (1) open channel flow, controlled through weir control and directly related to critical depth at the outlet; (2) orifice control flow, controlled by the sharp edges of the entrance to the outlet pipe with subsequent open channel flow in the pipe itself; (3) short tube control flow, controlled in the outlet pipe with a short tube type of control of various lengths; and (4) pipe control with pressure flow existing in the outlet pipe and flowing completely full. Slug flow was also observed where the flow in the pipe contained large bubbles and represented unsteady flow conditions. With the exit pipe set very close to the grating at high discharges, the catchbasin filled up, overflowed, and became totally submerged.

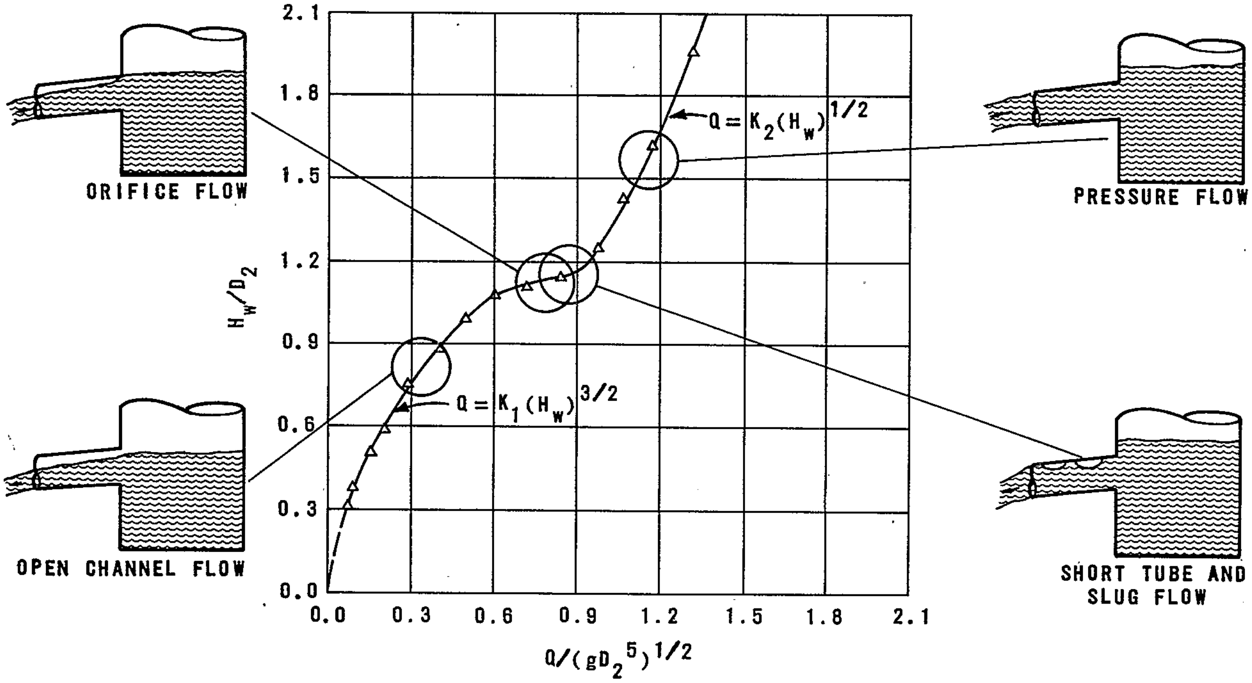


Figure 12. Typical discharge rating curve.

As shown in Figure 12, the discharge-to-headwater relationship can be directly associated to these flow conditions. For open channel flow with critical depth control, the relationship of discharge to headwater has an exponent of 3/2, indicating a large discharge capacity. The discharge-to-headwater relationship for pressure flow has an exponent of only 1/2, indicating a very small discharge capacity. Although the discharge rating curve for each catchbasin configuration is unique, all have the same characteristic shape.

Storage Basin--

Flow patterns in the storage basin depend on its volume, depth, and rate of discharge. The primary patterns are the jet descending from the grating and an eddy pattern induced by that jet in the storage basin. Distinct flow patterns were observed in the experimental program, ranging from a plunging jet for very large discharges inducing a macro eddy to a very weak descending jet sequence being dissipated in the basin. When the storage basin is shallow, the descending jet impinges upon the floor and can go both toward and away from the outlet.

The observed flow and control conditions are identified in Figure 13. Since both the exit conditions and storage basin flow patterns are unique to each basin configuration, the latter can be classified, on the basis of experimental observation, into three basic types: satisfactory, marginal, and unsatisfactory. Typical flow conditions in each broad classification are shown in Figure 14.

Summary--

A review of flow patterns controlled by exit conditions indicates that all flows less than 50 percent of maximum were open channel flows. This clearly indicates such a flow would be expected for the majority of flow patterns. Of the 24 basins investigated and summarized in Table 20, 8 showed satisfactory storage flow conditions (i.e., conditions conducive to solids capture), 4 were marginal, and 12 appeared unsatisfactory. Photographic documentation is presented in Figures 15 through 18.

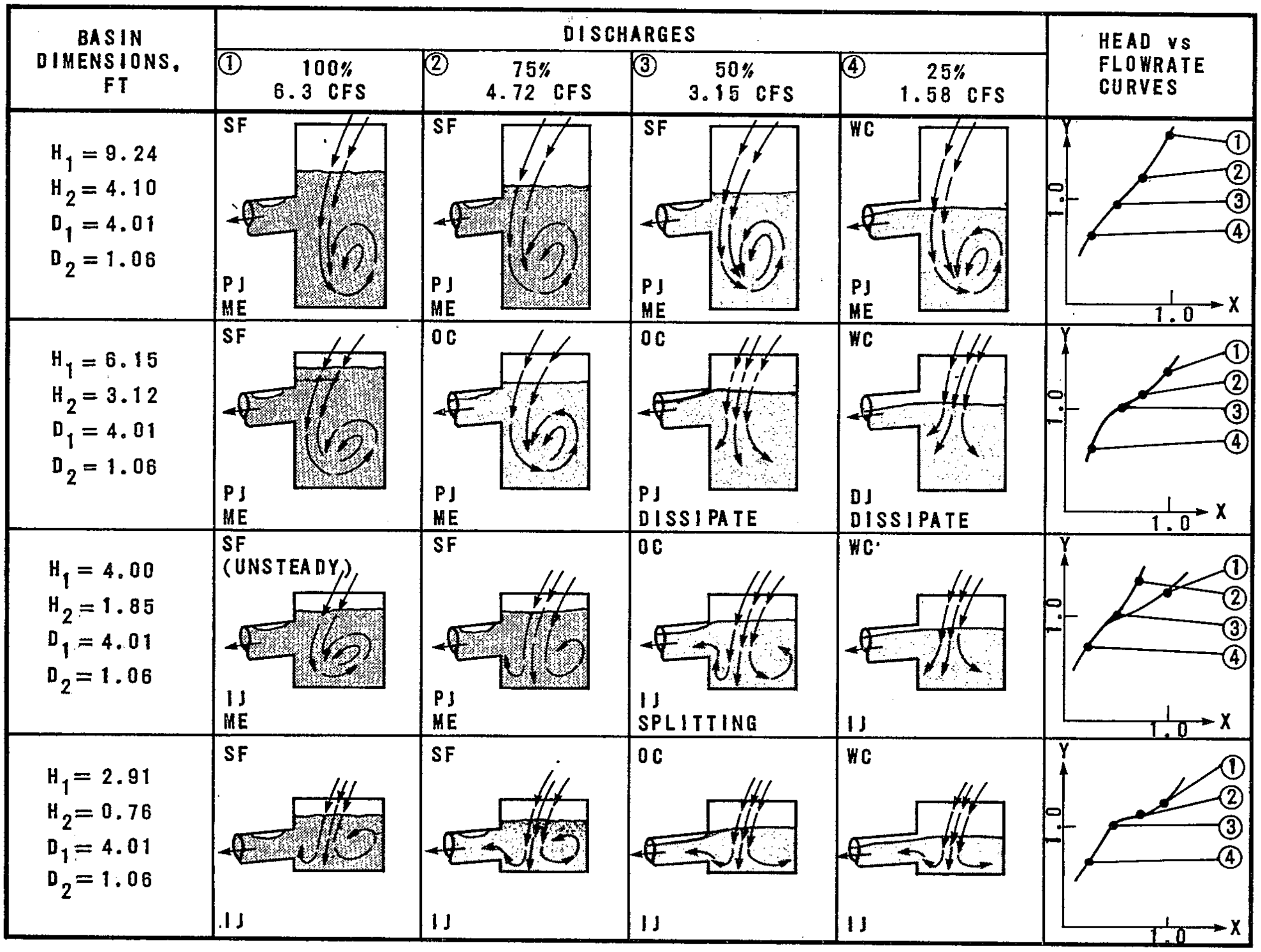
Nominal catchbasin depths of 183 to 244 cm (6 to 8 ft) with 50 percent or greater storage depths ($H_2/D_2 \geq 2.4$) exhibit the best flow conditions for solids capture. The shallow storage configurations ($H_2/D_2 \geq 1.5$) invariably appeared unsatisfactory.

Phase 2 - Standard Modifications

In Phase 2 of the experimental program, the influence of standard modifications to catchbasin inlet and outlet controls was investigated. The first modification involved placing a hood over the entrance to the outlet pipe, and the second involved the addition of a curb protrusion above a portion of the grated inlet. Four catchbasin configurations were tested, all chosen from the marginal or unacceptable categories to magnify any improvements in flow patterns.

In Configuration 11 (Table 20) a small diameter, short height, but deep storage basin was tested first. The curb was moved out 15.2 cm (6 in.) into the gutter but was notched to fully expose the inlet grating, thus simulating a combination grating and curb inlet. The effect on the discharge rating curve was minimal, even under very unstable conditions. Testing the same basin without a protruding curb, but with a hood over the outlet to typify common gas traps, produced a radical change in discharge capacity and a substantially different rating curve. The dramatic decrease in discharge capacity can be observed in Figure 19. Investigation of the influence of the curb and hooded outlet in combination again showed the dominance of the hood's influence and the slight influence of the curb.

The tests were repeated for Configurations 23, 4, and 2 with similar results. From Phase 2 it was concluded that hooded entrances drastically changed the discharge rating curve,



LEGEND

H_1	TOTAL HEIGHT FROM BOTTOM TO TOP OF GRATING
H_2	STORAGE BASIN HEIGHT
D_1	BARREL DIAMETER
D_2	EXIT PIPE DIAMETER
X	$Q/(gD_2{}^5)^{1/2}$
Y	H_W/D_2

ABBREVIATIONS

PJ	PLUNGING JET
IJ	IMPINGING JET
ME	MACRO EDDIES
OC	ORIFICE CONTROL
SF	SLUG FLOW
WC	WEIR CONTROL
DJ	DISSIPATING JET

Figure 13. Observed flow conditions.

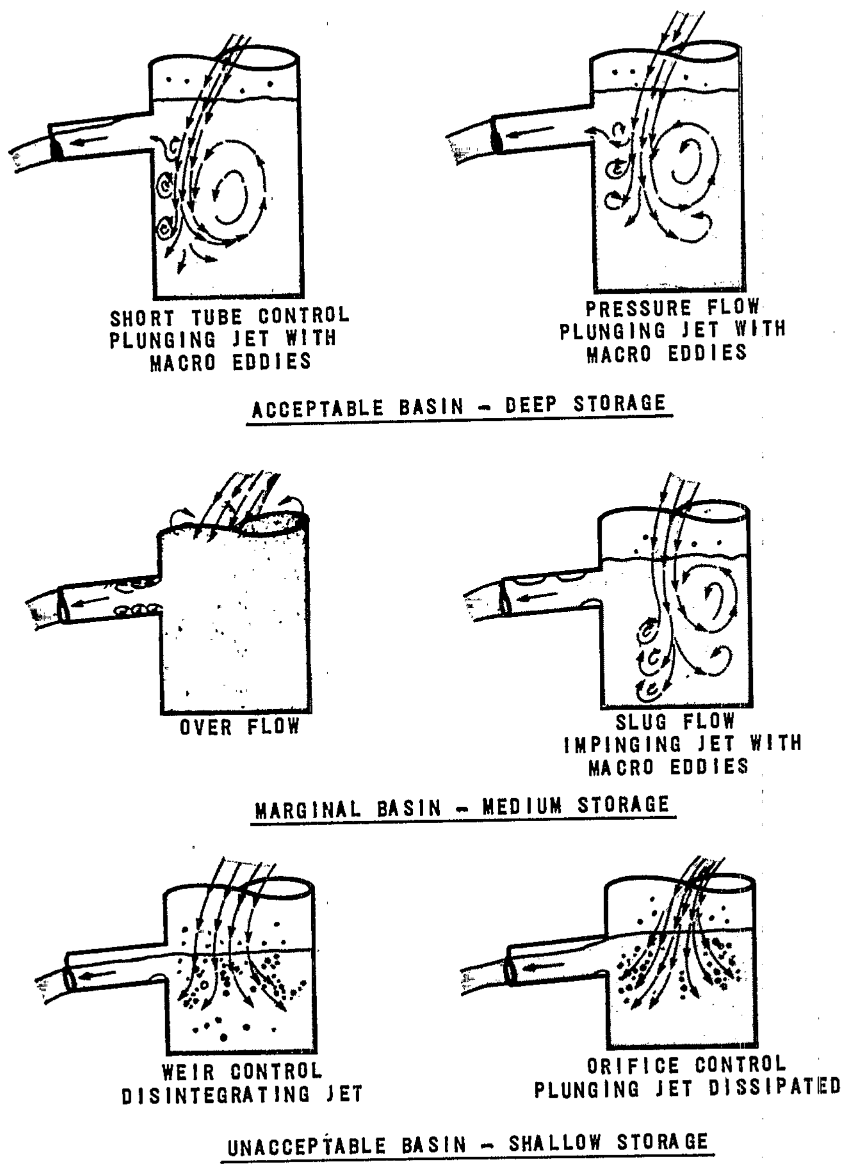


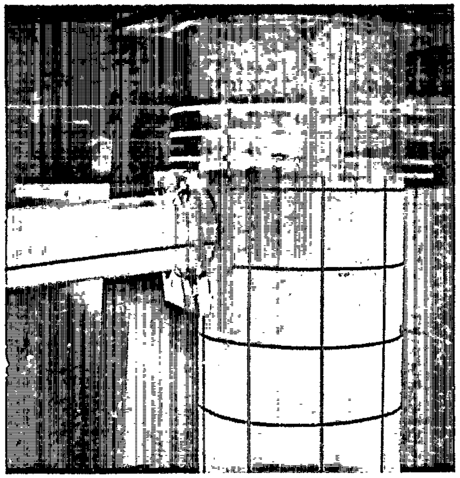
Figure 14. General performance classifications.

TABLE 20. SUMMARY OF PHASE 1 PROGRAM

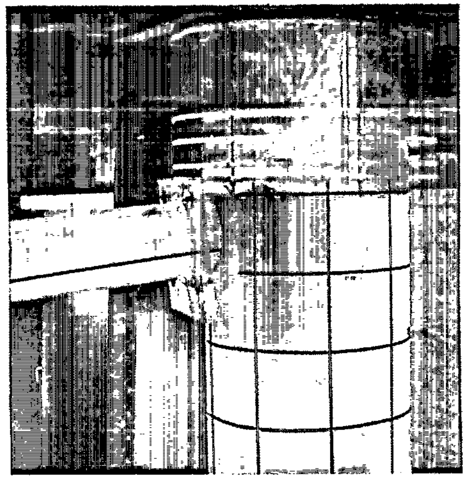
Nominal physical parameters, ft[a]								Flow conditions, H_w/D_2								
								% discharge								
Barrel size	D_1	D_2	Barrel length	H_1	Storage	H_2	H_2/D_2	100	75	50	25	20	8	4	Remarks[b]	Basin configuration
Large	5.00	1.00	Long	8.00	Deep	4.00	4.00	1.22	1.11	0.93	0.64	0.57	0.32	....	S	1
				6.00	Shallow	1.50	1.50	1.22	1.13	0.91	0.64	0.55	....	....	U	2
			Medium	6.00	Deep	3.00	3.00	1.19	1.13	0.96	0.64	0.54	....	....	S	3
				4.50	Shallow	1.12	1.12	1.11	1.08	0.90	0.63	0.58	0.36	....	U	4
			Short	4.00	Deep	2.00	2.00	1.16	1.07	0.91	0.68	0.60	0.38	0.30	M	5
				3.00	Shallow	0.75	0.75	1.16	1.04	0.95	0.76	0.65	0.41	0.32	U	6
Small	4.00	1.00	Long	8.00	Deep	4.00	4.00	1.58	1.20	0.95	0.64	0.60	0.30	....	S	7
				6.00	Shallow	1.50	1.50	1.53	1.18	0.96	0.62	0.60	....	....	U	8
			Medium	6.00	Deep	3.00	3.00	1.22	1.10	1.00	0.68	0.60	....	....	S	9
				4.50	Shallow	1.12	1.12	1.40	1.12	0.96	0.64	0.58	....	....	U	10
			Short	4.00	Deep	2.00	2.00	1.25	1.35	0.98	0.70	0.62	....	....	M	11
				3.00	Shallow	0.75	0.75	1.24	1.11	1.03	0.67	0.60	0.40	0.32	U	12
Large	5.00	1.25	Long	8.00	Deep	4.00	3.20	1.32	1.10	1.00	0.68	0.60	....	....	S	13
				6.00	Shallow	1.50	1.20	1.03	0.93	0.70	0.49	0.42	....	....	U	14
			Medium	6.00	Deep	3.00	2.40	1.03	0.93	0.76	0.49	0.43	....	....	S	15
				4.50	Shallow	1.12	0.90	1.00	0.89	0.70	0.49	0.43	....	....	U	16
			Short	4.00	Deep	2.00	1.60	1.02	0.93	0.72	0.54	0.51	....	....	M	17
				3.00	Shallow	0.75	0.60	1.06	0.94	0.72	0.52	0.46	0.32	0.28		18
Small	4.00	1.25	Long	8.00	Deep	4.00	3.20	1.10	0.97	0.74	0.45	0.42	....	....	S	19
				6.00	Shallow	1.50	1.20	1.08	0.93	0.72	0.52	0.46	....	....	U	20
			Medium	6.00	Deep	3.00	2.40	1.08	0.89	0.68	0.52	0.47	....	....	S	21
				4.50	Shallow	1.12	0.90	1.14	1.00	0.77	0.52	0.46	0.28	....	U	22
			Short	4.00	Deep	2.00	1.60	1.08	0.90	0.78	0.53	0.46	....	....	M	23
				3.00	Shallow	0.75	0.60	1.11	0.98	0.75	0.51	0.46	0.29	0.23	U	24

a. 30.48 cm = 1 ft.

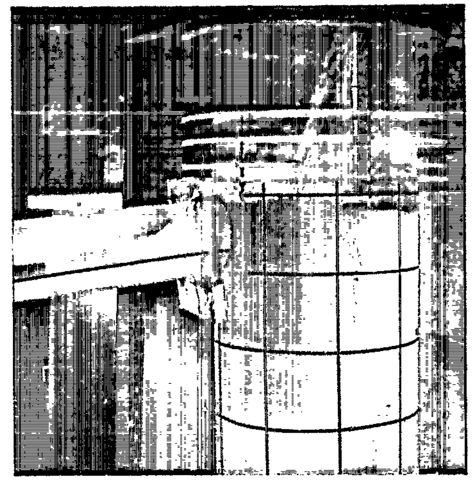
b. S = satisfactory storage; U = unsatisfactory storage; M = marginal storage.



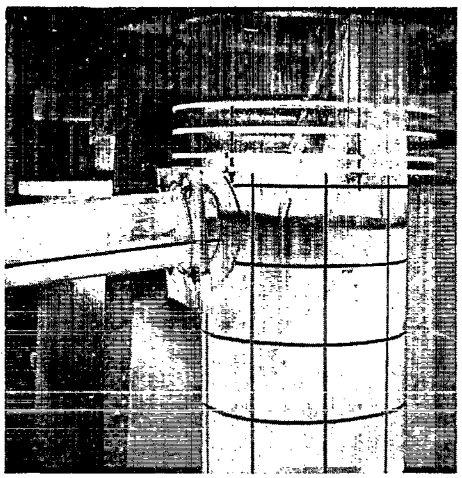
Photograph 4
$Q = 5.43$ cfs (86%) short tube control, plunging jet with macro eddy
$HW/D_2 = 1.12$ $Q/(gD_2^5)^{1/2} = 0.83$



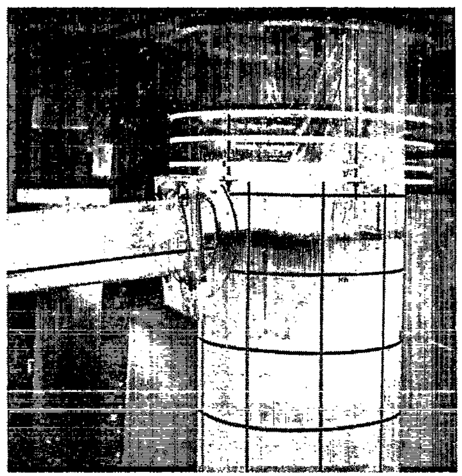
Photograph 5
$Q = 4.06$ cfs (64%) short tube control, plunging jet with macro eddy
$HW/D_2 = 1.02$ $Q/(gD_2^5)^{1/2} = 0.62$



Photograph 6
$Q = 2.72$ cfs (43%) short tube almost orifice control, plunging jet with macro eddy
$HW/D_2 = 0.91$ $Q/(gD_2^5)^{1/2} = 0.42$



Photograph 7
$Q = 1.36$ cfs (22%) weir control, plunging jet with macro eddy
$HW/D_2 = 0.55$ $Q/(gD_2^5)^{1/2} = 0.21$



Photograph 8
$Q = 1.08$ cfs (17%) weir control, plunging jet with macro eddy
$HW/D_2 = 0.48$ $Q/(gD_2^5)^{1/2} = 0.16$

$D_1 = 4.01$ ft; $D_2 = 1.06$ ft

$H_1 = 9.24$ ft; $H_2 = 4.10$ ft

$H_3 = 3.85$ ft; $D_1/D_2 = 3.78$

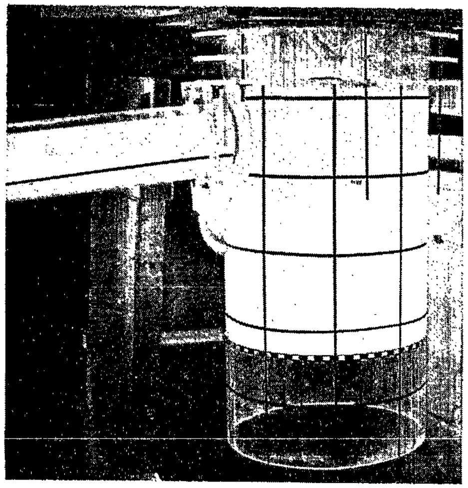
$H_1/D_2 = 8.72$; $H_2/D_2 = 3.87$

$H_3/D_2 = 3.63$

Control and Flow Conditions
In Very Deep Catchbasin ($H_1 = 9.24$ ft)

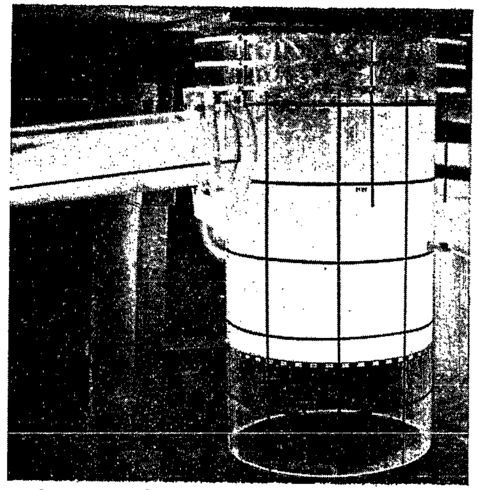
Satisfactory Storage Basin

Figure 15. Photographic record - configuration 7.



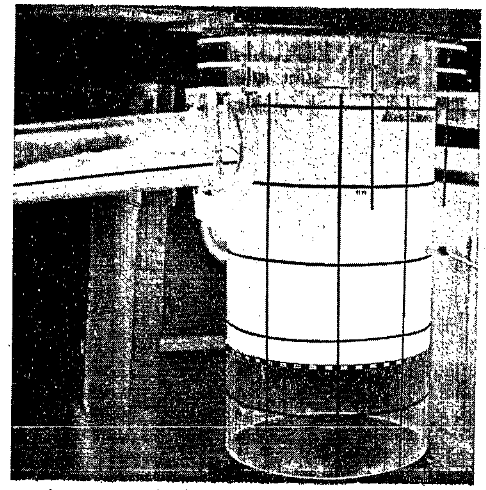
<u>Photograph 9</u>
<u>$Q = 5.43$ cfs</u> (86%) diving jet and macro eddies

$HW/D_2 = 1.17$ $Q/(gD_2^5)^{1/2} = 0.83$



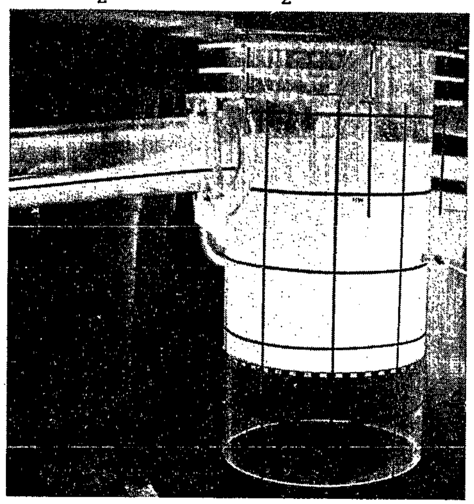
<u>Photograph 10</u>
<u>$Q = 4.06$ cfs</u> (64%) diving jet and macro eddies

$HW/D_2 = 1.06$ $Q/(gD_2^5)^{1/2} = 0.62$



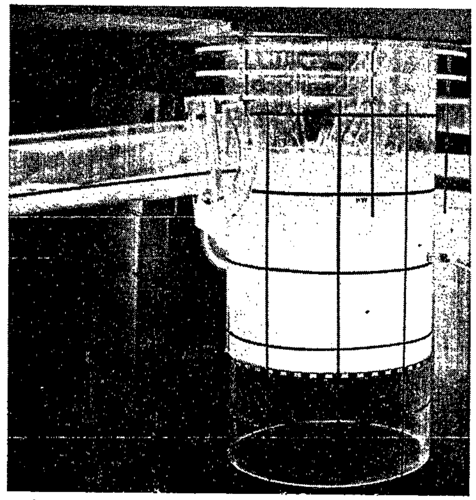
<u>Photograph 11</u>
<u>$Q = 2.72$ cfs</u> (43%) orifice control, diving jet dissipating

$HW/D_2 = 0.93$ $Q/(gD_2^5)^{1/2} = 0.42$



<u>Photograph 12</u>
<u>$Q = 1.36$ cfs</u> (22%) weir control, diving jet dissipating

$HW/D_2 = 0.60$ $Q/(gD_2^5)^{1/2} = 0.21$



<u>Photograph 13</u>
<u>$Q = 1.08$ cfs</u> (17%) weir control, diving jet dissipating

$HW/D_2 = 0.54$ $Q/(gD_2^5)^{1/2} = 0.16$

$D_1 = 4.01$ ft; $D_2 = 1.06$ ft

$H_1 = 6.15$ ft; $H_2 = 3.12$ ft

$H_3 = 1.97$ ft; $D_1/D_2 = 3.78$

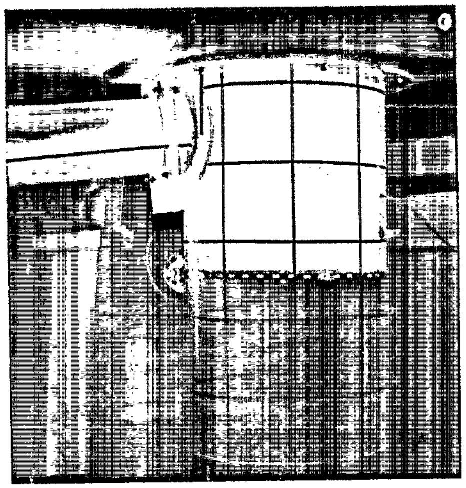
$H_1/D_2 = 5.80$; $H_2/D_2 = 2.94$

$H_3/D_2 = 1.86$

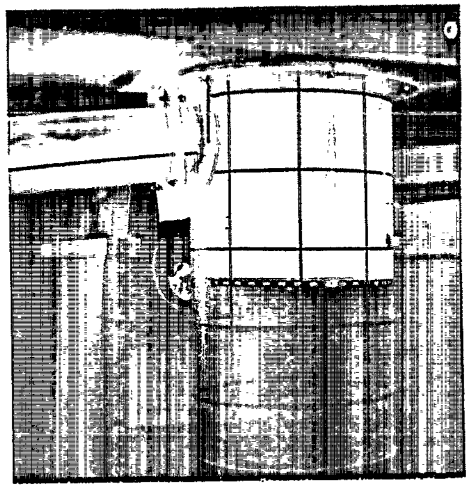
Control and Flow Conditions
In Deep Catchbasin ($H_1 = 6.15$ ft)

Satisfactory Storage Basins

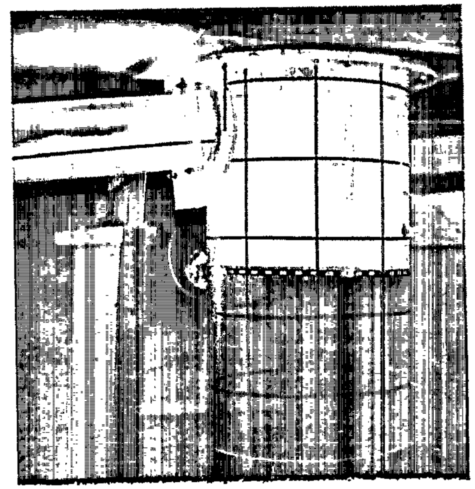
Figure 16. Photographic record - configuration 9.



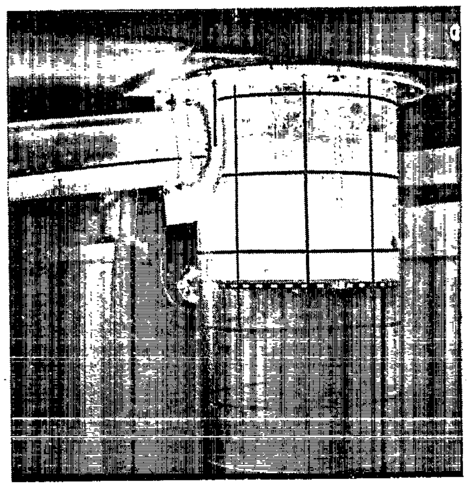
Photograph 14
$Q = 5.43$ cfs (86%) impinging jet
$HW/D_2 = 1.17$ to 1.67 $Q/(gD_2^5)^{1/2} = 0.83$



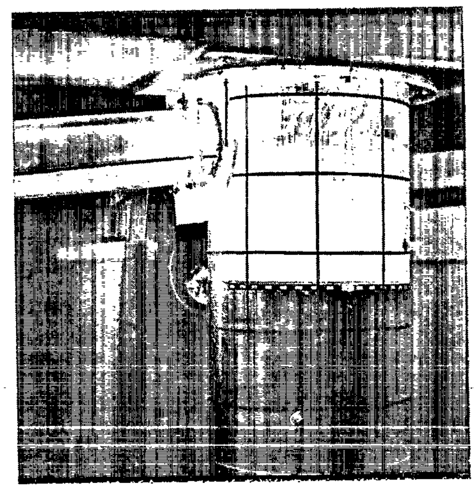
Photograph 15
$Q = 4.06$ cfs (64%) impinging jet
$HW/D_2 = 1.18$ $Q/(gD_2^5)^{1/2} = 0.62$



Photograph 16
$Q = 2.72$ cfs (43%) impinging jet
$HW/D_2 = 0.94$ $Q/(gD_2^5)^{1/2} = 0.42$



Photograph 17
$Q = 1.36$ cfs (22%) dissipating jet
$HW/D_2 = 0.62$ $Q/(gD_2^5)^{1/2} = 0.21$



Photograph 18
$Q = 1.08$ cfs (17%) dissipating jet
$HW/D_2 = 0.56$ $Q/(gD_2^5)^{1/2} = 0.16$

$D_1 = 4.01$ ft; $D_2 = 1.06$ ft

$H_1 = 4.00$ ft; $H_2 = 1.85$ ft

$H_3 = 1.09$ ft; $D_1/D_2 = 3.78$

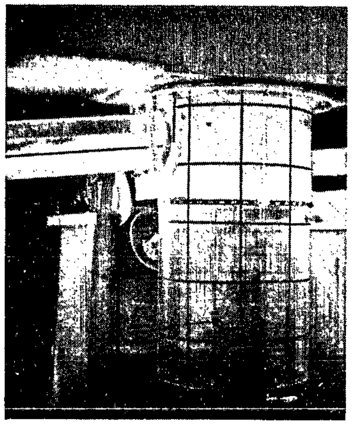
$H_1/D_2 = 3.77$; $H_2/D_2 = 1.74$

$H_3/D_2 = 1.03$

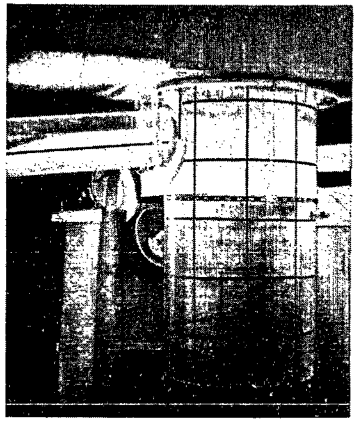
Control and Flow Conditions
In a Medium deep Catchbasin ($H_1 = 4.00$ ft)

Marginal Storage Basin

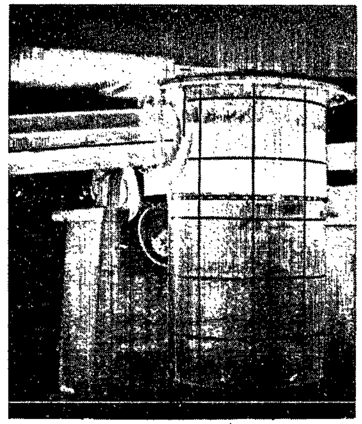
Figure 17. Photographic record - configuration 11.



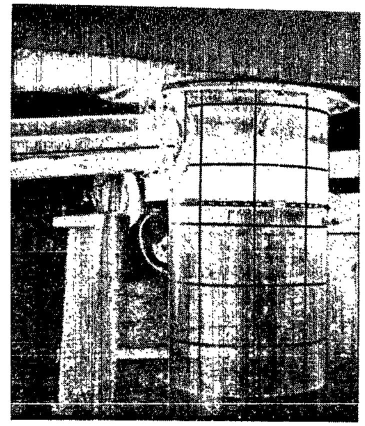
Photograph 19
Q = 5.43 cfs (86%) short tube control, impinging jet
$HW/D_2 = 1.05$ $Q/(gD_2^5)^{1/2} = 0.83$



Photograph 20
Q = 4.06 cfs (64%) short tube control, impinging jet
$HW/D_2 = 1.08$ to 1.23 $Q/(gD_2^5)^{1/2} = 0.64$



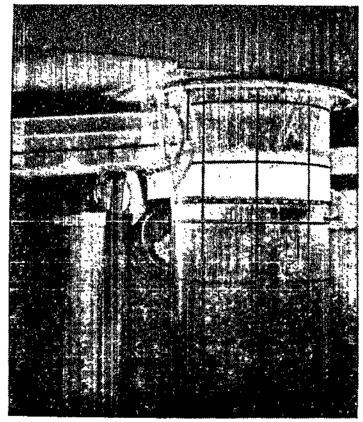
Photograph 21
Q = 2.72 cfs (43%) weir control, impinging jet
$HW/D_2 = 0.87$ $Q/(gD_2^5)^{1/2} = 0.42$



Photograph 22
Q = 1.36 cfs (22%) weir control, impinging jet
$HW/D_2 = 0.69$ $Q/(gD_2^5)^{1/2} = 0.21$

Photograph 23
Q = 1.08 cfs (17%) weir control, impinging jet
$HW/D_2 = 0.59$ $Q/(gD_2^5)^{1/2} = 0.16$

Photograph 24
Q = 0.43 cfs (6.8%) weir control, impinging jet
$HW/D_2 = 0.34$ $Q/(gD_2^5)^{1/2} = 0.066$



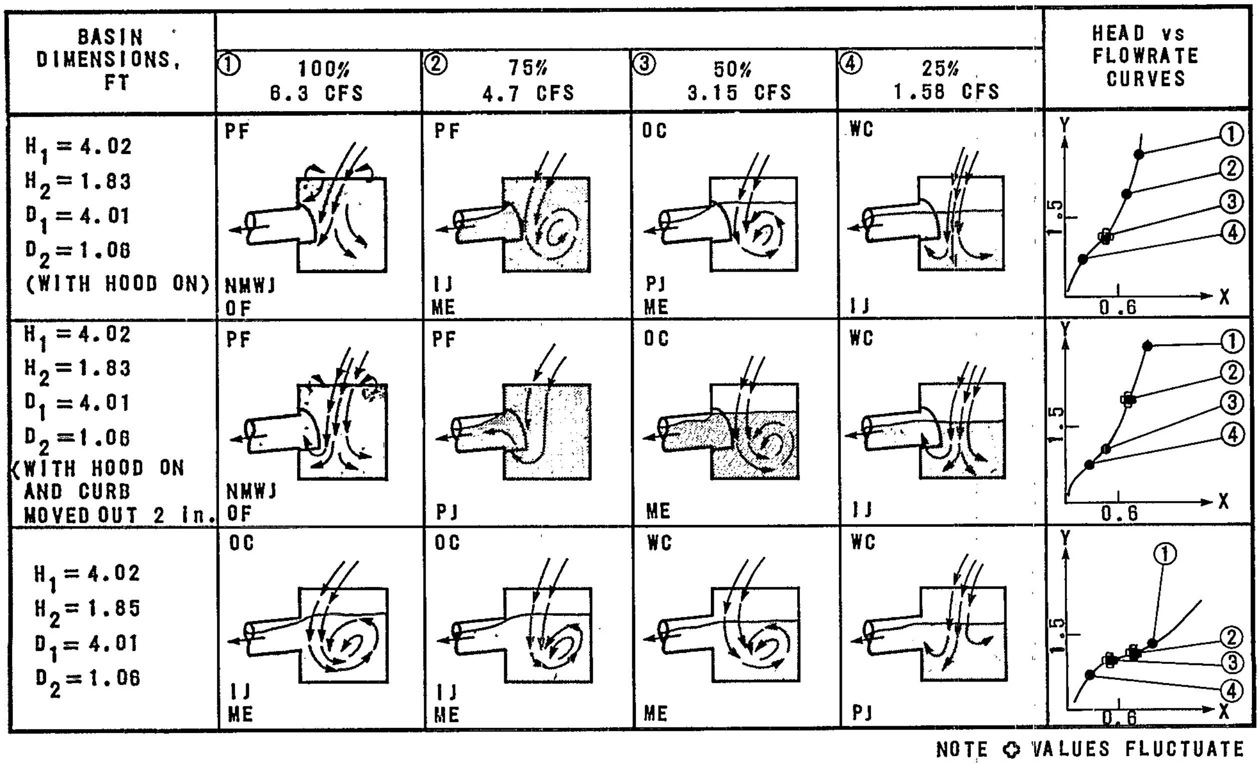
Photograph 25
Q = 0.22 cfs (3.4%) weir control, impinging jet
$HW/D_2 = 0.27$ $Q/(gD_2^5)^{1/2} = 0.034$

$D_1 = 5.01$ ft; $D_2 = 1.06$ ft
$H_1 = 3.65$ ft; $H_2 = 0.95$ ft
$H_3 = 1.64$ ft; $D_1/D_2 = 4.72$
$H_1/D_2 = 3.44$; $H_2/D_2 = 0.90$
$H_3/D_2 = 1.54$

Control and Flow Conditions
In Very Shallow Basin ($H_1 = 3.65$ ft)

Unsatisfactory Storage Basin

Figure 18. Photographic record - configuration 6.



LEGEND

H_1	TOTAL HEIGHT FROM BOTTOM TO TOP OF GRATING
H_2	STORAGE BASIN HEIGHT
D_1	BARREL DIAMETER
D_2	EXIT PIPE DIAMETER
X	$Q/(gD_2^5)^{1/2}$
Y	H_w/D_2

ABBREVIATIONS

PJ	PLUNGING JET
IJ	IMPINGING JET
ME	MACRO EDDIES
OC	ORIFICE CONTROL
SF	SLUG FLOW
WC	WEIR CONTROL
PF	PRESSURE CONTROL
OF	OVER FLOW
NMWJ	NO MAIN WATER JET

Figure 19. Influence of modifications on marginal basin.

especially in the range of orifice and short tube control, and drastically reduced the discharge capacity. Compared to flows under unhooded conditions, the influences of curb protrusions seemed to be minor.

Phase 3 - Sediment Capture

In Phase 3, qualitative evaluation procedures were used to define sediment retention for various conditions and these data were used to develop an optimal design configuration. Generally, the simulant approximated the medium-sized pollutant solids used in other experimental programs. Where justified, supplemental tests were run with finer or graded materials. Multiple flowrates were attempted, but emphasis was placed in the middle ranges.

Initial Configuration--

Configuration 16 (large diameter, medium height, shallow storage) was selected for the initial tests to set a base from which improvements could be expected. The simulant was commercial grade No. 30 sand. A maximum discharge of 232 L/s (8.2 cfs), 130 percent of expected maximum, plus simulant, was applied to a clean basin. This resulted in a solids capture on only 3.4 percent by dry weight (i.e., 96.6 percent of the simulant sluiced through the test unit and was recovered from the discharge sump).

The test was restarted using a flowrate of 152.9 L/s (5.4 cfs) and observation of the retention characteristics showed that 77 percent of the material sluiced through and only 23 percent was retained in the barrel. Short tube or orifice flow prevailed. Next, the discharge was further reduced to 76.5 L/s (2.7 cfs), resulting in open channel, weir control, and the retained material increased to 44 percent. Considering that the basic configuration was in the unsatisfactory range, the retention under the 76.5 L/s (2.7 cfs) flow was surprisingly good.

Seeking improvement, however, the storage basin depth was doubled (H_2/D_2 = 1.74, Configuration 17). The overall depth was increased from approximately 122 to 152 cm (4 to 5 ft), and the same 76.5 L/s (2.7 cfs) flowrate was applied. The retention jumped to 72 percent, indicating a marked advantage for deeper basins, particularly in the storage zone.

Deep Basins--

The deepest basin geometry, Configuration 1, was attempted next, holding the flowrate at 76.5 L/s (2.7 cfs). The retention showed a further improvement to 80 percent, which appears optimal for this flowrate. Then, the deepest 122 cm (4 ft) diameter basin, Configuration 7, was tested at a discharge of 152.9 L/s (5.4 cfs), and the retention was a satisfactory 42 percent, nearly twice the efficiency of the shallow basin used in the initial test.

Accumulation Impacts--

Using Configuration 1, a series of 10 consecutive runs were executed in which the solids were left to accumulate in the basin. Using No. 30 sand, the captured sediment increased rather uniformly, with 73 percent or better sediment retained in each run through the first five runs. At this point, corresponding to a volumetric level approaching 0.4 H_2, the capture efficiency dropped off sharply and became erratic.

Fine Material--

Finer composition sands (specific gravity 2.65) were used in two cases and mesh 100 gilsonite (specific gravity 1.06) was used in one case. A mesh 250 material was also used. Gilsonite and mesh 250 material sluiced right through the system under a discharge of 76.5 L/s (2.7 cfs). The fine sands results are reported under Phase 4.

Phase 4 - Recommended Design

From the studies conducted herein and the information from the earlier sections, a simple recommended design evolved that is appropriate for either 122 or 152 cm (4 or 5 ft) diameter basins, as shown in Figure 20. The circular cross-section is preferred from a cleaning and prefabrication viewpoint. The dimension from the outlet pipe crown to the street or inlet grade is primarily a structural consideration, as it contributes little to the hydraulic performance. To be cost effective, the maximum depth should be incorporated in the storage zone H_2 and the outlet pipe D_2 should be sufficiently large to pass most flows under open channel conditions.

In Phase 4, a complete series of rating and evaluation tests were performed using the model in the recommended design configuration.

Hydraulic Performance--

The discharge rating curve for the recommended basin is plotted on a dimensionless basis in Figure 21 with the identified flow conditions. The corresponding photographic record is shown in Figure 22. The discharge rating curve fixed the relationship between discharge Q, discharge head above outlet pipe invert H_w, and outlet diameter D_2 assuming free discharge.

Open channel flow conditions are maintained in the outlet pipe for flows up to approximately 50 percent of the design maximum.

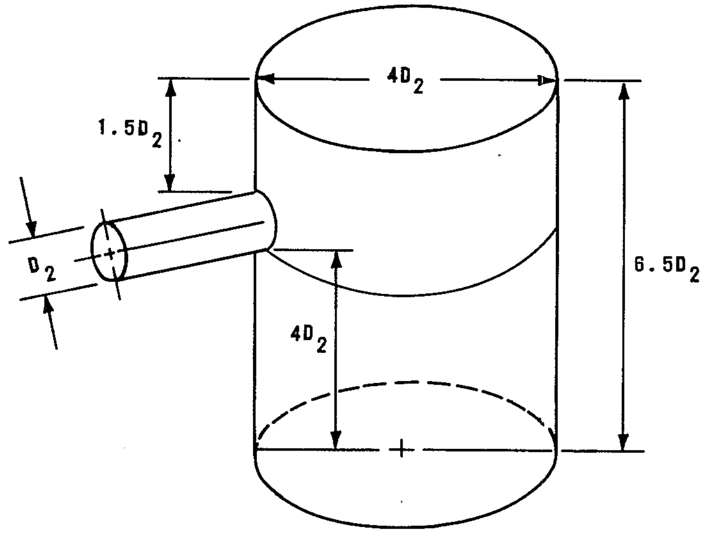


Figure 20. Recommended design.

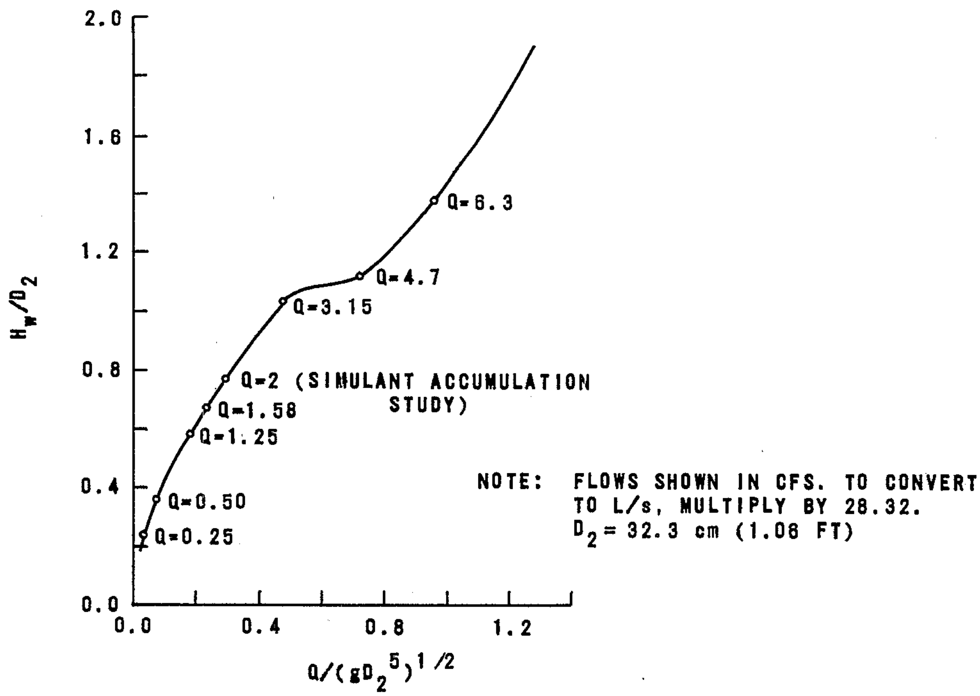
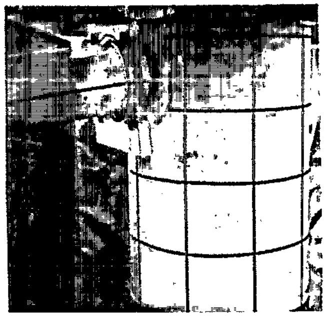
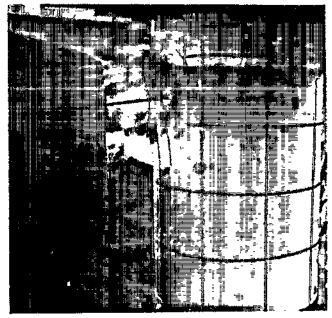


Figure 21. Discharge rating curve for recommended design.

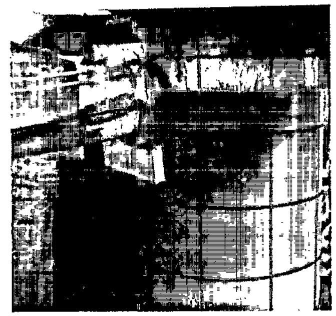


Photograph 26
Q = 6.30 cfs (100%) short tube control, plunging jet with macro eddy
HW/D_2 = 1.37 $Q/(gD_2^5)^{1/2}$ = 0.96

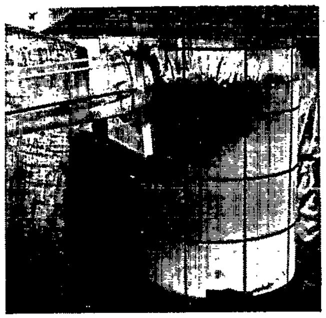
Photograph 27
Q = 4.70 cfs (75%) short tube control, slug flow, plunging jet with macro eddy
HW/D_2 = 1.11 $Q/(gD_2^5)^{1/2}$ = 0.72



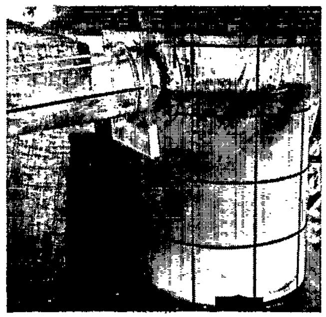
Photograph 28
Q = 3.15 cfs (50%) orifice control plunging jet with macro eddy
HW/D_2 = 1.02 $Q/(gD_2^5)^{1/2}$ = 0.48



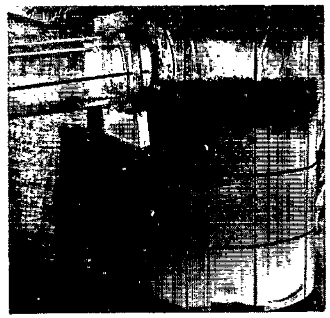
Photograph 29
Q = 1.58 (25%) weir control, diving jet
HW/D_2 = 0.66 $Q/(gD_2^5)^{1/2}$ = 0.24



Photograph 30
Q = 1.25 cfs (20%) weir control, dissipating jet
HW/D_2 = 0.57 $Q/(gD_2^5)^{1/2}$ = 0.18



Photograph 31
Q = 0.50 cfs (8.00%) weir control dissipating jet
HW/D_2 = 0.38 $Q/(gD_2^5)^{1/2}$ = 0.076



Photograph 32
Q = 0.25 cfs (4.00%) weir control dissipating jet
HW/D_2 = 0.24 $Q/(gD_2^5)^{1/2}$ = 0.038

D_1 = 4.01 ft; D_2 = 1.06 ft
H_1 = 6.69 ft; H_2 = 4.00 ft
H_3 = 1.50 ft; D_1/D_2 = 3.78
H_1/D_2 = 6.30; H_2/D_2 = 3.77
H_3/D_2 = 1.42

Control and Flow Conditions
Recommended Basin

Figure 22. Photographic record - recommended basin.

Sediment Capture--

A graded solids simulant, shown in Figure 11, was used to test the sediment capture characteristics of the recommended design as a function of flow, particle size, and accumulated deposits in the storage basin. For each test, a batch of simulant was prepared with the following size-weight distribution. Double batches were used in the accumulation test.

Size range, mm	Weight, g (lb)
>2.0	364 (0.8)
0.84 to 2.0	909 (2.0)
0.25 to 0.84	1,364 (3.0)
0.10 to 0.25	909 (2.0)
Total	3,546 (7.8)

With the exception of the accumulation test, the basin and setup were cleaned between each run. The results of flow variation on sediment capture in clean basins are shown in Table 21 and Figures 23 and 24. While there is a loss in efficiency at higher flows, a well-designed basin is surprisingly tolerant of wide flow variations *with respect to heavy solids removal*. For example, a twenty-fivefold increase in flow reduced the net removal efficiency only from 90 to 35 percent. However, in the small particle size range (the most critical range with respect to pollution load), the dropoff was much more dramatic: a sixfold increase in flow reduced the removal efficiency from 68 to 14 percent. These results must be interpreted only as trends, since replicate runs were not conducted and the specific gravity for all size ranges was held at 2.65.

TABLE 21. PERCENT SEDIMENT RETAINED IN BASIN VERSUS DISCHARGE

Size of simulant, mm	Q, cfs[a]						
	6.3	4.7	3.15	1.58	1.25	0.50	0.25
>2.0	75.20	83.24	90.17	96.12	96.34	98.98	99.44
0.84 to 2.0	50.03	57.93	78.62	93.19	96.00	98.88	99.33
0.25 to 0.84	33.04	26.41	56.85	72.51	81.18	91.54	97.46
0.10 to 0.25	4.64	6.37	7.67	14.72	32.23	45.24	68.60
0.10 to 2.0	34.44	35.18	53.24	65.42	73.98	82.31	90.74

a. L/s = cfs x 28.32.

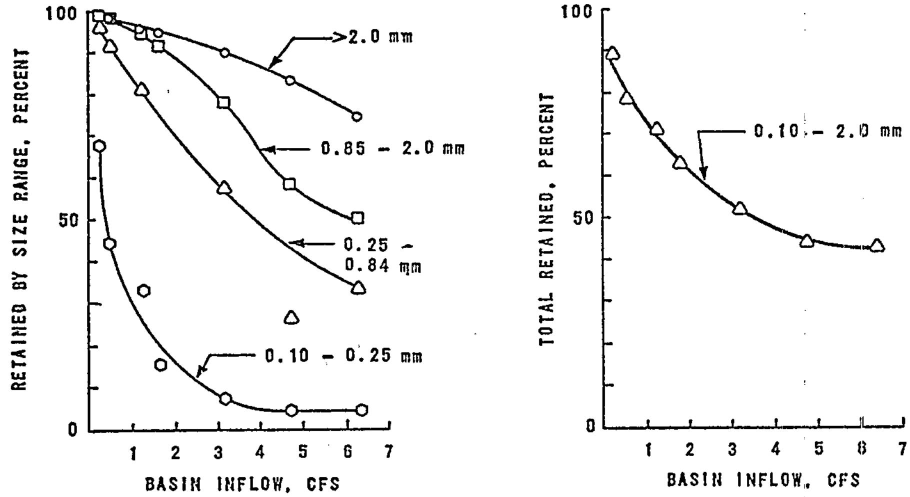


Figure 23. Sediment capture versus discharge.

In the final test, the simulant was allowed to accumulate in the basin through a series of runs at a constant flowrate. The results, as shown in Table 22 and Figures 25, 26, and 27, show the removal efficiencies to be relatively unaffected until a breakthrough point is reached, at which time they become erratic and even negative. This breakthrough in the experimental test occurred when the storage basin was filled to just over one-half its depth. The cumulative percent retained by particle size at the point of breakthrough is shown in Table 23.

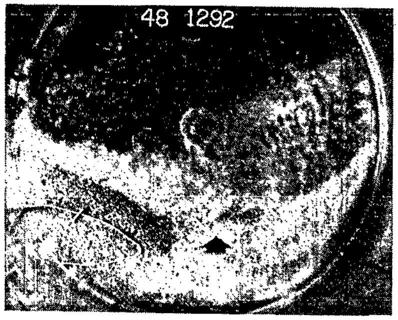
TABLE 22. SEDIMENT ACCUMULATION[a]

Event	Cumulative weight, lb[b]	Depth, as fraction of H_2[c]
1	11.4	.04
2	22.3	.08
3	33.3	.12
4	44.1	.15
5	55.1	.19
6	66.3	.23
7	77.6	.27
8	88.2	.30
9	98.6	.34
10	108.4	.37
11	116.9	.40
12	126.1	.43
13	135.1	.46
14	143.4	.49
15	151.3	.52
16	159.1	.55
17	162.4	.56
18	167.9	.58
19	170.4	.59
20	167.0	.57

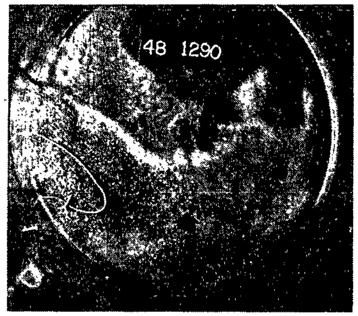
a. Q = 56.6 L/s (2.0 cfs).

b. g = lb x 454.

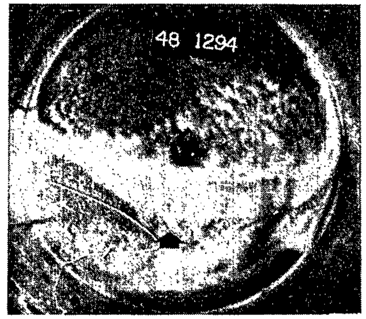
c. H_2 = distance from floor to invert of outlet pipe.



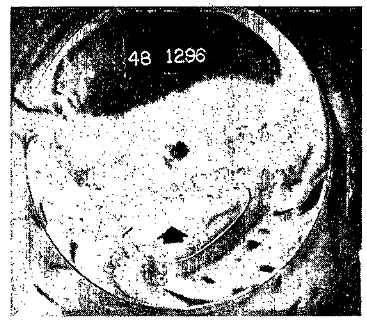
Photograph 33
Q = 6.30 cfs (100%) short tube control, plunging jet with macro eddy
$HW/D_2 = 1.39$ $Q/(gD_2^5)^{1/2} = 0.96$



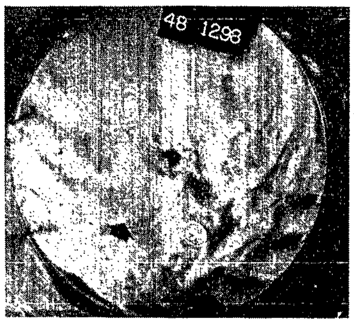
Photograph 34
Q = 4.70 cfs (75%) short tube control, slug flow, plunging jet with macro eddy
$HW/D_2 = 1.11$ $Q/(gD_2^5)^{1/2} = 0.72$



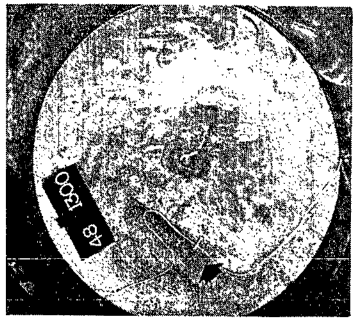
Photograph 35
Q = 3.15 cfs (50%) orifice control, plunging jet with macro eddy
$Hw/D_2 = 1.02$ $Q/(gD_2^5)^{1/2} = 0.48$



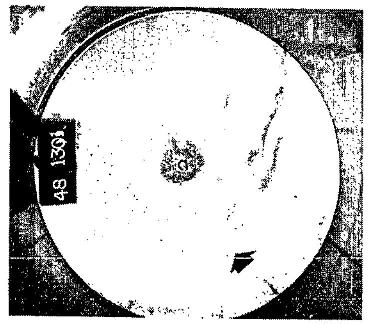
Photograph 36
Q = 1.58 cfs (25%) weir control, diving jet
$Hw/D_2 = 0.69$ $Q/(gD_2^5)^{1/2} = 0.24$



Photograph 37
Q = 1.25 cfs (20%) weir control, dissipating jet
$HW/D_2 = 0.57$ $Q/(gD_2^5)^{1/2} = 0.19$



Photograph 38
Q = 0.50 cfs (8.00%) weir control, dissipating jet
$HW/D_2 = 0.43$ $Q/(gD_2^5)^{1/2} = 0.076$



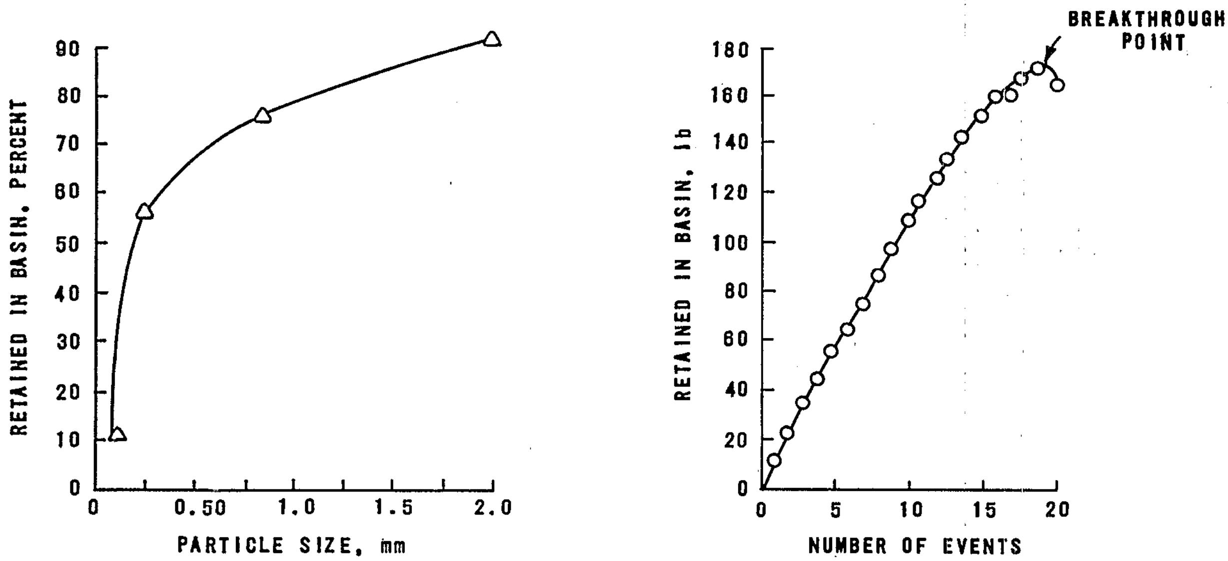
Photograph 39
Q = 0.25 cfs (4.00%) weir control, dissipating jet
$HW/D_2 = 0.29$ $Q/(gD_2^5)^{1/2} = 0.038$

Note: Contour Elevation 1 = 0.23 ft prototype

Indicates direction of flow

Graded Simulant Retained in Catchbasin At Different Flow Rates

Figure 24. Photographic record - sediment capture versus discharge.



NOTE: 1 EVENT CORRESPONDS TO THE ADDITION OF 7,092 g (15.6 lb) GRADED SIMULANT. Q=56.6 L/s (2.0 cfs)

Figure 25. Sediment capture versus accumulation.

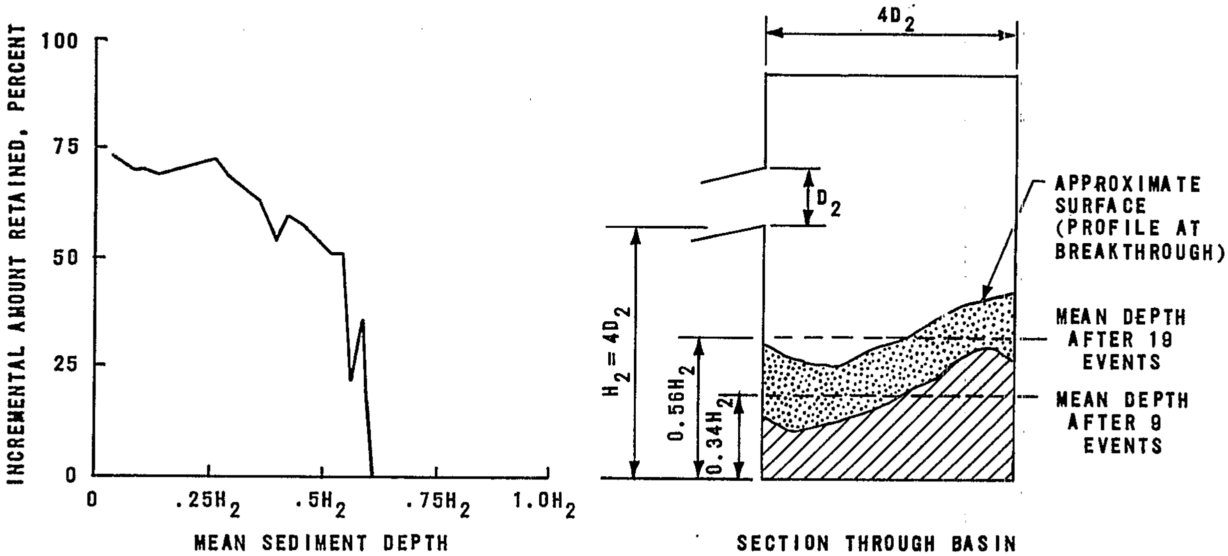
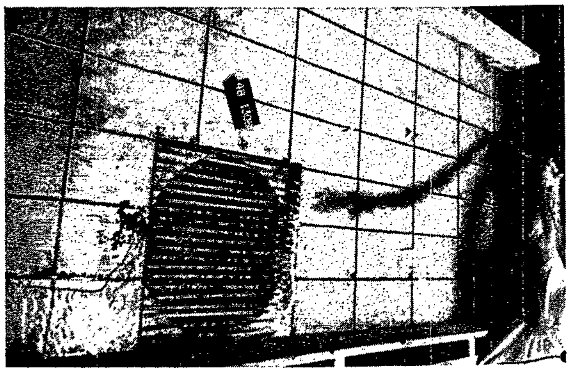
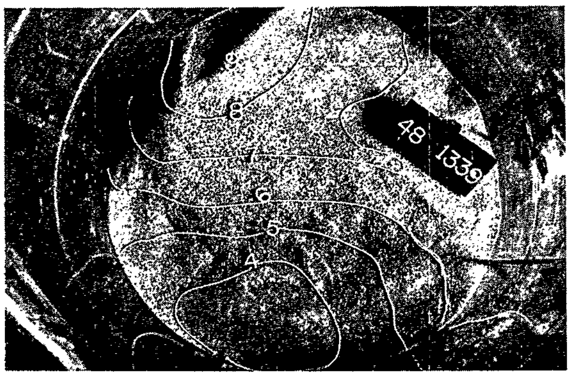


Figure 26. Sediment capture versus accumulated depth.

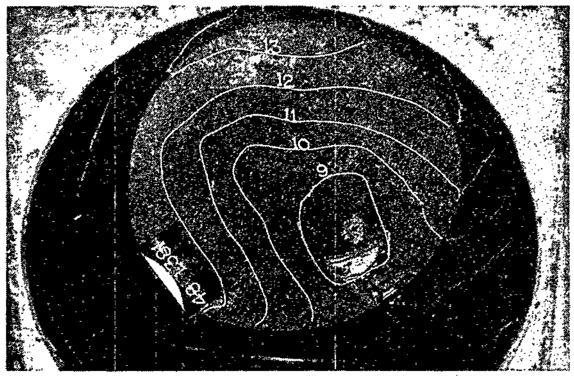


Photograph 40
Approach flow conditions during simulant accumulation study.

Photograph 41
Simulant accumulation after after 78 lb



Photograph 42
Simulant accumulation after 140 lb



Photograph 43
Simulant accumulation after 312 lb

Graded Simulant retained in Catchbasin During Accumulation Study

Q = 2 cfs

Note: Contour Elevation Numerals correspond to the following:

13 = 2.95 ft	10 = 2.27 ft	7 = 1.59 ft	4 = 0.90 ft
12 = 2.72 ft	9 = 2.04 ft	6 = 1.36 ft	3 = 0.68 ft
11 = 2.49 ft	8 = 1.81 ft	5 = 1.13 ft	2 = 0.45 ft

Figure 27. Photographic record - sediment accumulation.

TABLE 23. AGGREGATE CAPTURE EFFICIENCIES AT BREAKTHROUGH

	Size, mm			
	2.0	0.84 to 2.0	0.25 to 0.84	0.10 to 0.25
Cumulative % retained at optimum event	90.11	75.43	47.77	10.0[a]

a. Estimated. Direct measurement impossible because of carryover of fines to sump and recycle system. 58.74% measured in trap basin and tank.

CONCLUSIONS

The following conclusions are drawn from the hydraulic model analysis:

1. Properly designed and maintained catchbasins can be very efficient in removing medium to very coarse sands from stormwater runoff. Further, the removals remain high over a wide range of flows and reduce to approximately 35 percent at maximum design inflow.

2. Removal efficiencies, as expected, are very sensitive to particle size and specific gravity. Under the test conditions examined, the removal of fine sands ranged from fair to poor with increasing flow. Removals of very fine sand and low specific gravity material (gilsonite) were negligible at 40 percent of maximum flow.

3. Storage basin depth is the primary control for performance; efficiencies improve with increasing depth.

4. The accumulation of sediment in catchbasins does not appear to impair solids removal efficiencies until 40 to 50 percent of the storage depth is filled. Beyond this depth, removals drop rapidly, even to the point of negative values (washout exceeds sedimentation).

5. Of the standard modifications tested, hoods or traps were found to increase the discharge head requirements significantly. In the higher flow ranges, increased scour currents were observed as the flow was diverted downward by the obstruction of the outlet. By comparison, curb openings or protrusions had negligible effect.

SECTION 7

ASSESSMENT

To assess the role of catchbasins, three questions are of major concern: When should a catchbasin be used? Should existing basins be converted to inlets? When catchbasins are necessary, how should they be designed and maintained? The purpose of this section is to identify user experience and attitudes, to review the performance of existing catchbasins, to review some alternatives, and to provide an overall assessment of the use of catchbasins. The economic evaluation of the use of catchbasins is considered in Section 8.

USER EXPERIENCE AND ATTITUDES

The 1973 member survey conducted by the APWA [102] discloses some very interesting information on the role of catchbasins as viewed by the users. Although catchbasins are the subject of much criticism and debate, they are still widely used, as shown in Table 24.

By linear extrapolation of these sample results, there are approximately 900,000 catchbasins in the United States in cities of 100,000 and above and potentially 850,000 additional catchbasins in sewered areas of smaller communities.

TABLE 24. CATCHBASIN USAGE IN LARGE U.S. CITIES

	Combined system[a]		Separate system	
	No.	Population	No.	Population
Cities with population greater than 100,000[b]	62	30,787,781	91	24,180,093
Reporting in survey[c]	31	9,905,897	49	16,949,878
Reporting in catchbasins	18	5,028,190	20	5,989,376
No. of catchbasins	18	203,847	20	189,163

a. 1974 Needs Survey

b. 1970 Census data.

c. 1973 APWA questionnaire responses [102].

Further information drawn from the questionnaires, completed by Public Works Department representatives, are shown in Figures 28 and 29. The practice of using catchbasins in new construction continues to be strong (4:1). However, a trend by the minority to move positively away from such use appears to be growing. Clearly, the requirements and efficiency of cleaning catchbasins is the major concern, and their effectiveness is viewed almost exclusively from a solids removal viewpoint. Less than half of the respondents use traps in their catchbasins. Of those using traps, the reasons given were to control odors, 65 percent; to remove floating objects, 51 percent and other purposes, 32 percent.

CATCHBASIN PERFORMANCE

In the following discussion, catchbasin performance is considered primarily from the point of view of hydraulics and the removal of pollutants. Example problems dealing with the computations involved in the evaluation of catchbasin performance are presented. Odor production is also discussed.

Hydraulics

The hydraulic regime within the catchbasin is a function of inlet configuration and location; drainage area size and runoff coefficients; gutter longitudinal and street cross slopes; rainfall intensity and duration; inlet and outlet conditions; and internal geometry. Solids removal is affected by hydraulic detention time and the degree of turbulence. As would be expected, higher flow-through rates decrease the detention time and increase the turbulence, which, in turn, decreases solids removal efficiencies, particularly the finer sizes of solids. For example, a flow of 14.2 L/s (0.5 cfs) through the standard project catchbasin in a just-cleaned condition would have a detention time of 1.8 minutes, and a flow of 2.8 L/s (0.1 cfs) would have a detention time of 8.4 minutes. This range is similar to that used in aerated grit chambers, as presented later in the text. In general, the hydraulic regime in a catchbasin is highly turbulent, and because of the accumulation of sediment, extremely short detention times are the rule rather than the exception.

The techniques of reducing the turbulence and increasing detention times apparently have not been used widely for design criteria of catchbasins. Generally, within a city, a more-or-less standard catchbasin is used with little regard to the size of the drainage area or flow ranges to be expected. This results in very diverse solids removal efficiencies.

Inlet grate configurations are usually limited to bars parallel or perpendicular to the curb face with or without a vertical opening in the curb face. From the standpoint of reducing grate

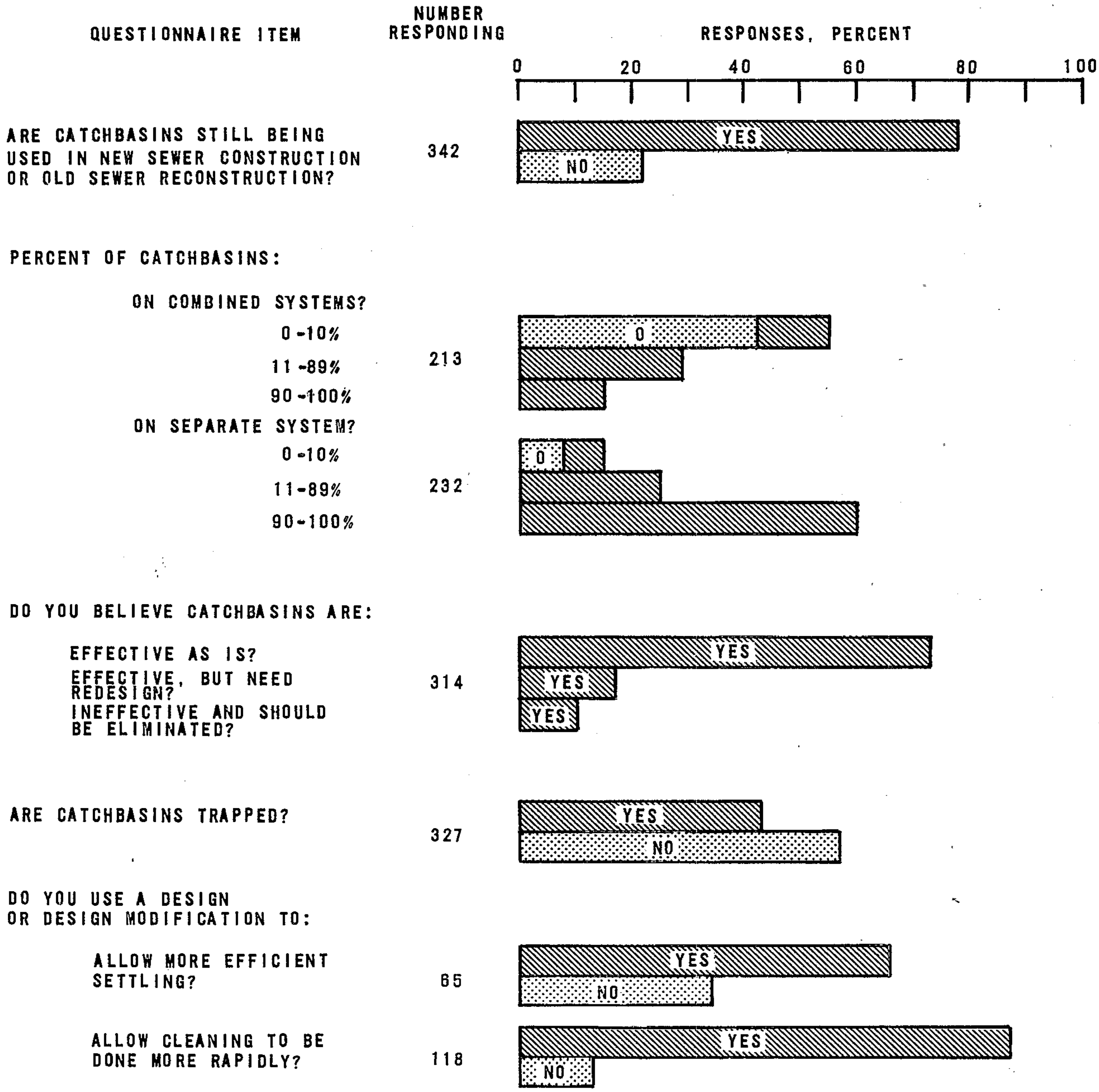


Figure 28. User experience and attitudes, 1973 [102].

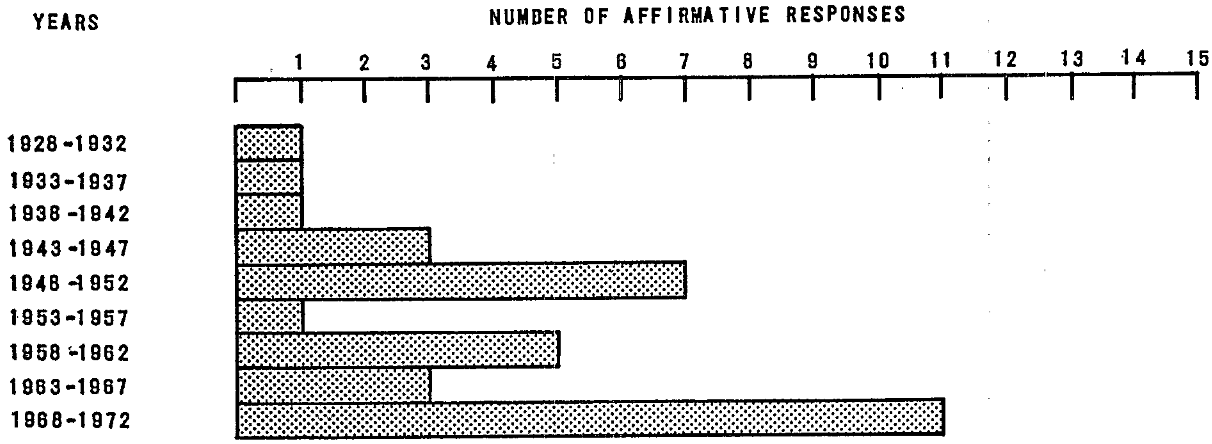


Figure 29. Year use of catchbasins stopped [102].

blinding, it is desirable to retain the vertical opening in the curb face. Unfortunately, this vertical opening also invites the use of the catchbasin as a garbage receptacle by the general public. Most vertical openings in the curb face are limited to 12.7 cm (5 in.) because most curbs are only 15.2 cm (6 in.) high.

From a hydraulic standpoint, the greatest efficiency is obtained by placing the inlet bar axis parallel to the flow, i.e., to the curb face. Because this creates a hazard for bicyclists, however, most inlet bars are placed perpendicular to the flow, thereby reducing the hydraulic efficiency.

Source and Removal of Pollutants

Catchbasin performance with respect to pollution is mixed. The trapped liquid that is purged from the basin to the collection network during each storm generally has a high pollution content and contributes to the intensification of the first-flush loadings. Countering this negative impact is the removal of pollutants associated with the solids retained in the basin and subsequently cleaned out.

Liquid Fraction--

As street waste receptacles, the pollution content of the retained liquid-solids mixture in catchbasins is both high and variable [65, 120]. Normalizing the data presented in Table 16 by casting out the extremes and averaging, the characteristics reduce to: COD, 6,400 mg/L; BOD, 110 mg/L; total nitrogen, 8 mg/L; and total phosphorus, 0.2 mg/L. For a typical retained volume of 545 L (144 gal), the approximate pollutant load (BOD_5)

held in a basin computes to 82 g (0.18 lb), or the equivalent waste discharged by one person in one day.

The APWA estimated the way in which soluble pollutants in a catchbasin at the start of a storm are flushed into a sewer [42]. They experimented by adding 6.8 to 20.4 kg (15 to 45 lb) of sodium chloride dissolved in water to a catchbasin containing 1,336 L (353 gal). Water from a hydrant was discharged through a hose and water meter to the gutter near the catchbasin. Samples were taken from the effluent when various quantities of water up to 6,378 L (1,685 gal) had been added to, and passed through, the catchbasin. The cumulative percent of salt discharged as a function of gallons of liquid added is illustrated in Figure 30.

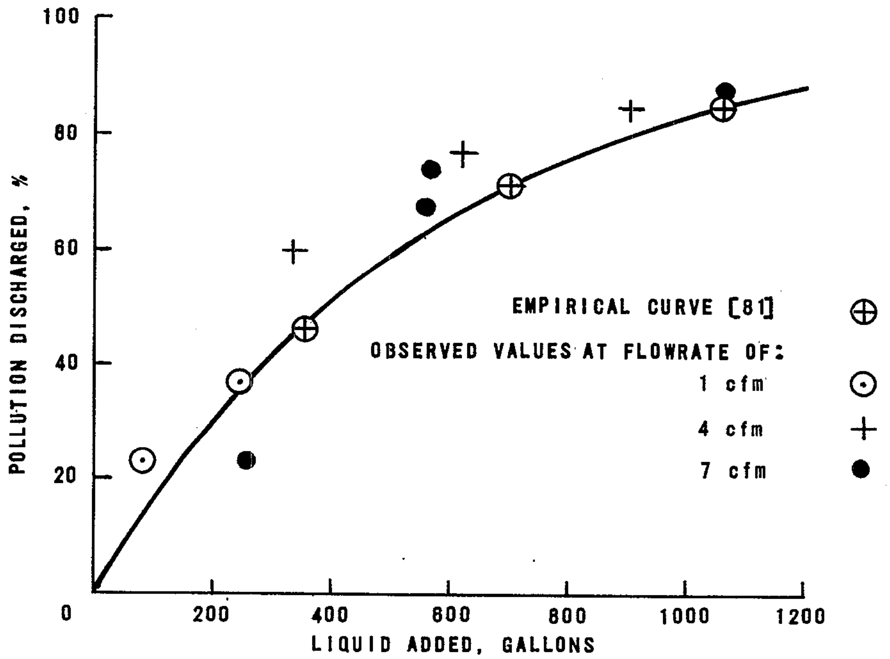


Figure 30. Relationship of flow into catchbasin and reduction of concentration on salt [adapted from 42].

An empirical formula developed to fit the curve in Figure 30 using BOD_5 as the pollutant is given in Equation 6 [81].

$$R = 100\left[1.0 - e^{-\frac{x}{1.6v}}\right] \qquad (6)$$

where R = percent of catchbasin BOD_5 removed
x = cumulative inflow to catchbasin, gal
v = trapped volume of liquid in the basin before storm, gal

EXAMPLE PROBLEM 1: POLLUTION POTENTIAL OF DISPLACED LIQUID CONTENTS OF CATCHBASINS

Determine the amount of pollution in terms of BOD5 released from catchbasins for the specified conditions and relate this amount to the potential impact on dry-weather treatment plant performance.

Specified Conditions

1. Average tributary area to catchbasin = 1.44 acres.
2. Volume of catchbasin sump = 1.7 yd^3, of which one-third is filled with sediment.
3. Rainfall intensity = 0.02 in./h for 4 h.
4. City population = 750,000.
5. Total number of catchbasins = 25,000.

Assumptions

1. BOD_5 concentration in basin before storm = 110 mg/L.
2. Runoff coefficient = 0.50.
3. Equation 6 is applicable.
4. BOD_5 in sewage = 0.20 lb/capita·d.

Solution

1. Determine the pollution load in the basin prior to the storm.

   Load = 110 mg/L x 1.7 yd^3 x 764.6 L/yd^3 x .67 = 95.8 g (0.21 lb)

2. Determine the total runoff to the catchbasin.

   Runoff = 0.02 in./h x 0.50 x 1.44 acres
   = 0.0144 acre-in./h = 0.0144 cfs
   Volume = 0.0144 cfs x 4 h x 3,600 s/h x 7.48 gal/f^3
   = 1,551 gal

3. Determine the pollution displaced from the basin using Equation 6.

$$\% \text{ displaced} = \left[1.0 - e^{\frac{-1,551}{1.6 \times 1.7 \times 0.67 \times 202}}\right] \times 100$$

$$= \left[1.0 - e^{\frac{-1,551}{368}}\right] \times 100$$

   = 98.5%

   = 0.207 lb/catchbasin

4. Determine the citywide release of pollution.

   Release = 25,000 catchbasins x 0.207
   = 5,171 lb

5. Express the release of pollution as related to dry-weather plant loading.
   Total plant loading = 750,000 people x 0.20
   = 150,000 lb/d

   Equivalent reduction in plant performance on day of storm = 5,171 lb ÷ 150,000 lb = 3.4%.

Comment

The reported BOD concentrations measured in catchbasins are consistently higher than concentrations normally found in running stormwater, frequently by as high as 5:1. This may be accounted for by (1) the dumping or flushing of waste material into basins between storms, (2) the concentrating effect (treatment) of the runoff as it passes through the small detention unit; (3) decomposition of the residual organic sediment over time, and (4) evaporation.

Sediment Fraction--

As determined in the hydraulic modeling studies, catchbasins can be quite effective in removing medium-to-coarse sands and, to a limited extent, they may also remove significant amounts of smaller particles. Sartor and Boyd [66] have identified pollutants in street surface contaminants associated by particle size in the dry state. Thus, by assuming a fixed percentage of the "dry" pollution remains with the particles in the wet and turbulent confines of a catchbasin, solids removals can be equated to pollution removals.

For first-cut assessments, ratios between particle-related pollution in the dry and wet states have been assumed as shown in Table 25.

TABLE 25. ASSUMED RELATIONSHIPS BETWEEN DRY STATE AND WET STATE CHARACTERISTICS

To convert dry state value for[a]	To obtain wet state value
Total solids and heavy metals, multiply by[b]	1.0
Organics, nutrients, bacteria, and pesticides, multiply by[b]	0.5

a. As reported in Tables 14 and 15.

b. Pollution assumed adhering to particles and not washed free.

These assumptions are consistent with the high pollution levels found in catchbasin residuals and in pollution loadings associated with the solids fraction removed in wastewater treatment facilities.

The performance of a catchbasin in capturing solids can be related, at least qualitatively, to the performance of an aerated grit chamber found in many sewage treatment plants. Solids removal in both systems increases with increasing detention times. The two systems differ in that the turbulence pattern in a grit chamber, and therefore the size of particles that are kept in suspension, can be more closely controlled. Otherwise, the predicted performance of an aerated grit chamber and a catchbasin at similar detention times follows the same pattern, as seen in Figure 31. Data for catchbasin performance are from the experimental work presented in Section 6; data for an aerated grit chamber are based on theoretical settling rates. A properly designed and operated air system would keep most particles below a given size in suspension, as shown in the figure.

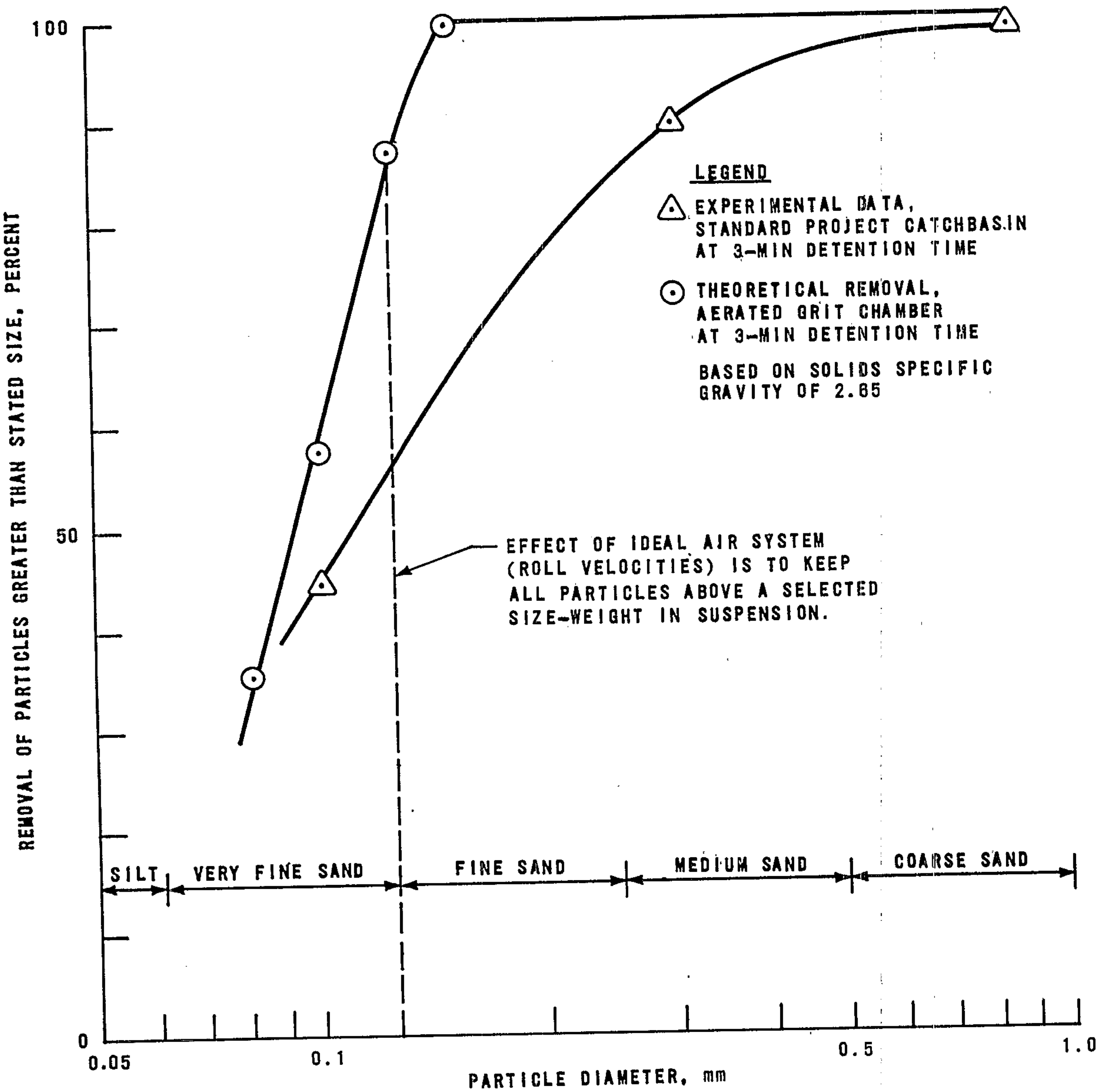


Figure 31. Comparison of catchbasin and grit chamber performance.

The impact of flowrate and particle size on optimal catchbasin removals, as determined experimentally, is illustrated in Figure 32. Descriptions of the tests and other presentations of the data are included in the preceding sections of this report. While prototype field tests were beyond the scope of the present study [note that 0.76 m^3 (1 yd^3) of simulant weighs 1,362 kg (1.5 tons)], a few field tests were performed earlier by Sartor and Boyd [66] from which comparisons can be drawn.

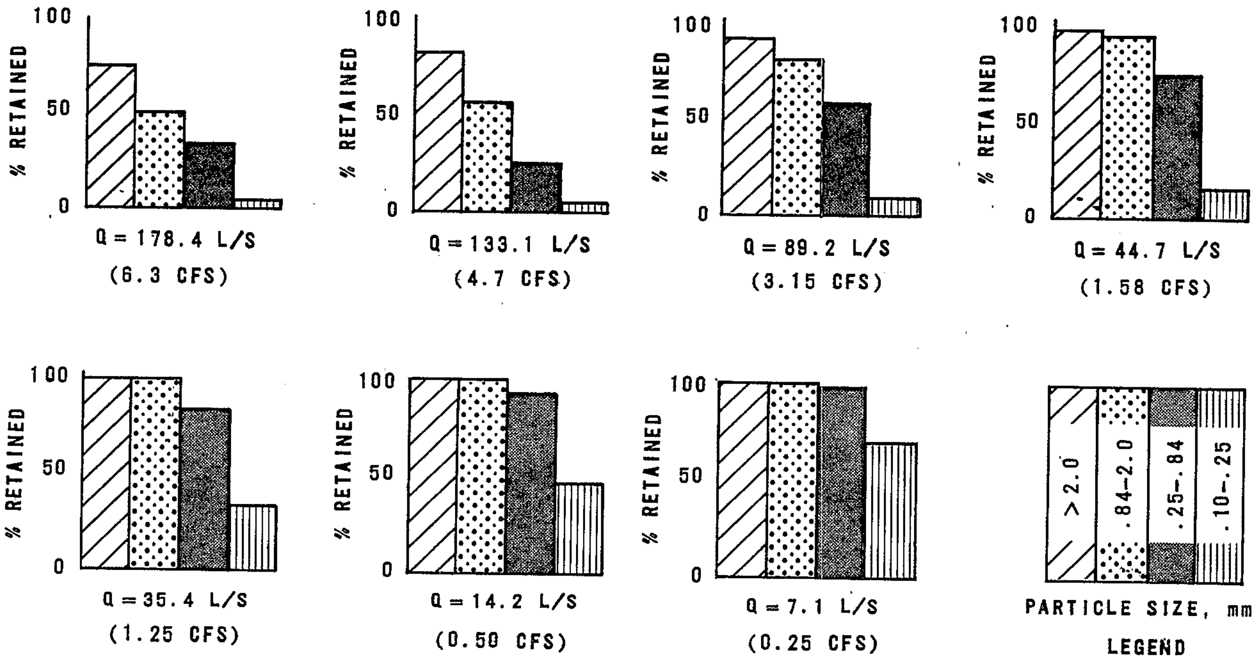


Figure 32. **Model basin performance versus flow.**

In the first field test, a graded simulant was washed into a clean catchbasin in San Francisco. The test was run at a set flow condition 7.9 L/s (0.28 cfs), and the removal efficiencies versus time for various size particles were determined as shown in Figure 33. Note that virtually all of the particles larger than 0.246 mm (fine sand) were removed and that virtually all of the particles smaller than 0.10 mm (very fine sand and silts) passed through. A comparison of removals achieved in the modeling studies and this field test is shown in Table 26. The comparisons are considered very good recognizing that the model dimensions were optimized.

The low removals in the smaller size ranges are particularly significant because most of the pollutants, (e.g., 59.6 percent volatiles, 56.8 percent BOD_5, 80.1 percent COD, 77.0 percent nitrates, 92.2 percent phosphates, and 43.4 percent total solids)

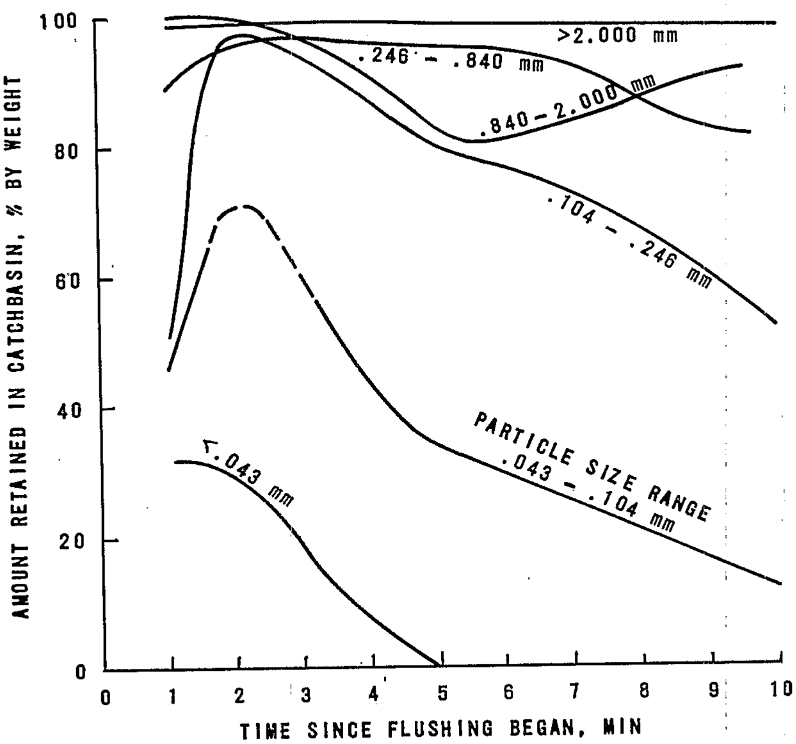


Figure 33. Prototype performance versus time [66].

TABLE 26. COMPARISON OF REMOVALS IN MODEL AND PROTOTYPE TESTS

Size of simulant, mm	Removals, %		
	Model Q = 7.1 L/s (0.25 cfs)	Field[a,b] Q = 7.9 L/s (0.28 cfs)	Model Q = 14.2 L/s (0.50 cfs)
>3.0	99.4	97.8	99.0
0.84 to 2.0	99.3	91.1	98.9
0.25 to 0.84	97.5	82.3	91.5
0.10 to 0.25	68.6	51.1	45.2
<0.10	....	12.6	....

a. Value 10 minutes after flushing began.

b. From Sartor and Boyd [66].

are contained in the 0.25 mm diameter and finer size particles (see Table 15), which indicates that catchbasins may be relatively ineffective in reducing pollution.

Later in the field study, tests were run on "dirty" catchbasins to see how much of the contents would be removed by various flowrates of clean city water over a 40-minute time interval. The test was described as follows [66]:

> The catchbasins all had several thousand pounds of solids in them, with a layer of water (and floating debris) up to the outlet level. The water first discharged was very dirty, composed primarily of this supernatant water, some of the floating matter, plus particulate matter suspended by the turbulence flow. Within a few minutes that water became reasonably clear but still contained particulates. Even after nearly an hour's flushing, the discharge contained much particulate matter. At the end of an hour, inflow was stopped and the volume of basin contents was measured.

The results are summarized in Table 27.

TABLE 27. TEST OF "DIRTY" CATCHBASINS [66]

Catchbasin	Catchment area, ha (acres)	Inflow rate, L/s (cfs)	Weight of solids in basin at outset, kg (lb)	Equivalent depth of sediment[a]	Solids flushed from basin during storm	
					Weight, kg (lb)	Fraction, %
A	0.39 (0.96)	7.9 (0.28)	929 (2,047)	0.75 H_2	13.4 (29.6)	1.2
B	0.23 (0.57	7.9 (0.28)	1,162 (2,559)	0.94 H_2	13.6 (30.0)	1.1
C	0.10 (0.25)	6.5 (0.23)	1,580 (3,481)	1.27 H_2	9.8 (21.6)	0.6

a. Based on standard configuration shown in Figure 1: H_2 = 121.9 cm (4.0 ft), D_1 = 83.8 cm (2.75 ft), dry unit weight = 1,846 kg/cm^3 (115 lb/ft^3).

It can be concluded that, at normal rates of runoff, most of the sediment material originally contained in catchbasins tends to remain there.

Again referring to the model studies, under substantially higher inflows--56.6 L/s (2.0 cfs)--catchbasins were shown to be ineffective for even coarse solids removals when the accumulated sediment exceeded 50 to 60 percent of the storage basin depth (0.5-0.6 H_2), but performance was relatively unaffected until this breakthrough point was reached.

EXAMPLE PROBLEM 2: POLLUTION REMOVED BY SEDIMENTATION IN CATCHBASINS

Determine the amount of material that will enter a storm sewer for the specified conditions and the amount of material that will be removed as a function of the number of times a catchbasin is cleaned each year.

Specified Conditions

1. For the area under consideration, the curb length per catchbasin = 0.10 curb mile and the average tributary area to a catchbasin = 1.44 acres.
2. The volume of the catchbasin sump = 1.7 yd^3.
3. Annual precipitation = 35.1 in.
4. Storm events per year = 50.

Assumptions

1. Representative event duration = 5 h.
2. Unit weight of material retained in catchbasin = 110 lb/ft^3.
3. Equation 3 is applicable, and runoff factors varying from 0.8 to 0.5 will be used for computation.
4. Maximum effective sump storage between cleanings = 50% of sump volume.

Solution

1. Determine the effective capacity of the catchbasin in pounds.

   $$\text{Capacity} = 1.7 \text{ yd}^3 \times 27 \text{ ft}^3/\text{yd}^3 \times 110 \text{ lb/ft}^3 \times 0.5$$
   $$= 2{,}524 \text{ lb per cleaning}$$

2. Determine the amount of available material that can enter each catchbasin for the following constituents: total solids, volatile solids, BOD_5, COD, Kjeldahl nitrogen, nitrates, phosphates, and total heavy metals. This is accomplished by multiplying the values given in Table 14 by 0.10, which is the distance in curb miles that is connected to each catchbasin. The results are given in the following tabulation:

Material available for entry into sewer with each storm

Constituent	Value, lb/0.10 curb mile
Total solids	140
Volatile solids	10
BOD_5	1.3
COD	9.5
Kjeldahl nitrogen	0.2
Nitrates	0.01
Phosphates	0.11
Total heavy metals	0.16

3. Compute the representative rainfall intensity in inches per hour.

   $$\text{Intensity} = 35.1 \div (50 \text{ events} \times 5 \text{ h})$$
   $$= 0.14 \text{ in./h}$$

4. Using total solids as an example, determine the amount of material that actually enters the catchbasin using Equation 4.

Computation summary for Equation 4

P_o	i	A	r	t	$P_o - P$	% removed
140	0.14	0.8	0.11	5	129	92.0
140	0.14	0.7	0.10	5	126	90.0
140	0.14	0.6	0.08	5	118	84.1
140	0.14	0.5	0.07	5	112	80.0

5. Determine the amount of total solids that enters each catchbasin annually. Assuming that the total solids available for removal are the same for each storm, the amount that enters each catchbasin during a year for various runoff factors is given in the following tabulation.

	Total solids	
A	lb/storm	lb/yr[a]
0.8	129	6,450
0.7	126	6,300
0.6	118	5,900
0.5	112	5,600

a. lb/storm x 50 storms/yr.

6. Determine the average rate of inflow to the basin for the following range of runoff factors:

High inflow = 0.11 in./h x 1.44 acres = 0.16 cfs
Low inflow = 0.07 in./h x 1.44 acres = 0.10 cfs

7. Estimate the amount of material actually retained in the catchbasin. For probable best conditions, use model data for the closest available flow range (Table 21, Q = 0.25 cfs). For probable worst conditions, use aggregate capture efficiencies at breakthrough (Table 23). Using the data in Table 15 in which the fraction of particles associated with each particle size range is given and Table 25 which accounts for dry to wet state conversion, the amount of material entering the sewer that will be removed in the catchbasin is given in the following tabulation:

Percentage of material retained in catchbasin for individual storm

	Probable % retained	
Constituent	Worst	Best
Total solids	42.1[a]	75.0
Volatile solids	15.2	25.5
BOD_5	15.5	26.6
COD	7.5	14.1
Kjeldahl nitrogen	14.6	27.4
Nitrates	9.5	17.1
Phosphates	2.3	6.0
Total heavy metals	37.4	64.4
Total pesticides	13.6	29.7

a. Total solids [24.4 x 0.9011 + 7.6 x 0.7543 + 24.6 x 0.4777 + 27.8 x 0.100] x 1.0 = 42.1

8. Determine the amount of material that will be removed as a function of the number of times a catchbasin is cleaned each year assuming best removals. The amounts are summarized in the following tabulation:

Percentage of total amount of material entering catchbasin removed as a function of the cleaning frequency

	Cleaning frequency, times/yr				
Constituent	0.5	1.0	2.0	3.0	4.0
Total solids	19.6	39.1[a]	75.0	75.0	75.0
Volatile solids	6.6	13.3	25.5	25.5	25.5
BOD5	6.9	13.9	26.6	26.6	26.6
COD	3.7	7.4	14.1	14.1	14.1
Kjeldahl nitrogen	7.1	14.3	27.4	27.4	27.4
Nitrates	4.4	8.9	17.1	17.1	17.1
Phosphates	1.6	3.1	6.0	6.0	6.0
Total heavy metals	16.8	33.6	64.4	64.4	64.4
Total pesticides	7.7	15.5	29.7	29.7	29.7

a. [(2,524 (see step 1) x 1.0 cleaning frequency)/(6,450 (see step 5) x 0.750 (see step 7)] x 100 = 52.2% of total solids in sediment removed which equals 52.2% x 75.0% (see step 7) = 39.1% of total solids entering basin.

Comment

The percent retained values determined in step 7 of the solution represent the probable ranges of material that could be removed in the catchbasin assuming 100 percent efficiency, adequate cleaning, and the use of the recommended or equivalent catchbasin design.

Odors

The use of a trap on a catchbasin can provide a water seal to control odors. During a prolonged dry period, however, the water evaporates and the seal is probably lost. In a survey of 725 catchbasins in San Francisco [65], it was found that more than 45 percent were too full of debris to determine whether a trap existed or not. Of the remaining 468 catchbasins, 30 percent had no trap. Odors were observed in only 3 catchbasins. In the same area, 38 percent of the catchbasins that had a trap had no seal. In the catchbasins that had an odor (1 percent), the odor did not appear to be related to the seal condition.

Thus, it appears that the water seal trap incorporated in many catchbasins is not necessary and, in fact, causes problems of clogging and maintenance. The emission of sewer gas from a catchbasin does not seem to be a greater nuisance than the odors generated within a septic catchbasin sump. The water seal trap in a catchbasin should in many cases be eliminated.

REVIEW OF ALTERNATIVES

The principal alternatives to the use of catchbasins involve replacement with inlets, sewer cleaning, street cleaning, and the use of flow-attenuation devices and off-line storage.

Standard Inlets

Catchbasins can be replaced by standard inlets without any adverse effects where the sewers are laid at sufficient grade to provide self-cleaning velocities. In this case, the catchbasin replacement may provide a benefit by reducing the cost of catchbasin cleaning.

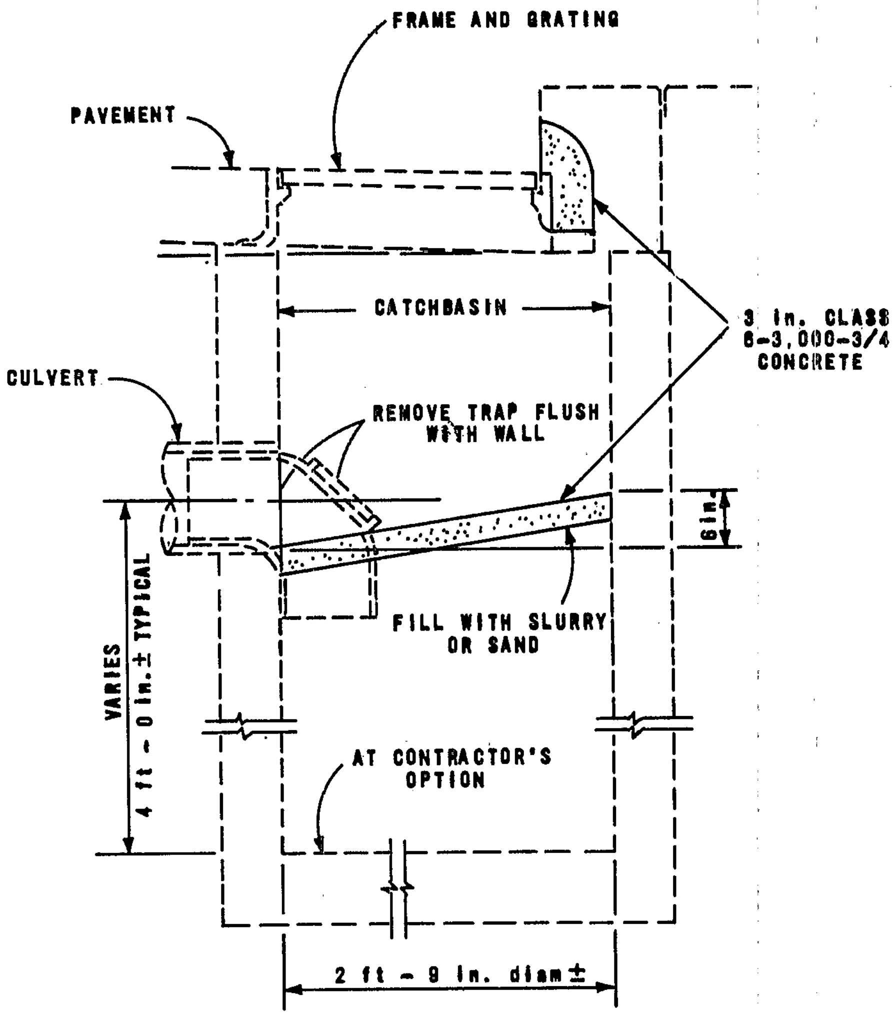
In the San Francisco Bay Area, both catchbasins and inlets are currently in use. Catchbasins are used predominantly in older sections of the communities, particularly where combined sewers either are in use or were originally constructed but have now been abandoned.

Inlets are being used exclusively in new construction throughout the area. Catchbasins are being converted to inlets in some municipalities, and inlets are being installed to replace catchbasins when road reconstruction takes place. Catchbasins are being eliminated even where combined sewers are still in use. An example of a conversion standard used in San Francisco is shown in Figure 34. To date, approximately 1,000 units have been converted within the city.

Sewer Cleaning

If a catchbasin is replaced by a standard inlet and the sewer is not laid at sufficient grade to provide self-cleaning velocities, the effect will be increased sewer cleaning costs. These may be offset, however, by the savings in catchbasin cleaning costs. Such cost comparisons are considered in Section 8.

Maintenance personnel in cities with catchbasins have some strong feelings with regard to the use of catchbasins and the conversion of catchbasins into inlets. They feel that increased use of inlets will cause restricted flow in storm sewers from sediment buildup. This sediment buildup can be excessive during low-flow periods. Yet, to date, among the municipalities interviewed, no problems have developed, and there has been no need to drag or extensively clean any storm sewers except for a few small lines--15.2 or 20.3 cm (6 or 8 in.) diameter. Some of these lines have plugged despite the existence of catchbasins on the particular offending line.



NOTE:

1. EXISTING FACILITIES SHOWN AS DASHED LINES.
2. NEW WORK SHOWN AS SOLID LINES OR AS INDICATED.

SOURCE: CITY AND COUNTY OF SAN FRANCISCO,
DEPARTMENT OF PUBLIC WORKS,
BUREAU OF ENGINEERING.

Figure 34. Conversion of catchbasin to inlet detail.

Street Cleaning

Street cleaning is not--but possibly should be--related to the type of stormwater collection system in use. Street cleaning is performed for mostly cosmetic or aesthetic reasons rather than to prevent dirt and pollution from contaminating surface runoff. Downtown and business districts are cleaned most frequently, often daily, while residential areas are cleaned less frequently, as few as four times per year.

To minimize sewer cleaning cost intensified by the absence of a catchbasin, the street cleaning program may have to be stepped up to reduce the amount of material entering the sewer. The costs of increased street cleaning must be weighed against the costs of sewer cleaning, with the added benefit of street cleaning's reduction of pollutants evaluated as a benefit of increased street cleaning.

In conjunction with street cleaning, the subject of public education in keeping the streets clean and not using the storm drain inlets as receptacles for trash, garbage, and crankcase drainings is worth emphasizing. As shown in the San Francisco survey of catchbasin contents, the wide variability of the BOD_5 and COD values clearly indicates a contribution of other-than-normal street surface contaminants.

Flow-Attenuation Devices and Onsite Storage

Some type of upstream flow-attenuation device or onsite storage unit may eliminate the need for many catchbasins as well as provide for increased treatment of combined flows by lowering the peak discharge flow to the treatment plant. The reduction in stormwater overflows would do much to decrease the pollution load on receiving waters.

The objective of onsite storage of runoff is either to prevent storm flow from reaching the drainage system or to change the timing of the runoff by controlling the release rate. Retention is the term for total containment, and detention is the common term for delaying and controlling the release rate to smooth out the peak flows. As a watershed undergoes urbanization, the amount of impervious area increases, and the natural drainage system is usually encroached upon by development. Greater quantities of storm runoff are generated by the paved areas, yet the flow must be transported by the limited drainage system. The result is an unacceptable form of onsite storage where basements, underpasses, and city streets serve as the reservoirs.

One alternative to solve the problem is to build a manmade drainage system with concrete-lined channels or large-diameter sewer pipe to carry the runoff out of the basin. However, this solution may be unacceptable either because it is too expensive or because it compounds the problem by quickly moving large quantities of water downstream and flooding lower watersheds.

A second alternative is to control the runoff where it is generated--including urbanized areas--by the controlled flooding of off-highway cloverleafs and medians, parking areas, park lands, and roof tops--and hold it in retention or detention ponds. Decreasing the flowrate may allow the natural drainage system to serve the watershed or, at least, may require a less extensive, less costly manmade system.

The impact on catchbasin usage is twofold: (1) if the natural drainage system survives or is reinstituted, catchbasins are unnecessary; and (2) if runoff rates--hence particulate carrying velocities--are significantly reduced, more solids will remain on the watershed instead of being flushed into the system, again reducing the need for catchbasins.

Consolidation

Where catchbasins are necessary for either odor/floatable control or sediment removal, their number may be reduced by consolidating the flows of several inlets through a single catchbasin before entering a drain or sewer. For example, at street intersections there are typically three catchbasins to intercept gutter flows without requiring any flow to pass across a traveled way. If two were inlets and were connected to a third which was a catchbasin, the same function would be accomplished, but the cleaning requirement (setups) would be less and the purged liquid pollution would be cut by 67 percent. With less setups required, the frequency of cleaning could be increased with potentially further benefits.

ASSESSMENT

Inherent Problems

Some of the problems associated with the use of catchbasins are:

- A single catchbasin configuration cannot perform optimally for all possible flow conditions.
- The particle sizes most difficult to retain in a catchbasin are the sizes associated with the highest level of pollution.
- Inlet grate hydraulic performance and bicycle safety do not appear to be compatible.
- Catchbasins can act as septic tanks and can generate soluble BOD_5 between storm events. This material is

washed out of the catchbasin and contributes to the "first flush" pollution load of the stormwater runoff.

- Catchbasin contents can generate obnoxious odors due to the decomposition of the organic matter trapped by the basin or dropped into the basin by people.

- Catchbasin cleaning and maintenance programs are expensive and frequently inadequate.

- Failure to clean catchbasins regularly can render them ineffective for any beneficial function, e.g., solids removal, odor trap, or even unobstructed flow from streets to collections.

Pollutant Contribution

As has been noted in the preceding discussion, catchbasin performance is mixed with respect to pollution, even with proper maintenance in effect. A perspective as to the potential balance between good and bad is given in the following example.

EXAMPLE PROBLEM 3: ANNUAL POLLUTION ASSESSMENT OF CATCHBASIN PERFORMANCE

Given the conditions expressed in the preceding problems, determine the aggregate effectiveness of the catchbasins over a period of years in terms of BOD_5 removed.

Specified Conditions

1. Total number of catchbasins = 25,000.
2. Curb length per catch basin = 0.10 curb mile.
3. Annual precipitation = 35.1 in.
4. Catchbasins are cleaned twice a year.
5. The pollution load displaced from each basin is 0.21 lb BOD_5 for each of 50 storms occurring in a year.
6. The runoff coefficient = 50%.

Assumptions

1. The annual rainfall can be characterized as 50 equal 5-h storms.
2. BOD_5 removal by sedimentation will total 26.6% of the applied load.

Solution

1. Determine the annual loss of BOD_5 by liquid volume displacement.

   BOD_5 loss = 25,000 basins x 50 storms/yr x 0.21 lb/basin per storm
   = 262,500 lb/yr

2. Compute the BOD_5 entering a catchbasin each storm (following procedures of earlier example).

   BOD_5 entering = 1.3 lb available x 0.80 removed from streets
   = 1.04 lb

3. Determine the annual removal of BOD_5 by sedimentation.

   BOD_5 removed = 25,000 basins x 50 storms x [1.04 lb x 0.266]/basin per storm
   = 345,800 lb/yr

4. Compute the annual net benefit.

Benefit = 345,800 lb removed - 262,500 lb lost

= 83,300 lb removed

5. Express as a percent of the annual total applied load.

Beneficial removal = 83,300 (from step 4) ÷ [25,000 x 50 x 1.04 (steps 2 and 3)] x 100

= 6.4% of applied load

Comment

The problem illustrates that from a pollution abatement standpoint the benefits of catchbasins are limited. Of course, with the cleaning frequency of twice per year, the liquid fraction pollution might average half the specified value, thereby increasing the benefit; however, the gross improvement is still small (16.5% versus 6.4%).

A comparison of the effectiveness in terms of ultimate BOD removed annually would probably be more meaningful. However, no data could be found indicating the ultimate BOD expected from urban surface runoff. The make-up of urban surface runoff is sufficiently different from other wastes for which ultimate BOD and reaction rate constants are known, preventing meaningful extrapolation of existing data. Also, there are no data available on the reactions that take place on material within the sump of a catchbasin.

Toxic materials may cause a lag period in the BOD reaction or suppress the BOD result, particularly the BOD_5 result. Since storm-generated discharges may contain large amounts of heavy metals and other materials which are toxic to the biochemical processes, the BOD determined may be lower than the actual oxygen demand.

It is also possible that septic conditions in catchbasins may result in the digestion of large organic particles and refractories. This could make additional material available in forms more conducive to biological degradation. Thus, it is possible for not only the soluble BOD_5 in the catchbasin to increase, but also for the ultimate BOD to increase.

The BOD_5 test is generally used to indicate the oxygen demand of the wastewater. A first order equation is generally used to describe the BOD progression with time; namely,

$$y = L(1 - 10^{-kt})$$

in which y = BOD, L = carbonaceous ultimate demand, k = reaction rate constant, and t = time of sample incubation period in days. Using the above equation and a series of BOD determinations at varying time intervals, the values of "L" and "k" can be estimated. If different wastes have the same BOD_5 but different rates of deoxygenation, the ultimate demands can vary significantly.

The BOD_{20} (20-day BOD) test can be used to better estimate the ultimate oxygen demand of a waste. The main advantage is that the importance of estimating the correct k value is reduced. As the BOD approaches the ultimate value, the variation caused by different k values is lessened. In the BOD_{20} determination, a significant portion of the nitrogenous demand is included and the effects of toxicity are less since the organisms have had sufficient time to adapt to the environment.

Another test that can be used to evaluate the ultimate BOD and reaction rate constant is the delta chemical oxygen demand (ΔCOD) test. The total oxygen demand (TOD) test, a chemical rather than a biological test, can be used to estimate the ultimate BOD.

Wullschleger, et al., have recommended that both the BOD_5 and the TOD tests be used as oxygen demand indicators [121]. The TOD test was chosen as the indicator of the total potential oxygen demand and the BOD_5 test satisfied the need for a comparative and biochemical test.

Cleaning Programs

The literature sources, especially the textbook references, indicate that the major problem associated with a catchbasin installation is an inadequate cleaning program. The major obstacle appears to be the cost involved and the apparent lack of concern of many public officials. The catchbasin cleaning program is often neglected in favor of activities that are more visible and thus may make a greater impression on the general public [9].

The allocation of manpower to inlet and catchbasin cleaning is a problem confronted by all municipalities. Many municipalities have learned that the key to a successful program is regular maintenance. If these devices are not cleaned routinely, the problem becomes uncontrollable very rapidly. The cleaning crews must divide their time between a regularly scheduled cleaning program and emergency repairs and cleanings required during wet weather. Often, a job performed during an actual rainstorm must be checked and completed after the storm has passed when more time is available. This cycle of emergency repair and follow-up can occupy most of a cleaning crew's time and thereby prevent routine maintenance from being performed, hence becoming a self-perpetuating and ever-increasing problem.

There is a tendency to modernize cleaning methods, but because of the configuration of many of the older catchbasin designs, many cities must continue to use less efficient hand and/or bucket cleaning methods. Besides being inefficient in manpower use, these methods do not provide as adequate a cleaning as the more modern eductor or vacuum cleaning methods.

Although it might be conceivable that a city with very few catchbasins would find it uneconomical to invest in a modern vacuum cleaning vehicle, the multiple-use features of these machines make this unlikely.

Ray Richards, City Engineer for Marion, Indiana (population 40,253), enthusiastically supported the mechanization of his community's catchbasin cleaning effort in a recent Public Works article [110]. The Marion program is described in the following quotation taken from the article:

> Part of our correctional program, started in July, 1974, has involved planned preventive maintenance through the 254-mile storm drain system. The worst sewer lines and manholes have now been cleaned, or soon will be, by a combination of jet cleaner and Elgin Jet-Eductor. Complaints now average three per storm [--down from 25 or more before program implementation].
>
> Previously, we cleaned manholes and catchbasins using manually-operated dip spoons and clamshell buckets. Throwing material up and onto a dump truck slowed the work so that the task took a two-man crew from 20 to 45 minutes to complete. The Eductor does a better job and in less time. Now it rarely takes two men more than 5 to 10 minutes

per catch basin from the time they pull up to the site until the work is done.

Cleanout is simplified, too. There are no extension tubes for the men to attach; no accessory equipment and no hand tools are needed. The Eductor and its suction nozzle are all that is necessary to remove stones, bricks, leaves, litter and muck.

Because no dump trucks are required to support the machine, time is saved by the crew. And, of course, the equipment and personnel needs for a catch basin cleaning job are reduced. Also, we find that the men do not tire as they did in the past.

The Elgin unit has helped us change our entire program...Now, instead of rushing from one emergency to another, we have established a planned preventive maintenance schedule. Because the Eductor has made the job so fast and effortless, we hope to clean catch basins in a 12-month cycle. Thus, we will get to each basin more frequently, particularly those which are troublesome and those located close to commercial and industrial establishments. Cleanout on a regular basis has the additional advantage of restoring full design flow to the sewer lines. Our program now is one of action, not reaction.

Conclusions

From the information thus far reviewed, the general response to the questions raised at the beginning of this section is that catchbasins should be used only where there is a solids transporting deficiency in the downstream collection sewers and drains, or at specific sites where available surface solids are unusually abundant (such as beach areas, construction sites, unstable embankments, etc.). The advantages to be considered in the conversion of existing catchbasins to inlets, assuming these criteria are satisfied, are (1) a direct reduction in the "first flush" pollutant load, (2) a reduction in required maintenance, and (3) the opportunity to reallocate the conserved labor. Design criteria for new basins were given in the preceding section, and the recommended cleaning frequency should be adjusted to limit the sediment buildup to 40 to 50 percent of the sump capacity.

Now let's look at the economics.

SECTION 8

ECONOMIC EVALUATION

The economic evaluation of alternative storm and combined sewer designs with respect to the use of catchbasins or inlets is described and illustrated in this section. Economic criteria are presented, along with basic cost information, an analysis of alternatives, and a brief summary discussion.

ECONOMIC CRITERIA

To properly assess the economic feasibility of alternative storm sewer installations, it is necessary to prepare detailed cost estimates. Before such estimates can be prepared, however, economic criteria must be selected to ensure that equivalent costs are compared. For example, a true evaluation of alternatives can be based on present worth or annual cost. In general, annual cost comparisons are preferred because the significance of the cost components is more easily understood. For this reason, annual cost comparisons are used in this report.

Components of annual costs include operation, maintenance, supervision, depreciation, and interest on borrowed capital. Annual interest and depreciation, commonly referred to as "fixed costs," are computed using the capital recovery method [107]. The recommended recovery period (also referred to as useful life) for storm sewers will vary from 20 to 40 years. Often, short return periods are used when future plans are uncertain, especially with regard to regionalization. The current (November 1976) interest rate charged on borrowed money varies from 7 to 10 percent.

Because costs are changing so rapidly, both nationally and locally, it is extremely important that any cost evaluation be referenced to some index. One of the most common is the Engineering News-Record Construction Cost (ENRCC) index. Other important indexes include the EPA Sewer Cost and Treatment Plant indexes. When possible, index values should also be adjusted to reflect local costs, which may be higher or lower than the national index. An ENRCC index of 2000 is used in this report. The following formula can be used to adjust the reported costs to another index value:

$$\text{adjusted cost} = (\text{reported cost}) \left(\frac{\text{value of index}}{2000}\right)$$

COST DATA AND INFORMATION

To properly evaluate alternative plans involving the use of catchbasins or inlets, data must be available on catchbasin and inlet construction costs, cleaning costs for catchbasins and inlets, and sewer cleaning costs.

Catchbasin and Inlet Costs

After a drainage system has been designed, inlet facilities can be constructed using either a standard inlet or a catchbasin without affecting the design, since both devices have practically the same maximum hydraulic capacity. Typical cost data for catchbasins and inlets are presented in Table 28. The reported costs will vary, depending on the size of the catchbasin or standard inlet used by a particular city, but it can be assumed that the construction cost of a typical catchbasin will be about 20 to 40 percent more than the cost of a standard inlet. Catchbasin costs are shown in Figure 35 as a function of retained storage capacity.

TABLE 28. COST DATA FOR CATCHBASINS AND INLETS

	Catchbasins		Inlets	
	Range	Avg	Range	Avg
Total installed cost, $[a]	400-1,000	800	300-800	600

a. Based on an ENRCC index of 2000.

Catchbasin and Inlet Cleaning Costs

Catchbasin cleaning, when done adequately, is an expensive aspect of catchbasin use. The operation and maintenance costs of a catchbasin consist of (1) the catchbasin cleaning and debris disposal costs, (2) maintenance costs of those items of the catchbasin not found in a standard inlet, such as the trap and sump, and (3) the operation and maintenance costs of the catchbasin cleaning equipment prorated if used for other purposes, such as leaf removal from gutters. Catchbasin cleaning costs will vary, depending on the method used, the required cleaning frequency, the amount of debris removed, and debris disposal costs.

Typical costs for cleaning catchbasins by hand, with an eductor, and by vacuum, are reported in Table 29 both for those regions

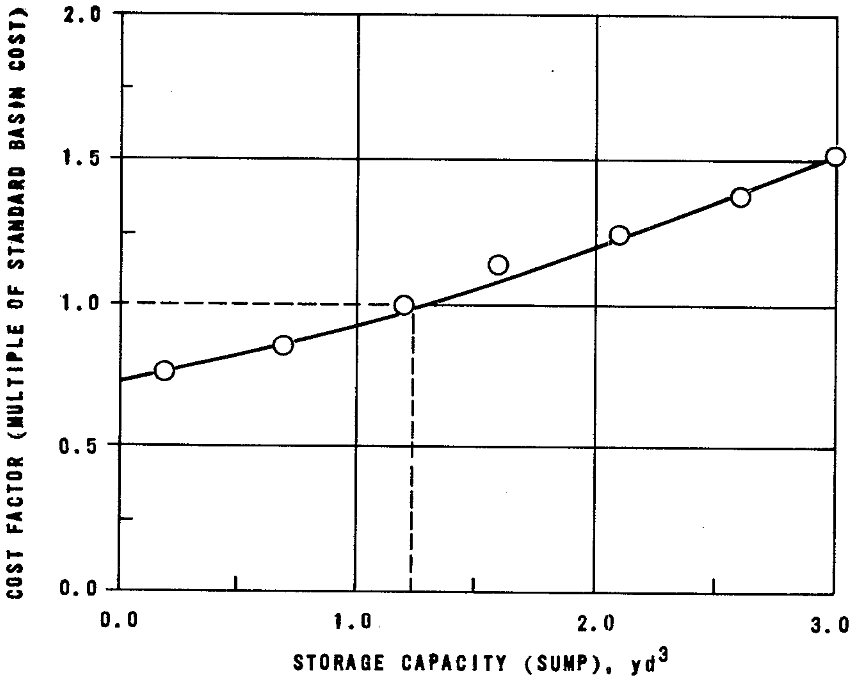


Figure 35. Catchbasin cost versus storage capacity

TABLE 29. CATCHBASIN CLEANING COSTS[a,b]

Statistical measure[c]	Manual cleaning			Eductor cleaning			Vacuum cleaning		
	$/catch-basin	$/m³	($/yd³)	$/catch-basin	$/m³	($/yd³)	$/catch-basin	$/m³	($/yd³)
Regions with heavy winter snowfall									
Sample size	17	10		5	6		26	14	
Geometric mean, M_g	10.53	9.08	(6.94)	3.23	3.01	(2.30)	4.94	9.86	(7.54)
Standard deviation, σ_g	4.53	10.10	(7.72)	3.38	17.76	(13.58)	2.97	2.20	(1.68)
National									
Sample size	51	37		10	10		51	37	
Geometric mean, M_g	7.66	18.86	(14.42)	5.92	5.35	(4.09)	7.99	11.24	(8.59)
Standard deviation, σ_g	3.04	11.18	(8.55)	3.30	13.18	(10.08)	3.05	5.95	(4.55)

a. Based on an ENRCC index of 2000.

b. Data from APWA survey.

c. See Appendix B.

(using breakdowns of survey data by state) with heavy winter snowfall and all of the regions considered together. The cost comparisons between cleaning methods appear reasonable; however, the unit costs as a group appear low and should be verified against local experience. In the case of hand cleaning,

cleaning costs would be expected to be more expensive in regions with heavy snowfall because of exposure. Cleaning costs with eductor and vacuum systems in regions with heavy snowfall should be lower because there are more catchbasins per unit area, and the basins are usually cleaned more frequently. Geographic location as related to the pollution load is also a factor.

Although there is little information or cost data available, inlet cleaning costs must be considered in any analysis of alternatives. On the basis of limited data, it appears that cleaning costs for inlets are about $3.00 per inlet using a vacuum system. The costs will vary with location and the design of the inlet.

Sewer Cleaning Costs

Cleaning costs for sewers will vary with the size of the sewer and amount of material to be removed. Representative sewer cleaning costs based on the sewer size are reported in Table 30. In view of the magnitude of the costs involved in cleaning sewers of any type, accurate cost data must be obtained for local conditions before preparing an economic evaluation of alternatives where sewer cleaning costs will be a central issue.

TABLE 30. REPRESENTATIVE SEWER CLEANING COSTS[a]

	Cost	
Sewer size and type	$/cm diam per lin m	($/in. diam per lin ft)
Diameter ≤122 cm (≤48 in.)[b]		
Storm	0.095	(0.075)
Combined	0.195	(0.15)
Diameter >122 cm (>48 in.)		
Storm	0.13	(0.10)
Combined[c]	0.26	(0.20)

a. Based on an ENRCC index of 2000.

b. Range $0.03 to $0.19 in. diam per lin ft [111].

c. In Boston, 13,000 ft of 60 in. diam combined sewer was cleaned for a total cost of $11.50 per foot of sewer [112].

ECONOMIC ANALYSIS OF ALTERNATIVES

Because of the expense involved, sewer cleaning frequency is a prime consideration in the installation of a catchbasin.

Ultimately, the cost differential between the installation of catchbasins and the installation of inlets can be defined as:

Δcost = Δ installation cost + Δ sewer cleaning cost + Δ catchbasin/inlet cleaning cost + Δ pollution costs associated with use of catchbasins

The pollution cost term is composed of (1) cost savings associated with grit or pollution load savings attributable to the catchbasin cleaning program and (2) costs associated with any pollution load attributable to the use of catchbasins. These two costs are difficult to evaluate in most systems but may be measurable in large systems. For practical purposes, the decision on whether or not to install a system with catchbasins or inlets can be made by comparing (1) the annual costs for the initial installation of catchbasins or inlets, (2) the yearly cleaning costs, and (3) the equivalent annual costs for sewer cleaning for each system. The actual computations involved in the preparation of an economic evaluation of alternatives are illustrated in the following examples. The first two examples deal with the conversion of catchbasins to inlets in an existing system. The third example deals with the question of whether to install catchbasins or inlets in a new installation. The fourth example illustrates the choice between the purchase of additional equipment and investing in structural improvements.

EXAMPLE PROBLEM 4: ECONOMIC EVALUATION OF CONVERTING CATCHBASINS TO INLETS IN AN EXISTING STORM SEWER SYSTEM

Prepare an annual cost comparison between the continued operation of a storm sewer with catchbasins and the same system if the catchbasins are converted to inlets for return periods of 10, 20, 30, and 40 years.

Specified Conditions

1. Total number of catchbasins in storm sewer system = 140.
2. Storm sewer sizes, lengths, and volumes:

Diam, in.	Length, ft	Volume, ft3
12	10,000	7,850
18	5,000	8,840
24	4,000	12,570
36	4,000	28,270

3. Storm sewers with catchbasins are cleaned once every 10 years.
4. Existing catchbasins are well designed, cleaned twice every year, and achieve a 50 percent capture of the entering material.

Discussion

Separate storm sewer systems are traditionally designed to provide localized flood relief at minimum cost. This frequently results in mixed systems of natural channel, improved open channel, and enclosed conduit subsystems in various combinations. As a result, street drainage, which may or may not be routed through catchbasins, constitutes only a portion of the solids entry to the system. In this example it is assumed that the solids deposited in the enclosed conduit subsystem become cost effective to remove when the total volume of the enclosed conduits is reduced 10 percent [57,530 ft^3 x 0.10 = 5,753 ft^3].

In the specified case of storm sewers with catchbasins, this accumulation is reached every 10 years on the average, representing an annual accumulation of of 575 ft^3 per year, even though the storm sewers have been constructed with "self-cleaning" velocities.

Under the modified conditions, catchbasins replaced with inlets, the accumulation rate will be increased in proportion to the additional solids entering but not carried through the system. Assuming the catchbasins each had a sump volume of 1.7 yd^3 and were cleaned on the average when they were 40 percent full, the total sediment removed per year per basin was 36.7 ft^3 [1.7 yd^3 x 27 ft^3/yd^3 x 2 times per year x .40 full = 36.7 ft^3] and for all catchbasins was 5,141 ft^3 per year [140 basins x 36.7 ft^3 = 5,141 ft^3]. Because of the "self cleaning" velocities most, say 90 percent, of this material would pass through the storm sewer system. The remaining 10 percent, however, represents an additional annual accumulation in the storm sewers of 514 ft^3 per year; thus almost doubling the accumulation rate from 575 ft^3 per year to 1,089 ft^3 per year and shortening the time between sewer cleanings from 10 years to 5 years (see Assumption 6 below).

Assumptions

1. Catchbasins and sewers have just been cleaned.
2. The cost of cleaning each catchbasin using a vacuum system = \$8 per cleaning (see Table 29).
3. Sewer cleaning costs are as specified in Table 30.
4. The cost of converting a catchbasin to an inlet = \$200.
5. Each inlet will have to be cleaned once every 2 years at a cost of \$3 per inlet.
6. If the catchbasins are converted inlets, it is anticipated that the sewers will have to be cleaned once every 5 years.
7. Interest rate = 8%.
8. Inflation rate for sewer cleaning costs = 4%.
9. Catchbasin and inlet cleaning costs will increase by \$0.50 and \$0.15 each year, respectively. These cost increases are consistent with improvements in equipment which tend to decrease costs.

Solution

1. Determine the sewer cleaning costs at today's prices.

Pipe diam, in.	Length, ft	Cost, \$ Per lin ft	Cost, \$ Total
12	10,000	0.90	9,000
18	5,000	1.35	6,750
24	4,000	1.80	7,200
36	4,000	2.70	10,800
Total for system			33,750

2. Determine the future sewer cleaning costs taking into account inflation and converting those costs to present worth.

Time, yr	Factor[a]	Cost, \$	Present worth Factor[b]	Present worth Cost, \$
0	1.000	33,750	1.0000	33,750
5	1.217	41,074	0.6806	27,955
10	1.480	49,950	0.4632	23,137
15	1.801	60,784	0.3152	19,159
20	2.191	73,946	0.2145	15,861
25	2.666	89,977	0.1460	13,137
30	3.243	109,451	0.0994	10,879
35	3,946	133,177	0.0676	9,003
40	4.801	162,034	0.0460	7,454

a. Single payment compound amount factor at 4% for the period shown in years.

b. Single payment present worth factor at 8% for the period shown in years.

3. Determine the present worth of the sewer cleaning costs for each alternative plan for the various return periods, and convert those costs to a uniform annual cost for those periods.

	Alternative 1[a]			Alternative 2[b]		
Period, yr	Present worth, $	Factor[c]	Annual cost, $	Present worth, $	Factor[c]	Annual cost, $
10	23,137	0.14903	3,448	51,092	0.14903	7,614
20	38,998[d]	0.10185	3,972	86,112	0.10185	8,770
30	49,877	0.08883	4,431	110,128	0.08883	9,783
40	57,331	0.08386	4,808	126,585	0.08386	10,615

a. Retain catchbasins.

b. Convert catchbasins to inlets.

c. Capital recovery factor at 8% for the period shown in years.

d. From Step 2 ($38,998 = $23,137 + $15,861).

4. Determine the initial cost of converting the catchbasins to inlets, and convert this cost to a uniform annual cost.

Conversion cost = 140 x $200/conversion = $28,000.

Convert the initial cost to annual cost.

Period, yr	Factor	Annual cost, $
10	0.14903	4,173
20	0.10185	2,852
30	0.08883	2,487
40	0.08386	2,348

5. Determine the annual cost of cleaning the catchbasins for the various return periods.

Period, yr	Base cost, $	Gradient factor[a]	Gradient cost, $	Annual cost, $
10	2,240	3.87	542[b]	2,782
20	2,240	7.04	986	3,226
30	2,240	9.19	1,287	3,527
40	2,240	10.57	1,480	3,720

a. Accounts for yearly incremental increase in cost at i = 8% [107 pp 50-52].

b. 140 basins x $0.50 annual cost increase x 3.87 x 2 cleanings/yr.

6. Determine the annual cost of cleaning the inlets for the various return periods.

Period, yr	Base cost, $	Gradient factor	Gradient cost, $	Annual cost, $
10	210	3.87	41	251
20	210	7.04.	74	284
30	210	9.19	96	306
40	210	10.57	111	321

7. Prepare a summary of the annual costs for each alternative.

		Annual cost, $				
Alternative	Return period, yr	Catchbasin conversion	Sewer cleaning	Catch-basin cleaning	Inlet cleaning	Total
1 - Retain catchbasins	10	---	3,449	2,782	---	6,230
	20	---	3,972	3,226	---	7,198
	30	---	4,431	3,527	---	7,958
	40	---	4,808	3,720	---	8,528
2 - Convert catchbasins to inlets	10	4,173	7,614	---	251	12,038
	20	2,852	8,770	---	284	11,906
	30	2,487	9,783	---	306	12,576
	40	2,348	10,615	---	321	13,284

Comment

From the computational summary presented in Step 7 of the solution, it can be concluded that the cost and required frequency of cleaning the existing sewers is the dominating economic consideration with respect to conversion of catchbasins to inlets. For example, if the sewer cleaning frequency were to remain the same after conversion (i.e., sewer cleaning costs would be the same in each alternative), the economic advantage would switch to Alternative 2 by the 20th year. [$2,852 conversion + $3,972 sewer cleaning + $284 inlet cleaning = $7,108 which is less than $7,198].

EXAMPLE PROBLEM 5: RECONSIDERATION OF PROBLEM 4 WHERE SEWER CLEANING CONCERNS ARE LIMITED TO A SMALL PORTION OF THE SYSTEM.

Repeat the annual cost comparison of Problem 4 assuming that 90 percent of the specified storm sewer system is known to be free of solids sedimentation problems.

Specified Conditions

1. Same as Problem 4, except that trouble spots with respect to solids deposition are known and limited to 10 percent of the pipe network.

Assumptions

1. The trouble spots are contiguous and cleaning unit costs remain the same.
2. The storm sewer sizes and lengths requiring cleaning remain in the same proportions as in Problem 4.

Solution

1. Repeat Step 7 of Problem 4, except reduce the sewer cleaning costs to 10 percent of their previous value.

Alternative	Return period, yr	Annual cost, $				
		Catchbasin conversion	Sewer cleaning	Catch-basin cleaning	Inlet cleaning	Total
1 - Retain catchbasins	10	--	345	2,782	--	3,127
	20	--	397	3,226	--	3,623
	30	--	443	3,527	--	3,970
	40	--	481	3,720	--	4,201
2 - Convert catchbasins to inlets	10	4,173	761	--	251	5,185
	20	2,852	877	--	284	4,013
	30	2,487	978	--	306	3,771
	40	2,348	1,061	--	321	3,730

Comment

Knowledge and understanding of the operational characteristics of the specific system under study is an essential input to the analysis for proper decision-making.

EXAMPLE PROBLEM 6: ECONOMIC EVALUATION OF INSTALLING CATCHBASINS OR INLETS IN A NEW DEVELOPMENT

Prepare an economic comparison based on annual cost of the installation of catchbasins and inlets in a proposed new development in which separate storm sewers are to be used. Omit the storm sewer construction cost, as it will be the same for both systems. Also, determine the sewer cleaning frequency at which the annual costs for the two alternatives are essentially the same.

Specified Conditions

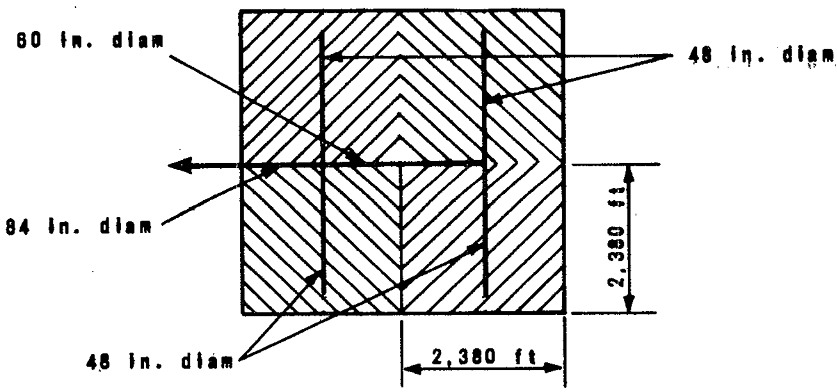
1. Development area = 520 acres.
2. Separate storm sewers are to be installed.
3. Return period for project = 36 years.
4. Interest rate = 8%.
5. Neglect inflation costs in economic analysis.

Assumptions

1. Catchbasin density = 0.46/acre.
2. Cost of cleaning each catchbasin using a vacuum system = $8 (see Table 29).
3. Cost of cleaning each inlet = $3.
4. Sewer cleaning costs as specified in Table 30.
5. Catchbasins will be cleaned twice per year.
6. Inlets will be cleaned once per year.
7. Cleaning of storm sewers with catchbasins will occur once every 18 years.
8. Prepare computations assuming that the storm sewers with inlets will have to be cleaned every 6, 9, 12, 15, and 18 years (see discussion under Example Problem 4).

Solution

1. Total number of catchbasins required = 240 (520 acres x 0.46 catchbasins/acre).
2. Using four 130-acre units, a typical layout for the interceptor storm sewers is presented below:



3. The corresponding storm sewer pipe size distribution for each 130-acre parcel might be as follows:

Pipe diam, in.	Length, ft
10	530
15	4,450
18	880
24	3,100
30	1,030
36	1,200
48	1,900

The exact pipe size distribution will vary with each location.

4. Compute the cost of cleaning the storm sewers.

Pipe diam, in.	Total length, ft	Cost, $ Per ft	Total
10	2,120	0.75	1,590
15	17,800	1.12	19,936
18	3,520	1.35	4,752
24	12,400	1.80	22,320
30	4,120	2.25	9,270
36	4,800	2.70	12,960
48	7,600	3.60	27,360
60	2,380	4.50	10,710
84	1,190	6.30	7,497
Total cost			116,395

5. Compute the present worth of future cleaning costs.

Time, yr	Factor[a]	Cost, $
6	0.6302	73,352
9	0.5002	58,221
12	0.3971	46,220
15	0.3152	36,688
18	0.2502	29,122
24	0.1577	18,355
27	0.1252	14,573
30	0.0994	11,570
36	0.0626	7,286

a. Single payment present worth factor at 8% for the period shown in years.

6. Determine the total present worth of future cleaning costs and convert them to annual costs.

Alternative	Cleaning interval, yr	Total present worth, $	Factor[a]	Annual cost, $
Storm sewers with catchbasins	18	36,408[b]	.08535	3,107
Storm sewers with inlets	6	185,905	.08535	15,867
	9	109,202	.08535	9,320
	12	71,861	.08535	6,133
	15	48,258	.08535	4,119
	18	36,408	.08535	3,107

a. Capital recovery factor at 8% for 3-year period.
b. Sum of present worths (Step 5) for 18th and 36th year.

7. Determine the annual cost of installing catchbasins.

$800/catchbasin x 240 catchbasins x 0.08535 = $16,387/yr

8. Determine the annual cost of installing inlets.

$600/inlet x 240 inlets x 0.08535 = $12,290/yr

9. Determine the annual cleaning cost for catchbasins.

240 catchbasins x 2 cleanings/yr x $8/catchbasin = $3,480/yr

10. Determine the annual cleaning cost for inlets.

240 inlets x 1 cleaning/yr x $3/inlet = $720/yr

11. Prepare a summary of annual costs excluding storm sewer construction costs, which will be the same for both systems.

Alternative	Cleaning interval, yr	Annual cost, $ Construction	Catchbasin or inlet cleaning	Sewer cleaning	Total
Storm sewers with catchbasins	18	16,387	3,840	3,107	23,334
Storm sewers with inlets	6	12,290	720	15,867	28,877
	9	12,290	720	9,320	22,330
	12	12,290	720	6,133	19,143
	15	12,290	720	4,119	17,129
	18	12,290	720	3,107	16,117

12. Determine the sewer cleaning frequency at which the costs for the two systems are essentially the same. Based on the cost information presented in Step 11, the annual cost for the two systems will be about the same when the sewer cleaning frequency for the system with inlets is approximately equal to 8.5 years.

EXAMPLE PROBLEM 7: ECONOMIC COMPARISON BETWEEN STRUCTURAL AND NONSTRUCTURAL ALTERNATIVES

This example illustrates yet another option to be considered by city administrators. Should a proposed capital investment be placed into equipment that will improve the effectiveness of maintenance of the existing system, or should a corresponding investment be used for structural modifications that will reduce the need for maintenance?

A community has 5,000 catchbasins that are presently cleaned once per year. This cleaning frequency has proven to be inadequate and plans have been proposed either to:

1. Double the cleaning frequency by the purchase and operation of a new mechanical cleaner, or
2. Convert sufficient existing catchbasins to inlets to allow present crews to clean the remaining catchbasins twice per year and each inlet once every 2 years.

Which alternative will be more economically attractive over the next 20 years?

Specified Conditions

1. A new mechanical cleaner will cost $30,000, and with a crew it can clean an average of 5,000 catchbasins per year. The useful life of the cleaner is 10 years.
2. The average cost of cleaning a catchbasin is $8.00.
3. The average cost of cleaning an inlet is $3.00.
4. The cost to convert a catchbasin to an inlet is $200.
5. Interest rate = 8%.

Assumptions

1. Sewers are self-cleaning and will not be impacted by the conversion.
2. Neglect inflation costs in the economic analysis.
3. Neglect pollution control aspects.

Solution

1. Compute the existing cleaning capability in dollars.

   5,000 catchbasins x 1 time/yr x $8/catchbasin = $40,000

2. Determine the number of catchbasins that will have to be converted to inlets to meet maintenance objectives with existing crews.

   (a) No. catchbasins x \$8 x 2 times/yr + No. inlets x \$3 x 0.5 times/yr = \$40,000
   (b) No. catchbasins + No. inlets = 5,000.

   Solving (a) and (b) simultaneously,

   No. catchbasins = 2,241
   No. inlets = 5,000 - 2,241 = 2,759
   = No. of catchbasins to be converted

3. Compute the capital cost of conversion, and express the amount as annual cost over 20 years.

   Capital cost = 2,759 x \$200 = \$551,800
   Equivalent annual cost (capital recovery factor - 8% - 20 yr)
   = 0.10185 x \$551,800
   = \$56,200

4. Compute the present worth of purchasing one mechanical cleaner now and a complete replacement unit 10 years from now, and express the amount as annual cost over 20 years.

   Capital cost = \$30,000 + (single payment present worth factor - 8% - 10 yr) x \$30,000 = \$30,000 + (0.4632) x \$30,000 = \$43,896

   Equivalent annual cost = 0.10185 x \$43,896 = \$4,471.

5. Determine the annual cost for alternative (a).

   5,000 x \$8 x 2 times/yr + \$4,461 (from Step 4) = \$84,471

6. Determine the annual cost for alternative (b).

   \$40,000 (from Step 2) + \$56,200 (from Step 3) = \$96,200

   Thus, the purchase of a mechanical cleaner would be more economically attractive.

Comment

If inflation were a major consideration, as illustrated in Problem 4, Assumption 9, or if the evaluation period were significantly longer, the cost advantage could very well shift to the structural alternative. The choice, however, is not exclusively economic as is shown in the following example.

EXAMPLE 8: POLLUTION CONTROL AND OTHER COST CONSIDERATIONS

Given that the use of inlets in preference to catchbasins reduces surface maintenance problems and costs, the questions remain as to what extent has the cost merely been transferred to another maintenance area and how has overall pollution control been effected? Compare the annual unit costs of removal of sediment and pollution in terms of BOD_5 for the following:

1. A separate storm sewer system with catchbasins
2. The same system without catchbasins
3. A conventional 10 Mgal/d activated sludge wastewater treatment facility

Specified Conditions

1. Criteria and assumptions of Problems 4 and 5 apply.
2. The activated sludge treatment plant removes 90% of an average influent BOD_5 load of 200 mg/L.

Assumptions

1. The average annual capital and operation and maintenance costs of a 10 Mgal/d activated sludge plant are \$950,100 and \$283,200, respectively [113].

2. Within this plant the average annual capital and operation and maintenance costs of the aerated grit chamber alone are \$26,480 and \$16,425, respectively.
3. The average quantity of grit removed at the plant is 3.5 ft^3 per million gallons of wastewater.

Solution

1. For system No. 1, compute the average annual cost of removing solids from catchbasins.

   [\$8.00 x 140 catchbasins x 2 cleanings per year] ÷ 5,141 ft^3 solids removed = \$0.44/ft^3

   Assuming a weight of 110 lb/ft^3, this is equivalent to \$0.44/ft^3 ÷ 110 lb/ft^3 = \$0.004/lb total solids removed.

2. For system No. 1, recompute the average annual cost in terms of BOD_5 removed

   [\$8.00 x 140 catchbasins x 2 cleanings per year] ÷ [1.04 lb/storm x 50 storms x 140 basins x 0.064 removed (following procedures of Problem 3)] = \$4.81/lb BOD_5 removed.

3. For system No. 2, compute the additional cost of removing street solids from the storm sewer system assuming 10% by volume settles out in the pipes.

   [\$7,614 - \$3,449 (annual cost change for 10-yr return period, Step 7, Problem 4)] ÷ 514 ft^3 removed = \$8.10/ft^3.

   Assuming a weight of 110 lb/ft^3, this is equivalent to \$0.074/lb total solids removed for conditions described in Problem 4 and \$0.0074/lb total solids removed for conditions described in Problem 5.

4. For system No. 2, the BOD_5 removed is considered negligible.

5. For system No. 3, the average annual cost of removing solids through the aerated grit chamber is

   [\$26,480 capital + \$16,425 O&M] ÷ [3.5 ft^3/Mgal x 10 Mgal/d x 365 d] = \$3.36/ft^3

6. For system No. 3, the average annual cost of removing BOD_5 is

$$[\$950{,}100 \text{ capital} + \$283{,}200 \text{ O\&M}] \div \left[200 \text{ mg/L} \times 0.90 \text{ removed} \times 10 \text{ Mgal/d} \times 365 \text{ d} \times 8.34 \frac{\text{lb/Mgal}}{\text{mg/L}}\right] = \$0.225/\text{lb } BOD_5 \text{ removed.}$$

Comment

In a combined sewer system, trapping and cleaning street solids from catchbasins, if practiced effectively, could significantly reduce peak grit loadings on the treatment plant headworks. This net cost savings, as well as reduced wear in headworks pumps and screens should be considered when evaluating catchbasin effectiveness. It should also be noted that in many combined systems, solids buildup in the pipe system may be largely a dry-weather flow phenomenon, as a result of reduced carrying velocities; thus, observation of the real system behavior is a necessity. For pollution control benefits other than solids, the impact of catchbasins is likely to be small, based on presently available data.

DISCUSSION

The economic evaluations illustrated in this section emphasize the importance of systematic and accurate recordkeeping in catchbasin and inlet maintenance programs and in sewer cleaning. The approach discussed is basically one of how an alternative course of action will prove to be economical in the long run, as compared to other possible actions. Contributing factors include the time period under consideration, the interest rate, and the anticipated inflationary or noninflationary trends.

The dominant cost factor for decision-makers appears to be sewer cleaning. How will the required cleaning frequency change, and which areas of the pipe network will be subjected to increased deposition as a result of using inlets versus catchbasins? If the differences are small, the use of inlets is favored.

Selected recent developments, a case history example, and suggested continuing program needs are considered in the following section.

SECTION 9

RECENT DEVELOPMENTS AND CONTINUING PROGRAM NEEDS

As has been documented in the previous sections, catchbasins historically have been constructed solely as a reaction device. That is, when solids deposition in sewers was found or suspected to be a problem, catchbasins were installed to trap these solids so that they could be removed at a more convenient location.

Recent thought, however, as now being evaluated through Public Law 92-500, Section 208 Environmental Management Studies, is directed at action rather than reactionary measures. Through the adoption and implementation of best management practices, perhaps we will no longer have to accept as a given condition that gutter flows will be high in inorganic solids, thus closing out the historic role for catchbasins. The purpose of this section is to present briefly and review (1) some recent developments in the design and operation of catchbasins, (2) a case history example, and (3) some thoughts on continuing program needs.

RECENT DEVELOPMENTS

Four aspects of recent developments in the design and operation of catchbasins are described: source controls, shock flow reduction, catchbasin modification, and system controls.

Source Controls

Best management practices are designed to remove or reduce the problem at the source. High solids loadings in gutter flows (catchbasin feed water) are the result of two things: (1) a high available supply of erodible material and (2) suspending and carrying intensities of flow. Remove the supply (through street sweeping, construction site controls, effective ground covers, general good housekeeping, etc.) and reduce the rate of flow (impounding, infiltration-percolation, selective flow routing, check dams, grassed buffer strips, etc.), and you may reduce or eliminate the problem. Because there has been too little demonstration to date on controlled versus uncontrolled broad test areas, the results that can be achieved, unfortunately, remain ill-defined.

Shock Flow Reduction

A system for reducing shock flows on storm drain systems has been developed in Denmark and Norway over the past 15 years [114]. The system basically consists of a storage basin with a rate control orifice on the outlet pipe. Flow enters the basin through the top grating and passes through a sediment trap (optional) into the storage area. When a predetermined level is reached in the basin, discharge begins. The orifice control then regulates the discharge flow to a reduced amount as compared to the inflow.

The sediment trap, located just under the inlet gratings, can be obtained in different materials, depending on the desired size of particle to be trapped. The trap is in the form of a bucket or filter bag, both of which are reusable. The filter bag is capable of retaining solids down to approximately 50 microns. The bucket type is used to trap a much larger size material.

Peak flow reductions to the sewer system (up to 95 percent have been reported) can preclude the need for collection system enlargement, and it is presumed that large quantities of sediment will be retained in the basin or filter. Removal of the sediment presents the same problems and opportunities as with catchbasins.

This system is patented and is undergoing promotional marketing in the United States and Canada at the present time. A demonstration concept proposed for a United States application in Cleveland is shown in Figure 36. By retarding the street runoff inflows to the collection system, preferential capacity is given to roof and building drainage, thus hopefully reducing basement flooding and overflows.

Catchbasin Modification

Existing catchbasins can be modified for one of two major purposes. First, the function of trapping solids can be eliminated by filling the sump of the catchbasin with concrete or some other suitable material. Second, the catchbasin geometry can be altered to effect better solids separation. In addition to these major modifications, the catchbasin can be modified by removing the water seal trap or by making the catchbasin self-draining.

Filling the sump to eliminate the solids separation feature of a catchbasin will allow the solids in the runoff to pass to the sewer. Unless the sewer has adequate velocities to be reasonably self-cleaning or the runoff contains very little sediment, filling the sump should be viewed with caution because this could greatly increase sewer cleaning costs, as has previously been discussed. Designers should evaluate the sewers

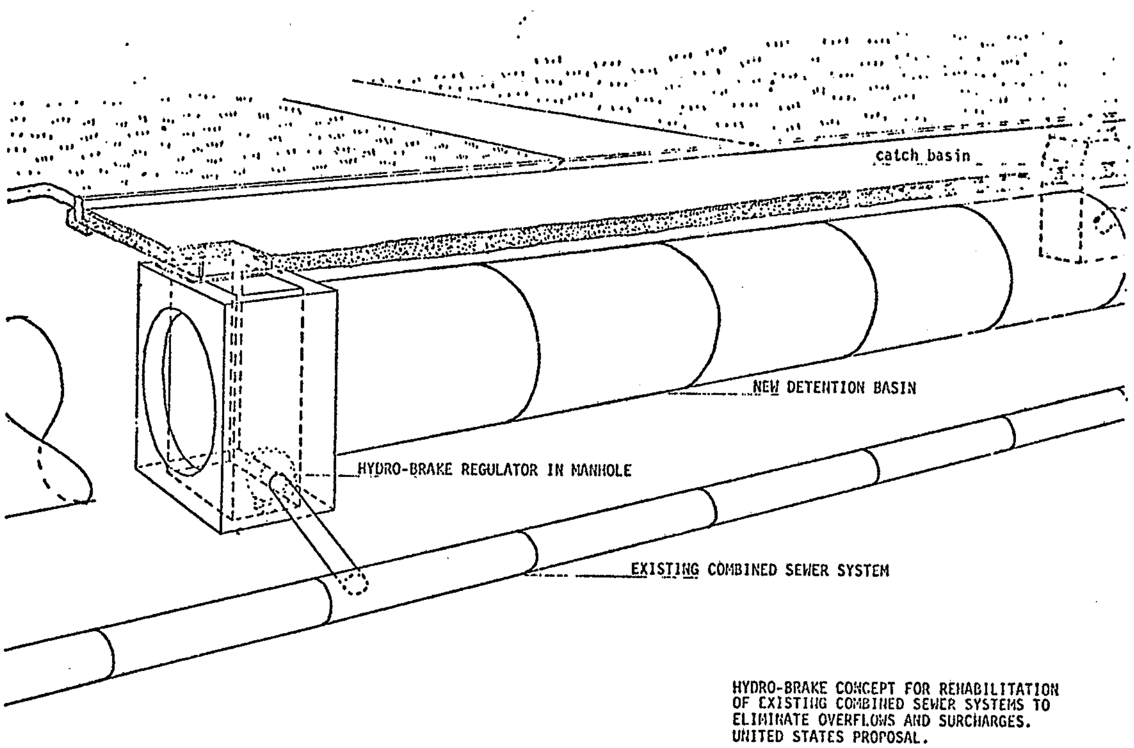


Figure 36. Shock flow reduction concept [114].

to ensure that self-cleaning velocities are maintained before recommending that catchbasin sumps be filled. A case history of this approach is outlined later in this section.

Recommendations for optimal catchbasin geometry were presented earlier. On the basis of the hydraulic model analyses, it is concluded that supplemental baffling or extensive design modifications would not be cost effective. The reason is that present configurations effectively remove coarse solids if there is proper maintenance, and selective removal of small particle size and low specific gravity material (which constitutes the maximum pollutant load) is impractical.

Removing the water seal trap is conditionally recommended on the basis of the San Francisco catchbasin survey [65] in which it was found that odor is not necessarily a result of not having a trap but probably is generated in most cases by septic conditions in the catchbasin itself. The cleaning program for catchbasins would be more efficient without the various types of water seal traps, and the construction costs would be lower.

The increased efficiency of the catchbasin cleaning program might lessen the chances of odor generation by preventing septic conditions from occurring in the catchbasin.

In this same area of reducing septic conditions in the catchbasins, providing a self-draining feature would help to keep the catchbasin contents dry and could lessen the chance of odor generation between cleanings. The problems associated with the construction and maintenance of such a drainage feature, however, appear to outweigh the benefits.

System Controls

Settling basins, flush tanks, and improved solids (swirl) separators are potential system controls to augment or replace catchbasins.

Settling Basins and Flush Tanks--

Conceptually, the objective to be achieved by replacing catchbasins with settling basins is to reduce the cost and to increase the effectiveness of stormwater solids separation techniques. An undergound structure that would be large enough to effectively trap the solids in the stormwater at peak flowrates is envisioned. This basin would also attenuate the storm flow reducing downstream carrying capacity requirements, thus reducing combined sewer overflows in a similar manner to that described under shock flow reduction. After the storm has subsided, the liquid portion would continue to discharge to the sewer and would eventually be treated at a wastewater treatment facility.

In a study conducted by FMC Corporation for the EPA, it was concluded that it was feasible to construct flush tanks in conjunction with keeping combined sewer laterals clear of sediment deposits from dry-weather buildup [104]. The principle in the operation of a flush tank is the release of additional water to the sewer to create a sufficient velocity in the sewer to transport the sedimentary material. The same principle could be used in the controlled cleansing of combined sewer trunklines and storm drains. Either a flush tank or control gate could retard the storm flow until sufficient water was stored to provide the required cleaning velocities, or it could release water from its own supply and perhaps generate flushwaves in sequence to periodically flush the storm drains.

Ideally, the benefits of shock flow reduction and system flushing could be combined if the waters that are temporarily held back contained minimum solids. This introduces a third family of devices--the swirl and helical separators.

Swirl and Helical Separators--

Swirl and helical separators rely on the centrifugal acceleration caused by changing the direction of a stream of water to separate the heavier solids from the overflow water [93, 94, 95, 96, 97, 115, 116, 117, 118, 119]. These devices have been investigated for treating storm flows so that a concentrated stream can be intercepted and sent to the wastewater treatment plant, while the overflow water, which is relatively clean compared to the normal combined sewer overflow, is allowed to continue on to the receiving waters. In the foregoing conceptual application, the overflow stream would be directed to the flush tank to be released only after the downstream collection system drained to near prestorm conditions. Obviously, the complexity of such an approach precludes its being assessed in the form of a general case.

CASE HISTORY

The City of San Francisco, Department of Public Works, has embarked on a phased program to convert catchbasins to inlets in a carefully selected and monitored manner [120]. This program, initiated in 1969, has resulted in the conversion of nearly 1,000 units (out of a total of 25,000) to date, all associated with scheduled street reconstruction and sewer projects. Because the first-phase selection criteria require only scheduled construction for other projects and the nondetection of odors in the affected manholes, the units are located randomly throughout the city.

Evaluation has included matching of odor complaints (recorded with the Bureau of Water Pollution Control between 1967 and 1973) to the location of the units, a preliminary statistical breakdown of the existing inlets with respect to factors contributing to the generation of odors, comments from the Health Department on the effects of public health and rodent control, and comments from the bureau on the maintenance and odor complaints.

Seven of 360 odor complaints over the 6-year study period were in the vicinity of a converted unit. Thus, official complaints in the vicinity of converted units are running at less than half of the citywide rate.

The Health Department comments are particularly enlightening. Eliminating the sumps is endorsed because standing water in catchbasins provides a breeding ground for mosquitos; however, the loss of the water trap creates a situation that may worsen the rat problem [120]:

> The main reason for concern appears to be the practice of [the public] dumping garbage into catchbasins. The curb

inlets provide a large opening that makes the dumping of garbage convenient. This opening also allows rats to enter the catchbasins to use the garbage as a food supply. Furthermore, without the trap, rats in the sewer system readily detect and have easy access to the garbage.

The present solution is to restrict the curb inlet openings (see Figure 34). Based upon its experience to date, the city has identified the following criteria with respect to proceeding with the conversion of catchbasins to inlets in the next phase:

1. Does not create a public nuisance by providing a vent for odors from the sewer main;

2. Does not contribute to public health problems by continuing to be a convenient dump and becoming more accessible as a food source for rats;

3. Minimizes the public nuisance and vehicular and pedestrian traffic hazard of plugged catchbasins; and,

4. Minimizes the maintenance effort of cleaning catchbasins; and, does not transfer the maintenance problems to a more difficult situation of cleaning culverts and sewer mains.

The city's program is continuing with a contract now being prepared to convert 250 additional units.

CONTINUING PROGRAM NEEDS

To obtain the data and information required to further evaluate the function and continued use of catchbasins or other devices, continuing demonstration programs must be developed and implemented. Proposed objectives and a discussion of some recommended studies are presented in the following discussion.

Objectives

The overall objectives of continuing programs should be to delineate clearly the following:

1. The impact of best management practices in reducing solids and other pollutant loads in surface runoff that must be collected from urban areas.

2. The effectiveness, through field scale demonstration, of closely monitored catchbasin cleaning programs with respect to impacts of cleaning frequency and techniques on solids carryover, general pollution abatement, and associated costs.

3. The problem of solids deposition within real sewer systems and the extent to which this problem is mitigated by properly functioning catchbasins. Is surface runoff introduced through catchbasins or inlets the prime source of the deposit material or merely a contributing source?

4. The cost effectiveness of converting catchbasins to inlets in a major prototype demonstration.

Implementation

Implementation of these programs should be carried out in a minimum of three to five regionally representative urban areas using two similar catchments in each area (one for control and one for demonstration) of, say, not less than 100 nor more than 1,000 acres. Desirable regions would be northeast, midwest, southern, and western because of their differences in climate, hydrology, and system characteristics. The term of the demonstrations would be from 1 to 2 years to cover full seasonal impacts. Ten to 20 percent of the catchbasins in each demonstration site would be monitored weekly on a fixed schedule for sediment accumulation or erosion, trap effectiveness, quality characteristics of the retained flow after mixing, and general observations as to the conditions of the catchment.

In addition, at least two catchbasins in each catchment should be equipped and monitored (quantity and quality) through sequential sampling of the basin influent and effluent during, say, ten storm events.

The results would be compiled, related to hydrology, basin condition, best management practice, cost, etc., and a performance assessment given. Where appropriate, the demonstration would include monitoring of sediment accumulations within the downstream collection system. All maintenance activities in the test catchments would be logged as to labor, equipment, material, and costs, and an assessment as to the transferability of results given.

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Appendix A

GLOSSARY

CATCHBASIN - A chamber or well, usually built at the curb line of a street, for the admission of surface water to a sewer or subdrain, having at its base a sediment sump designed to retain grit and detritus below the point of overflow.

COMBINED SEWER - A sewer receiving both surface runoff and sewage.

CURB-OPENING INLET - Vertical opening in the face of a curb for the admission of surface water.

DISSOLVED SOLIDS - The anhydrous residues of the dissolved constituents in water which cannot normally be separated from the water by laboratory filtering.

INLET - A structure that provides an entrance for surface water into a drain which is located below ground. Does not have a sump for trapping solids as in a catchbasin.

INLET GRATE - Framework of bars over an inlet or catchbasin for the admission of surface water.

LATERAL - A sewer which discharges into a branch or other sewer and has no common sewer tributary to it.

SANITARY SEWER - A sewer which normally carries domestic sewage and into which stormwater, surface water, and groundwater are precluded, so far as possible, unless intentionally admitted.

SETTLEABLE SOLIDS - Suspended solids which will subside in quiescent water or other liquid in a reasonable period. Such period is commonly, though arbitrarily, taken as one hour.

SEWER - A pipe or conduit generally closed, but normally not flowing full, for carrying sewage and other waste liquids.

STORM SEWER - A sewer which carries stormwater and surface water, street wash and other wash water, or drainage, but excludes sewage and industrial wastes.

SUSPENDED SOLIDS - Solids that either float on the surface of, or are in suspension in, water or other liquids, and which are largely removable by laboratory filtering.

TOTAL SOLIDS - The dissolved and undissolved mineral constituents in water.

Appendix B

ANALYSIS OF CATCHBASIN SURVEY DATA

The principal objective pursued in the analysis of experimental or survey data is comprehension of its significance. Typically, the approach followed when analyzing data related to a given variable is to define this central tendency and dispersion. The measures used most commonly for this purpose are the arithmetic mean and the standard deviation. In general, these measures are adequate so long as the data are more or less evenly distributed above and below the mean. Unfortunately, this is often not the case with certain types of experimental and survey data.

As an example, data dealing with catchbasins tend to be unevenly distributed or skewed. The reason for this is that the more extreme values tend to deviate beyond the mean to a greater extent than do the values that are less than the mean. This can be seen clearly in the sample data reported in Table B-1. Often, when sample data are skewed, they can be analyzed using skewed-probability paper or log-probability paper. For the data considered in this report, it was found that a geometric distribution was best. For a geometric distribution the mean, M_g , and the standard deviation, σ_g , are computed using the following expressions:

$$\log M_g = (\Sigma \log x)/n$$

$$\log \sigma_g = \sqrt{(\Sigma \log^2 x_g)/(n-1)}$$

$$\log x_g = \log x - \log M_g$$

TABLE B-1. SUMMARY DATA ON AREA PER CATCHBASIN FOR CITIES IN THE UNITED STATES [102]

City	Incorporated city area, mi^2	Number of catchbasins	Area per catchbasin, acre
1	36.7	32,000	0.7
2	18.9	1,100	1.2
3	18.4	10,090	1.2
4	45.4	25,000	1.2
5	13.3	5,500	1.5
6	29.9	12,000	1.6
7	34.3	8,350	2.6
8	60.3	14,546	2.7
9	22.4	3,561	4.0
10	50.2	6,000	5.4
11	29.4	3,500	5.4
12	26.1	2,500	6.7
13	83.9	5,100	10.5
14	19.0	1,100	11.1
15	41.8	2.069	12.9
16	95.2	4,000	15.2
17	316.9	10,500	19.3
18	131.5	2,000	42.0

$mi^2 = 2.59\ km^2$
acre = 0.4047 ha

Appendix C

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CONVERSION FACTORS
U.S. Customary to SI Metric

U.S. customary	Abbr.	Multiplier	Symbol	SI metric unit
acre	acre	0.405	ha	hectare
acre-foot	acre-ft	1,233.5	m^3	cubic metre
cubic foot	ft^3	28.32	L	litre
cubic feet per minute	cfm	0.0283	m^3/min	cubic metres per minute
cubic feet per second	cfs	28.32	L/s	litres per second
cubic inch	in.^{3}	16.39 0.0164	cm^3 L	cubic centimetre litre
cubic yard	yd^3	0.765 764.6	m^3 L	cubic metre litre
degree Fahrenheit	°F	0.555 (°F-32)	°C	degree Celsius
feet per minute	ft/min	0.00508	m/s	metres per second
feet per second	ft/s	0.305	m/s	metres per second
foot (feet)	ft	0.305	m	metre(s)
gallon(s)	gal	3.785	L	litre(s)
gallons per acre per day	gal/acre·d	9.353	L/ha.d	litres per hectare per day
gallons per capita per day	gal/capita·d	3.785	L/capita·d	litres per capita per day
gallons per day	gal/d	4.381×10^{-5}	L/s	litres per second
gallons per square foot per day	gal/ft^2·d	1.698×10^{-3} 0.283	m^3/m^2·h m^3/ha.min	cubic metres per square metre per hour cubic metres per hectare per minute
gallons per minute	gal/min	0.0631	L/s	litres per second
gallons per square foot per minute	gal/ft^2.min	2.445 0.679	m^3/m^2·h L/m^2.s	cubic metres per square metre per hour litres per square metre per second
gallons per square foot	gal/ft^2	40.743	L/m^2	litres per square metre
horsepower	hp	0.746	kW	kilowatts
inch(es)	in.	2.54	cm	centimetre
inches per hour	in./h	2.54	cm/h	centimetres per hour
million gallons	Mgal	3.785 3,785.0	ML m^3	megalitres (litres x 10^6) cubic metres
million gallons per acre per day	Mgal/acre·d	0.039	m^3/m^2·h	cubic metres per square metre per hour
million gallons per day	Mgal/d	43.808 0.0438	L/s m^3/s	litres per second cubic metres per second
mile	mile	1.609	km	kilometre
parts per billion	ppb	0.001	mg/L	milligrams per litre
parts per million	ppm	1.0	mg/L	milligrams per litre
pound(s)	lb	0.454 453.6	kg g	kilogram grams
pounds per acre per day	lb/acre·d	0.112	g/m^3·d	grams per square metre per day
pounds per day per acre	lb/d·acre	1.121	kg/ha·d	kilograms per hectare per day
pounds per 1,000 cubic feet	lb/1,000 ft^3	16.077	g/m^3	grams per cubic metre
pounds per million gallons	lb/Mgal	0.120	mg/L	milligrams per litre
pounds per cubic foot	lb/ft^3	16.02	kg/m^3	kilograms per cubic metre
pounds per square foot	lb/ft^2	4.882×10^{-4}	kg/cm^2	kilograms per square centimetre
pounds per square inch	lb/in.^{2}	0.0703	kg/cm^2	kilograms per square centimetre
square foot	ft^2	0.0929	m^2	square metre
square inch	in.^{2}	6.452	cm^2	square centimetre
square mile	mi^2	2.590	km^2	square kilometre
square yard	yd^2	0.836	m^2	square metre
standard cubic feet per minute	std ft^3/min	1.699	m^3/h	cubic metres per hour
ton (short)	ton	0.907	Mg (or t)	megagram (metric tonne)
yard	yd	0.914	m	metre

TECHNICAL REPORT DATA
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15. SUPPLEMENTARY NOTES

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16. ABSTRACT

An overview and assessment of current catchbasin technology has been prepared to provide engineers and municipal managers with technical and economic information on catchbasins and some alternatives so that they can make intelligent, informed decisions on runoff collection systems in light of pollution control legislation, the municipality's financial status, and its particular stormwater runoff characteristics.

Various catchbasin configurations and sizes were evaluated for hydraulic and pollutant removal efficiencies using hydraulic modeling analyses.

Detailed study findings are presented in sections dealing with (1) a state-of-the-art review, (2) a review of variables affecting catchbasin efficiency, (3) hydraulic modeling analyses, (4) an assessment of the role of catchbasins, (5) an economic evaluation of alternative storm and combined sewer designs, and (6) a review of recent developments and continuing program needs. Detailed example problems of the evaluation of catchbasin performance and economics are included.

A recommended catchbasin design configuration based upon hydraulic performance and sediment capture efficiency is presented.

17. KEY WORDS AND DOCUMENT ANALYSIS

a. DESCRIPTORS	b. IDENTIFIERS/OPEN ENDED TERMS	c. COSATI Field/Group
*Catch Basins, *Combined Sewers, *Storm Sewers, *Surface Waters, Runoff, *Water Pollution, *Water Quality	Catchbasin design, economic assessment, hydraulic models, pollution abatement, storm runoff, urban hydrology	13B

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