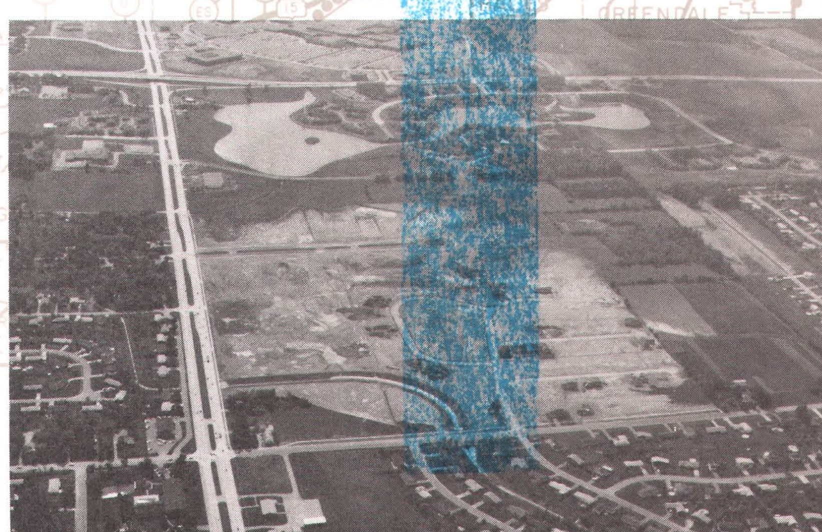
TECHNICAL REPORT NUMBER 18

# STATE OF THE ART OF WATER POLLUTION CONTROL IN SOUTHEASTERN WISCONSIN





## volume three

## URBAN STORM WATER RUNOFF

SOUTHEASTERN WISCONSIN REGIONAL PLANNING COMMISSION

Special acknowledgement is due Lyman F. Wible, P.E., SEWRPC Water Quality Program Coordinator, and Robert P. Biebel, P.E., SEWRPC Sanitary Engineer, for their contributions to this report.





*Cover photo courtesy of Park Plaza Joint Venture, Brown Deer, Wisconsin*

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NUMBER 18

# STATE OF THE ART OF WATER POLLUTION CONTROL IN SOUTHEASTERN WISCONSIN

## Volume Three

## URBAN STORM WATER RUNOFF

Prepared by Stanley Consultants, Inc.,
for the
Southeastern Wisconsin Regional Planning Commission
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July 1977



Inside Region $2.50
Outside Region $5.00

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SOUTHEASTERN WISCONSIN REGIONAL PLANNING COMMISSION

916 NO. EAST AVENUE • P.O. BOX 769 • WAUKESHA, WISCONSIN 53186 • TELEPHONE (414) 547-6721

Serving the Counties of: KENOSHA MILWAUKEE OZAUKEE RACINE WALWORTH WASHINGTON WAUKESHA

July 5, 1977

## STATEMENT OF THE EXECUTIVE DIRECTOR

Pursuant to the provisions of Section 208 of the Federal Water Pollution Control Act, the Southeastern Wisconsin Regional Planning Commission on July 1, 1975, undertook an areawide water quality management planning program. The objectives of this program are: to determine current stream and lake water quality conditions within the Region; to compare these conditions against established water use objectives and supporting water quality standards; to explore alternative means of meeting those objectives and standards through the abatement, as necessary, of both point and diffuse sources of water pollution; and to recommend the most cost-effective means of meeting the established objectives and standards over time. The formulation of sound recommendations for the abatement of water pollution and attainment of water use objectives requires, among other things, definitive knowledge of the state of the art of the technology of wastewater treatment and disposal. If the areawide water quality management plan is to be sound and practical, it must seek to apply, as necessary, the best available wastewater treatment technology and avoid the proposed application of outmoded, unsound, unreliable, or unsafe practices.

In order to assure that the areawide water quality management plan would be founded on a sound technical basis, the Commission retained a consulting engineering firm—Stanley Consultants, Inc.—to conduct a review of the state of the art of water quality management. The study was intended to provide definitive data on the applicability, effectiveness, reliability, and cost of the various techniques currently available for the treatment of sanitary and industrial wastewaters, urban storm water runoff, rural storm water runoff, and the residual solids—or sludges—resulting from the treatment of these wastewaters. The findings of this review of the state of the art are presented in a four volume report. This, the third volume, presents the state of the art of the control of pollution from urban storm water runoff. The information contained in the report, like that contained in the fourth volume which deals with control of pollution from agricultural runoff, is required in the areawide water quality management planning effort to deal with diffuse, as opposed to point, sources of water pollution.

Because there has been considerably less experience to date with the abatement of water pollution from diffuse sources than from point sources, the state of the art of the former is less well developed than for the latter. Although there is a long history of municipal engineering experience in the control of the quantity of storm water runoff, there is little experience in the control of the quality of such runoff.

Consequently, methods proposed for the abatement of pollution from urban storm water runoff have generally been adaptations of methods intended to control the rates of discharge and the total quantities of urban storm water runoff or adaptations of methods to control the quantity and quality of combined sewer overflows. There has been a significant amount of research and development as well as practical field experience in the control of combined sewer overflows. Some of these techniques, as noted in this report, may be transferable to the control of urban storm water quality. Nevertheless, the state of the art of control of diffuse pollution sources does differ substantially from the control of point source pollution in the difference in predicting the effectiveness of control techniques. Knowledge of attendant reductions in levels of nutrients, pathogenic organisms, heavy metals, or toxic and hazardous substances is limited. This report presents in a concise manner the known information about cost and effectiveness of the techniques available to control water pollution associated with urban storm water runoff.

It is the hope of the Commission staff that, in addition to properly reflecting the current state of the art of waste water management, this volume and its three companion volumes will contribute to that state of the art by providing a concise presentation of the techniques involved; evaluating their application to water quality management within southeastern Wisconsin; and presenting the technical information in a format which permits consideration of the cost of alternative means of meeting the water use objectives for the lakes and streams of the Region.

Respectfully submitted,

Kurt W. Bauer
Executive Director

**STANLEY CONSULTANTS, INC**

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November 17, 1976

Southeastern Wisconsin Regional
Planning Commission
916 N. East Avenue
Old Courthouse
Waukesha, Wisconsin 53186

Attention Mr. Kurt W. Bauer, Executive Director

Gentlemen:

Re: State-of-the-Art Studies
208 Water Quality Management
Planning Program

We are pleased to submit our final draft report entitled "Urban Intermittent Point and Nonpoint Wastewater Control Alternatives and Cost Information." This report represents a departure from other state-of-the-art investigations as review of available information indicates that the state-of-the-art for storm water runoff control is in its infancy. Little is known of the loadings, impact, or effectiveness of controls for storm water management. An attempt has been made in this report to provide usable information on each topic. Indications are that the state-of-the-art will be developed as part of 208 planning programs throughout the nation.

This final draft report reflects modifications and additions to our September 27, 1976, preliminary draft report as a result of your constructive comments relative to that document.

We have appreciated the opportunity to prepare this element of the Regional Water Quality Management Program. Should you have any questions during your use of this report, please feel free to call us.

Sincerely,

STANLEY CONSULTANTS, INC.

RG Fritchie

R. G. Fritchie, P. E.
Project Manager

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# Chapter I

# INTRODUCTION

This report presents information on the technical capabilities and costs of alternative techniques for management and control of urban storm water runoff. Techniques are described where possible in terms of capabilities, costs, operational experience, and applicability to the study area. Emphasis is given to those techniques which can be feasibly and reliably applied within the Region if subsequent analysis indicates the need for such controls.

## SCOPE

The specific scope of this investigation includes:

1. Evaluation of structural processes for control of urban storm water runoff including collection and treatment of storm water from separate sewer system areas and in-system or end-of-pipe treatment arrangements, as well as a general review of the methods for control of combined storm and sanitary sewer overflows.

2. Descriptions of processes developed above, instances where the processes have been applied, and the results obtained.

3. Development of schematic diagrams and cost data over a range of flows and/or capacities for feasible control approaches involving structural controls.

4. Evaluation of nonstructural control techniques for reducing pollution loads reaching storm drainage systems.

5. Descriptions of control techniques and the framework and potential costs associated with nonstructural controls.

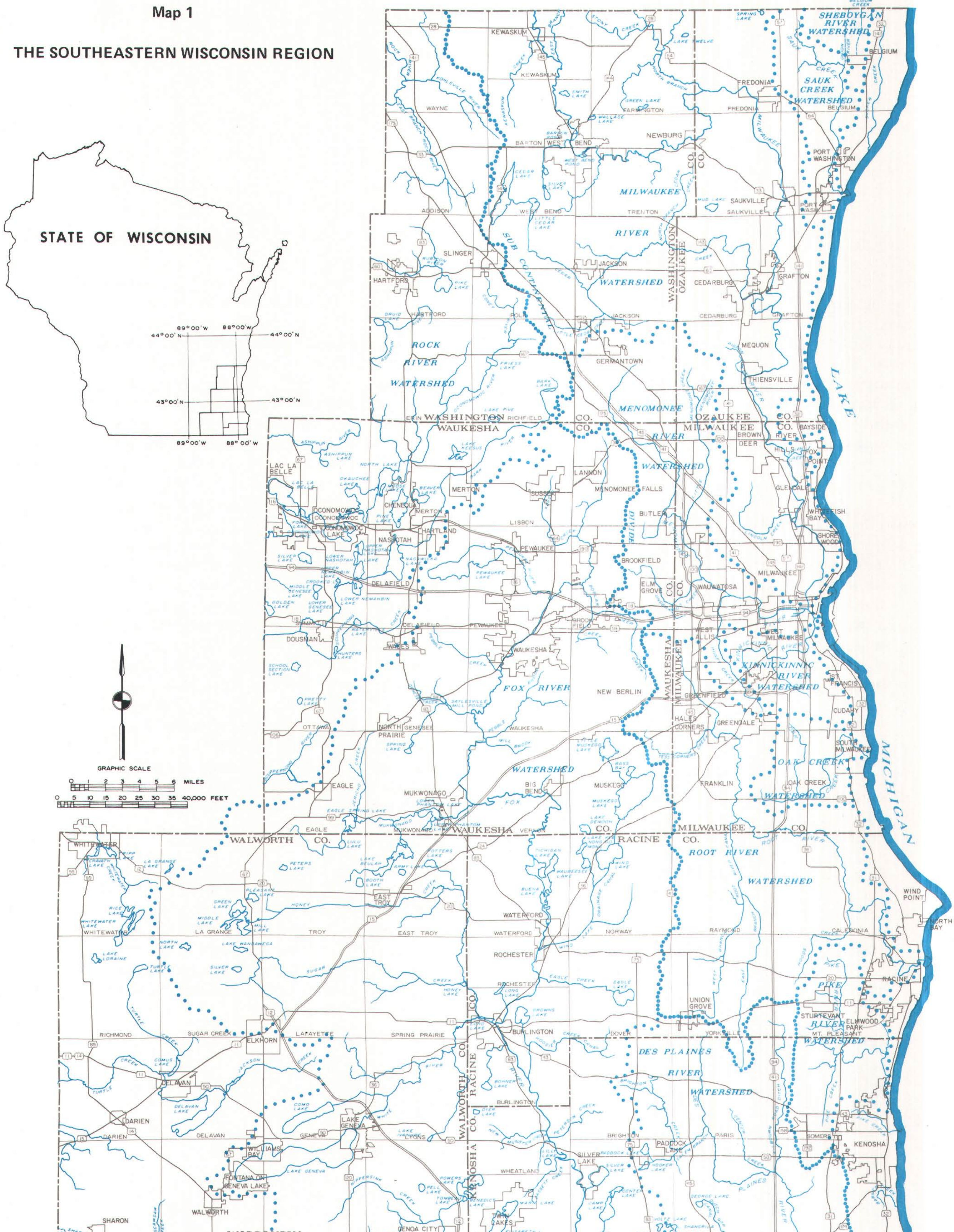
The major emphasis of this report is on storm water runoff from urban lands exclusive of storm water that becomes mixed with urban wastewaters either in combined sewers or in sewer system infiltration and inflow. A brief review of pollution abatement alternatives for these intermittent point sources is provided since many of the structure control options available for urban storm water runoff have been developed for application to these sources of water pollution, despite the differences in composition of combined sewage and urban runoff. Combined sewer overflows and storm sewer discharges also differ in that the combined sewers have a continuous flow component and in some cases may be dealt with more economically by treatment at a specific location, whereas the even more dynamic nature of storm water discharges generally requires practices to manage the urban surface for control of wastes before discharge. Combined sewage and urban storm water runoff are similar in that they are collected from multiple points of waste generation or from areas which receive wastes from different sources and are discharged at identifiable points along the streams and lakes of the Region. Accordingly, it is difficult to classify either of these sources of wastewater as either a point or nonpoint pollution source. A full discussion of combined sewer overflow pollution abatement is beyond the scope of this investigation as noted in Chapter II.

## STUDY AREA

Processes and techniques for the control of pollution from storm water runoff have been evaluated for potential application in the Southeastern Wisconsin Region including Kenosha, Milwaukee, Ozaukee, Racine, Walworth, Washington, and Waukesha Counties (see Map 1).

Map 1

THE SOUTHEASTERN WISCONSIN REGION




Source: SEWRPC.

## Chapter II

## COMBINED SEWERS

### INTRODUCTION

The two basic sources of urban runoff are rainfall and snowmelt. The nature of the urban surface and climatic conditions determine the relative amounts of runoff that reach surface and ground waters, or evaporate back to the atmosphere. Precipitation that reaches surface waters from urban areas is conveyed by overland flow, groundwater flow, or by man-made structures. The man-made structures include surface drainage channels that replace natural channels, subsurface drainage pipes intended to transmit only storm waters (storm sewers), and subsurface drainage pipes intended to carry urban wastewaters during dry weather and storm waters mixed with wastewaters during precipitation-runoff events (combined sewers). Many storm sewers serve as relief points for overloaded sanitary sewers (designed to carry wastewaters only) and as convenient (though not always legal) conveyors of other urban wastewaters (such as cooling waters). Storm sewers can function as combined sewers in those instances even though they were designed to collect urban runoff only.

A comprehensive review of state of the art practices for combined sewer overflow abatement is not within the scope of this investigation. The rationale for limiting the investigations of these practices includes:

1. A major investigation of combined sewer overflow abatement alternatives for the Milwaukee area is currently in progress[1] to refine the combined sewer overflow abatement plan presented in SEWRPC Planning Report No. 13, A Comprehensive Plan for the Milwaukee River Watershed.

2. Completed and ongoing projects for Racine and Kenosha[2] have partly resolved combined sewer overflow problems in those communities and both communities plan further major investigations to develop a solution to the combined sewer overflow problem.

3. The results of the above investigations are to be incorporated into ongoing 208 planning activities, and will serve to address at a detailed and localized level, the site-specific alternatives for resolution of pollution caused by all of the combined sewer overflows in the Region.

Much of the technology for treating high-volume short duration flows characteristic of combined sewer overflows and storm sewer discharges has been developed for combined sewer overflows. A review of appropriate technology as it may be transferred to storm water treatment is included in Chapter V. A review of the studies conducted in the Region is included in this chapter. State of the art investigations for combined sewer overflow pollution abatement have recently been completed[3] and should be consulted for additional information on the topic.

### EXTENT OF PROBLEM

Table 1 gives the extent of combined sewer service areas for the Region. In 1970 there were 397 square miles of urban area in the Region, 309 square miles of which were served by public sanitary sewerage systems. About 10 percent of the sewered areas are served by combined sewers.

About 113 additional square miles of urban land is planned for development by the year 2000, based upon preliminary recommendations of the regional land use plan which is presently being finalized by the Commission. Most of this area will be drained by natural channels or storm sewer systems.

In future years, the impact of storm water runoff will increase. Without corrective action, the impact of combined sewered areas will remain relatively unchanged. It is envisioned that programs outlined in the referenced combined sewer overflow abatement studies will reduce the impact of combined sewered areas to acceptable levels. Plans to reduce the present and future impact of storm water discharges from urban areas will be developed in the 208 planning effort based on the available techniques described in this report for the control of storm water runoff from urban areas.

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[1] *Stevens, Thompson & Runyan, Inc., for the Metropolitan Sewerage District of the County of Milwaukee, Combined Sewer Overflow Abatement, various volumes.*

[2] *C. A. Hansen, M. K. Gupta, and R. W. Agnew, "Two Wisconsin Cities Treat Combined Sewer Overflows," Water and Sewage Works, August 1973; R. W. Agnew et al, "A Biological Adsorption System for the Treatment of Combined Sewer Overflow," paper presented at the 46th WPCF Annual Conference, Cleveland, Ohio, October 2, 1973; and Southeastern Wisconsin Regional Planning Commission, A Regional Sanitary Sewerage System Plan for Southeastern Wisconsin, Planning Report No. 16, February 1974.*

[3] *Stevens, Thompson & Runyan, Combined Sewer Overflow Abatement, and J. A. Lager and W. G. Smith; Metcalf and Eddy, Inc., Urban Storm Water Management and Technology: An Assessment, EPA 670/2-74-040, December 1974.*

Table 1

EXTENT OF COMBINED SEWERS IN REGION: 1970

| Entity | Total Area Served (square miles) | Total Area Served by Combined Sewers (square miles) |
|---|---|---|
| Milwaukee-Metropolitan Sewerage District and Contract Service Area. . . . . . . . | 194.0 | 26.9 |
| City of Kenosha . . . . . . . . . . . . . . . . . . . . . | 20.3 | 1.6 |
| City of Racine . . . . . . . . . . . . . . . . . . . . . . | 13.0 | 2.0 |
| Southeastern Wisconsin Region . . . . . . . . . . . | 309.0 | 30.5 |

*Source: SEWRPC.*

The "Preliminary Water Quality Findings" report of the Milwaukee combined sewer overflow study[4] determined that water quality standards could not be achieved in the Milwaukee, Menomonee, or Kinnickinnic Rivers in Milwaukee without control of storm sewer discharges (resulting from connections to surcharging sanitary sewers) in their study area. Both the storm sewer discharges and combined sewer overflows have contributed to low dissolved oxygen levels and high fecal coliform levels in the Rivers. Major benthic oxygen demands due to solids deposited in the Rivers from these sources were noted.

## COMBINED SEWER OVERFLOW STUDIES IN THE REGION

A number of studies have been and are being conducted in the Region on strategies for the control of combined sewer overflows.[5] Pertinent information from these past investigations as reported in the literature is summarized in Table 2. Studies by city are summarized below.

### Milwaukee

Past studies have evaluated storage, screening-dissolved air flotation, and rotating biological contactors. Results are shown in Table 2. The use of pressure sewers inside existing sewers as a sewer separation device has also been investigated.[6] Present investigations[7] are focusing on four control strategies:

1. Storage of overflow and gradual treatment.
2. Sewer separation.
3. Treatment at overflow points.
4. River treatment (aeration, disinfection, dredging).

Treatment options being examined are shown in Figure 1. Certain nonstructural control concepts (street cleaning, inflow/infiltration reduction) and beneficial use concepts (hydroelectric power generation with storm waters) are also being investigated.

A major project goal of combined sewer overflow pollution abatement programs is to evaluate the impact of combined sewer overflow controls on other waste loads reaching the receiving stream. A preliminary assessment of the relative impact of combined sewer overflow controls was included in an interim report on the ongoing

[4] *Stevens, Thompson & Runyan, Combined Sewer Overflow Abatement.*

[5] *Stevens, Thompson & Runyan, Combined Sewer Overflow Abatement; SEWRPC, A Comprehensive Plan for the Milwaukee River Watershed, Volumes 1 and 2; Hansen, Gupta, and Agnew, "Two Wisconsin Cities Treat Combined Sewer Overflows"; Agnew, et al, "A Biological Adsorption System"; D. G. Mason, "The Use of Screening/Dissolved-Air Flotation for Treating Combined Sewer Overflows," Combined Sewer Overflow Abatement Technology, FWQA 11024-6/70, June 1970; Consoer, Townsend, and Associates for the City of Milwaukee, Wisconsin and U. S. EPA, "Humbolt Avenue Pollution Abatement Demonstration Project," September 1974; F. S. Welch and D. J. Stucky, Combined Sewer Overflow Treatment by the Rotating Biological Contactor Process, Autotrol Corporation, Milwaukee, Wisconsin, EPA 670/2-74-050, 1974; Rex Chainbelt, Inc., "Screening/Flotation Treatment of Combined Sewer Overflows," January 1972; J.A. Lager, "Stormwater Treatment: Four Case Histories," Civil Engineering ASCE, December 1974; and Proceedings of a Research Conference—Urban Runoff Quantity and Quality, ASCE, 1975, edited by W. Whipple, Jr.*

[6] *J. A. Lager and W. G. Smith; Metcalf and Eddy, Urban Storm Water Management.*

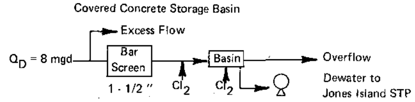
[7] *Stevens, Thompson & Runyan, Combined Sewer Overflow Abatement.*

**Table 2**

**SUMMARY OF COMBINED SEWER OVERFLOW TREATMENT PROJECTS IN STUDY AREA**

| Project | Size | Area Served (Acres) | Cost Data[a] | | Raw Waste Quality BOD5 | TSS | COD | TKN | NH4 | NO2 | NO3 | TP | OP | TS | Fecal Coliform (no./100 ml) |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| MILWAUKEE (7, 20) Covered Concrete Storage Basin | 3.9 mg | 570 | Storage Tank = $738,000; Control Bldg., etc. = $1,363,000; Annual O & M = $62,000 | Initial | 150 | 397 | 439 | 14.6 | 4.6 | 0.013 | 0.827 | 13.4 | 8.8 | 813 | 14,200 |
| | | | | 0-30 min. | 143 | 348 | 436 | 13.6 | 4.5 | 0.013 | 0.749 | 13.0 | 7.6 | 775 | 13,700 |
| | | | | 30-60 min. | 128 | 270 | 383 | 11.3 | 3.9 | 0.011 | 0.565 | 10.1 | 6.1 | 661 | 8,000 |
| | | | | 1-2 hrs. | 97 | 192 | 280 | 8.4 | 3.1 | 0.013 | 0.520 | 9.1 | 5.4 | 681 | 6,900 |
| | | | | 2 hrs. | 87 | 193 | 256 | 8.6 | 3.3 | 0.013 | 0.629 | 8.4 | 4.9 | 550 | 6,200 |
| | | | | Dry Weather | 112 | 150 | 238 | 20.7 | 11.7 | 0.010 | 0.5 | 18.4 | 10.7 | -- | 38,000 |
| MILWAUKEE (3, 6, 20) Screening - Dissolved Air Flotation | 5.0 mgd | 495 | Screen/Flotation System = $71,000; Pumping, instruments, etc. = $36,000; Annual O & M: With chemicals = $4,400; Without chemicals = $1,200 | First Flush | 170-182 | 330-848 | 500-765 | 17-24 | -- | -- | -- | -- | -- | 750-950 | 1,420 |
| | | | | 1 hr. | 26-53 | 113-174 | 113-166 | 3-6 | -- | -- | -- | -- | -- | 330-420 | 625 |
| MILWAUKEE (8, 20) Rotating Biological Contactor | 1.5 mgd | 35 | Pumps, grit chamber, contactor = $82,000; Final Clarifier = $96,000; Annual O & M = $5,000 | Flow = 0.05 mgd | 345 | 349 | 550 | 40.5 | -- | -- | -- | 8.5 | -- | -- | |
| | | | | Flow = 0.4 mgd | 395 | 315 | 617 | -- | -- | -- | -- | -- | -- | -- | |
| KENOSHA (3, 4, 20) Contact Stabilization | 23 mgd | 8,000 (1,200 w/CSO) | Total Cost = $1,280,000; Annual O & M = $37,000 | Raw - 23 events | 102 | 314 | -- | 11.0 | -- | -- | -- | 4.8 | -- | 704 | 348 |
| | | | | Raw - 46 events | 114 | 297 | -- | 15.1 | -- | -- | -- | 4.8 | -- | 696 | 266 |
| RACINE (1, 3, 20) Screening - Dissolved Air Flotation | 14 mgd | 82 | Cost = $495,000 | 14 mgd Raw | 80 | 235 | -- | -- | -- | -- | -- | 3.0 | -- | 599 | |
| | 44 mgd | 364 | Cost = $1,555,000; Annual O & M = $20,000 | 44 mgd Raw | 60 | 332 | -- | -- | -- | -- | -- | 2.2 | -- | 661 | |

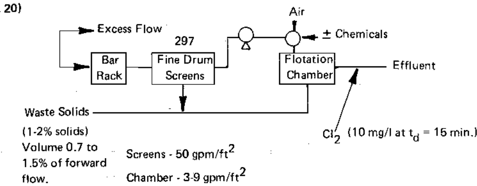
**MILWAUKEE (7, 20)** Covered Concrete Storage Basin




Removals In 1/71-10/72 Period:

Caught 67 percent of runoff (121 mg)
Caught 68 percent of $BOD_5$ (100,000 lbs)
Caught 70 percent of TSS (225,000 lbs)
Percent $BOD_5$ removed = $25\ (1 - e^{-0.20\ t})$ (lb/hr)
Percent TSS removed = $40\ (1 - e^{-0.20\ t})$ (lb/hr)
Where t = hours of detention of inflow

**MILWAUKEE (3, 6, 20)** Screening - Dissolved Air Flotation




Coliforms ranged from 13 to 3,100 per 100 ml and were reduced to 0 to 1,500 per 100 ml by chlorination. Expect an effluent of 48 mg/l TSS, 20 mg/l $BOD_5$, 4.2 mg/l TKN, and 69 mg/l COD averaged over the storm at flow of 3.3 gpm/ft $^2$ and chemical feed of 20 mg/l $Fa_{Cl_3}$ and 5 mg/l cationic polyelectrolyts

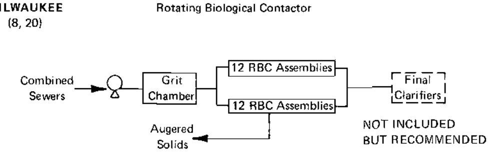
Percent Removals

| | Screen: Spring | Screen: Summer/ Summer/ | Screen and Flotation: Without Chemicals Spring | Screen and Flotation: With Chemicals Summer/Fall |
|---|---|---|---|---|
| $BOD_5$ | 23.4[a] | 20.3 | 48.4 ± 15.7 | 50.8 ± 12.5 |
| COD | 33.9 | 22.4 | 52.9 ± 8.7 | 53.4 ± 8.6 |
| TSS | 28.8 | 24.9 | 53.7 ± 11.7 | 68.3 ± 8.4 |

Average Percent Removals

| | Screen: First Flush | Screen: >1 Hour | Screen and Flotation: First Flush | Screen and Flotation: Without Chemicals >1 Hour | Screen and Flotation: With Chemicals >1 Hour |
|---|---|---|---|---|---|
| $BOD_5$ | 33 | 27 | 55 | 35 | 60 |
| COD | 39 | 26 | 64 | 41 | 57 |
| TSS | 36 | 27 | 72 | 43 | 71 |
| TKN | -- | -- | 46 | 29 | 24 |

**MILWAUKEE (8, 20)** Rotating Biological Contactor

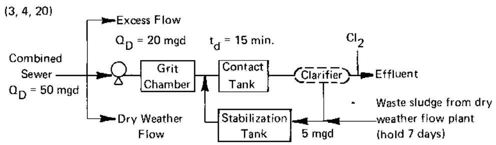



System as tested did not have a final clarifier and biological sloughing from the units led to high effluent solids following storm events

Percent Removals

| | $BOD_5$ | COD | TSS | M | P |
|---|---|---|---|---|---|
| Flow = 0.05 | 77 | 70 | 77 | 38 | 53 |
| Flow = 0.4 | 54 | 33 | 70 | -- | -- |
| Flow = 1.5 | -- | 20 | -- | -- | -- |

**KENOSHA (3, 4, 20)** Contact Stabilization

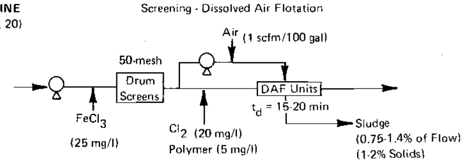



The facilities do not eliminate all overflows from the study area, but do treat wet weather discharges that reach the plant

Percent Removals

| | $BOD_5$ | TSS | TKN | P | Coliform |
|---|---|---|---|---|---|
| 23 Events | 83 | 92 | 50 | 50 | 92 |
| 46 Events | 83 | 93 | 47 | 46 | 91 |

**RACINE (1, 3, 20)** Screening - Dissolved Air Flotation




Average Percent Removals

| | $BOD_5$ | TSS | TP | TS |
|---|---|---|---|---|
| 44 Events - 14 mgd | 50 | 60 | 47 | 26 |
| 32 Events - 44 mgd | 60 | 66 | 60 | 37 |

[a] *Consoer, Townsend, and Associates for the City of Milwaukee, Wisconsin, and U. S. EPA, "Humboldt Avenue Pollution Abatement Demonstration Project," September 1974, and J. A. Lager and W. G. Smith; Metcalf and Eddy, Inc., Urban Storm Water Management and Technology: An Assessment, EPA 670/2-74-040, December 1974.*

[b] *C. A. Hansen, M. K. Gupta, and R. W. Agnew, "Two Wisconsin Cities Treat Combined Sewer Overflows," Water and Sewage Works, August 1973; D. G. Mason, "The Use of Screening/Dissolved-Air Flotation for Treating Combined Sewer Overflows," in Combined Sewer Overflow Abatement Technology, FWOA 11024-6/70, June 1970; and Lager and Smith, Urban Storm Water Management and Technology.*

[c] *F. S. Welch and D. J. Stucky, "Combined Sewer Overflow Treatment by the Rotating Biological Contractor Process," Autotrol Corporation, Milwaukee, Wisconsin, EPA 670/2-74-050, 1974; and Lager and Smith, Urban Storm Water Management and Technology.*

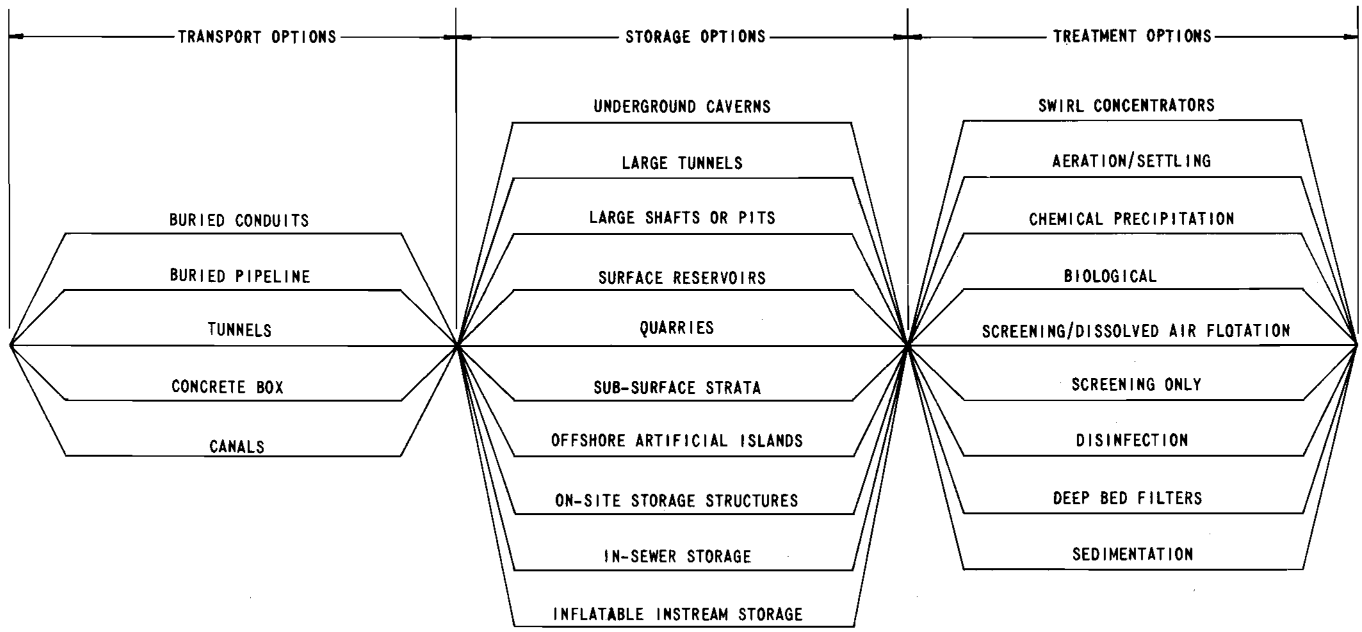
[d] *Hansen, Gupta, and Agnew, "Two Wisconsin Cities Treat Combined Sewer Overflows"; R. W. Agnew et al, "A Biological Adsorption System for the Treatment of Combined Sewer Overflow," paper presented at the 46th WPCF Annual Conference, Cleveland, Ohio, October 2, 1973; and Lager and Smith, Urban Storm Water Management and Technology.*

[e] *Stevens, Thompson & Runyan, Inc., for the Metropolitan Sewerage District of the County of Milwaukee, Combined Sewer Overflow Abatement, various volumes; Hansen, Gupta, and Agnew, "Two Wisconsin Cities Treat Combined Sewer Overflows"; and Lager and Smith, Urban Storm Water Management and Technology.*

*Source: Stanley Consultants.*

Figure 1

**STORAGE/TREATMENT OPTIONS BEING EXPLORED IN THE METROPOLITAN SEWERAGE DISTRICT OF THE COUNTY OF MILWAUKEE COMBINED SEWER OVERFLOW STUDY**




*Source: Adapted from Stevens, Thompson & Runyan, Inc.*

Milwaukee combined sewer overflow pollution abatement study.[8] The preliminary results are given in Table 3, although no specific statistical level of confidence can be assigned to the values since the assessment is based upon monitoring data from a single storm event for each River.

Kenosha

The Kenosha contact stabilization treatment system has proved effective in treating the excess wastewaters that reach the facility as well as serving for sludge processing from the dry weather treatment facility. A report on the system indicates 93 percent removal of suspended solids and 83 percent removal of $BOD_5$ was achieved during 46 events.[9] The facility was operated for 254 hours in 1972 and treated about 58 percent of total overflows in the Kenosha system. Programs to trap and hold more overflow in the sewer system so that the wastewater can be treated are underway. Most small storms (rainfall less than 0.5 inches in 24 hours) are presently contained.

Racine

The screening/dissolved air flotation system at Racine is expected to process about 150 million gallons per year from a drainage area of 450 acres.[10] Operating data are presented in Table 2.

[8] *By Stevens, Thompson & Runyan.*

[9] *Rex Chainbelt, "Screening/Flotation Treatment of Combined Sewer Overflows."*

[10] *Lager, "Stormwater Treatment: Four Case Histories."*

RELATION TO STORM WATER PROBLEMS

The combined sewer overflow problem is in reality a storm water runoff problem. The relative load of urban storm water runoff is mixed with the relative load of sewerage system wastewaters (flowing and previously settled). When this mixture of storm water and wastewater exceeds the capacity of the interceptor sewer to the treatment plant, overflows to the stream occur.

Various methods can be used to reduce the impact of the composite load on the receiving streams as outlined in this chapter. Their relation to storm water control is outlined below.

Sewer Separation

Separation of the storm water runoff from the community sanitary wastewaters has the advantage of adequate treatment for all of the sanitary wastewaters regardless of precipitation events. To obtain full separation in existing systems is difficult at best. In fact, it is more common for a partial separation to be achieved, since the cost of disconnection of residential footing drain is generally prohibitive. However, most of the total storm water load does reach surface waters without treatment. In systems served by combined sewers, a portion of the storm water load (runoff from small storms) receives treatment at treatment facilities. The relative annual load reduction from separation programs has not received detailed study. This relative load reduction is the additional pounds from discharge to the receiving waters removed by treatment of all sanitary wastewaters versus the pounds removed by treatment of a portion of the

Table 3

ASSESSMENT OF RELATIVE IMPACT OF EXISTING COMBINED SEWER OVERFLOWS DURING STORM EVENTS IN THE MILWAUKEE AREA

| River | $BOD_5$ Load (Percent of River Load) | Fecal Coliform Load (Percent of River Load) |
|---|---|---|
| Milwaukee[a] . . | 35 | 78 |
| Menomonee . . | 49 | 99 |
| Kinnickinnic. . | 14 | 36 |

[a] *Estimates in the source cited below indicate that if interconnections between the sanitary and storm sewers outside of the combined sewer overflow study area for this River are eliminated, then the contribution of $BOD_5$ attributable to the existing combined sewer overflows would decrease to 26 percent, and the contribution of fecal coliforms attributable to the existing combined sewer overflows would increase to 99.8 percent of the River load.*

*Source: Stevens, Thompson & Runyan.*

combined sewage.[11] One study reports that if storm waters should require treatment, then combined sewer systems may be a more economical total approach than separate sewers. Most communities in the Region have ordinances or building codes requiring separate sewerage systems.[12] In addition, the U. S. EPA will not currently fund combined sewers under the construction grants program.[13]

A concept that has received limited study is separating areas served by combined sewers from areas served by separate sewer systems. It would be necessary to construct bypass sewers around the combined sewer service area and new treatment facilities for the isolated combined sewer service area. The separate area (the majority of the land area in the three cities in the study area) could receive continuous treatment in existing facilities. The concept may be feasible in areas where sewage from separated areas flows through combined areas. The combined area pollution potential should be reduced by application of this concept due to a reduction in the load and flow available for overflow. Deposition of materials in the combined sewers between storms (the primary cause of high initial loads during large runoff events) should likewise be reduced with the reduced load being transmitted in the sewer.

The sewer systems of the Milwaukee-Metropolitan Sewerage Commissions are arranged in such a manner that portions of the sewage from sanitary sewers of a portion of the separate area are diverted around the existing combined sewer area to the newer South Shore wastewater treatment plant.

Sewer Cleaning

Cleaning and flushing of sewers between storms can reduce the load potential of a storm event. Overflows would then have a composition representing a true composite of storm water runoff and flowing wastewaters. Due to the large volume of storm water contained in wastewater, the characteristics of the overflow would approach storm water runoff quality, and methods to treat storm water outlined in this report may be more appropriate than methods developed for combined sewer overflows within sewer cleaning.

Storage

Storage is expected to be an integral part of any storm water runoff control strategy. Storage near the site of precipitation reduces peak flows through storm sewer systems. Storage after transmission of storm flow will generally be cost-effective in reducing the size of subsequent treatment units (if needed) by similarly reducing peak flows and design capacity requirements.

Street Cleaning

Only a portion of the loads that reach an urban surface from human activities reach urban streets. Cleaning the streets will remove a portion of this material before it can be flushed into storm sewer or combined sewer systems. A cleaner urban environment will lead to cleaner runoff from that environment and reductions in loads reaching surface waters.

Treatment

The flow attenuation capabilities of storage facilities will greatly reduce the design capacity needed for treatment facilities, reduce their cost, and provide a degree of operational reliability. For these reasons, direct treatment—except for flow through sedimentation/storage facilities at sewer discharge points—is usually not cost-effective for storm water runoff control. Any additional treatment using options outlined in this report will follow sedimentation storage facilities, if necessary, to produce a higher quality of effluent than sedimentation/storage alone can provide.

[11] *N. V. Colston, Jr., Characterization and Treatment of Urban Land Runoff, EPA-670/2-74-096, December 1974.*

[12] *C. V. Ardis, K. J. Dueker, and A. G. Lenz, "Storm Drainage Practices of Thirty-Two Cities (Wisconsin), Journal of Hydraulics Division, ASCE, Volume 95, No. HYI, January 1969.*

[13] *Black, Crow, and Eidness for the Savannah District, Corps of Engineers, "Nonpoint Pollution Evaluation—Atlanta Urban Area," May 1975.*

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# Chapter III

## SOURCES AND MOVEMENTS OF POLLUTANTS

### INTRODUCTION

A recent research conference[1] indicated the need for identifying the relative contribution of the following sources to urban runoff quality:

1. On-street materials including animal wastes, garbage, grit, oil, road salt, cinders, and residual particulates resulting from auto tire and brake use.

2. Off-street materials including animal wastes, garbage, fertilizers, chemicals, pesticides, and refuse waiting for collection.

3. Deposition of air-borne particulates.

4. Materials discharged from floor drains of home, business, and industry.

5. Silt from construction activities.

6. Leakage and overflow from defective and surcharged sanitary and combined sewers.

7. Liquid wastes discharged to storm sewers from improper point source connections.

In general, more is unknown than is known about the quantity of pollutants from each source that is added to the urban surface and removed during runoff. Researchers have generally tried to quantify certain sources[2] or to measure the cumulative effect by making quality/quantity measures of runoff.[3] In an attempt to make this data useful for planning endeavors, results of such investigations have generally been correlated to land use around the source area or discharge point.

The lack of data on the pollutant load from various sources and limited understanding of the movement of the potential pollutants from their sources to receiving waters (surface and ground) as a result of transport mechanisms (gravity, wind, precipitation, snowmelt) has hampered assessment of the effects of source discharges and made determination of necessary control techniques a difficult task. An understanding of the sources and movement of pollutants is essential in evaluating alternative control strategies.

Attempts have been made to quantify the relative contribution of the various sources to surface waters.[4] Further information quantifying urban runoff loads is being developed in the SEWRPC 208 planning program and other water quality management planning programs (other 208 areas, the International Joint Commission studies on the Great Lakes, the Washington County sediment control project to name a few) which are expected to significantly advance the state of the art presented in this chapter.

### LOADINGS FROM THE AIR

Materials added to the air by natural and human activities eventually settle to the earth as dry fallout or in precipitation washout or rainout. Pertinent data on quantities and characteristics applicable to the Region are summarized in Table 4. Urban areas tend to demonstrate somewhat greater loadings than rural areas. The concentrations in precipitation are important since they would represent the concentrations found in stream flows following precipitation events providing no dilution, pickup, or deposition occurred in runoff. They may represent the best quality that can be obtained by a totally clean urban environment. Data from a Florida study[5] demonstrating the importance of rainfall are shown in Table 5. Note that measured loadings from rural and residential areas could be entirely due to precipitation characteristics.

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[1] *Proceedings of a Research Conference—Urban Runoff Quantity and Quality, ASCE, 1975, edited by W. Whipple, Jr.*

[2] *American Public Works Association, "Water Pollution Aspects of Urban Runoff," WP-20-15, January 1969, and J. D. Sartor and G. B. Boyd, "Water Pollution Aspects of Street Surface Contaminants," EPA-R2-72-081, November 1972.*

[3] *S. R. Weibel, R. J. Anderson, and R. L. Woodward, "Urban Land Runoff as a Factor in Stream Pollution," JWPCF, 38:8, August 1964, and J. G. Cleveland, R. H. Ramsey, and P. R. Walter, "Stormwater Pollution From Urban Land Activity," AVCO Economic Systems Corp., June 1970.*

[4] *V. Kothardaraman, Water Quality Characteristics of Storm Sewer Discharges and Combined Sewer Overflows, Circular 109, Illinois State Water Survey, 1972; R. C. Loehr, "Characteristics and Comparative Magnitude of Nonpoint Sources," JWPCF, 46:8, August 1974; and A. M. Vitale and P. M. Spray for Council on Environmental Quality, "Total Urban Water Pollution Loads: The Impact of Storm Water," Enviro Control, Inc., 1974.*

[5] *M. P. Wanielister, Y. A. Yousef, and W. M. McLellon, "Transient Water Quality Responses from Nonpoint Sources," paper presented at the 1975 Water Pollution Control Federation Conference, October 1975.*

## Table 4

## DEPOSITION OF POLLUTANTS FROM ATMOSPHERE ONTO THE LAND SURFACE THROUGH THE ACTIONS OF DUSTFALL, RAIN, AND SNOW

| Location | Loadings (lbs/acre/year) | | | | | | | Notes | Reference |
|---|---|---|---|---|---|---|---|---|---|
| | $BOD_5$ | TSS | TN | $NH_3$-N | $NO_3$ | TP | OP | | |
| Lake Wingra . . . . . . . . . . | -- | -- | 13.6 | 3.6 | 3.0 | 0.70 | 0.13 | Dry Fallout | J. W. Kluesner, "Nutrient Transport and Transformation in Lake Wingra, Wisconsin," PhD Thesis, Water Chemistry Department, University of Wisconsin, Madison, 1972. |
| Lake Wingra . . . . . . . . . . | -- | -- | 7.0 | 2.5 | 2.8 | 0.20 | 0.16 | Precipitation Washout (35.5 " rain) | Ibid. |
| Rural Wisconsin . . . . . . . . | -- | -- | 11.7 | 2.6 | 2.4 | -- | -- | Precipitation (S = 14.7 lbs/acre/yr) | R. G. Hoeft, D. R. Keeney, and L. M. Walsh, "Nitrogen and Sulfur in Precipitation and Sulfur Dioxide in the Atmosphere in Wisconsin," Journal of Environmental Quality, Volume 1, No. 2, 1972 |
| Rural Wisconsin . . . . . . . . | -- | -- | 26.9 | 10.9 | 3.1 | -- | -- | Precipitation Near Barnyard | Ibid. |
| Wisconsin. . . . . . . . . . . . | -- | -- | 8.9 | -- | -- | 0.09-0.9[a] | -- | Rainfall, Snowfall, and Dry Fallout | J. D. Chapin and P. D. Uttormark, "Atmospheric Contributions of Nitrogen and Phosphorus," University of Wisconsin Water Resources Center, Madison, Wisconsin, February 1973. |
| Milwaukee . . . . . . . . . . . | -- | 470 | -- | -- | -- | -- | -- | Dustfall-Residential | D. Athayde, "Best Management Practices," in Proceedings Urban Storm Water Management Seminars, WPD 03-76-04, January 1976. |
| Milwaukee . . . . . . . . . . . | -- | 915 | -- | -- | -- | -- | -- | Dustfall-Commercial | Ibid. |
| Milwaukee . . . . . . . . . . . | -- | 1,500 | -- | -- | -- | -- | -- | Dustfall-Industrial | Ibid. |
| Milwaukee . . . . . . . . . . . | -- | 525 | -- | -- | -- | -- | -- | Dustfall-Agricultural | Ibid. |

| Location | Concentrations (mg/l) | | | | | | | Notes | Reference |
|---|---|---|---|---|---|---|---|---|---|
| | $BOD_5$ | TSS | TN | $NH_3$-N | $NO_3$ | TP | OP | | |
| East Shore Lake Michigan . . | -- | -- | -- | -- | -- | 0.032 | 0.014 | Rain[b] | T. J. Murphy and P. V. Doskey for U. S. Environmental Protection Agency, Inputs of Phosphorus from Precipitation to Lake Michigan, EPA 600/3-75-005, December 1975. |
| East Shore Lake Michigan . . | -- | -- | -- | -- | -- | 0.038 | 0.023 | Snow | Ibid. |
| East Shore Lake Michigan . . | -- | -- | -- | -- | -- | 0.0024 | 0.0015 | Snow from Year 1650 | Ibid. |
| Rural Wisconsin . . . . . . . . | -- | -- | 2-12 | 0-3 | 0.1-0.5 | -- | -- | Precipitation | R. G. Hoeft, D. R. Keeney, and L. M. Walsh, "Nitrogen and Sulfur in Precipitation and Sulfur Dioxide in the Atmosphere in Wisconsin," Journal of Environmental Quality, Volume 1, No. 2, 1972. |
| Rural Wisconsin . . . . . . . . | -- | -- | 2-31 | 0-13 | 0.0-1.7 | -- | -- | Precipitation Near Barnyard | Ibid. |
| Rural Ohio. . . . . . . . . . . . | 3 | 4 | -- | 0.43 | 0.37 | 0.035 | 0.02 | Rain-Weighted Mean | Stanley Consultants for the Miami Conservancy District, Nonpoint and Intermittent Point Source Controls—Development of Structural Control Techniques and Cost Information, January 1976. |
| Rural Ohio. . . . . . . . . . . . | 1-9 | 1-18 | -- | 0.13-1.3 | 0.00-0.80 | 0.00-0.11 | 0.00-0.05 | Rain-Range of Values 11 Storms | Ibid. |
| Atlanta . . . . . . . . . . . . . . | 4 | 10 | 0.21 | 0.13 | 0.05 | 0.03 | -- | Rain-Weighted Mean | Black, Crow, and Eidness for the Savannah District, Corps of Engineers, "Nonpoint Pollution Evaluation—Atlanta Urban Area," May 1975. |
| Rural Ohio. . . . . . . . . . . . | 6 | 11.7 | 1.17 | 0.5 | 0.4 | -- | 0.08 | Rain | R. C. Loehr, "Characteristics and Comparative Magnitude of Non-point Sources," JWPCF, 46:8, August 1974. |
| Urban Ohio . . . . . . . . . . . | 10 | 13 | 1.27 | 0.3 | 0.4 | -- | 0.24 | Rain | Ibid. |

*[a] Dry fallout load equals three times precipitation load for TP (two for TN) and snow contributes 25-50 percent of annual precipitation load.*

*[b] The total phosphorus concentration was 25 ug/l in the rain when the air contained 0.055 $ug/m^3$ and was 56 ug/l in rain when air contains 0.110 $ug/m^3$.*

*The concentration decreased as the amount of rain increased as shown below.*

| | | | | | | |
|---|---|---|---|---|---|---|
| *Total rainfall (cm)* | *< 0.5* | *0.5 to 1* | *1 to 1.5* | *1.5 to 2* | *2 to 3* | *> 3* |
| *Median TP Concentration (mg/l)* | *0.075* | *0.040* | *0.025* | *0.020* | *0.015* | *0.010* |

*Source: Stanley Consultants.*

Table 5

**LOADINGS IN RUNOFF FROM DIFFERENT LAND USES COMPARED TO LOADINGS IN RAINFALL**
**(lbs/acre/inch)**

| Location | $BOD_5$ | TSS | TKN | $NO_3$ | TP | OP |
|---|---|---|---|---|---|---|
| Orlando, Florida (Commercial) | 0.5-8.5 | 5.3-17.4 | 0.05-0.30 | 0.11-0.13 | 0.05-0.06 | 0.03-0.05 |
| Orlando, Florida (Residential) | 0.9-1.8 | 3.0-3.6 | 0.02-0.04 | 0.01-0.04 | 0.03-0.05 | 0.01-0.02 |
| Florida (Rural) | 0.17-0.23 | 0.18-0.21 | 0.016-0.018 | 0.003-0.004 | 0.03-0.04 | -- |
| Orlando, Florida (Rainfall) | 0.25 | 0.6-3.2 | 0.002-0.14 | 0.004-0.06 | 0.01-0.05 | 0.01-0.02 |

*Source: Adapted from paper by M. P. Wanielister, Y. A. Yousef, and W. M. McLellon.*

## LOADINGS ON THE URBAN SURFACE

Dry atmospheric fallout and residues from human activities tend to cause a buildup of materials on the urban surface which become available for flushing to surface waters during precipitation events or snowmelt runoff periods. Some current analytical methodologies[6] use data on the accumulation of the dust and dirt fraction of materials on urban streets to predict urban runoff quality.

The primary sources of dust and dirt in the urban area are from construction activities, roadway use, industrial point sources, and imported dust from wind erosion of agricultural fields. Industries may contribute substantial particulate loadings particularly near the industrial source.

The usual procedure for assessing the pollutant load associated with materials settling on urban roads has been to collect the solids and determine the strength of the soluble fraction of those solids. The results are expressed in terms of weight of pollutant per weight of solids collected. The method used to collect the solids has varied from investigation to investigation. The APWA study[7] collected samples by sweeping and vacuuming. The URS Research Company studies[8] used rainfall simulation (1/2 inch/hr for one hour), vacuum sweeping (two passes), hand sweeping (two passes), and flushing (after hand sweeping) to collect samples. The Biospherics, Inc., study used procedures to determine loads induced by traffic only by eliminating atmospheric fallout, street litter, spills, and off-street runoff.[9]

The potential pollutant load associated with deposited solids from these studies, which include data for the City of Milwaukee, is presented in Table 6. Estimates of total pollution loads using these factors depend on the determination of the solids loadings on the streets. Data on solids loadings for sample areas in the City of Milwaukee are given in Table 7. Loadings due to traffic alone in Washington, D. C., were found to be a function of traffic volume with $2.38 \times 10^{-3}$ pounds of solids being deposited for each axle-mile traveled. (Total $\frac{\text{load}}{\text{mile}} = \frac{2.38 \times 10^{-3}\ \text{lbs}}{\text{axle-mile}} \times$ average daily traffic $\times \frac{\text{axles}}{\text{vehicle}}$). A final consideration is that the pollutant loadings are related to particle size with smaller sizes contributing relatively more of the load than larger sizes. Data for the City of Milwaukee area are presented in Table 8. Presumably all data for the City of Milwaukee shown in Table 6 and Table 8 are based on measurements made at the locations listed in Table 7. Additional data on these locations is indicated in Table 9.

It is important to realize that the load from washoff of street surface contaminants is not the only load that could potentially reach area streams from urban surfaces. Other loadings that in many cases have not been adequately quantified were listed in the introduction of this chapter. The sources of the contaminants that reach the street also remain not clearly defined. In tests in Cincinnati,[10] 730 lbs/acre of suspended solids were measured in urban runoff in a year in which 506 lbs/acre of dustfall occurred. Other sources of loadings on the urban surface

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[6] *L. A. Roesner et al, "A Model (STORM) for Evaluating Runoff—Quality in Metropolitan Master Planning," ASCE Technical Memorandum No. 23, ASCE, New York, New York, April 1974; Metcalf and Eddy, University of Florida, Water Resources Engineers for the U. S. Environmental Protection Agency, "Storm Water Management Model," Volumes I-IV (SWMM), July 1971; and G. Amy et al, Water Quality Management Planning for Urban Runoff, EPA 440/9-75-004, December 1975.*

[7] *APWA, "Water Pollution Aspects of Urban Runoff," WP-20-15, January 1969.*

[8] *J. D. Sartor and G. B. Boyd, "Water Pollution Aspects of Street Surface Contaminants," EPA-R2-72-081, November 1972; R. E. Pitt and R. Amy, "Toxic Materials Analysis of Street Surface Contaminants," URS Research Co. for U. S. EPA, January 1973; and J. D. Sartor, G. B. Boyd, and F. J. Agardy, "Water Pollution Aspects of Street Surface Contaminants," JWPCF, Volume 46, No. 3, March 1974.*

[9] *A. D. McElroy et al, Loading Functions for Assessment of Water Pollution from Nonpoint Sources, EPA/2-76-151, May 1976.*

[10] *Weibel, Anderson and Woodward, "Urban Land Runoff as a Factor in Stream Pollution."*

Table 6

POLLUTIONAL STRENGTH OF STREET DEPOSITS IN SELECTED CITIES
(lbs/100 lbs solids)

| Constituent | City of Milwaukee[a,d] | 10-City Average[a,e] | Chicago[b,f] | Washington, D.C.[c,g] |
|---|---|---|---|---|
| $BOD_5$ | 0.44 | 0.96 | 0.50 | 0.228 |
| COD | 1.80 | 6.79 | 4.00 | 5.38 |
| Total Phosphorus (P) | 0.01 | 0.079 | 0.005 | 0.061 |
| Nitrate Nitrogen (N) | 0.002 | 0.0067 | -- | 0.0079 |
| Total Kjeldahl Nitrogen | 0.053 | 0.157 | 0.048 | 0.0156 |
| Zinc | 0.160 | 0.046 | -- | 0.147 |
| Copper | 0.022 | 0.014 | -- | 0.012 |
| Lead | 0.056 | 0.041 | -- | 1.172 |
| Nickel | 0.0012 | 0.0036 | -- | 0.018 |
| Mercury | -- | 0.0052 | -- | -- |
| Chromium | 0.0018 | 0.0079 | -- | 0.0078 |
| Cadmium | 0.00012 | $8.4 \times 10^{-7}$ | -- | -- |
| Pesticides | | | | |
| DDD | $1.9 \times 10^{-8}$ | $4.8 \times 10^{-8}$ | -- | -- |
| DDT | $3.8 \times 10^{-8}$ | $4.4 \times 10^{-8}$ | -- | -- |
| Dieldrin | $38 \times 10^{-8}$ | $1.7 \times 10^{-8}$ | -- | -- |
| P-C-B's | $1.3 \times 10^{-4}$ | $78 \times 10^{-8}$ | -- | -- |
| Methoxychlor | $3.1 \times 10^{-4}$ | -- | -- | -- |
| Lindane | $12 \times 10^{-8}$ | -- | -- | -- |
| Coliforms (Number/lb) | | | | |
| Total | $18 \times 10^{6}$ | $70 \times 10^{6}$ | -- | -- |
| Fecal | $2.6 \times 10^{3}$ | $4 \times 10^{6}$ | -- | -- |

[a] *The strength of the soluble fraction of materials smaller than 2,000 μ.*

[b] *The strength of the soluble fraction of materials smaller than 3,200 μ.*

[c] *The strength of materials added by traffic only.*

[d] *Sartor and Boyd, Water Pollution Aspects of Street Surface Contaminants.*

[e] *Ibid.*

[f] *American Public Works Association, "Water Pollution Aspects of Urban Runoff." GMC Elroy et al, Loading Functions for Assessment of Water Pollution from Nonpoint Sources.*

*Source: Stanley Consultants.*

and characteristics of the materials as gathered from the literature are summarized in Table 10. Yard and garden debris (leaves, grass, clippings, weeds) presents a potential source of organic, phosphorus, and nitrogen load on surface waters as the organic matter decays. Special consideration should be given either to restrict the common practice of piling such debris in streets or to provide prompt removal of the debris before it can decay.

The total load on the urban surface from natural and cultural activities under the present state of the art is unknown. The relative contribution of various sources to this load also is unknown. These facts made the recommendation of sound pollution abatement practices for source control difficult, if not impossible, to develop. The approach used in this investigation is to present the removals of contaminants that can be quantified by methods that can be assessed for cost and effectiveness. The determination of the cost-effectiveness of one action versus another action in terms of pollutants removed and the resultant improvement in stream water quality is beyond the scope of this report. A clean urban environment leads to relatively cleaner urban storm water runoff. Source control methods for loadings on the urban surface (air pollution control programs, street cleaning programs, road salt use reduction programs, fertilizer use, or other load reduction programs) must generally be advocated for their beneficial, though in many respects, unquantifiable improvement in urban runoff quality.

Table 7

STREET SURFACE LOADINGS IN THE CITY OF MILWAUKEE

| Street Location | Street Type[a] | Street Width (feet) | Land Use | Solids Loading Rate[b] (lbs/1,000 $ft^2$/day)[c] |
|---|---|---|---|---|
| N. 6th Street and W. Lloyd Street. . . . . . . . . | Asphalt | 24 | Residential | 12.0 |
| N. 5th Street and W. Vine Street . . . . . . . . . | Asphalt | 20 | Multifamily | 9.2 |
| S. 23rd Street and W. Bridge Street. . . . . . . . | Concrete | 36 | Residential | 3.5 |
| W. Lapham Street and S. 10th Street. . . . . . . | Asphalt | 36 | Multifamily | 66.0 |
| E. Becher Street and S. Allis Street. . . . . . . . | Asphalt | 32 | Industrial | 5.2 |
| E. Greenfield Avenue and S. Barclay Street . . | Asphalt | 32 | Heavy Industrial | 160.0 |
| E. Mason Street and N. Broadway. . . . . . . . . | Asphalt | 50 | Central Business | 3.3 |
| S. 27th Street and W. Parnell Avenue . . . . . . | Concrete | 50 | Shopping Center | 2.7 |

[a] *The results of all studies indicated to the researchers (J. D. Sartor and G. B. Boyd, Water Pollution Aspects of Street Surface Contaminants) that loadings from asphalt streets were about 80 percent higher than loadings from concrete surfaces. About 75 percent of the streets in the City of Milwaukee have asphalt surfaces. The fact that many asphalt streets are located in older more intensely used sections of the City may account for some of this increase.*

[b] *Values are average intensities of solids less than 2,000 microns) that would be found if the contaminants were spread uniformly across the full width of the street. Tests indicate that 99 percent of the solids are found within one foot of the curbs.*

[c] *Data presented in the study in footnote a indicates the rate of total load increase is attentuated as the number of days since rainfall or street sweeping occurred. (The seven-day loading equals three to four times the values in this table instead of seven times the values. This result has not been observed in some other studies. See N. V. Colston, Jr., Characterization and Treatment of Urban Land Runoff.*

*Source: Derived from data by J. D. Sartor and G. B. Boyd.*

Table 8

POLLUTION LOAD VERSUS PARTICLE SIZE IN THE CITY OF MILWAUKEE

| Particle Size (microns) | Solids (percent) | $BOD_5$ (percent) | COD (percent) | Solids Removed By Sweeping[a] (percent) |
|---|---|---|---|---|
| >2,000 | 24.1 | 4 | 0 | 79 |
| 840-2,000 | 40.8 | 21 | 1 | 66 |
| 246-840 | 20.4 | 18 | 4 | 60 |
| 104-246 | 5.5 | 13 | 15 | 48 |
| 43-104 | 1.3 | 14 | 28 | 20 |
| <43 | 7.9 | 30 | 52 | 15 |

[a] *Overall 47 percent of the solids (3.72 lbs/1,000 $ft^2$ to 1.96 lbs/1,000 $ft^2$) were removed in one pass with broom sweeper operating at 5.5 miles per hour on a concrete street. Other tests indicate only 30 percent removal on asphalt streets.*

*Source: Based on data of J. D. Sartor and G. B. Boyd.*

**Table 9**

**CHARACTERISTICS OF TEST SITES IN THE CITY OF MILWAUKEE UTILIZED IN STREET SURFACE LOADING STUDY**

| | Low/Old | | Medium/New | Medium/Old | Industry | | Central Business District | Suburban Shopping Center |
|---|---|---|---|---|---|---|---|---|
| | Single | Multi | Single | Multi | Medium | Heavy | | |
| Code Number | Mi-1 | Mi-2 | Mi-3 | Mi-5 | Mi-7 | Mi-8 | Mi-9 | Mi-10 |
| Site Location | N. 6th Street and W. Lloyd Street | N. 5th Street and W. Vine Street | S. 23rd Street and W. Bridge Street | W. Lapham Street and S. 10th Street | E. Becher Street and S. Allis Street | E. Greenfield Avenue and S. Barclay Street | E. Mason Street and N. Broadway | S. 27th Street and W. Parnell Avenue |
| Date | 4-28-71 | 4-28-71 | 4-29-71 | 4-28-71 | 4-28-71 | 4-29-71 | 4-27-71 | 4-29-71 |
| Street | | | | | | | | |
| Pavement | Asphalt | Asphalt | Concrete | Asphalt | Asphalt | Asphalt | Asphalt | Concrete |
| Condition | Good | Poor | Good | Fair | Fair | Fair | Excellent | Fair |
| Width (ft) (crown to gutter) | 12 | 10 | 18 | 18 | 16 | 16 | 25 | 25 |
| Gutter | Asphalt | Concrete | Concrete | Concrete | Asphalt | Asphalt | Asphalt | Concrete |
| Curb | Concrete | Concrete | Concrete | Concrete | Concrete | Concrete | Concrete | Concrete |
| Parking Strip | Dirt | Dirt | Lawn | Dirt | Concrete | Dirt | Concrete | Dirt |
| Sidewalk | Concrete | Concrete | Concrete | Concrete | Concrete | Concrete | Concrete | Concrete |
| Area Beyond Sidewalk | Grass | Dirt | Lawn | Lawn | Buildings | Dirt | Buildings | Parking Lot |
| Size of Test Area ($ft^2$) | 440 | 460 | 600 | 800 | 600 | 600 | 600 | 600 |
| Volume of Water (gal) | 10 | 8 | 13 | 15 | 8 | 17 | 8 | 25 |
| Parking Density | Light | No Parking | Light | No Parking | No Parking | No Parking | No Parking | Light |
| Traffic | | | | | | | | |
| Main types of vehicles | Auto | Auto | Auto | Auto | Mixed | Truck | Auto | Auto |
| Density | Light | Light | Light | Light | Moderate | Heavy | Heavy | Moderate |
| Average speed (mph) | 15-20 | 15-25 | 20-25 | 20-25 | 15-20 | 15-20 | 30-35 | 25-30 |
| Minimum distance from curb (ft) | 4 | 2-3 | 6-8 | 6 | 4-6 | 4-6 | 8 | 8 |
| Days Since Last Rain | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| Days Since Last Cleaned | 7 | 6 | 7 | 9 | 8 | 8 | 1 | 7 |
| Cleaning Method | Swept | Swept | Swept | Swept | Swept | Swept | Swept | Swept |

*Source: J. D. Sartor and G. B. Boyd.*

## LOADINGS FROM THE URBAN SURFACE

In addition to studies that have been done in attempts to quantify loadings to the urban surface, the literature is replete with reports on the quality of runoff from the urban surface. Most such studies have analyzed the quantity and quality of discharges from storm or combined sewers following precipitation events. Loadings reported represent the total load that reach the stream via the sewers from the various sources previously discussed. One study characterized the loads as shown in Table 11.

The flow weighted mean concept allows a determination of total pollutants reaching the stream by estimating the volume of runoff and using the concentrations to calculate pound loadings. The concentration of pollutants varies throughout the runoff period, with maximum concentrations several times the values in Table 11. Studies in northeast Ohio related runoff load to intensity of rainfall as shown in Table 12. Few studies have been done to quantify the pollutional load that is due to snowmelt in urban areas. Other quality/quantity data that is available has been summarized in "Characteristics and Comparative Magnitude of Nonpoint Sources" by R. C. Loehr in Journal of Water Pollution Control Federation, 46:8, August 1974, and Urban Storm Water Management and Technology: An Assessment by J. W. Lager and W. G. Smith, EPA, December 1974.

Studies on loadings from urban areas have indicated various relationships between the total pounds of pollutants discharged and the total rainfall occurring in a storm. Weibel et al, found nearly linear relationships between the inches of rainfall and the total pounds of $BOD_5$ and TSS discharged.[11] De Flippi et al[12] and others[13] found a linear relationship between the log of the total pounds discharged and inches of rainfall. Friedland, et al developed a relationship of the form Y = a/(b + i) where Y = lbs/acres-inch, i = inches of runoff in a storm.[14] The constants a and b varied for different constituents as noted in the following tabulation:

[11] *"Urban Land Runoff as a Factor in Stream Pollution," JWPCF.*

[12] *J. A. De Flippi and C. S. Shik, "Characteristics of Separated Storm and Combined Sewer Flows," JWPCF, Volume 43, No. 10, October 1971.*

[13] *Turner, Coolie, and Branden for New Castle Country 208 Areawide Waste Treatment Management Program, "Storm Water Quality Summary," November 1975.*

[14] *A. O. Friedland, T. G. Shey, and H. S. Ludwig, "Quantity and Quality Relationships for Combined Sewer Overflows," Advances in Water Pollution Research, Proceedings of the Fifth International Conference on Water Pollution Research, Pergamon Press, London, England, 1970.*

## Table 10

### SELECTED SOURCES AND CHARACTERISTICS OF LOADINGS ON THE URBAN SURFACE

| Source | Loading Information | Characteristic Information | Reference |
|---|---|---|---|
| Trees . . . . . . . . . . | Oaks—2,300-5,000 lbs/acre/year. Average = 3,100 lbs/acre/year of dry matter. Pines—1,500-3,400 lbs/acre/year. Average = 2,400 lbs/acre/year of dry matter. From 70-75 percent of tree litter is leaves, 60 percent of which fall in autumn | Nitrogen makes up from 0.3 to 0.7 percent of the dry weight fallen, phosphorus 0.05 to 0.24 percent. Average loadings are 16 lbs/acre/year nitrogen and two lbs/acre/year phosphorus | J. P. Heany *et al*, *Urban Stormwater Management Modeling and Decision Making*, EPA-R2-73-257, May 1973. |
| Grass . . . . . . . . . . | From 3,700-5,500 lbs grass/acre of lawn/year may be removed by grass cutting. If removed from lawn to the street, can add to runoff load from the street | Nitrogen makes up from 1.7 to 2 percent of dry weight of grass, phosphorus ranges from 0.2 to 0.8 percent. About 50 percent of nitrogen and 90 percent of the phosphorus can be removed in the clippings | *Ibid.* |
| Street Litter . . . . . . | In Chicago studies, about 17 percent of material found on the streets was litter (nonvegetative matter greater than 3,200$\mu$). About 0.15 lbs/acre/day of rags, 3.5 lbs/acre/day of paper, and 9 lbs/acre/day of other material were found in residential areas | No quality data available. Very little of the organic load from streets was determined to be from litter in Chicago. The eventual decomposition of material can add loadings to the urban surface | American Public Works Association, *Water Pollution Aspects of Urban Runoff*, WP-20-15, January 1969. |
| Animal Droppings. . . | Droppings from birds, dogs, cats, rats in sewers, can add loads to the urban surface. Difficult to quantify, difficult to control | 300-380 mg $BOD_5$/g solids, 550-720 mg COD/g solids for dogs. Most excreta from urban animals will be similar on a dry weight basis | *Ibid.* |
| Road Salt . . . . . . . | From 400-1,200 lbs/mile/application or from 25-100 tons/road mile/season | Very high chlorides in runoff have led to chloride levels of near 2,700 mg/l in Milwaukee area. The sodium ferrocyanide or ferric ferrocyanide use as agents to prevent caking can induce loads to the urban surface from these material. The use of sodium hexametaphosphate or sodium chromate as corrosion controls can also induce loads | R. Field and E. R. Struzeski, Jr., *Water Pollution and Associated Effects from Street Salting*, EPA-R2-73-257, May 1973 |

*Source: Stanley Consultants.*

## Table 11

### GENERALIZED SURFACE RUNOFF QUALITY AS MEASURED BY FLOW WEIGHTED MEAN CONCENTRATIONS

| Runoff Type | $BOD_5$ (mg/l) | TSS (mg/l) | TN (mg/l) | TP (mg/l) | Total Coliform (mpn/100 ml) |
|---|---|---|---|---|---|
| Combined sewer overflows . . . . . . . . . . . . | 115 | 410 | 11 | 4 | $5 \times 10^6$ |
| Bypassed sanitary waste to storm sewer . . . . | 115 | 410 | 11 | 4 | $5 \times 10^6$ |
| Surface runoff . . . . . . . . . . . . . . . . . . . . | 30 | 630 | 3 | 1 | $4 \times 10^5$ |
| Storm sewer discharges. . . . . . . . . . . . . . . | 30 | 630 | 3 | 1 | $4 \times 10^5$ |

*Source: J. A. Lager and W. G. Smith; Metcalf and Eddy, Inc.*

**Table 12**

**TYPICAL POLLUTION LOAD FROM COMBINED AND STORM SEWERS IN SELECTED CITIES**

| Intensity (in 3 hrs) | Runoff (mg/100 acres) | Runoff (inches) | Combined Sewers BOD (mg/l) | Combined Sewers BOD Load (lbs/100 acres) | Storm Sewers BOD (mg/l) | Storm Sewers BOD Load (lbs/100 acres) |
|---|---|---|---|---|---|---|
| 0.15 | 0.00 | 0.000 | -- | -- | -- | -- |
| 0.20 | 0.02 | 0.007 | 162 | 27 | 29 | 5 |
| 0.30 | 0.05 | 0.018 | 151 | 63 | 27 | 11 |
| 0.40 | 0.12 | 0.044 | 141 | 141 | 25 | 25 |
| 0.50 | 0.18 | 0.066 | 130 | 195 | 23 | 35 |
| 0.60 | 0.24 | 0.088 | 120 | 240 | 22 | 43 |
| 0.70 | 0.32 | 0.118 | 109 | 291 | 20 | 52 |
| 0.80 | 0.39 | 0.144 | 99 | 322 | 18 | 58 |
| 0.90 | 0.46 | 0.169 | 88 | 338 | 16 | 61 |
| 1.00 | 0.53 | 0.195 | 78 | 344 | 14 | 62 |
| 1.10 | 0.62 | 0.228 | 67 | 346 | 12 | 62 |
| 1.20 | 0.73 | 0.269 | 57 | 347 | 10 | 62 |

*Source: Burgess and Niple.*

| Constituent | a | b |
|---|---|---|
| COD | 12 | 0.01 |
| TSS | 24 | 0.001 |
| TN | 0.6 | 0.01 |
| OP | 0.1 | 0.01 |
| Heavy Metals | 2.1 | 0.1 |

Others have found that the total pounds of pollutants are related to total rainfall if the period of time between storms is constant.[15] As more time passes between storms, greater loads accompany a given rainfall event. The intensity of the storm in these studies seemed to affect the rate of discharge and the peak concentration of the contaminants, causing first flushes to occur in some cases, but not in other cases.[16]

Data comparing rainfall and total pollutant loadings from various areas of the country for combined sewer service areas are presented in Table 13. Similar data for Durham, North Carolina, have been developed from data presented by R. C. Loehr in "Characteristics and Comparative Magnitude of Nonpoint Sources"[17] for an area served by open storm drainage systems (surface channels). These data are presented in Table 14. The data generally indicate that loadings increase as rainfall amounts increase. The averages indicate that average reported $BOD_5$ runoff loads from the area served by the storm drainage system are comparable to the $BOD_5$ loads from areas served by combined sewers, while suspended solids and phosphorus loads associated with the storm water runoff were higher than indicated for the combined sewer overflows and the total Kjeldahl nitrogen loading associated with the storm water runoff was lower than that associated with combined sewer overflow.

Data presented in the Tulsa study[18] has been recalculated to show pollution loading in terms of solid strength, and deposition rates in terms of lbs/1,000 $ft^2$/day of road surface for comparison with Tables 6 and 7. This data is shown on Table 15. This comparison indicates that the strength of materials is higher than shown in Table 6, but the total loadings of materials per unit of area is less than indicated in Table 7. This may indicate selective transport of contaminants.

MOVEMENT OF POLLUTANTS

A direct link between material loadings on the urban surface and deposition of materials in waterways following precipitation events has not been made. As precipitation strikes the surface, certain constituents of the deposited materials are moved as suspended or dissolved substances toward the waterway. Suspended materials may redeposit on streets, in sewers, in catch basins, and similar places before reaching the waterway (and thus become available for further movement during subsequent runoff events).

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[15] *Sartor and Boyd, Water Pollution Aspects of Street Surface Contaminants, and Burgess and Niple, "Southwest Ohio Water Plan," draft.*

[16] *Weibel, Anderson and Woodward, "Urban Land Runoff as a Factor in Stream Pollution" and Turner, Coolie, and Braden, "Storm Water Quality Summary."*

[17] *N. V. Colston, Jr., Characterization and Treatment of Urban Land Runoff.*

[18] *J. G. Cleveland, R. H. Ramsey, and P. R. Walter, "Stormwater Pollution from Urban Land Activity," AVCO Economic Systems Corp., June 1970.*

Table 13

RUNOFF LOAD VERSUS RAINFALL FOR AREAS SERVED BY COMBINED SEWERS

| Storm Rainfall (inches) | Storm Pollution Loading (lbs/acre) | | | | | Location |
|---|---|---|---|---|---|---|
| | $BOD_5$ | TSS | TP | TKN | $NO_3$ | |
| 0.15 | 0.39 | 1.92 | 0.018 | -- | 0.002 | Bucyrus, Ohio |
| 0.16 | 0.43 | 1.14 | 0.012 | -- | 0.001 | Bucyrus, Ohio |
| 0.16 | 0.28 | 1.03 | 0.007 | -- | 0.001 | Bucyrus, Ohio |
| 0.18 | 0.26 | 3.13 | 0.013 | -- | 0.004 | Bucyrus, Ohio |
| 0.20 | 0.57 | 3.26 | 0.029 | -- | 0.001 | Bucyrus, Ohio |
| 0.25 | 0.50 | 3.92 | 0.015 | -- | 0.003 | Bucyrus, Ohio |
| 0.26 | 1.12 | 5.20 | 0.035 | -- | 0.004 | Bucyrus, Ohio |
| 0.26 | 0.92 | 3.41 | 0.026 | -- | 0.004 | Bucyrus, Ohio |
| 0.35 | -- | 20.49 | 0.084 | 0.50 | -- | San Francisco, Ca. |
| 0.40 | -- | 1.29 | 0.012 | -- | 0.001 | Washington, D.C. |
| 0.50 | 3.35 | -- | -- | -- | -- | Bucyrus, Ohio |
| 0.64 | 4.62 | -- | -- | -- | -- | Atlanta, Ga. |
| 0.68 | 4.99 | -- | -- | -- | -- | Atlanta, Ga. |
| 0.90 | 1.11 | 20.37 | 0.118 | -- | 0.118 | Bucyrus, Ohio |
| 1.10 | 3.21 | -- | 0.051 | 0.20 | -- | Washington, D.C. |
| 1.20 | 1.85 | 17.32 | 0.042 | -- | 0.094 | Bucyrus, Ohio |
| 1.20 | 0.47 | 9.29 | 0.018 | -- | 0.047 | Bucyrus, Ohio |
| 1.20 | -- | 9.86 | 0.039 | -- | 0.055 | Washington, D.C. |
| 1.42 | -- | 20.63 | 0.085 | 0.51 | -- | San Francisco, Ca. |
| 1.50 | 1.25 | 28.82 | 0.042 | 0.15 | -- | Washington, D.C. |
| Total 12.71 | 25.32 | 151.08 | 0.646 | 1.36 | 0.335 | -- |
| Average 0.64 | 1.58 | 9.44 | 0.038 | 0.34 | 0.026 | -- |

*Source: Data derived from A. M. Vitale and P. M. Spray.*

The most extensively studied movement of pollutants is the movement of materials from streets to storm sewers during rainfall events. The general equation[19] describing this washoff function is:

$N_c = N_o\,(1 - e^{-Krt})$, where:

$N_c$ = weight of material of given particle size washed from street.
$N_o$ = weight of material of given particle size initially on street.
t = minutes of rainfall.
r = intensity of rainfall inches/hr.
K = constant hr/inch/minute which varies from 0.006 for particles of 2,000 $\mu$ size to 0.02 for particles of 10 $\mu$ size.

Other investigations[20] have used similar relationships. One of these is:

$P_o - P = P_o\,(1 - e^{-4.6rt})$, where:

$P_o$ = amount of pollutant on surface at beginning of storm.
$P_o - P$ = amount of pollutant washed away in time, t.
P = amount of material remaining on surface.
r = rate of runoff (inches/hour).

The factor of 4.6 was derived by assuming 90 percent of pollutants would be washed from the surface in one hour of runoff of 0.5 inch/hour. The washoff in a 24-hour period has been reported[21] to be independent of rainfall intensity. The removals as a function of rain volume given were:

| Rainfall (inches) | Calculated Removal of Pollutants (percent) |
|---|---|
| 0.5 | 90 |
| 0.27 | 70 |
| 0.15 | 50 |
| 0.08 | 30 |
| 0.02 | 10 |

[19] *Sartor and Boyd, Water Pollution Aspects of Street Surface Contaminants.*

[20] *Metcalf and Eddy, University of Florida, Water Resources Engineers for the U. S. Environmental Protection Agency, Storm Water Management Model, Volumes I-IV (SWMM), July 1971.*

[21] *McElroy et al, Loading Functions for Assessment of Water Pollution from Nonpoint Sources.*

Table 14

RUNOFF LOAD VERSUS RAINFALL FOR AN URBAN AREA SERVED BY NATURAL DRAINAGE

| Storm Rainfall (inches) | Storm Pollution Loading (lbs/acre) | | | | |
|---|---|---|---|---|---|
| | $BOD_5$ | TSS | TP | TKN | COD |
| 0.04 | 0.034 | 0.33 | 0.002 | 0.002 | 0.186 |
| 0.05 | -- | 0.11 | 0.001 | -- | 0.072 |
| 0.11 | 0.341 | 9.95 | 0.010 | 0.005 | 2.55 |
| 0.19 | -- | 6.72 | 0.007 | 0.005 | 1.16 |
| 0.24 | 0.872 | 14.19 | 0.017 | 0.014 | 3.49 |
| 0.25 | -- | 7.28 | 0.007 | 0.005 | 1.04 |
| 0.33 | 1.88 | 10.41 | 0.008 | 0.005 | 1.80 |
| 0.33 | 0.49 | 22.91 | -- | -- | 2.42 |
| 0.38 | 1.23 | 115 | 0.056 | 0.027 | 14.40 |
| 0.43 | -- | -- | 0.016 | -- | 5.81 |
| 0.44 | 0.09 | 79 | 0.023 | 0.025 | 6.75 |
| 0.46 | -- | 37 | -- | -- | 4.18 |
| 0.50 | -- | 19 | 0.007 | 0.006 | 2.63 |
| 0.50 | 1.00 | 25 | 0.012 | 0.003 | 1.90 |
| 0.55 | 0.73 | 20 | 0.032 | 0.083 | 6.07 |
| 0.60 | 1.63 | 56 | 0.161 | 0.049 | 14.35 |
| 0.71 | 2.76 | 100 | 0.037 | 0.029 | 9.85 |
| 0.79 | -- | 84 | -- | -- | 11.96 |
| 0.96 | -- | 151 | 0.071 | 0.067 | 17.49 |
| 1.14 | -- | 276 | 0.110 | 0.071 | 27.35 |
| 1.19 | 1.14 | 278 | 0.203 | 0.127 | 37.09 |
| 1.51 | 6.50 | 400 | 0.135 | 0.076 | 40.10 |
| 1.55 | 3.59 | 18 | 0.056 | 0.181 | 4.98 |
| Total 13.25 | 22.29 | 1,730 | 0.971 | 0.780 | 218 |
| Average 0.576 | 1.59 | 79 | 0.049 | 0.043 | 9.45 |

*Source: Derived from data of N. V. Colston, Jr.*

Such removal rates have been combined with deposition rate functions to provide continuous simulation of runoff quality. Values of pollutant loadings and levels associated with days of zero precipitation are shown in Table 16 for one area. Values shown in Table 16 will be modified, wherever possible, based on more local data obtained by SEWRPC, for use in the Region's water quality management planning program.

Results of applying the above analytical methodologies in attempts to duplicate measured runoff quantities and characteristics have been only marginally successful. The more sophisticated mathematical models are generally more accurate than less sophisticated procedures in predicting runoff quantity. Good agreement between observed and predicted loadings has generally not been obtained regardless of procedures used.

In addition to materials deposited on the urban surface, precipitation washoff causes another significant source of contaminant loading, urban sediment from soil erosion. Urban sediment loading has been reported to range from 240 tons/square mile/year for grassland to over 48,000 tons/square mile/year for areas undergoing construction activities.[22] The annual distribution of sediment load is related to direct precipitation runoff.

The characteristics of the sediment will be similar to the characteristics of the soil removed by erosion. Values presented in the SEWRPC planning report, A Comprehensive Plan for the Milwaukee River Watershed, applicable to southeast Wisconsin soils are presented in Table 17. Control of soil erosion on sites undergoing urban development can be significant in reducing total stream loadings by preventing these materials from entering the waterways.

[22] *U. S. Environmental Protection Agency, Methods for Identifying and Evaluating the Nature and Extent of Nonpoint Sources of Pollutants, EPA 430/9-73-014, U. S. Government Printing Office, October 1973.*

**Table 15**

**RUNOFF QUALITY IN AREAS SERVED BY SEPARATE SEWERS**

| Area | Predominant Land Use | Concentrations (mg/l)[a] | | | | | Ratio of Pollutants to Total Suspended Solids (lbs/100 lbs TSS[b]) | | | | Calculated Total Solids Loading[c] (lbs/1,000 $ft^2$/day) |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | TSS | $BOD_5$ | COD | TKN | OP | $BOD_5$ | COD | TKN | OP | |
| 1 | Industrial | 2,052 | 13 | 100 | 1.11 | 3.49 | 0.63 | 5.4 | 0.05 | 0.17 | 3.28 |
| 2 | Commercial | 169 | 8 | 45 | 0.95 | 0.86 | 4.73 | 26.6 | 0.56 | 0.51 | 0.45 |
| 3 | Residential | 280 | 8 | 65 | 1.48 | 1.92 | 2.86 | 23.2 | 0.53 | 0.69 | 0.66 |
| 4 | Industrial-Residential | 340 | 14 | 103 | 0.97 | 1.05 | 4.12 | 30.3 | 0.29 | 0.31 | 0.86 |
| 5 | Residential | 136 | 18 | 138 | 0.72 | 0.87 | 13.24 | 101.5 | 0.53 | 0.64 | 0.22 |
| 6 | Industrial | 195 | 12 | 90 | 0.65 | 0.86 | 6.15 | 46.2 | 0.33 | 0.44 | 0.27 |
| 7 | Residential | 84 | 8 | 48 | 0.80 | 0.67 | 9.52 | 68.0 | 0.95 | 0.80 | 0.36 |
| 8 | Residential | 240 | 15 | 115 | 0.69 | 1.15 | 6.25 | 47.9 | 0.29 | 0.48 | 0.27 |
| 9 | Residential | 260 | 10 | 117 | 0.67 | 1.02 | 3.85 | 45.0 | 0.26 | 0.39 | 0.23 |
| 10 | Commercial | 300 | 11 | 107 | 0.83 | 0.70 | 3.67 | 35.7 | 0.28 | 0.23 | 0.37 |
| 11 | Residential-Commercial | 401 | 14 | 116 | 0.66 | 1.11 | 3.49 | 28.9 | 0.16 | 0.28 | 0.36 |
| 12 | Airport | 89 | 8 | 45 | 0.39 | 0.54 | 8.99 | 50.6 | 0.44 | 0.61 | 2.59 |
| 13 | Residential | 332 | 15 | 88 | 1.46 | 1.18 | 4.52 | 26.5 | 0.44 | 0.36 | 0.40 |
| 14 | Golf Course | 445 | 11 | 53 | 0.96 | 0.99 | 2.47 | 11.9 | 0.22 | 0.22 | 0.09 |
| 15 | Residential | 183 | 12 | 42 | 0.36 | 0.81 | 6.56 | 23.0 | 0.20 | 0.44 | 0.34 |

[a] *Values are averages of samples taken over one year storm events.*

[b] *Values are derived from concentrations. No direct relation to Table 6 data, is intended to be inferred.*

[c] *Values per 1,000 $ft^2$ of roadway occurring in the area and based on the total solids loading: both data items are presented in the source reference.*

*Source: J. G. Cleveland, R. H. Ramsey, and P. R. Walter.*

## SUMMARY

The principal diffuse pollutant loads on surface waterways from urban land activity result from urban erosion and washoff of materials deposited on the urban surface by natural and human activities. The state of the art in assessing the magnitude and movement of materials from the urban land surface to urban waterways has been briefly reviewed. No precise and accurate method has been adequately demonstrated to date. The use of mass loadings per rainfall event appears to be one of the most descriptive quantifications utilized. Such loadings are derived from precipitation washout; washoff of materials previously accumulated on street, parking lot, roof, and other surfaces; resuspension and movement of prior storm washoff temporarily stored on the watershed; soil sediments due to erosion, principally on construction sites; and other miscellaneous or unevaluated sources such as sewer overflows, illegal sewer connections, and incidental spills.

Control strategies based on these sources must assess:

1. Removals that can be gained by removing deposited material (urban surface cleaning).
2. Removals of prior storm deposits (catch basin cleaning, sewer cleaning, and flushing).
3. Control of soil erosion.
4. Prevention of deposits (clean air programs, solid waste management programs, road salt application programs).
5. Collection and treatment of runoff prior to discharge.

## Table 16

## POLLUTANT LOADING RATES FOR LAND SURFACE WASHOFF FUNCTIONS AND SUBSURFACE CONCENTRATIONS OF POLLUTANTS FROM DIFFERENT LAND USES

| Land Use | Estimated Connected Impervious Area (percent) | BOD | | | Conductivity | | | Total Coliform Organisms | | | Fecal Coliform Organisms | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | IMP[a] | PER[b] | SUB[c] | IMP | PER | SUB | IMP | PER | SUB | IMP | PER | SUB |
| | | (lb/ac/day) | | (mg/l) | (mho/cc/day) | | (mhos/cm) | ($10^6$/ac/day) | | (number/100 ml) | ($10^6$/ac/day) | | (number/100 ml) |
| Industrial. . . . . . . | 75-100 | 0.39 | 0.39 | 2.5 | 110 | 110 | 500 | 10,000 | 10,000 | 600 | 170 | 170 | 100 |
| Commercial . . . . . | 45-90 | 0.46 | 0.46 | 2.5 | 40 | 40 | 400 | 9,000 | 9,000 | 400 | 90 | 90 | 100 |
| High Density Residential 10 D.U./acre[d] . . | 15-45 | 0.13 | 0.13 | 2.0 | 38 | 38 | 300 | 9,800 | 9,800 | 400 | 95 | 95 | 100 |
| Medium Density Residential 5-10 D.U./acre. . | 5-30 | 0.07 | 0.07 | 1.5 | 17 | 17 | 200 | 1,260 | 1,260 | 300 | 46 | 46 | 75 |
| Low Density Residential 2-5 D.U./acre . . | 3-20 | 0.04 | 0.04 | 1.0 | 12 | 12 | 160 | 1,200 | 1,200 | 100 | 36 | 36 | 50 |
| Open Space and Rural 2 D.U./acre. . . . | 0.5-10 | 0.018 | 0.018 | 0.5 | 14 | 14 | 100 | 1,000 | 1,000 | 100 | 10 | 10 | 50 |
| Agriculture (Pastures) . . . . . | 0-5 | 3.1 | 3.1 | 1.0 | 5 | 5 | 75 | 120,000 | 120,000 | 50,000 | 51,000 | 51,000 | 5,000 |
| Agriculture (Farming). . . . . | 0-5 | 0.02 | 0.02 | 0.5 | 5 | 5 | 75 | 500 | 500 | 1,000 | 50 | 50 | 200 |
| Forests (Douglas Fir). . . | 0-5 | 0.01 | 0.01 | 0.05 | 1 | 1 | 25 | 1.0 | 1.0 | 90 | 0.1 | 0.1 | 5 |

| Land Use | Estimated Connected Impervious Area (percent) | Organic Nitrogen | | | $NO_2$ | | | $NO_3$ | | | $PO_4$ | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | IMP | PER | SUB | IMP | PER | SUB | IMP | PER | SUB | IMP | PER | SUB |
| | | (lb/ac/day) | | (mg/l) | (lb/ac/day) | | (mg/l) | (lb/ac/day) | | (mg/l) | (lb/ac/day) | | (mg/l) |
| Industrial. . . . . . . . | 75-100 | 0.0068 | 0.0068 | 0.01 | 0.2 | 0.2 | 0.1 | 0.0025 | 0.0025 | 0.4 | 0.03 | 0.03 | 0.2 |
| Commercial . . . . . . | 45-90 | 0.01 | 0.01 | 0.01 | 0.2 | 0.2 | 0.1 | 0.0020 | 0.0020 | 0.35 | 0.04 | 0.04 | 0.2 |
| High Density Residential 10 D.U./acre[d] . . . | 15-45 | 0.013 | 0.013 | 0.01 | 0.02 | 0.02 | 0.05 | 0.0015 | 0.0015 | 0.3 | 0.02 | 0.02 | 0.2 |
| Medium Density Residential 5-10 D.U./acre. . . | 5-30 | 0.0066 | 0.0066 | 0.01 | 0.02 | 0.02 | 0.05 | 0.0010 | 0.0010 | 0.25 | 0.0063 | 0.0063 | 0.2 |
| Low Density Residential 2-5 D.U./acre . . . | 3-20 | 0.004 | 0.004 | 0.01 | 0.002 | 0.002 | 0.05 | 0.0010 | 0.0010 | 0.2 | 0.0042 | 0.0042 | 0.2 |
| Open Space and Rural 2 D.U./acre. . . . . | 0.5-10 | 0.003 | 0.003 | 0.01 | 0.0026 | 0.0026 | 0.005 | 0.0014 | 0.0014 | 0.15 | 0.002 | 0.002 | 0.2 |
| Agriculture (Pasture) . . . . . . | 0-5 | 0.25 | 0.25 | 0.005 | 0.1 | 0.1 | 0.1 | 0.042 | 0.042 | 1.5 | 0.35 | 0.35 | 0.2 |
| Agriculture (Farming) . . . . . . | 0-5 | 0.0047 | 0.0047 | 0.01 | 0.025 | 0.025 | 0.1 | 0.014 | 0.014 | 1.0 | 0.00023 | 0.00023 | 0.2 |
| Forests (Douglas Fir). . . . | 0-5 | 0.0021 | 0.0021 | 0.1 | 0.00001 | 0.00001 | 0.01 | 0.00032 | 0.00032 | 0.02 | 0.000024 | 0.000024 | 0.1 |

[a] *Impervious area rate of accumulation.*

[b] *Pervious area rate of accumulation.*

[c] *Subsurface concentration.*

[d] *D. U./acre = dwelling units per acre.*

*Source: $CH_2M$-Hill Consultants.*

Table 17

**CONSTITUENTS OF TYPICAL STREAM SEDIMENTS IN SOUTHEASTERN WISCONSIN**

| Constituent | Quantities Found in Sediment[a] |
|---|---|
| Nitrogen (N). . . . . . . . . . . . . . | 0.16 to 0.6 grams/100 grams of sediment with from 5 to 15 percent available as ammonia and nitrate nitrogen. The remainder is organically bound in the soil. |
| Phosphorus (P) . . . . . . . . . . . . | 0.07 to 0.3 grams/100 grams sediment with from 5 to 10 percent available as orthophosphate. |
| Organic Matter . . . . . . . . . . . . | 1.6 to 15 grams/100 grams sediment. |
| Pesticides[b] . . . . . . . . . . . . . . . | From 0.01 to 0.32 parts per million (ppm) of common pesticides (aldrin, chlordane, DDE, DDT, dieldrin, heptachlor, trifluralin) were found in soils. |
| Heavy Metals[c]. . . . . . . . . . . . . | Range highly variable, average values are Cr = 36 ppm, Cu = 14 ppm, Fe = 15,000 ppm, Pb = 14 ppm, NI = 13 ppm, Ti = 3,000 ppm, Zn = 36 ppm. Usually less than 1 percent is soluble. |

[a] *The concentration found in sediment is usually two to four times the concentration found in the soil due to on-land sediment deposits from erosion of the larger sediment particles that have fewer pollutants attached.*

[b] *Atrazine and Ramrod losses ranged from 0.16 to 1.8 percent of material applied.*

[c] *The concentration of arsenic in soils ranged from 0.34 to 10.0 ppm.*

*Source: A. D. McElroy et al.*

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## Chapter IV

# PREVENTIVE POLLUTION CONTROL CONCEPTS AND COSTS

## INTRODUCTION

Control of diffuse source pollution in urban areas must be focused in two broad areas:

1. The control of inputs to the air, land, surface water, and groundwater systems which can cause harm to the natural system.

2. The control of transfers between the air, land, surface water, and groundwater systems.

Many inputs and transfers are the result of natural events and cannot be effectively controlled. Human activities in urban areas increase source activity and may concentrate inputs and facilitate transfers.

Most structural control alternatives that have been tested consist of systems for intercepting runoff waters from urban areas and providing treatment prior to the ultimate transfer from the land surface to surface waters. The structural controls, as discussed here, are taken to include those methods which do not require the construction of major treatment installations, but rather they favor preventive measures. Most nonstructural control alternatives consist of methods to control inputs and transfers from the land to the urban drainage system.

Most pollution abatement techniques for storm water control have been directed to treatment of the overflows from combined sewers where the storm water has been mixed with community wastewaters. Essentially all projects have been sponsored by the U. S. Environmental Protection Agency's Storm and Combined Sewer Technology Research, Development, and Demonstration Program and have been designed to demonstrate new or improved methods of control for combined sewer overflows. The emphasis has been on treating whatever contaminants may exist in the overflows prior to their discharge to surface waters. Studies in the Region have been summarized earlier in Chapter II.

## POLLUTION CONTROL REQUIREMENTS

Developing adequate control requirements for storm drainage systems is difficult since:

1. Little is known of the quantitative impact and/or need for control of storm drainage waters.

2. Storm drainage systems often are composed of several parts which have been planned and built at various times by different parties in the absence of any comprehensive development plan.

3. Systems may also serve as conveyance systems for continuous point source discharges.

4. There is a general lack of control technologies which have been demonstrated to be economically practicable.

5. The diverse ownership of and operating responsibilities for different parts of a storm drainage system make it extremely difficult (legally or conceptually) to implement control strategies.

Most continuous point source dischargers are subject to the provisions of the National Pollutant Discharge Elimination System (NPDES) whether they discharge directly to a surface water or through a storm drainage system. In Wisconsin the NPDES program is administered through the Wisconsin Pollutant Discharge Elimination System (WPDES).

While not intending to require a WPDES permit for every ditch and culvert in the nation, the U. S. EPA as a result of a court case (National Resources Defense Council vs. Train 396 F. Supp. 1393, 7 ERC 1881) has issued regulations bringing certain separate storm drainage systems under the requirements of WPDES. Background information on the requirements is contained in the Code of Federal Regulations of December 5, 1975, and March 18, 1976. Basically, the regulations provide that general WPDES permits may be issued for separate storm sewers defined as "a conveyance or system of conveyances (including, but not limited to, pipes, conduits, ditches, and channels) located in an urbanized area and primarily operated for the purpose of collecting and conveying storm water runoff." In the Southeastern Wisconsin Region areas, as defined in the regulation, include areas in and around Racine, Kenosha, and Milwaukee, all of which have some combined sewer areas as described in Chapter II. U. S. EPA does not envision effluent limitation guidelines for storm sewers at this time. A two-phase permit program appears to be evolving. The first phase would consist of inventory, sampling, monitoring, and development of economically achievable plans to abate significant pollution. The second phase would require that the developed abatement plan be carried out. Much of the first phase activities would be undertaken as part of or in conjunction with 208 water quality management plans.

No effluent quality or mass emission requirements are currently applied in the Southeastern Wisconsin Region for storm water discharges.

## CONTROL CONCEPTS

The current strategy for control of urban storm drainage pollution is the development and adoption of "best management practices" for source control. For existing urban areas, best management practices may consist of limited source controls such as street sweeping as the

## Table 18

## NONSTRUCTURAL CONTROL CONCEPTS FOR RUNOFF CONTROL

| Goals | Objectives | Methods in Urban Areas |
|---|---|---|
| Minimize Erosion | Maintain agricultural productivity<br>Prevent siltation of streams and reservoirs<br>Prevent attached pollutants from reaching waterways | Construction site controls<br>Use of vegetative cover<br>Sediment trap basins |
| Maintain Soil Infiltration | Continue ground water recharge<br>Reduce volume of runoff<br>Reduce runoff peak flows | Use of vegetative cover<br>Soil aeration<br>Artificial drainage |
| Minimize Flooding Damage | Reduce flood potential<br>Reduce stream bank erosion<br>Reduce damagable property<br>Provide equitable protection | Control runoff rate<br>Flood plain development controls<br>Dikes, dams, levees, and floodwalls<br>Floodproofing of structures |
| Minimize Human Wastes from Entering Waters | Control septic systems<br>Treat collected wastes<br>Control urban runoff<br>Control sewer leakage<br>Control wastes produced | Point source treatment systems<br>Infiltration/inflow control<br>Sanitation practices<br>Phosphate detergent bans |
| Minimize Animal Wastes from Entering Waters | Control livestock wastes<br>Control urban drainage<br>Control erosion | Soil conservation practices<br>Point source treatment systems<br>Livestock waste treatment systems |
| Minimize Chemical Agents from Entering Waters | Control erosion<br>Control material stockpiles<br>Control application and use<br>Control materials made<br>Control air pollution<br>Treat human and animal wastes | Dikes, diversions<br>Product restrictions<br>Point source treatment systems<br>Soil conservation practices |

*Source: Stanley Consultants.*

only practical approach. Practices which emphasize attenuation of the rate of runoff are emerging as the best management practices for newly developing areas.[1] Controlling runoff to preserve a watershed's natural runoff characteristics may have multiple benefits depending on the objective sought. Table 18 presents potential methods for runoff control that can be used to reach alternative objectives and goals. Many methods can be applied to satisfy more than one objective and to obtain more than one goal.

[1] *D. Athayde, "Best Management Practices," in Proceedings, Urban Storm Water Management Seminars, WPD 03-76-04, January 1976.*

Successful utilization of nonstructural controls for storm water pollution abatement depends on methods which provide multiple benefits. Most nonstructural control methods consider pollution abatement as a secondary benefit and have a basic purpose other than pollution abatement: for example, street cleaning for aesthetics, onsite detention for flood control, and preservation of riverside parkways for recreation and flood control.

## POLLUTION CONTROL METHODS

Control methods to prevent surface water pollution from storm water runoff in urban areas can be grouped into three major systems:

1. Methods to control the volume and rate of runoff.

2. Methods to control erosion and sediment delivery caused by runoff waters.

3. Methods to remove materials picked up or potentially picked up by runoff waters.

Methods that have been reported in the literature for these basic systems are grouped in Table 19. Technical information on each method is provided in the remainder of this chapter and in Chapter V.

Table 19

NONSTRUCTURAL CONTROL METHODS OF RUNOFF CONTROL FOR URBAN AREAS

| |
|---|
| Methods[a] to control the volume and rate of runoff |
| Rooftop storage or runoff controllers |
| Removal of roof and other drain connections |
| Onsite detention tanks, basins, and ponds |
| Onsite seepage beds, pits, basins, and areas |
| Porous pavement and porous surfaces |
| Lawn aeration |
| Parking lot and plaza area storage |
| Diversion berms and channels |
| In-sewer storage |
| Methods to control erosion and sediment delivery |
| Vegetative cover |
| Mulching and seeding |
| Surface stabilization |
| Sodded ditches |
| Temporary check dams |
| Sediment basins |
| Dikes, levees, and floodwalls |
| Methods to remove materials potentially picked up by runoff waters |
| Air pollution control |
| Solid waste control |
| Street sweeping |
| Catch basin cleaning |
| Sewer flushing |
| Deicing material control |
| Vegetative filter strips |
| Swale storage |
| Dikes |

[a] *Storage basins, aerated lakelets, and any further treatment are considered to be structural controls involving collection and treatment of storm waters from large areas prior to discharge and are therefore addressed in Chapter V.*

*Source: Stanley Consultants.*

Methods to Control the Volume and Rate of Runoff

Most installed storm water detention devices have been provided by developers because onsite detention was required by a local public agency having jurisdiction over storm water drainage. A few have been installed after detailed investigations revealed that onsite storage would significantly reduce the cost (as compared to conventional storm sewers) of handling storm waters. Storm water detention devices are used primarily to reduce the frequency and extent of local flooding. Their primary function is to provide a system whereby natural drainage systems of an area is not functionally changed by development.

Pollution control benefits from the methods accrue since: (1) more water, partially purified by soil filtration and action of soil microbes, may infiltrate to groundwater, (2) controlling the velocity of runoff can reduce erosion and scour potential, and (3) temporary storage allows deposition of some particulates at the storage site.

Rooftop Storage or Runoff Controls

Rooftop areas can range from about 50 percent of the total surface area in developed commercial areas to about 15 percent in established residential areas. The flat roofs usually found in commercial and industrial areas can be used to temporarily store water by using any of several ponding rings available or by installing gravel barriers on roofs.[2] Buildings designed for the snow load in Wisconsin can usually store up to six inches of water providing leakage can be avoided. Flow from the roofs is usually restricted by the devices to less than 0.15 inches/hour. Rainfall in excess of this intensity will pond and be released at the slower rate. Up to the point of maximum storage capacity, a reduction in roof peak flows of 10 to 20 percent has been demonstrated.[3] A reduction in peak total runoff rates from areas containing 2 to 4 percent flat roofs using roof storage has been reported at from 5 to 11 percent.[4] Some storage and runoff attenuation for sloping roofs can be obtained for intense short duration storms by using findams.

Cost for rooftop storage can range from 2 to 10 cents/ft$^2$ of roof area. No significant total runoff volume reduction or direct pollutant removal is obtained by use of the systems. An unquantifiable reduction of stream loading due to reduced scour downstream of the roof may occur.

Because of the structural problems associated with the potential buildup of ice on roofs in southeastern Wisconsin, the system appears to have compelling disadvantages.

[2] *H. G. Poertner, Practices in Detention of Urban Stormwater Runoff, APHA Special Report 43, June 1974.*

[3] *J. Tourbier and R. Westmacott, Water Resources Protection Measures in Land Development—A Handbook, Water Resources Center, Delaware University, April 1974.*

[4] *Poertner, Practices in Detention of Urban Stormwater Runoff, and Tourbier and Westmacott, Water Resources Protection Measures in Land Development.*

Table 20

COST AND PERFORMANCE OF DETENTION BASINS

| Amount of Runoff Storage | Size | Mass Removals (percent) | | Cost Capital[a] (dollars/acre) | Annual Operation and Maintenance[b] (dollars/acre) |
|---|---|---|---|---|---|
| | | TSS | $BOD_5$ | | |
| 0.1 in/acre | 2,700 gal/acre | 20 | 10 | 180 | 35 |
| 0.5 in/acre | 13,600 gal/acre | 40 | 25 | 600 | 30 |
| 1.0 in/acre | 27,200 gal/acre | 60 | 30 | 850 | 30 |
| 1.5 in/acre | 40,700 gal/acre | 70 | 35 | 1,200 | 30 |
| 5.0 in/acre | 136,000 gal/acre | 75 | 40 | 3,600 | 25 |

[a] *Based on earthen structure with pipe outlet. Concrete basins or tanks will cost about four times this amount. Valid for basins serving 50 acres or less. Engineering News Record Construction Cost Index = 2,445.*

[b] *Cost is more for smaller facilities since sediment would have to be removed more often to retain storage volume.*

*Source: Based on data from H. G. Poertner; J. Tourbier and R. Westmacott; A. Waldo; and C. W. Mallory.*

Removal of Roof Drain and Other Connections

Rainfall is removed from roofs by gravity flow, usually through downspouts. The downspouts can be directly linked to the storm drainage system. If not linked directly to storm sewers or combined sewers, the flow from downspouts travels overland to streets where the storm water enters the system through street inlets to storm sewers, or flows to natural drainage channels.

In addition to downspout connections, storm sewers often have other direct connections that transmit flow from continuous point sources. Such sources can represent significant loads on surface waters. In Dayton, Ohio, dry-weather flow from storm sewer outlets was estimated at 55 mgd discharging 4,400 lb/day $BOD_5$ and 75,700 lb/day of suspended solids. In comparison, flows to the Dayton wastewater treatment facility were 51 mgd which discharged 13,600 lb/day of $BOD_5$ and 23,000 lb/day of suspended solids.[5] Because of the continuous dry-weather flow, "first flush" phenomenon were not observed in samples from the storm sewers.[6]

Limited runoff volume reduction and significant peak flow reduction can occur if downspouts are not directly connected to storm sewers. Allowing water to run over the ground surface can result in some sediment removal by entrapment, but has the potential for dissolving and transporting fertilizers, weed sprays, or other materials from urban lawns to the waterway. A community survey in Springfield, Illinois,[7] determined that 40 percent of the buildings had downspout connections to the city's combined sewer system. The survey cost $45,000 (about $2 per building). Downspout disconnection costs were $50 to $100 per building. Reductions in basement flooding, combined sewer overflows, and wastewater treatment operating costs were noted after downspout disconnections, indicating an attenuation of peak flows.

Onsite Detention Tanks, Basins, and Ponds

Detention facilities reduce peak runoff flows from drained areas by supplying temporary storage of runoff waters during storm events. The storage is usually provided by having a controlled outlet on a basin so that flow in excess of the outlet discharge rate backs up, filling the basin. Dry tanks and basins have the outlet near the bottom, while wet basins and ponds have a raised outlet and a permanent pool of water. Detailed methods of sizing detention basins are given elsewhere.[8] Storage capacities ranging from 0.5 to 1.5 inches of runoff from the contributing area are usually specified depending on the degree of peak flow reduction desired. Volume requirements are thus 14,000 to 40,000 gallons per acre served. Peak flow reductions for a given drainage area will range from 30 to 70 percent for these storage capacities. The detention volume needed for a typical one-third acre lot for 50 percent peak flow attenuation would be 1,200 $ft^3$ or a basin 14-foot x 14-foot x 6-foot deep. Larger facilities would be needed for larger sites. Unit cost information for detention basins and their effectiveness in removing pollution load by sedimentation is presented in Table 20.

Detention facilities have proven successful in controlling runoff rates economically for sizable areas. Accumulated silt and urban debris, muddy appearance of water during storms, mosquito breeding and algae control in ponded basins, and general safety considerations are possible drawbacks which must be considered in planning and maintaining such facilities. Buried detention tanks such

[5] *W. T. Eiffert and P. J. Fleming, "Pollution Abatement Through Sewer System Control," JWPCF, Vol. 41, No. 2, Part 1, February 1969.*

[6] *Stanley Consultants for the Miami Conservancy District, Nonpoint and Intermittent Point Source Controls—Application of Structural and Nonstructural Control Techniques, May 1976.*

[7] *Poertner, Practices in Detention of Urban Stormwater Runoff.*

[8] *Tourbier and Westmacott, Water Resources Protection Measures in Land Development.*

as that at N. Humboldt Avenue in Milwaukee overcome many aesthetic and safety drawbacks of open basins and open ponding areas, as well as offering possible utilization of the sites for recreational and other uses, but are much more expensive to construct. Montgomery County, Maryland, has extensive detention facilities installed for flow attenuation purposes.[9]

There are several storm water detention basins in the Region which illustrate the applicability of such systems to the Region. Such basins include the installation at the Northridge Lakes residential complex, the Milwaukee Area Technical College North Campus Center at Mequon, residential subdivision facilities in Brookfield, and storm sewer system elements in the City of Racine.

Onsite Seepage Beds, Pits, Basins, and Areas

The goal of the prior three methods is to reduce runoff rate. The goal of this and the following two methods is to reduce runoff volume by facilitating precipitation movement to groundwater. These infiltration structures are usually constructed by excavating the soil and backfilling with gravel. They are successful only if the groundwater table is below their base so that storm water can penetrate and be stored in the gravel, and if the permeability of the subsoil is adequate to drain the structures in a reasonable period of time.

Dutch (sometimes called French) drains are a special type of seepage device that can be used to catch flow from roof runoff around buildings. Flow is directed to a gravel-filled trench with or without a cover material such as porous brick lattice or thin layer of sod. The structure can be sized to store all of the water or to store lesser amounts and serve as a detention device with overflow. Its construction cost has been reported at $32/cubic yard of stored water (adjusted to the Engineering News Record Construction Cost Index (ENRCCI) of 2,445 for August 1976). For a typical 1,500 square foot residence at a design storage of six inches of rain, the cost per residence would be $890.

Similar gravel-filled trenches have been used to store runoff from parking lots. About four cubic yards of excavation is required to provide one cubic yard of storage space. The larger size of the pits provides a lower unit cost of about $25 per cubic yard of stored water.

Storage basins and areas have become popular for handling storm water runoff from highways. Facilities are usually open basins in relatively permeable soil. Construction costs would be similar to detention basins, with operating costs about three times as high due to the need to annually till the soil to maintain infiltration rates.[10]

[9] *Poertner, Practices in Detention of Urban Stormwater Runoff.*

[10] *R. J. Weaver, "Recharge Basins for Disposal of Highway Storm Drainage," New York State, Department of Transportation, NTIS, PB-201 959, May 1971.*

The quality of water entering infiltration facilities is an important consideration. High levels of silt may quickly clog surface or subsurface areas, reducing the infiltration capacity. Potential pollution of groundwaters by infiltration procedures which bypass the natural filtering and purifying soil layers is an ever present problem.

Porous Pavement and Porous Surfaces

Various types of porous surfaces ranging from porous pavement to open lattice blocks have been used to allow infiltration in areas that would otherwise be made impervious by the land use of the area (highways, sidewalks, driveways, parking lots). Most are applicable only to new construction or incorporation into planned reconstruction since the cost of replacing existing surfaces with porous surfaces as a storm water pollution abatement alternative would be prohibitively expensive.

Porous pavements have found use as surfaces (a one-inch overlay on normal pavement) to prevent hydroplaning in northern climates. Their use as the only pavement material over a gravel subbase in northern climates may be limited due to paving destruction by alternate freezing and thawing of a semisaturated subbase.[11] Infiltration rates of the pavement range from five inches/hour to over 25 inches/hour.[12] The rates must be maintained by vacuum sweeping after each rain to avoid surface clogging.[13] In warmer climates, the pavements have been tested on parking lots and are planned for inclusion on most pavement surfaces in the residential woodlands development near Houston.[14]

A 2-inch surface over 12-inch subbase over a soil with a permeability greater than 0.042 ft/day that may be suitable for parking lots or playgrounds will cost about $6.60/square yard (about 60 percent more than conventional pavement). A 6-inch surface over 20-inch subbase suitable for most streets will have a cost of about $120/cubic yard of asphaltic pavement material. Cost savings due to a reduction in curb, gutter, and storm sewer requirements make the concept attractive if local ordinances permit use of the material in lieu of conventional drainage practice.

Grassed driveways constructed by placing a thin layer of topsoil over brick lattice with lattices filled with rock have been used.[15] Costs for such a system are about $70

[11] *J. A. Lager and W. G. Smith; Metcalf and Eddy, Inc., Urban Storm Water Management and Technology: An Assessment, EPA 670/2-74-040, December 1974.*

[12] *E. Thelan et al, Investigation of Porous Pavements for Urban Runoff Control, EPA 11034 DUX., March 1972.*

[13] *Tourbier and Westmacott, Water Resources Protection Measures in Land Development.*

[14] *Poertner, Practices in Detention of Urban Stormwater Runoff.*

[15] *Tourbier and Westmacott, Water Resources Protection Measures in Land Development.*

per cubic yard of driveway volume. Open lattice blocks and spaced bricks and blocks have often been used in urban sidewalk developments as architectural features and as systems to allow water to reach plants grown in such developments.

All of these devices will reduce runoff by increasing the percentage of pervious area in developments. The effectiveness and cost of the systems in a total drainage area may be difficult to assess.

Lawn Aeration

Urban lawns have a low infiltration rate when compared to natural grasslands. Perforation of lawns as is done for golf courses can increase infiltration and aeration and reduce runoff rates and volumes. The cost of this operation on a lawn would be about $12 to $16. The effectiveness of this method is difficult to quantify, and the implementation of the method on a watershed basis may be difficult.

Parking Lot and Plaza Area Storage

This method is similar to the detention basin concept except that the parking lot and/or plaza area is used to temporarily store water by sloping drainage to a restricted flow outlet. The concept is a very cost-effective approach since little additional costs will be involved for grading and operation maintenance over a conventionally designed lot and may allow smaller drainage systems downstream of the outlet. Little pollutant removal would be expected. Pollutant removal can be increased by screening the outlets or installing large catch basins below the outlet providing hydraulic efficiency can be maintained.

Diversion Berms and Channels

Any obstruction to direct flow of runoff overland which increases the time of flow from the runoff source to the runoff receiver will lower peak flows from an area. A concentrated runoff stream can be dispersed evenly over large surface areas by proper location of berms, channels, or other diversions. The method is effective in reducing the erosive force of moving water. The layout, effectiveness, and cost of structures to change flow patterns are site specific. Diversions which direct runoff across grassed areas are preferable to diversions which direct runoff across paved areas since the grass will act as a sediment filter.

In-Sewer Storage

The volume of storm sewers in a community is large. This volume can be used to store storm water runoff using the sewers as detention facilities. The concept has been applied primarily in combined sewer areas (Seattle, Minneapolis, Detroit) to reduce the volume and occurrence of overflows.[16] These applications have shown that sufficient sewer capacity is available to trap the first 0.05 inch to 0.10 inch of rain. Storm sewer storage systems would probably find greatest use in reducing design capacity and increasing operation response time for end-of-pipe treatment concepts where space limitations preclude off-line storage.

Seattle's experience in a computer-operated regulated gate control program was reported to cost $400/acre for computer control equipment and $200/acre for gate control equipment at an annual operating cost of $5/acre.[17]

Summary

Methods to reduce the volume and rate of runoff from urban areas are generally considered helpful in lowering the pollution load on surface waters. Reducing the velocity of flow reduces erosion and sediment transport, whereas reducing the volume of water also reduces the load of dissolved pollutants.

## METHODS TO CONTROL EROSION AND SEDIMENT DELIVERY

The most generally effective method to control erosion is vegetative cover. The cover serves to intercept and disperse the kinetic energy of rainfall, preventing soil from becoming dislodged and accessible for transport by runoff waters. Control methods for erosion from land areas all involve systems to duplicate the effect of vegetative cover. The removal of dislodged materials from one place to another is termed sediment transport. Many methods are available to provide surfaces where the transport is limited to a few inches (surface scarification for example).

Flowing water has a tremendous capacity to erode surfaces in its path. This can lead to gullies, streambank erosion, and similar mass soil movements.

Prevention of eroded soil from entering waterways is usually accomplished by providing areas to decrease the velocity of runoff waters so that material will settle out, or eroded soil is restrained from entering waterways by providing grassed areas where solids may be filtered out.

The erosion and sediment delivery from established urban areas is minimal. Construction activities in urban areas are a prime source of fugitive dust and accumulated dustfall and a significant contributer to solids loading in streams

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[16] *Lager and Smith, Urban Storm Water Management and Technology.*

[17] *U. S. Environmental Protection Agency, Evaluating Transportation Controls to Reduce Motor Vehicle Emissions in Major Metropolitan Areas, Research Environmental Triangle Park, North Carolina, November 1972.*

as bare earth is eroded. Extensive information[18] is available on erosion control from construction areas and will not be repeated here. Relevant methods of controlling erosion from construction activities are summarized in Table 21 indicating cost and effectiveness of the various practices.

Effective erosion control and sediment reduction planning on construction sites consist of disturbing the smallest areas possible, providing protective cover on disturbed areas as quickly as possible, and using sediment traps or basins to minimize sediment transport from the site. The costs provided in Table 21 for soil erosion and sediment control measures on construction sites are estimates that can be used for planning purposes. Costs per unit area are useful for comparison or for estimating overall costs of erosion control, but should be used with caution because of variables encountered in different areas in the Region. The most economical plan for an area usually involves combinations of the practices which, if designed and installed by experienced parties, can effect a major reduction in soil loss and sedimentation at a minimal cost.

## METHODS TO REMOVE MATERIALS POTENTIALLY PICKED UP BY RUNOFF WATERS

Urban housekeeping techniques are being proposed by the U. S. EPA as a cost-effective control technique for managing urban runoff pollution problems,[19] but no references were found in the literature indicating the effectiveness of such techniques in reducing total urban runoff load or in improving the quality of streams. The techniques will probably accomplish both functions, but the quantitative effectiveness of such practices on reducing water pollution from a watershed is currently unknown.

Urban housekeeping techniques are aimed at removing (or preventing) material deposition on the urban surface. This reduces quantities available for runoff transport. Methods were summarized in Table 19 and are discussed below.

### Air Pollution Control

Wind erosion in rural areas, construction activities' road use, and industrial point sources in urban areas are the primary source of dust in the air. Significant quantities of particulate material are also added by combustion of fossil fuels and wearing of urban surfaces by human activities. Other sources such as material storage piles and unpaved lots rarely affect a regional system. Because of the location of urban areas in the study area and prevailing wind directions, most combustion emissions are deposited in Lake Michigan and not on land.[20]

The end result of an effective air pollution control program is that emissions from various sources are reduced to acceptable levels. Implementation of air pollution control technology (precipitators, cyclones, fabric filters, scrubbers) will reduce the dispersed impact that air pollutants can have on water quality; but since some control equipment uses water to remove air pollutants, further control may be required to prevent these pollutants from reaching surface waters. Control methods related to type of fuel burned (low sulfur coal, unleaded gas) can reduce deposition of certain materials on urban surfaces.

Information presented in Chapter III indicates correlation between dustfall and total pollutant loadings on (and materials removed from) the urban surface. Reduction in dust from various practices in urban areas is shown in Table 22. The quantity of dust generated without the controls is probably highly variable, but has not been adequately quantified for generalized application in water quality planning.

Potential reductions in particulate emissions from vehicular traffic are given in Table 23. These may be used to predict relative reductions from the base loadings discussed in Table 6 of Chapter III.

One of the long practiced methods of disposing of leaves has been by open burning. Prohibition of such burning by local ordinances will minimize air pollution from this source, but means that adequate leaf disposal systems (compost piles, city collection) must be adopted to prevent water pollution that may result from organic and nutrient leaching from the dredging organic matter.

Reductions in particulate deposition from air pollution point source controls are difficult to predict. Loadings approaching residential area dustfall rates as shown in Table 4 may occur.

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[18] *U. S. Soil Conservation Service, Controlling Erosion on Construction Sites, Agricultural Information Bulletin 347, U. S. Government Printing Office, Washington, D. C., 1970; U. S. Environmental Protection Agency, Guidelines for Erosion and Sediment Control Planning and Implementation, EPA-R2-72-015, U. S. Government Printing Office, Washington, D. C., August 1972; U. S. Department of Interior, Urban Soil Erosion and Sediment Control, 15030 DTLO 5/70, U. S. Government Printing Office, Washington, D. C., May 1970; U. S. Environmental Protection Agency, Comparative Costs of Erosion and Sediment Controls, Construction Activity, EPA-430/9-73-016, U. S. Government Printing Office, Washington, D. C., 1973; and U. S. Environmental Protection Agency, Processes, Procedures, and Methods to Control Pollution Resulting from All Construction Activity, EPA 430/9-73-007, October 1973.*

[19] *U. S. Environmental Protection Agency, Proceedings Urban Stormwater Management Seminars, WPD-03-76-04, January 1976.*

[20] *SEWRPC, Natural Resources of Southeastern Wisconsin, Planning Report No. 5, June 1963.*

Table 21

URBAN CONSTRUCTION EROSION AND SEDIMENT REDUCTION CONTROLS

| Controls | Application | Unit Cost (in dollars) (ENRCCI = 2445) | Effectiveness |
|---|---|---|---|
| **Surface Stabilization Methods** | | | |
| Scarification | Cross-slope roughening | -- | Reduces gullying on short slopes |
| Top Soil Removal | Aids in revegetation, strip 9" and reapply | 0.60/sq. yard | Long term |
| Gravel | On roads (1 ton/yd$^2$), in swales (1 ton/yd$^2$) and temporary berms | 4-6/cu. yard | Coarse sediment trap |
| Asphalt Binder | Emulsion (300-500 gal/acre) to stabilize mulch or surface from wind blowing | 0.20/sq. yard | 98 percent soil loss reduction |
| Latex Emulsions | Emulsion to penetrate surface to bind soil | 0.30/sq. yard | 95 percent soil loss reduction |
| **Surface Covering Methods** | | | |
| Hay or Straw Mulching | Spread at 120-150 bales/acre (20-30 tons/acre) and disc in on slopes > 5 percent | 1,500/acre | 98 percent soil loss reduction |
| Wood Chip Mulching | Apply 1-inch deep over surface (10-15 tons/acre). (May use wood chipper on removed vegetation) | 3,800/acre | 94 percent soil loss reduction |
| Paper Netting | Applied over seeding on steep slopes (can be reused) | 8,500/acre | 90 percent soil loss reduction |
| Sodding | For permanent protection (usually 1 inch thick) | 18,000/acre | 99 percent soil loss reduction |
| Seeding | 25-50 lbs seed/acre (on areas stripped of topsoil add 2,000 lbs lime, 800 lbs fertilizer per acre) | 250/acre (600-800/acre) | 95 percent soil loss reduction |
| Wood Cellulose Fiber | Hydromulch at 1-2 tons/acre (hydromulch cost $600-$800/acre) | 0.30/sq. yard for fiber | 95 percent soil loss reduction |
| **Sediment Trapping Methods** | | | |
| Straw Bale Barriers | Spaced at 100' centers on contour of denuded slopes | 6/ft | Between 40 and 60 percent solids trapped |
| Shallow Trenches | Around stockpiled top soil or mounded materials | 5/100 ft | Between 70 and 90 percent solids trapped |
| Sand Bag Check Dams | As check dam, gravel weirs used 4-6' up and down stream | 3/ft/ft height | Between 50 and 60 percent solids trapped |
| Straw Bale Check Dams | As check dam, gravel weirs used 4-6' up and down stream | 2/ft/ft height | Between 40 and 60 percent solids trapped |
| Concrete Check Dam | For permanent installation—with chute spillway ($7/ft$^2$) | 350/cu. yard | Between 70 and 90 percent solids trapped |
| **Sediment Transport Reduction Methods** | | | |
| Sediment Basins | Trap 0.5" to 1" of runoff from tributary area, cleaned when capacity is cut in half | See Table 20 | See Table 20 |
| Filter Screens | Grass filter strips around inlets or between site and stream channel | 0.50/ft$^2$ | Traps sediment after movement |
| Diversion Berms | Forces lateral (cross-slope) direction to water flow (2' x 4') | 2.50/ft length/ft height | Reduces erosion |
| **Channel, Slope, and Bank Protection Measures** | | | |
| Sodded Ditches | For velocities less than 8 feet per second in drainage channels | 1-4/yard$^2$ | Traps sediment, reduces gullying |
| Timber Frame | 2" x 4" frames are constructed on steep slopes and sod is put in frames | 24,000/acre | Prevents gullying |
| Check Dams | Can be used in channels to reduce gully erosion | See Above | Prevents gullying |
| Rip-Rap | Rock facing on stream and channel banks | 0.80-1.50/yd$^2$/inch thickness | Reduces bank erosion |
| Gabions | Rock filled wire mesh on steeper banks or areas where dumping is difficult | 1.20-1.80/yd$^2$/inch thickness | Reduces bank erosion |

*Source: Stanley Consultants.*

Reductions in dustfall and hence dust and dirt accumulations on streets may or may not reduce loadings to area streams from urban runoff. Loadings (lbs pollutant/lbs solids and lbs solids/area) presented in Chapter III were for the soluble materials from dust and dirt collected from streets. Dust and dirt do not have to be carried from the streets to waterways for the soluble fraction to enter these waterways. It is only necessary that the runoff water come in sufficient contact with the dust and dirt so that the pollutants are solubilized. Materials

Table 22

DUST CONTROLS AND REMOVAL EFFICIENCIES

| Construction Controls | Percent Controlled | Road Dust Controls | Percent Controlled |
|---|---|---|---|
| Watering . . . . . . . . . . . . . . . . . . . . . . . . | 40-50 | Paving and right-of-way improvements | 80-85 |
| Chemical Stabilization of Completed Cuts and Fills . . . . . . . . . . . . | 60-80 | Surface treatment with penetration chemicals | 40-50 |
| Treatment of Temporary Access and Haul Road on or Adjacent to Site. . . . . . . | 40-50 | Soil stabilization chemicals worked into the roadbed | 40-50 |
| Minimal Exposure Periods for Active Construction Sites . . . . . . . . . . . . | 40-50 | | |

*Source: U. S. Environmental Protection Agency.*

Table 23

ESTIMATED EMISSION REDUCTION FROM TRAFFIC CONTROLS

| Transportation Control Method | Estimated Emission Reduction[a] (percent) |
|---|---|
| Inspection/Maintenance . . . . . | 4-15 |
| Catalytic Retrofit . . . . . . . . . | 10-60 |
| Gaseous Fuel Systems . . . . . . | 15 |
| Traffic Flow Techniques. . . . . | 20 |
| Bypassing Through Traffic . . . | 5 |
| Improvement in Public Transportation . . . . . . . . . | 5 |
| Motor Vehicle Restraints . . . . | 5-25 |
| Work Schedule Change . . . . . . | 3 |

[a] *These values are general estimates, more accurate assessments for the Region can be made using the procedures given in the U. S. EPA publication, Evaluating Transportation Controls to Reduce Motor Vehicle Emissions in Major Metropolitan Areas. They may overestimate reductions due to more adequate air pollution control devices on 1975 and later model vehicles.*

*Source: U. S. Environmental Protection Agency.*

contributed to loads from streets other than by dust and dirt may still exist (materials may have attached to dust and dirt particles simply because they were there).

Solid Waste Controls

Street litter and its various constituents may significantly add to urban runoff loads. A tremendous variety of materials which defy quantification can be added by litter. Control of litter will improve the aesthetic appearance of the urban area and improve runoff quality. Many materials can be spilled from vehicles, and adequate transport modes to prevent spillage are needed to control this potential source of street litter.

Street Sweeping

Analytical methodologies that use the loadings induced by the soluble fraction of the dust and dirt found in urban streets[21] will conclude that increased frequency and effectiveness of street sweeping will lower urban runoff loads. The effectiveness of brush sweepers in removing particulates from Milwaukee streets was presented in Table 8. Descriptions, removal characteristics, and costs for three types of sweepers are presented in Table 24. All costs have been adjusted to August 1976 values.

Catch Basin Cleaning

Catch basins are relatively effective in removing large particles (greater than 2,000 $\mu$) from street runoff waters. Catch basin liquid and sediment can be equivalent to a highly concentrated wastewater. Samples from Milwaukee[22] had the following characteristics:

| Location | COD | TP | $NO_3$ |
|---|---|---|---|
| Residential Area—Liquid (mg/l) | 8,250 | 1.5 | 9.0 |
| Residential Area—Sediment (mg/g) | 7,750 | 3.0 | 16.0 |
| Industrial Area—Sediment (mg/g) | 11.8 | 0.1 | 0.7 |

[21] *L. A. Roesner et al, "A Model (STORM) for Evaluating Runoff-Quality in Metropolitan Master Planning," ASCE Technical Memorandum No. 23, ASCE, New York, New York, April 1974; Metcalf and Eddy, University of Florida, Water Resources Engineers for the U. S. Environmental Protection Agency, Storm Water Management Model, Volumes I-IV (SWMM), July 1971; G. Amy et al, Water Quality Management Planning for Urban Runoff, EPA 440/9-75-004, December 1974; and J. P. Heany et al, Urban Stormwater Management Modeling and Decision Making, EPA-R2-73-257, May 1973.*

[22] *J. D. Sartor and G. B. Boyd, Water Pollution Aspects of Street Surface Contaminants, EPA-R2-72-081, November 1972.*

Table 24

STREET SWEEPING COST AND EFFECTIVENESS

| Sweeper Type | Removal Mechanism[b] | Operating Speed[c] | Costs[a] | | | Removals[d] (percent) | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | Typical Vehicle | Dollars/Curb Mile | Dollars/Hour | Solids | $BOD_5$ | TKN | TP | Metals | Pesticides |
| Pickup Broom | Gutter broom moves material to main pickup broom which sweeps material to a storage hopper | 4-8 mph | $25,000 | 2-8 | 15-25 | 55 | 43 | 44 | 22 | 50 | 45 |
| Regenerative Air | Air is used to blast material from the streets into a storage hopper | 4-8 mph | $33,000 | 2-14 | 20-30 | 60 | 60 | 50 | 30 | 60 | 50 |
| Vacuum | Suction removes materials from streets. The material is wetted in the sweeper and deposited in a vacuum chamber | 4-8 mph | $38,000 | 3-10 | 20-25 | 70-80[e] | 75 | 60 | 40 | 75 | 60 |

[a] *Black, Crow, and Eidness and Jordan, Jones, and Goulding, Inc., Study and Assessment of the Capabilities and Cost of Technology for Control of Pollutant Discharges from Urban Runoff, for National Commission on Quality Control, February 1976.*

[b] *U. S. Environmental Protection Agency, Proceedings Urban Stormwater Management Seminars, WPD-03-76-04, January 1976.*

[c] *Black, Crow et al, Study and Assessment of the Capabilities and Cost of Technology.*

[d] *Removals are for one pass; the same percentage removal of remaining materials on subsequent passes may be expected. Volume of material picked up ranges from 0.2 to 0.5 cubic yards per curb mile cleaned. Data given in Water Pollution Aspects of Street Surface Contaminants by Sartor and Boyd and Black, Crow, and Eidness and Jordan, Jones, and Goulding, Inc., Study and Assessment of the Capabilities and Cost of Technology for Control of Pollutant Discharges from Urban Runoff.*

[e] *In Chicago studies, APWA, Water Pollution Aspects of Urban Runoff, vacuum sweeping after mechanical sweeping removed 95 percent of dust and dirt.*

*Source: Stanley Consultants.*

The use of catch basins has been questioned in new developments[23] due to the high cost of cleaning and their limited effectiveness in reducing loadings. Inadequate cleaning can lead to odors, mosquito breeding, and reduce the basin efficiency. Cleaning is accomplished by hand, clamshell, vacuum eductor, or vacuum by an attachment to a vacuum sweeper. Average costs (August 1976) per basin cleaned for each method are $19.00, $14.00, $11.00, and $8.00, respectively.[24]

Catch basins may be a logical place to increase storage and provide more pollutant removal in an urban drainage system. The larger the catch basin is, the more it would approach the size of sedimentation basins. The size may be limited by potential interference with other utilities. Use of large catch basins may justify smaller storm sewer sizes downstream of the basin. It may also be possible to revise inlet and outlet structures from such basins by providing screening or bar racks to obtain higher removals than the basin alone can provide.

Catch basins will typically cost from $1.00 to $1.20 per gallon of storage provided.

Sewer Flushing

Sewer flushing has been used in combined sewer areas to clean small diameter pipes. Flush tanks (capital costs of $3,000 with annual Operation and Maintenance (O&M) equal to $80) were investigated to flush sewers periodically and reduce first flush effects from overflow events in Detroit.[25] One tank per 4.5 acres removed 60 percent of the solids accumulation; two tanks per 4.5 acres removed 72 percent of the solids. Flushing of storm sewers during dry-weather events would similarly transmit the load to the stream over a longer time and reduce first flush effects. As previously mentioned, continuous flushing with cooling waters in Dayton, Ohio, seemed to prevent first flush loadings from storm sewers.[26] However, this system appears more applicable to combined sewer areas than to areas served by separate sanitary and storm sewer systems.

[23] *Ibid. and Lager and Smith; Metcalf and Eddy, Urban Storm Water Management and Technology.*

[24] *Sartor and Boyd, Water Pollution Aspects of Street Surface Contaminants, and U. S. Environmental Protection Agency, Proceedings Urban Stormwater Management Seminars.*

[25] *U. S. Environmental Protection Agency, Proceedings Urban Stormwater Management Seminars.*

[26] *Stanley Consultants for the Miami Conservancy District, Nonpoint and Intermittent Point Sources Controls—Application of Structural and Nonstructural Control Techniques, May 1976.*

Table 25

GUIDELINES FOR SNOW REMOVAL CHEMICAL APPLICATION RATES

| Weather Conditions | | | Application Rate (Pounds of Material per Mile of Two-Lane Road or Two-Lanes of Divided) | | | |
|---|---|---|---|---|---|---|
| Temperature | Pavement Conditions | Precipitation | Low- and High-Speed Multilane Divided | Two- and Three-Lane Primary | Two-Lane Secondary | Instructions |
| 30° F and above | Wet | Snow | 300 salt | 300 salt | 300 salt | Wait at least 0.5 hour before plowing |
| | | Sleet or freezing rain | 200 salt | 200 salt | 200 salt | Reapply as necessary |
| 25-30° F | Wet | Snow or sleet | Initial at 400 salt; repeat at 200 salt | Initial at 400 salt; repeat at 200 salt | Initial at 400 salt; repeat at 200 salt | Wait at least 0.5 hour before plowing; repeat |
| | | Freezing rain | Initial at 300 salt; repeat at 200 salt | Initial at 300 salt; repeat at 200 salt | Initial at 300 salt; repeat at 200 salt | Repeat as necessary |
| 20-25° F | Wet | Snow or sleet | Initial at 500 salt; repeat at 250 salt | Initial at 500 salt; repeat at 250 salt | 1,200 of 5:1 sand/salt; repeat same | Wait about 0.75 hour before plowing; repeat |
| | | Freezing rain | Initial at 400 salt; repeat at 300 salt | Initial at 400 salt; repeat at 300 salt | 1,200 of 5:1 sand/salt; repeat | Repeat as necessary |
| 15-20° F | Dry | Dry snow | Plow | Plow | Plow | Treat hazardous areas with 1,200 of 20:1 sand/salt |
| | Wet | Wet snow or sleet | 500 of 3:1 salt/calcium chloride | 500 of 3:1 salt/calcium chloride | 1,200 of 5:1 sand/salt | Wait about one hour before plowing; continue plowing until storm ends; then repeat application |
| Below 15° F | Dry | Dry snow | Plow | Plow | Plow | Treat hazardous area with 1,200 of 20:1 sand/salt |

*Source: U. S. Environmental Protection Agency.*

Sewer flushing proved to be a more cost-effective approach than overflow collection and treatment for combined sewers in the Boston area. The flushing program alone would remove 30 to 50 percent of the annual solids loading from overflow events, whereas flushing in conjunction with overflow storage and chlorination was predicted to provide 85 to 95 percent mass loading reductions. In combined systems, flushing removes the solids to treatment facilities which do not exist as a flush receiver for storm sewer discharges.

Deicing Material Control

When snow and ice removal efficiencies and costs are both considered, the use of salt in highway deicing is far superior to other methods.[27] The most feasible approach to reducing salt loadings is to reduce salt application on roads. Guidelines suggested by the U. S. EPA on salt application are given in Table 25. Prewetting of salt with methyl alcohol or propylene glycol (10-12 gallons at 50 percent per 300 lbs salt) has been used in order to accelerate the action of salt which also reduces total salt requirements.

Proper salt storage reduces localized stockpile runoff and area contamination. Many types of storage ranging from plastic sheet covering (about $5/ton) to various crib or dome structures ($20-$40/ton capacity) are available.

Chloride loads in rivers and wastewaters at Milwaukee during winter months are 40 to 50 percent higher than summer months presumably due to salt washoff from streets. Current practice in the Region has been surveyed by the Commission as part of the 208 program. Available results of this survey are shown in Table 26. There are about 18 snow days per year when salt application is required.[28]

Vegetative Filter Strips

Diverting contaminated water over grass covered areas has proved to be a successful method of sediment control in grassed waterways on agricultural land and in overland flow (land treatment of wastewaters). Establishment of filter strips along the banks of urban streams would remove some portion of the solid material contained in runoff.[29] Additional benefits are potential use as recreation sites, protection from streambank erosion, reduced flood damage, maintenance of natural shorelines, and prevention of direct runoff from impervious areas to urban streams. The concept entails commitments of maintenance dollars and control of flood plain uses.

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[27] *Black, Crow, and Eidness and Jordan, Jones, and Goulding, Inc., Study and Assessment of the Capabilities and Cost of Technology for Control of Pollutant Discharges from Urban Runoff, for National Commission on Water Quality, February 1976.*

[28] *A. D. McElroy et al, Loading Functions for Assessment of Water Pollution from Nonpoint Sources, EPA/2-76-151, May 1976.*

[29] *Black, Crow, and Eidness for the Savannah District, Corps of Engineers, "Nonpoint Pollution Evaluation—Atlanta Urban Area," May 1975.*

Table 26

SALTING/SANDING PRACTICES IN THE REGION

| Agency or Community | Classification of Street or Highway | Total Estimated Number of Lane Miles in Jurisdiction | Reported Rate of Application of Each Chemical or Abrasive: Type of Chemical or Abrasive Used | Reported Rate of Application of Each Chemical or Abrasive: Application Rate Per Lane Mile | Estimated Total Amount Used During the Winter of 1975-1976: Salt (tons) | Estimated Total Amount Used During the Winter of 1975-1976: Sand (tons) | Estimated Total Amount Used During the Winter of 1975-1976: Liquid Calcium (gallons) |
|---|---|---|---|---|---|---|---|
| State of Wisconsin Division of Highways (Kenosha County) | Freeways, Expressways, and other U. S. and State Highways | 364 | Salt<br>Liquid Calcium Chloride | 100-300 pounds<br>1.5 gallons | 4,099 | 0 | 0 |
| State of Wisconsin Division of Highways (Milwaukee County) | Freeways, Expressways, and other U. S. and State Highways | 1,100 | Salt<br>Dry Calcium Chloride | 300 pounds<br>25 pounds (only applied at temperature below 25°F) | 31,822 | 0 | 26,367 |
| State of Wisconsin Division of Highways (Ozaukee County) | Freeways, Expressways, and other U. S. and State Highways | 255 | Salt<br>Dry Calcium Chloride | 300-500 pounds<br>50-70 pounds | 3,505 | 0 | 0 |
| State of Wisconsin Division of Highways (Racine County) | Freeways, Expressways, and other U. S. and State Highways | 425 | Salt | 100-300 pounds | 5,562 | 0 | 0 |
| State of Wisconsin Division of Highways (Walworth County) | Freeways, Expressways, and other U. S. and State Highways | 486 | Salt | 150-300 pounds | 5,010 | 0 | 0 |
| State of Wisconsin Division of Highways (Washington County) | Freeways, Expressways, and other U. S. and State Highways | 430 | Salt<br>Dry Calcium Chloride | 300-500 pounds<br>50-70 pounds | 6,535 | 0 | 0 |
| State of Wisconsin Division of Highways (Waukesha County) | Freeways, Expressways, and other U. S. and State Highways | 692 | Salt<br>Dry Calcium Chloride | 150-300 pounds<br>Variable 5-25 percent of salt | 11,030 | 0 | 2,500 |
| | | | Liquid Calcium Chloride | Approximately 10 gallons per ton of salt | N/A | N/A | N/A |
| Kenosha County Highway Department | County Highways and other U. S. and State Highways | 505 | N/A | N/A | 4,671 | 24 | 0 |
| Milwaukee County Highway Department | U. S., State, and County Highways | 1,200 | Salt<br>Dry Calcium Chloride<br>Liquid Calcium Chloride | 300 pounds<br>Depends on temperature<br>10 gallons per ton of salt | 38,980 | 0 | 15,000 |
| Ozaukee County Highway Department | County Highways | 97 | N/A | N/A | N/A | N/A | N/A |
| Racine County Highway Department | County Highways | 153 | N/A | N/A | 6,970 | 200 | N/A |
| Walworth County Highway Department | County Highways | 500 | N/A | N/A | 9,950 | 0 | 0 |
| Washington County Highway Department | Other U. S., State, and County Highways | 861 | Salt<br>Calcium Chloride | 300 pounds<br>N/A | 14,537 | 0 | 0 |
| Waukesha County Highway and Transportation Commission | Other U. S., State, and County Highways | 471 | Salt or Sand/Salt Mixture | 300± pounds<br>200± pounds | 8,110 | 800 | 0 |
| Cities of: | | | | | | | |
| Brookfield | U. S., State, County, and Local Highways and Streets | 208 | N/A | N/A | 1,600 | 7,873 | 0 |
| Burlington | State, County, and Local Highways and Streets | 34 | N/A | N/A | 475 | N/A | N/A |
| Cedarburg | State, County, and Local Highways and Streets | 28 | Salt | 300 pounds | 434 | 75 | 0 |
| Cudahy | County and Local Highways and Streets | 53 | N/A | N/A | 1,350 | N/A | N/A |
| Delafield | U. S., State, County, and Local Highways and Streets | 41 | N/A | N/A | N/A | N/A | N/A |
| Delavan | State and Local Highways and Streets | 25 | N/A | N/A | 200 | 70 | 0 |
| Elkhorn | State, County, and Local Highways and Streets | 25 | N/A | N/A | N/A | N/A | N/A |
| Franklin | State, County, and Local Highways and Streets | 106 | N/A | N/A | 337 | N/A | N/A |
| Glendale | State, County, and Local Highways and Streets | 58 | N/A | N/A | N/A | N/A | N/A |
| Greenfield | U. S., State, County, and Local Highways and Streets | 109 | N/A | N/A | 1,200 | N/A | N/A |

Table 26 (continued)

| Agency or Community | Classification of Street or Highway | Total Estimated Number of Lane Miles in Jurisdiction | Reported Rate of Application of Each Chemical or Abrasive: Type of Chemical or Abrasive Used | Reported Rate of Application of Each Chemical or Abrasive: Application Rate Per Lane Mile | Estimated Total Amount Used During the Winter of 1975-1976: Salt (tons) | Estimated Total Amount Used During the Winter of 1975-1976: Sand (tons) | Estimated Total Amount Used During the Winter of 1975-1976: Liquid Calcium (gallons) |
|---|---|---|---|---|---|---|---|
| Cities of: | | | | | | | |
| Hartford | State, County, and Local Highways and Streets | 27 | Salt | 400 pounds | 706 | 0 | 0 |
| Kenosha | State, County, and Local Highways and Streets | 226 | Salt<br>Sand/Salt Mixture | 400 pounds<br>600 pounds | 2,571 | 176 | 0 |
| Lake Geneva | State, County, and Local Highways and Streets | 29 | N/A | N/A | 52 | N/A | N/A |
| Mequon | State, County, and Local Highways and Streets | 165 | Salt<br>Sand/Salt Mixture | 500 pounds<br>700 pounds | 1,533 | 50 | 0 |
| Milwaukee | U. S., State, County, and Local Highways and Streets | 1,346 | Salt | 200 pounds | 42,260 | 515 | 2,350 |
| Muskego | State, County, and Local Highways and Streets | 108 | Salt | 400 pounds | 1,362 | 120 | 0 |
| New Berlin | State, County, and Local Highways and Streets | 190 | N/A | N/A | 1,000 | N/A | N/A |
| Oak Creek | U. S., State, County, and Local Highways and Streets | 103 | N/A | N/A | 2,000 | N/A | N/A |
| Oconomowoc | State, County, and Local Highways and Streets | 35 | N/A | N/A | 380 | N/A | N/A |
| Port Washington | State, County, and Local Highways and Streets | 33 | Salt | 400 pounds | 1,186 | 0 | 0 |
| Racine | State, County, and Local Highways and Streets | 238 | Salt<br>Sand/Salt Mixture | 500 pounds<br>800 pounds | 5,509 | N/A | 0 |
| St. Francis | Local Highways and Streets | 26 | N/A | N/A | 500 | N/A | N/A |
| South Milwaukee | Local Highways and Streets | 63 | N/A | N/A | 1,500 | N/A | N/A |
| Waukesha | U. S., State, County, and Local Highways and Streets | 137 | Salt | 400 pounds | 3,102 | N/A | 0 |
| Wauwatosa | U. S., State, and Local Highways and Streets | 167 | Salt | 225 pounds | 5,902 | 0 | 0 |
| West Allis | U. S., State, and Local Highways and Streets | 177 | | | 6,235 | N/A | N/A |
| West Bend | State, County, and Local Highways and Streets | 74 | Salt<br>Sand/Salt Mixture | 650 pounds<br>1,000 pounds | 1,179 | N/A | N/A |
| Whitewater | State, County, and Local Highways and Streets | 33 | N/A | N/A | 110 | N/A | N/A |
| Villages of: | | | | | | | |
| Bayside | State, County, and Local Highways and Streets | 24 | N/A | N/A | 400 | N/A | N/A |
| Brown Deer | State, County, and Local Highways and Streets | 46 | N/A | N/A | 900 | N/A | N/A |
| Butler | County and Local Highways and Streets | 11 | N/A | N/A | 66 | N/A | N/A |
| Eagle | State, County, and Local Highways and Streets | 7 | N/A | N/A | 45 | N/A | N/A |
| Elm Grove | State, County, and Local Highways and Streets | 41 | N/A | N/A | 600 | N/A | N/A |
| Fredonia | State, County, and Local Highways and Streets | 6 | N/A | N/A | 38 | N/A | N/A |
| Genoa City | County and Local Highways and Streets | 7 | N/A | N/A | 66 | N/A | N/A |
| Germantown | State, County, and Local Highways and Streets | 108 | N/A | N/A | 900 | N/A | N/A |
| Grafton | State, County, and Local Highways and Streets | 22 | N/A | N/A | 300 | N/A | N/A |
| Greendale | State, County, and Local Highways and Streets | 54 | N/A | N/A | 970 | N/A | N/A |
| Hales Corners | State, County, and Local Highways and Streets | 38 | N/A | N/A | 500 | N/A | N/A |
| Hartland | State, County, and Local Highways and Streets | 13 | N/A | N/A | 150 | N/A | N/A |

Table 26 (continued)

| Agency or Community | Classification of Street or Highway | Total Estimated Number of Lane Miles in Jurisdiction | Reported Rate of Application of Each Chemical or Abrasive: Type of Chemical or Abrasive Used | Reported Rate of Application of Each Chemical or Abrasive: Application Rate Per Lane Mile | Estimated Total Amount Used During the Winter of 1975-1976: Salt (tons) | Estimated Total Amount Used During the Winter of 1975-1976: Sand (tons) | Estimated Total Amount Used During the Winter of 1975-1976: Liquid Calcium (gallons) |
|---|---|---|---|---|---|---|---|
| Villages of: | | | | | | | |
| Jackson | State and Local Highways and Streets | 5 | N/A | N/A | 20 | N/A | N/A |
| Kewaskum | State, County, and Local Highways and Streets | 10 | N/A | N/A | 20 | N/A | N/A |
| Villages of: | | | | | | | |
| Menomonee Falls | State, County, and Local Highways and Streets | 173 | N/A | N/A | 1,200 | N/A | N/A |
| Oconomowoc | State, County, and Local Highways and Streets | 8 | N/A | N/A | 55 | N/A | N/A |
| Paddock Lake | State, County, and Local Highways and Streets | 16 | N/A | N/A | 104 | N/A | N/A |
| Pewaukee | State, County, and Local | 16 | N/A | N/A | 100 | N/A | N/A |
| River Hills | State and Local Highways and Streets | 22 | N/A | N/A | 400 | N/A | N/A |
| Sharon | County and Local Highways and Streets | 8 | N/A | N/A | 1 | N/A | N/A |
| Shorewood | Local Highways and Streets | 29 | Salt | 800 pounds | 650 | N/A | N/A |
| Sussex | State, County, and Local Highways and Streets | 12 | N/A | N/A | 225 | N/A | N/A |
| Thiensville | Local Highways and Streets | 15 | N/A | N/A | 599 | N/A | N/A |
| Union Grove | State and Local Highways and Streets | 11 | N/A | N/A | 46 | N/A | N/A |
| Waterford | State, County, and Local Highways and Streets | 11 | N/A | N/A | 45 | N/A | N/A |
| West Milwaukee | Local Highways and Streets | 13 | N/A | N/A | 558 | N/A | N/A |
| Whitefish Bay | Local Highways and Streets | 39 | N/A | N/A | 750 | N/A | N/A |
| Williams Bay | State and Local Highways and Streets | 14 | N/A | N/A | 80 | N/A | N/A |
| Towns of: | | | | | | | |
| Addison | State, County, and Local Highways and Streets | 95 | N/A | N/A | 66 | N/A | N/A |
| Bristol | State, County, and Local Highways and Streets | 73 | N/A | N/A | 28 | N/A | N/A |
| Brookfield | U. S., State, County, and Local Highways and Streets | 36 | N/A | N/A | 400 | N/A | N/A |
| Burlington | State, County, and Local Highways and Streets | 85 | N/A | N/A | 500 | N/A | N/A |
| Caledonia | State, County, and Local Highways and Streets | 151 | N/A | N/A | 100 | N/A | N/A |
| Cedarburg | State, County, and Local Highways and Streets | 72 | N/A | N/A | 526 | N/A | N/A |
| Geneva | State, County, and Local Highways and Streets | 97 | N/A | N/A | 136 | N/A | N/A |
| Jackson | State, County, and Local Highways and Streets | 75 | Salt | 300 pounds | 700 | N/A | N/A |
| Kewaskum | State, County, and Local Highways and Streets | 55 | N/A | N/A | 150 | N/A | N/A |
| LaGrange | State, County, and Local Highways and Streets | 78 | N/A | N/A | 64 | N/A | N/A |
| Linn | State, County, and Local Highways and Streets | 73 | N/A | N/A | 300 | N/A | N/A |
| Merton | State, County, and Local Highways and Streets | 78 | N/A | N/A | 132 | N/A | N/A |
| Mt. Pleasant | State, County, and Local Highways and Streets | 118 | Salt | 100 pounds | 523 | N/A | N/A |
| Oconomowoc | State, County, and Local Highways and Streets | 83 | N/A | N/A | 225 | N/A | N/A |
| Pewaukee | U. S., State, County, and Local Highways and Streets | 92 | N/A | N/A | 600 | N/A | N/A |

Table 26 (continued)

| Agency or Community | Classification of Street or Highway | Total Estimated Number of Lane Miles in Jurisdiction | Reported Rate of Application of Each Chemical or Abrasive: Type of Chemical or Abrasive Used | Reported Rate of Application of Each Chemical or Abrasive: Application Rate Per Lane Mile | Estimated Total Amount Used During the Winter of 1975-1976: Salt (tons) | Estimated Total Amount Used During the Winter of 1975-1976: Sand (tons) | Estimated Total Amount Used During the Winter of 1975-1976: Liquid Calcium (gallons) |
|---|---|---|---|---|---|---|---|
| Towns of: | | | | | | | |
| Pleasant Prairie | State, County, and Local Highways and Streets | 118 | N/A | N/A | 300 | N/A | N/A |
| Polk | State, County, and Local Highways and Streets | 91 | N/A | N/A | 380 | N/A | N/A |
| Raymond | State, County, and Local Highways and Streets | 77 | N/A | N/A | 180 | N/A | N/A |
| Richfield | State, County, and Local Highways and Streets | 103 | N/A | N/A | 3,105 | N/A | N/A |
| Waterford | State, County, and Local Highways and Streets | 71 | N/A | N/A | 240 | N/A | N/A |
| Whitewater | State, County, and Local Highways and Streets | 59 | N/A | N/A | 493 | N/A | N/A |

*NOTE: Only approximately 25 percent of the lane miles in the Village of Hartland; 50 percent of the lane miles in the City of Port Washington, the Village of Jackson, and the Town of Mt. Pleasant; and 80 percent of the lane miles in the Village of Elm Grove are reportedly salted or sanded.*

*N/A — Not Available.*

*Source: SEWRPC.*

Swale Storage

Swales are gently sloping drainage channels utilized in residential developments to collect and conduct water away from residences. Swales can pond four to six inches of water from the contributing area for ground percolation or controlled runoff. Swales are grass-covered components of the lawn. They thus serve to control nutrient leaching from lawns as well as controlling runoff. Use of gravel drains at the bottom of swales aids percolation to ground waters.

Dikes

Dikes around storage facilities are a method of controlling random spill events from such facilities. The material is stored until application of corrective chemical agents, spillage removal, or other practices remove the surface water contamination potential of the spills. To avoid groundwater quality problems, the spillage area should be sealed against percolation and infiltration of materials. Dikes will cost from $0.40 to $0.70 per cubic yard of material in place with liners costing $0.20 to $1.00 per square foot of surface depending on materials used (latex, clay, rubber, gunnite, or asphalt). Dikes and diversions, as well as general good housekeeping techniques, can serve to contain materials from material stockpile and transfer areas.

Summary

Materials are added to the urban surface from various sources. Control techniques consist of controlling the application rate of materials, removing the materials by specifically designed cleaning actions, or filtering the materials by directing flow over vegetated areas prior to stream discharge. The degrees of effectiveness of these techniques in reducing the level of specific pollutants are not known at this time, but intuition and logic would indicate a potential for beneficial impacts on water quality of urban streams, lakes, and ponds by adoption of these methods.

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# Chapter V

# STRUCTURAL POLLUTION CONTROL CONCEPTS AND COSTS

## INTRODUCTION

The objective of the various nonstructural control concepts discussed in Chapter IV is to reduce urban runoff contamination potential by reducing flow or potential load to runoff waters. The objective of structural control concepts is to reduce the pollution load by detention and treatment of runoff waters. Many of the nonstructural control techniques involve construction of facilities for small areas. Structural control for purposes of this report is defined as the collection and treatment of runoff waters from relatively large areas (over 50 acres). Collection will generally be by buried or open channel storm sewers. Collection of overland flow prior to discharge into surface waters would require construction of similar devices in areas presently unserved by storm drainage collection systems.

Treatment alternatives can be applied at each discharge point or at a composite of discharge points by additional collection system construction. Treatment methods can consist of all known wastewater treatment unit processes, but the most cost-effective and reliable approach will generally consist of storage of runoff waters followed by gradual discharge or followed by more advanced treatment than storage/sedimentation can provide.

## POLLUTION CONTROL CONCEPTS

Storm sewer discharge quality will vary greatly from runoff event to runoff event and at different times during a single runoff event as discussed in Chapter III. Coupled with this variability is the fact that runoff events "occur without respect for nights, holidays, and weekends, and give little advance warning."[1] Structural control concepts must recognize this inherent variability.

Storm drainage collection systems are designed to transmit the runoff from a certain frequency and duration of rainfall (the rate of snowmelt will usually be less) to protect property from storm water backup, street flooding, and basement flooding. Rainfall exceeding the design event will cause backup and street flooding (although surcharging of manholes and downstream pipes may force a flow 25 to 30 percent greater than the design flow through the system without property damage).

The size of direct treatment of storm drainage outlets is determined by the design peak flow (± the surface allowance) induced by the design rainfall event. The size of storage facilities is determined by the total volume of runoff from a runoff event. The size of treatment facilities following storage facilities is determined by a design emptying or pumpout rate from the storage facility.

Control concepts for storm water treatment cannot assume that water quality criteria will never be violated. Instead, a probabilistic approach must be taken that reduces the frequency of violations to some acceptable level. In addition, attention must be focused on water quality criteria that will apply during a high flow storm water runoff event. Concentration limits that apply at low flow may not be valid at high flow since their basins may be the impact that prolonged exposure to a given concentration would have on aquatic life. The concentration limits may be exceeded only for a relatively short period of time (hours instead of days) during runoff events.

The need for treatment of storm sewer discharges has not been clearly demonstrated. Structural control options may be appropriate in the following situations:

1. When there is a continuous discharge of wastewaters to storm sewers by several point sources and investigations indicate that end-of-pipe treatment would be more cost-effective than treatment at the separate point sources.

2. When sanitary sewers overflow to separate storm sewers during runoff events and investigations indicate that end-of-pipe treatment would be more cost-effective than either infiltration/inflow corrections to the sanitary sewerage system or construction of new overflow storage facilities at the sanitary sewer overflow point. (Recent practice to control excessive infiltration/inflow at wastewater treatment facilities indicates storage and treatment of excess infiltration/inflow may in some cases be more cost-effective than sewer system rehabilitation and inflow removals.)

3. When extensive monitoring and analysis indicate storm sewer discharges represent a significant water quality problem which cannot be corrected by the nonstructural controls itemized in Chapter IV.

[1] *J. A. Lager and W. G. Smith; Metcalf and Eddy, Inc., Urban Storm Water Management and Technology: An Assessment, EPA 670/2-74-040, December 1974.*

Structural control concepts are concepts of last resort in storm water management. This is primarily due to the tremendous capital cost of storage and treatment facilities. The most recent U. S. EPA needs survey estimates a national cost of $235 billion for structural control of storm water runoff, while control of combined sewers was estimated at $26 billion and point source treatment facilities at $89 billion. A national commitment to control storm sewer discharges would be the most massive public works project every undertaken by society (highways constructed to date have cost about $75 billion). [2]

Apportioning of the total cost of $235 billion by population indicates a cost in excess of $2 billion for storm water runoff control in the Southeastern Wisconsin Region. This would be a per capita cost of about $1,156, or about 34 percent of the annual per capita income in the Region (1970 values).[3] Clearly, the socioeconomic impacts of structural control concepts must be weighed against the environmental benefits prior to advocating the adoption of any structural control program.

Any program to control storm water discharges must be undertaken with full realization of the primitive state of knowledge concerning runoff quality, the effectiveness of treatment or control programs, and the impact that the discharges may have on water quality.

## POLLUTION CONTROL METHODS

Past[4] and more recent[5] investigations all indicate that storage of storm waters for subsequent release or further treatment is the most cost-effective structural treatment control option available. Whereas most of the pollution abatement techniques available for point source treatment have been investigated at pilot or full-scale for combined sewer overflows, the literature indicates that none of these processes has been tested in detail for treatment of separated storm water flow except detention storage (primarily used as flood control project with side benefits of pollution abatement through sedimentation).

Due to the lack of documented pilot and full-scale treatment systems for storm water treatment, a series of conceptual schematics has been developed for potential application in the Southeastern Wisconsin Region. These schematics are shown in Figure 2. Cost curves for the unit processes involved in the schematics are presented in Appendix B. Performance and cost of schematics are based on transfer of information from studies that have been completed for pollution abatement from combined sewer overflows.

All of the schematics involve collection systems and storage processes. These are discussed first followed by discussions of the alternatives shown in Figure 2.

### Storm Water Collection

The basic function of a storm drainage collection system is to remove storm rainfall from the land boundaries of a system to a discharge point at a rate sufficient to protect the land internal to the system from flooding damages. SEWRPC Planning Report No. 6, The Public Utilities of Southeastern Wisconsin, indicates that only the older and larger cities of the Region (the Milwaukee area and the Cities of Racine, Kenosha, and Waukesha) have extensive storm sewerage systems, many of which serve as combined sewers. That report goes on to state that "storm water drainage system designs . . . are not subject to the review of any existing state regulatory body. Thus design standards for such facilities vary substantially . . . not only from community to community, but within the community . . . because the designer has wide latitude in making basic assumptions concerning the degree of ultimate land development or the degree of protection required." Most smaller communities tend to use open surface channels except along major streets where subsurface storm drainage channels may be provided as an adjunct to the street construction. Increasing use of street ditches and natural watercourses for urban drainage in new suburban development in the Region has been reported.[6]

Storm water collection systems can consist of storm sewer pipes, storm drainage channels, road ditches, underground tunnels, or natural channels. Subsurface drainage systems in low-lying areas may have storm water pumping stations installed near the discharge point to prevent back-up during high river flows.

Present practice in Wisconsin for storm sewer design is quite varied.[7] The maximum rate of combined sewer

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[2] *U. S. Environmental Protection Agency, Proceedings Urban Stormwater Management Seminars, WPD-03-76-04, January 1976.*

[3] *Population and economic data taken from SEWRPC Technical Reports No. 10 and No. 11.*

[4] *C. W. Mallory, "The Beneficial Use of Stormwater," EPA-R2-73-139, January 1973.*

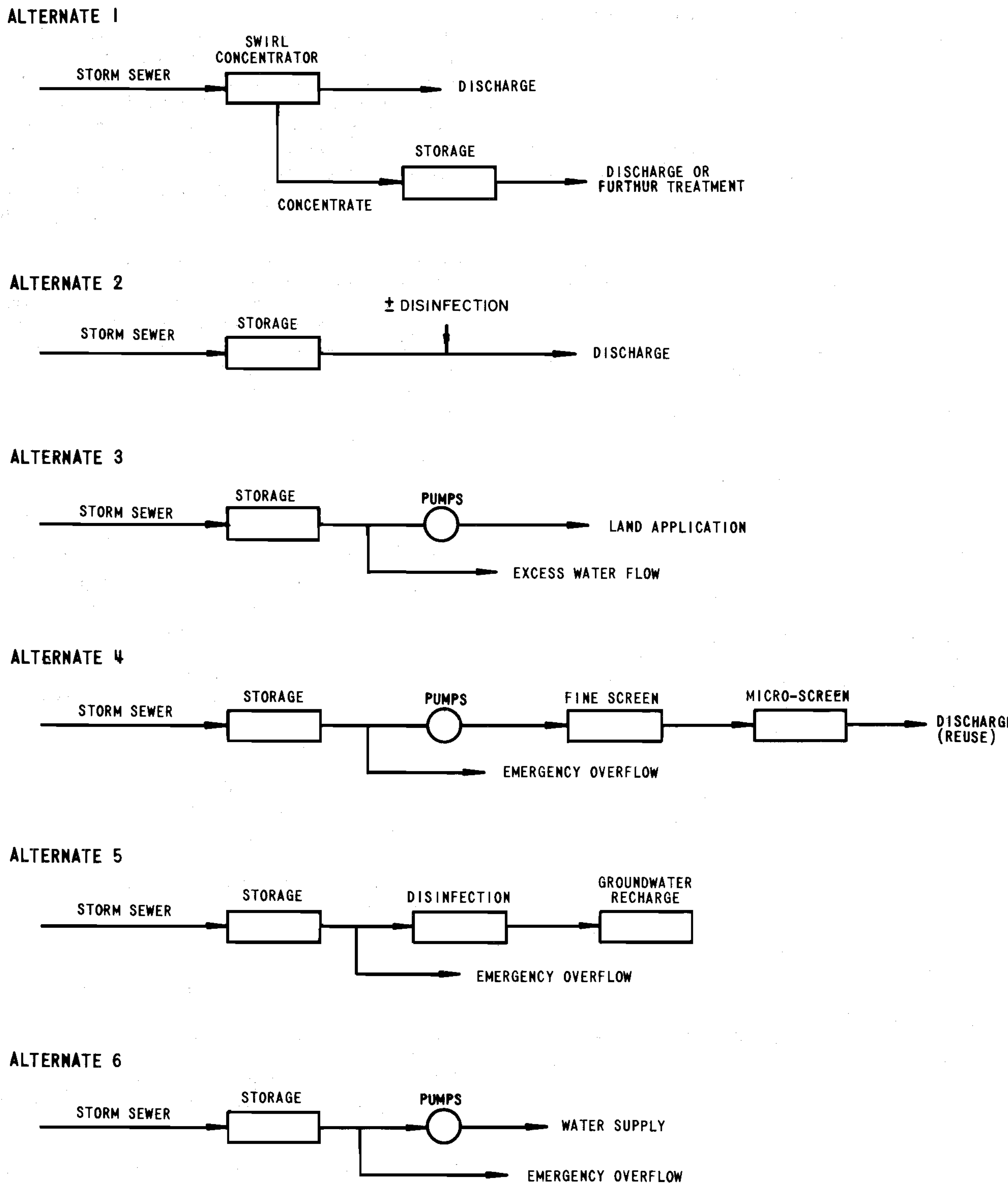
[5] *Stanley Consultants for the Miami Conservancy District, Nonpoint and Intermittent Point Source Controls—Development of Structural Control Techniques and Cost Information, January 1976; Stanley Consultants for the Miami Conservancy District, Nonpoint and Intermittent Point Source Controls—Application of Structural and Nonstructural Control Techniques, May 1976; and U. S. Environmental Protection Agency, Proceedings Urban Stormwater Management Seminars.*

[6] *SEWRPC, A Comprehensive Plan for the Milwaukee River Watershed, Volumes 1 and 2, 1971.*

[7] *C. V. Ardis, K. J. Dueker, and A. G. Lenz, "Storm Drainage Practices of Thirty-Two Cities (Wisconsin," Journal of Hydraulics Division, ASCE, Volume 95, No. HYI, January 1969.*

Figure 2

STRUCTURAL CONTROL SCHEMATICS




NOTE: OPTIONS TO THE ABOVE SCHEMATICS ARE DISCUSSED IN THE ACCOMPANYING TEXT

*Source: Stanley Consultants.*

overflow to be accommodated by conveyance works in the Milwaukee River watershed studies cited above[8] was selected at 0.5 inch/hour of runoff or its equivalent of 0.5 cfs/acre (generally exceeding capacity of existing system) to ensure that flow volume and not rate would be the limiting criteria for alternative plans.

For storm sewers, a review of practices in Wisconsin[9] indicated:

1. Most communities use the "rational" method for storm drainage design, Q (cfs) = C (runoff coefficient) i (inch/hour) A (acres).

2. Most communities do not vary intensity (I) as a function of the time of concentration, but select an intensity for a given time of concentration (5 minutes to 30 minutes).

3. Most communities obtain an intensity using a rainfall intensity-duration-frequency curve developed for that city to obtain an "I" for a duration equal to the assumed time of concentration for a preselected recurrence interval.

4. The recurrence interval ranges from 1-year to 10-year for residential areas. About 50 percent use 10-year; 25 percent use 5-year, and the rest use other values (usually less than 5-year).

5. The runoff coefficient (C) used averaged 0.8 for impervious shopping centers to 0.2 for parks. Values for general residential areas ranged from 0.33 to 0.40 with median values of 0.33 for clay loam soil, 0.35 for silt loam, and 0.40 for sandy soils, although most cities did not consider soil types when determining "C".

6. The peak rate of flow allowed in computing sewer flow time as a component of time of concentration varied from 10 to 20 feet per second. Minimum self-cleaning velocities varied from 2 to 3 feet per second.

7. Storm water inlet structures (most used standard two-foot length) were not designed based on hydraulic needs, but on standard practices of two, three, or four per intersection.

Practices used in the cited reference led to cost ranges from $8,000 to $65,000 (1967 dollar) for a storm drainage system designed to serve a standard 15-acre residential area. This range compares to other literature values[10] where storm water collection systems were reported to cost between $780 and $3,900 per acre (1966 dollars). The average was $2,420 per acre with annual operating costs of $8 to $23 per acre.

The costs for storm water collection systems depend on the system layout. Two cost curves for buried storm water systems and open channel drainage are presented in Appendix B. Data reported by Lawzewski for Milwaukee[11] indicate open channels will cost from $0.04 to $0.20 per lineal foot per cfs capacity. Subsurface conduits, being utilized more and more due to public aversion to altering natural stream channels, would cost twice that amount if designed for the 100-year storm. The cost for other conveyance systems (such as deep tunnels) are site specific and, therefore, difficult to generalize into cost curves. A recent tunnel consisting of a nine-foot-diameter bore finished to a seven-foot to eight-foot-diameter flow section and varying in depth from 40 feet to 430 feet (average depth 100 feet) cost about $1.82 million per mile ($345/ft).[12] The costs of tunnels being used in combined sewer overflow studies in the Region are indicated below.[13] These values are intended to provide "ball-park" estimates of anticipated costs.

| Conveyance System | Description | Approximate Cost[a] |
|---|---|---|
| Lined Shallow Tunnel | 30' to 60' deep crown concrete lined, 6' to 20' inside diameter | $118/ft dia./ ft length |
| Unlined Deep Tunnel | 250' to 400' deep crown grouted as necessary, 8' to 30' diameter | $31/ft dia./ ft length |
| Lined Deep Tunnel | 250' to 400' deep crown, 8' to 28' diameter | $46/ft dia./ ft length |

[a] *As of August 1976, applicable for minimum length of 5,000 ft for each diameter.*

[8] *SEWRPC, A Comprehensive Plan for the Milwaukee River Watershed.*

[9] *Ardis, Dueker, and Lenz, "Storm Drainage Practices of Thirty-Two Cities."*

[10] *Black, Crow, and Eidness for the Savannah District, Corps of Engineers, "Nonpoint Pollution Evaluation—Atlanta Urban Area," May 1975.*

[11] *Proceedings of a Research Conference--Urban Runoff Quantity and Quality, ASCE, 1975, edited by W. Whipple, Jr.*

[12] *A. M. Eldridge, "Austin's 11 Mile Sewer Tunnel Reflects Sound Economic, Environmental Alternatives," Civil Engineering, ASCE, August 1976.*

[13] *Stevens, Thompson & Runyan, Inc., for the Metropolitan Sewerage District of the County of Milwaukee, Combined Sewer Overflow Abatement, various volumes.*

Table 27

ALTERNATIVE STORAGE OPTIONS EVALUATED FOR THE LOWER MILWAUKEE RIVER WATERSHED

| Description | General Performance | Aesthetic Characteristics | Disruptive Effect | Likelihood of Public Acceptance | Estimated Cost[a] (dollars/mg stored) | Volume Stored (mg) |
|---|---|---|---|---|---|---|
| Buried concrete storage tanks in parks | Excellent for small area | Excellent | Low | Excellent | 300,000 | 114 |
| Floating concrete storage tanks in Lake Michigan | Excellent | Poor | High (Conveyance) | Poor | 550,000 | 114 |
| Collapsible rubber storage tanks along the Milwaukee River | Excellent for small areas | Poor | Low | Fair | 150,000 | 114 |
| Buried concrete storage tanks under the Milwaukee River | Excellent | Excellent | High | Excellent | 540,000 | 114 |
| Diked storage lagoon in Lake Michigan | Excellent | Poor | High (Conveyance) | Poor | 42,000 | 114 |
| Buried concrete storage tank in Maitland Field | Excellent | Excellent | High (Conveyance) | Excellent | 330,000 | 315 |
| Deep tunnel conveyance and mined storage beneath the Harbor | Excellent | Excellent | Low | Excellent | 100,000 | 315 |
| Deep tunnel conveyance and diked surface storage reservoirs | -- | -- | -- | -- | 50,000 | 315 |
| Open storage reservoirs along the Milwaukee River banks[b] | Good | Fair | High | Poor | -- | -- |
| Storage under piers and waterfront structures[c] | Poor | Excellent | Moderate | Fair | -- | -- |

[a] *Updated from January 1969 dollars to August 1976 dollars (ENRICCI 2445).*

[b] *The significant reduction of flood carrying capacity of the Milwaukee River channel and extreme disruption of existing urban development were considered as factors serious enough to eliminate full analysis of this method.*

[c] *Subsequent investigations indicated insufficient storage capacity available.*

*Source: SEWRPC.*

Storage Facilities

Temporary storage to reduce overflow volume has been a basic concept adopted in many studies on pollution abatement from combined sewer overflows. Storage in detention facilities serving small areas has been practiced to reduce flooding potentials from urban runoff waters. One case of storage for pollution control from storm water runoff was reported for freeway runoff control.[14] Drainage from about 16 miles of roadway is directed to a 3.0-million-gallon tank (780 feet x 42 feet x 12 feet) via a 102-inch sewer for settling prior to pumping to a lake. Oil skimmers and draglines are included to remove floating and settled material.

Tunnels, silos, mined storage areas, ponds, and storage tanks have been used to store combined sewer overflows. The cost and effectiveness of storage devices have tremendous variability depending on location, type of storage, and items included in reported cost data. A generalized cost curve has been included for aerated and unaerated surface storage in Appendix B. While most storage structures have been built separate and apart from the conveyance system, it is possible to integrate storage and collection by enlarging catch basins in the storm sewer system or by enlarging the conveyance system by installing larger pipes or making bigger tunnels, using the excess capacity of the collection system as storage.

A storage volume equal to two inches of runoff from the contributing area was used as the design basis for combined sewer overflow storage in the Milwaukee River watershed studies.[15] Storage alternatives analyzed in that study and their general characteristics and unit costs are shown in Table 27. An appropriate economy of scale factor may make the unit costs applicable for smaller storage facilities.

[14] *M. Rothstein, "Freeway Storm Runoff Will Be Clarified," Public Works, November 1975.*

[15] *SEWRPC, A Comprehensive Plan for the Milwaukee River Watershed.*

Various storage options are also being investigated in the ongoing combined sewer overflow studies in Milwaukee.[16] Conceptual costs for options evaluated are presented in Table 28.

Investigations of smaller facilities have been made in Milwaukee.[17] Based on a 4-million-gallon underground storage tank, a cost equation for volumes less than 10 million gallons was developed as follows:

$$\text{Tank cost (million dollars)} = 0.175 \text{ volume (MG)} \frac{\text{ENRCCI}}{2{,}075}$$

$$\text{Control building and appurtenances} = \$1{,}200{,}000 \frac{\text{ENRCCI}}{2{,}075}$$

Engineering and contingencies = 30 percent of total of above.

[16] *Stevens, Thompson & Runyan, Inc., Combined Sewer Overflow Abatement.*

[17] *Consoer, Townsend, and Associates for the City of Milwaukee, Wisconsin, and U. S. EPA, "Humboldt Avenue Pollution Abatement Demonstration Project," September 1974.*

Table 28

**STORAGE COSTS USED IN PRELIMINARY ANALYSIS OF ALTERNATIVE PLANS TO CONTROL COMBINED SEWER OVERFLOWS IN MILWAUKEE**

| Option | Storage Volume (mg) | Cost[a] (dollars/mg stored) |
|---|---|---|
| Shallow Pit Storage | | |
| 50' deep pit. . . . . . . . . . . . | 9-26 | 442,000 |
| 100' deep pit . . . . . . . . . . . | 34-98 | 237,000 |
| Deep Shaft Storage | | |
| Up to 250' diameter vertical . . | 35 | 185,000 |
| Shaft started 50' to 100' . . . . | 60 | 138,000 |
| Below ground. . . . . . . . . . . | 130 | 107,000 |
| Deep Cavern Storage | | |
| Under land . . . . . . . . . . . . | 85 | 159,000 |
| Under Lake Michigan . . . . . . | 85 | 164,000 |
| Artificial Island | | |
| Concrete boxes under island surface . . . . . . . . . . | 782 | 338,000 |

[a] *In alternatives evaluated in Combined Sewer Overflow Abatement by Stevens, Thompson & Runyan, Inc., an additional storage cost of about 18 percent for aeration of deep shafts and about 5 percent for aeration of caverns was used. In addition, facilities for pumping from storage, solids collection and pumping, and miscellaneous equipment averaged about $50,000 per mg stored.*

*Source: Stevens, Thompson & Runyan.*

Annual operating cost (1972 dollars):

| | |
|---|---|
| Power | $12,000 |
| Labor | $12,000 |
| Miscellaneous | $ 6,000 |

Overall removals of the storage facilities were estimated using the following equations:

$$\text{Percent } BOD_5 \text{ removal} = 25\ (1 - e^{-0.20t}) \text{ (lbs/hour)}$$

$$\text{Percent TSS removal} = 40\ (1 - e^{-0.20t}) \text{ (lbs/hour)}$$

Where t = detention period in tank (hours)

The SWMM model[18] uses a slightly different equation to predict solids removal as follows:

$$\text{Percent TSS removal} = 0.82\ e^{-SOR/2{,}780}$$

Where SOR = surface overflow rate ($gpd/ft^2$)

A minimum removal of 30 percent of the solids has been used in SWMM.[19]

Removals of other constituents by sedimentation/storage as reported in one storm water quality study,[20] are indicated by the data in Table 29.

Sizing of storage facilities is dependent on the selection of a design runoff volume from the contributing area. A design emptying rate of five to seven days after a rainfall event has been used in storm water retention facilities. Table 30 gives amounts of precipitation that may be expected for different return periods in the Region. An example will serve to point out the effectiveness of storage in reducing flow.

Consider a typical urban drainage basin having a drainage area of 200 acres. A typical time of concentration range at the outlet point from the area may be 30 to 60 minutes. Using the "rational" method, with C = 0.6 and 1 = 2.5-3.0 inches/hour, the peak flow from the drainage basin may range from 300 to 360 cubic feet per second (195-233 mgd). Conveyance systems would be designed for this flow using procedures common in the Region. An end-of-pipe treatment facility would also need to be designed for this flow. The total volume of runoff water

[18] *J. P. Heany et al, Urban Stormwater Management Modeling and Decision Making, EPA-R2-73-257, May 1973.*

[19] *Metcalf and Eddy, University of Florida, Water Resources Engineers for the U. S. Environmental Protection Agency, Storm Water Management Model, Volumes I-IV (SWMM) July 1971.*

[20] *Turner, Coolie, and Braden for New Castle County 208 Areawide Waste Treatment Management Program, "Storm Water Quality Summary," November 1975.*

Table 29

REMOVALS OBTAINED BY SEDIMENTATION/STORAGE OF STORM WATER

| Settlement Time | Concentration Remaining in Supernatant (mg/l) | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | TSS | VSS | $BOD_5$ | COD | TP | OP | TKN | $NH_4$ | $NO_3$ |
| 0 minutes | 231 | 38 | 25 | 62 | 0.38 | 0.15 | 1.95 | 0.2 | 0.5 |
| 10 minutes | 142 | 25 | 15 | 54 | 0.37 | 0.00 | 1.20 | 0.0 | 0.0 |
| 20 minutes | 125 | 21 | 14 | 54 | 0.33 | 0.00 | 1.10 | 0.0 | 0.0 |
| 60 minutes | 100 | 19 | 20 | 51 | 0.33 | 0.00 | 0.80 | 0.0 | 0.0 |
| 4 hours | 67 | 15 | 20 | 41 | 0.25 | 0.00 | 0.20 | 0.0 | 0.0 |
| 24 hours | 30 | 6 | 13 | 33 | 0.15 | 0.00 | 0.20 | 0.0 | 0.0 |

*Source: Turner, Coolie, and Braden.*

Table 30

AMOUNT OF PRECIPITATION OF STATED DURATION TO BE EXPECTED ONCE IN THE SPECIFIED NUMBER OF YEARS

| Duration[a] | Return Period of | | | | | |
|---|---|---|---|---|---|---|
| | 2 Years (inches) | 5 Years (inches) | 10 Years (inches) | 25 Years (inches) | 50 Years (inches) | 100 Years (inches) |
| 30 minutes | 0.97 | 1.29 | 1.50 | 1.77 | 1.97 | 2.17 |
| 1 hour | 1.16 | 1.57 | 1.84 | 2.19 | 2.44 | 2.70 |
| 2 hours | 1.40 | 1.30 | 2.24 | 2.66 | 2.96 | 3.28 |
| 3 hours | 1.50 | 2.04 | 2.41 | 2.86 | 3.19 | 3.53 |
| 6 hours | 1.75 | 2.38 | 2.82 | 3.35 | 3.74 | 4.15 |
| 12 hours | 2.04 | 2.78 | 3.30 | 3.94 | 4.39 | 4.37 |
| 24 hours | 2.35 | 3.24 | 3.84 | 4.58 | 5.16 | 5.71 |
| 2 days | 3.2 | 4.1 | 4.7 | 5.4 | 6.1 | 6.8 |
| 4 days | 3.7 | 4.9 | 5.4 | 6.6 | 7.1 | 8.0 |
| 7 days | 4.2 | 5.4 | 6.2 | 7.5 | 8.2 | 9.1 |
| 10 days | 4.6 | 6.0 | 7.0 | 8.4 | 9.5 | 10.3 |

*[a] Durations from 30 minutes to 24 hours based on "Development of Equations for Rainfall Intensity-Duration-Frequency Relationships," by S. G. Walesh in SEWRPC Technical Record, Volume 3, No. 5, March 1973; other values based on U. S. Department of Agriculture, Soil Survey of Milwaukee and Waukesha Counties, Wisconsin, July 1971. All values are for Milwaukee, but are applicable, within an accuracy of ± 10 percent, to the entire Southeastern Wisconsin Region.*

*Source: U. S. Department of Agriculture and SEWRPC.*

from the storms that may induce that rate of runoff may range from 7 to 11 million gallons. A storage basin for this area would probably be sized for a larger storm volume. Selection of the five-year-24-hour rainfall volume with the assumption of 80 percent total runoff would result in a volume of 14.1 million gallons. A basin of this size would totally contain the runoff from the design storm. Assuming a pumpout rate of five days, the outflow from the basin would be about 2.8 mgd (with this pumpout rate, a degree of protection is provided for total volume that may fall in two, four, seven, or 10 days with a five-year recurrence interval). Salient points from this example are:

1. A peak flow of 195 to 233 mgd is reduced to about 2.8 mgd by storage.

2. At a typical storage basin depth of 15 feet, storage would require an area of 3.2 acres (1.6 percent of the watershed area).

3. Because of the tremendous peak flow reduction of storage, direct end-of-pipe treatment for storm water flow will probably seldom be cost-effective when compared to the same type of treatment after storage.

4. Detention facilities upstream in the watershed may provide equivalent peak flow reduction and pollutant removal capabilities as storage at the discharge point of a watershed.

Alternative Overflow

A recent investigation[21] presented a cost and performance data summary for treatment options available for combined sewer overflow abatement. This summary table is presented in Table 31 for possible use in the continuing 208 water quality management planning efforts in the SEWRPC Region. Subsequent investigations[22] indicate that the high removal shown for microscreens may not occur in actual conditions on direct end-of-pipe treatment.

Conceptual alternatives for storm water treatment are discussed below. More detailed investigations of study area problems may readily eliminate some of the alternatives as being impracticable. The state of the art of storm water treatment makes it difficult to predict removals without pilot plant studies. Most removals given in Table 31 were taken from such studies and applied to the influent quality and alternatives evaluated therein. Few comparable pilot plant investigations have been made for storm water treatment alone. Until such studies are undertaken, the removals given in Table 31 can be considered to represent potential performance of the unit processes when applied to storm water.

Alternative 1

This concept utilizes the swirl concentrator as the least expensive direct treatment option to remove some

[21] *Stanley Consultants for the Miami Conservancy District, Nonpoint and Intermittent Point Source Controls—Application of Structural and Nonstructural Control Techniques, May 1976.*

[22] *Proceedings of a Research Conference—Urban Runoff Quantity and Quality, ASCE, 1975, edited by W. Whipple, Jr.*

Table 31

SUMMARY OF COMBINED SEWER OVERFLOW STRUCTURAL TREATMENT OPTIONS

| Unit Process[a] | Construction Cost[b] (dollar/mgd) | | | Operation Cost[b] (dollar/year) | | | Approximate Average Removal[c] | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | 5 mgd | 50 mgd | 500 mgd | 5 mgd | 50 mgd | 500 mgd | $BOD_5$ (percent) | TSS (percent) | P (percent) | TN (percent) | Fecal Coliform |
| Pretreatment | 37,000 | 27,000 | 25,000 | 4,000 | 25,000 | 140,000 | 15 | 15 | 0 | 0 | Low |
| Storage (cost per mg) | 24,000 | 20,000 | 17,600 | 3,900 | 10,000 | 39,000 | Depends on discharge point[d] | | | | Moderate |
| Aerated Storage (cost per mg) | 26,400 | 22,000 | 19,300 | 8,900 | 38,000 | 285,000 | Depends on discharge point[d] | | | | Moderate |
| Microstrainer | 22,000 | 16,400 | 16,400 | 3,800 | 19,000 | 72,000 | 50 | 70 | 15 | 10 | High |
| Dissolved Air Flotation | 52,000 | 50,000 | 50,000 | 5,000 | 50,000 | 500,000 | 40 | 60 | 15 | 10 | High |
| Dissolved Air Flotation with Chemicals | 52,000 | 50,000 | 50,000 | 8,300 | 82,500 | 825,000 | 60 | 80 | 70 | 20 | Moderate |
| Sedimentation Tanks | 100,000 | 90,000 | 84,000 | 3,000 | 25,000 | 220,000 | 30 | 50 | 10 | 2 | High |
| Disinfection | 68,000 | 56,000 | -- | 500 | 4,000 | -- | 0 | 0 | 0 | 5 | Low |
| High-Rate Disinfection | 3,500 | 3,300 | -- | 800 | 6,000 | -- | 0 | 0 | 0 | 5 | Low |
| Fine Screens | 20,000 | 20,000 | 20,000 | 4,000 | 25,000 | 140,000 | 15 | 15 | 0 | 0 | High |
| Swirl Concentrator | 10,000 | 2,000 | 500 | 1,600 | 5,000 | 30,000 | 5 | 20 | 0 | 0 | Low |
| High-Rate Filtration | 94,000 | 38,000 | 30,000 | 25,000 | 68,000 | 290,000 | 55 | 75 | 30 | 2 | Moderate |
| Pumping | 48,000 | 17,600 | 14,400 | 600 | 2,500 | 21,000 | -- | -- | -- | -- | -- |

[a] *Details can be found in Stanley Consultants, Nonpoint and Intermittent Point Source Controls—Development of Structural Control Techniques and Cost Information.*

[b] *Capital and operating and maintenance cost curves from Stanley Consultants, Nonpoint and Intermittent Point Source Controls—Application of Structural and Nonstructural Control Techniques, ENRCCI = 2,270.*

[c] *Effluent values will typically be higher during the first period of overflow and decrease as overflow continues.*

[d] *Storage alone estimated to remove 30 percent $BOD_5$, 60 percent TSS, 5 percent P, and 5 percent TN.*

*Source: Stanley Consultants.*

pollutants. The unit is being tested on combined sewer overflows in Syracuse, New York. The device has no moving parts but uses spiral flow of water to concentrate pollutants (centrifugal effect) into a small waste stream (30 to 1 concentrate) in a short detention time (10 seconds), but does induce high head loss (5 to 10 feet). Results under optimum conditions indicated a mass removal of 33 to 82 percent for suspended solids (TSS) and 30 to 80 percent for $BOD_5$[23] (effluent values about 100 mg/l TSS and 70 mg/l $BOD_5$). Under more typical conditions, dissolved organic and coliform removals are expected to be small (results indicate less than 5 percent). Overall pollutant removal is expected to be poor in storm water applications, but may be all that can be obtained in areas which preclude large storage facilities. High-rate disinfection in conjunction with (or separate from) the alternative would enhance coliform removal. In combined sewage overflow applications, the concentrate stream is directed to the treatment facility, which may not be practical in storm sewer discharges. Therefore, the concentrate stream in this alternative is directed to a storage/sedimentation facility.

Alternative 2

This alternative will produce a higher quality of effluent than Alternative 1. A storage basin to collect runoff from a drainage area is provided. Aeration of the basin would provide additional removals and prevent occurrence of odors. Disinfection by chlorination or other means would effectively reduce coliform bacteria in the discharge (although the use of chlorine may be limited due to its potential adverse affect on water quality). Processes basically using storage have been applied to combined sewer overflow discharges at the Cottage Farms Stormwater Treatment Plant, Boston, Massachusetts, and at Mt. Clemens, Michigan.[24] With an influent quality of 0-30 mg/l $BOD_5$ and 124-375 mg/l TSS, removals of 30 to 60 percent for TSS and 0 to 20 percent for $BOD_5$ were obtained at Cottage Farms. At Mt. Clemens, Michigan, a series of lagoons is used. The first lagoon is aerated; discharge is screened, and two additional lagoons serve as recreational ponds in a park. Overall reduction comparable to lagoon treatment of domestic wastewater was obtained. The final discharge was filtered to remove algae. Use of the storage basin concept in Milwaukee was summarized in Chapter II.

One of the major concerns in utilizing storage facilities has been the solids buildup in the sedimentation basins. In Springfield, Illinois, 21 percent of a 22 million gallon storage lagoon serving 2,210 acres was filled by sediment in two and one-half years.[25] Methods used in solids handling in combined sewer overflow storage reservoirs have ranged from resuspension for pumping to the dry-weather flow treatment facility as used at Humboldt Avenue in Milwaukee to hosing, dragline, endloaders, and similar methods. Most detention systems transport the solids to the wastewater treatment facility, but this practice has been questioned[26] due to the tremendous volume of solids and possible overload of solids handling equipment at those facilities (increased grit removal facilities may be required).

Volumes of sediment in storage basins would be directly related to the mass removal efficiency of the basin on the sediment load (3 to 30 tons/acre in urban areas) from the drainage area. Current practice includes the installation of a forebay (grit chamber structure) prior to the main storage facility to capture heavy solids. Draglines are used on small reservoirs (less than one acre) and hydraulic dredges and scoops on larger areas (can direct solids to forebay for removal).[27] From 260 to 1,000 cubic feet of wet sludge per million gallons (dry solids 10 to 20 cubic feet) can be expected.[28] In open grass basins, reestablishment of grass cover on deposited sediment appears to occur with no maintenance, but the potential of pollutants removed in the sediment leaching to groundwater exists without proper sediment and solids removal practices.

The number and location of storage reservoirs needed for an urban area will be a function of the area and available storage. The optimum system will usually lie somewhere between separate basins for each storm sewer discharge and a single basin for the entire area fed by a massive collection system. Priorities for installing basins will depend on the degree of pollutant loading contributed (by runoff, point sources, sanitary sewer overflows) by the storm sewer.

Flow through sedimentation basins with a permanent pool can be used to provide recreation areas.

Disinfection of the effluent can be practiced to enhance bacterial die-off that will naturally occur in the basin. A cost curve for this option is included in Appendix B.

Alternative 3

This alternative directs the discharge away from surface waters to land application. The system may have application for rainfall runoff for certain storm events. Excellent removal of pollutants can be expected. The application of storm water or snowmelt would be limited by frozen ground, wet ground, and the need for a large land area to

[23] *R. I. Field, "Give Stormwater Pollutants the Spin," The American City and County, April 1976.*

[24] *J. A. Lager and W. G. Smith; Metcalf and Eddy, Urban Storm Water Management and Technology: An Assessment, EPA 670/2-74-040, December 1974.*

[25] *Ibid.*

[26] *Ibid.*

[27] *H. G. Poertner, Practices in Detention of Urban Stormwater Runoff, APWA Special Report 43, June 1974.*

[28] *Lager and Smith, Urban Storm Water Management and Technology.*

dispense the runoff. The large cost in transmitting the water to an acceptable site is also a negative aspect. An application rate of less than 1.0 inches/hour for three hours in a day may be acceptable[29] on a soil initially at field capacity.

Alternative 4
This alternative adds fine screens (297 micron) and microscreens (35 micron) following storage to provide a higher degree of treatment (more solids and non-soluble organic removal) than storage alone can provide. The use of high-rate filtration (pilot plant studies completed on combined sewer overflow in Cleveland, Ohio, and in Rochester and New York City, New York) in lieu of microstrainers is a possible subalternative. Cost curves for fine screens, microstrainers, and high-rate filters are provided in Appendix B. Removals can be indicated by values in Table 29, but more extensive data is required to predict removals with any accuracy.[30] Consideration must be given to the handling and disposal of the screenings and the concentrate side stream from the microstrainer.

Alternative 5
This alternative directs the effluent from a clarified and disinfected runoff event to groundwater recharge basins. The concept is practiced in Dayton, Ohio, where high river water flow and some storm sewer discharges are directed to recharge basins after preliminary sedimentation (chlorination is not practiced).[31] The concept of groundwater recharge by trapping storm water has, of course, been practiced in many water short areas throughout the world.

Alternative 6
This alternative uses the water collected in storm water runoff events as a water supply. Water stored may be of high enough quality to be used for community purposes following adequate water treatment. A major use could be once-through cooling or a recirculated cooling pond for industrial cooling with the intermittent flushing serving as partial blowdown for control of total solids.

Alternatives Not Considered
Certain processes are not appropriate for storm water. Biological processes that have proved to be effective for combined sewer overflow are in this category. The relatively low organic strength and the difficulty of maintaining loadings between events preclude necessity for or practicality of this option.

Other solids removal steps (clarification by clarifiers or dissolved air flotation) may be appropriate to certain space-limited situations as the only option available. Design for peak flows will usually make units massive. A potential use is controlled chemical clarification process following storage where the flow equalization capabilities of the storage basins would make this practical. Cost curves for both unit processes are provided in Appendix B. Either could serve as replacement for the fine screen-microstrainer treatment provided in Alternative 4.

Instream treatment by disinfection for fecal coliform control can be considered, but the organic load from runoff water will probably not necessitate instream aeration. Dredging can remove accumulated solids.

## SUMMARY

Structural control options for storm water runoff have limited applicability due to their high cost and limited pollutant removal capabilities (solids and materials adsorbed on solids are basic components that can be removed effectively). Generally storage is the most cost-effective control option available. Type and level of treatment, if any, after storage depends on the desired water quality of the storm water discharged. A degree of water reuse can be provided by recharge (in basins or in land application) or by using the water as a supplement to other water supply sources. Various treatment schematics and cost curves for unit processes involved in the schematics are provided. The degree of pollutant control is indicated by removals that have been obtained by testing of combined sewer overflows. The state of the art of predicting removals from structural treatment options is equal to that of predicting loads to the process. Neither can be assessed with any degree of accuracy.

The lack of well defined storm drainage systems, in all but the major communities of the Region, precludes widespread use of structural treatment options without extensive additions to storm water collection systems.

A final concept that should be considered is the relative magnitude of loads due to urban runoff when compared to continuous discharges and runoff loads from nonurban areas. In most areas of the Region, nonurban land uses predominate. The solids loading from nonurban uses will probably exceed urban solids loading (although the total mass contribution per acre will probably be less). Control of solids from urban areas deserves consideration due to the many pollutants (metals, phosphates, organics) that can be transferred from urban areas to surface waters by attachment to solids.

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[29] *J. A. De Flippi and C. S. Shik, "Characteristics of Separated Storm and Combined Sewer Flows," JWPCF, Volume 43, No. 10, October 1971.*

[30] *Lager and Smith, Urban Storm Water Management and Technology.*

[31] *Black, Crow, and Eidness for the Savannah District, Corps of Engineers, "Nonpoint Pollution Evaluation—Atlanta Urban Area," May 1975.*

# APPENDICES

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Appendix A

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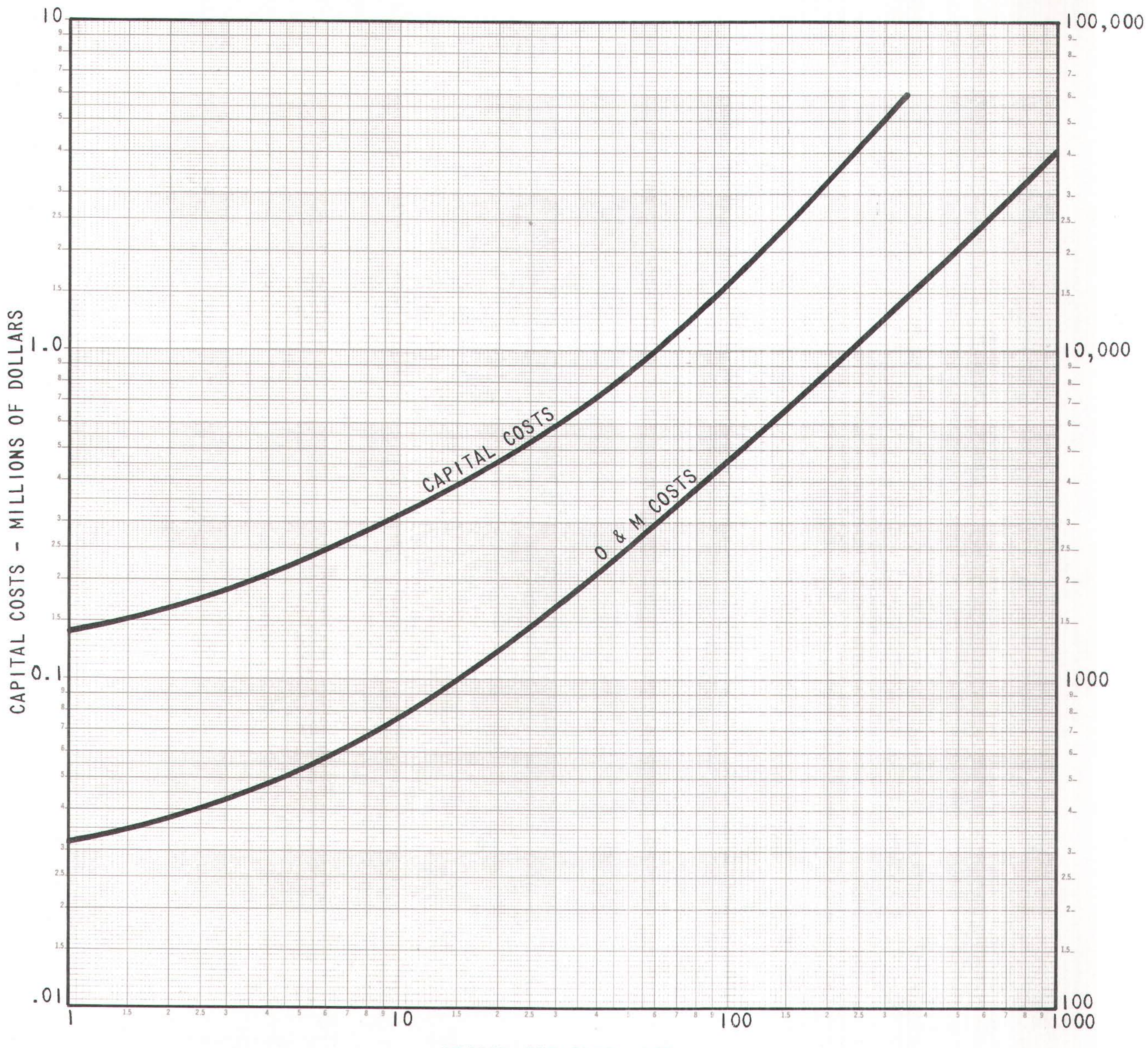
## Appendix B

## COST CURVES

Figure B-1

PUMPING STATIONS

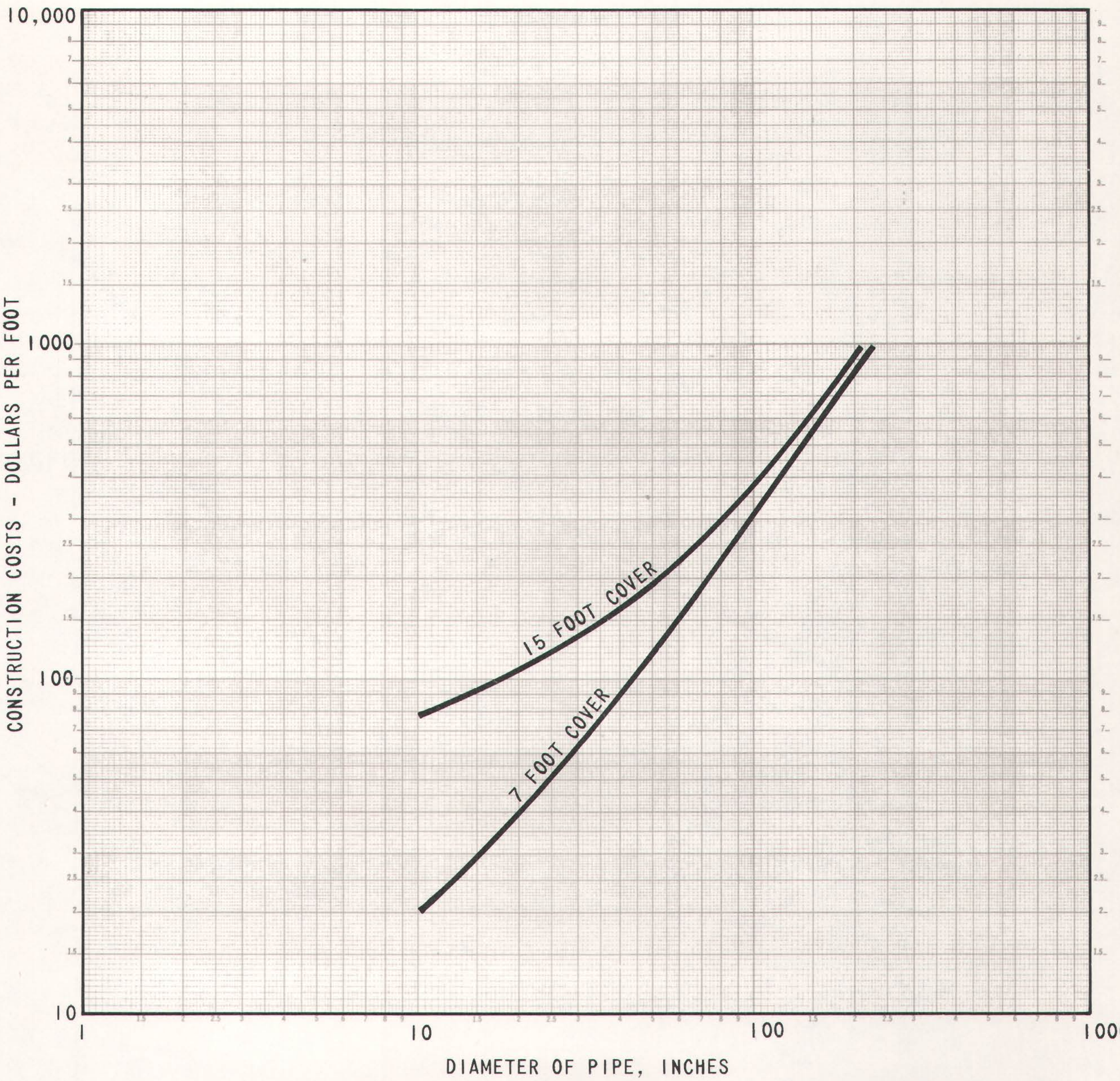



NOTE: ENRCCI = 2445 (AUGUST 1976)

*Source: Stanley Consultants.*

Figure B-2

GRAVITY STORM SEWERS




COSTS BASED ON: COVER OVER TOP AS SHOWN. UPDATES OF COSTS PROVIDED IN STEVENS, THOMPSON, AND RUNYAN, COMBINED SEWER OVERFLOW ABATEMENT

COSTS INCLUDE: CONCRETE SEWER PIPE INSTALLED IN TRENCH REQUIRING BRACING ONLY. RESTORATION OF EARTHEN SURFACE.

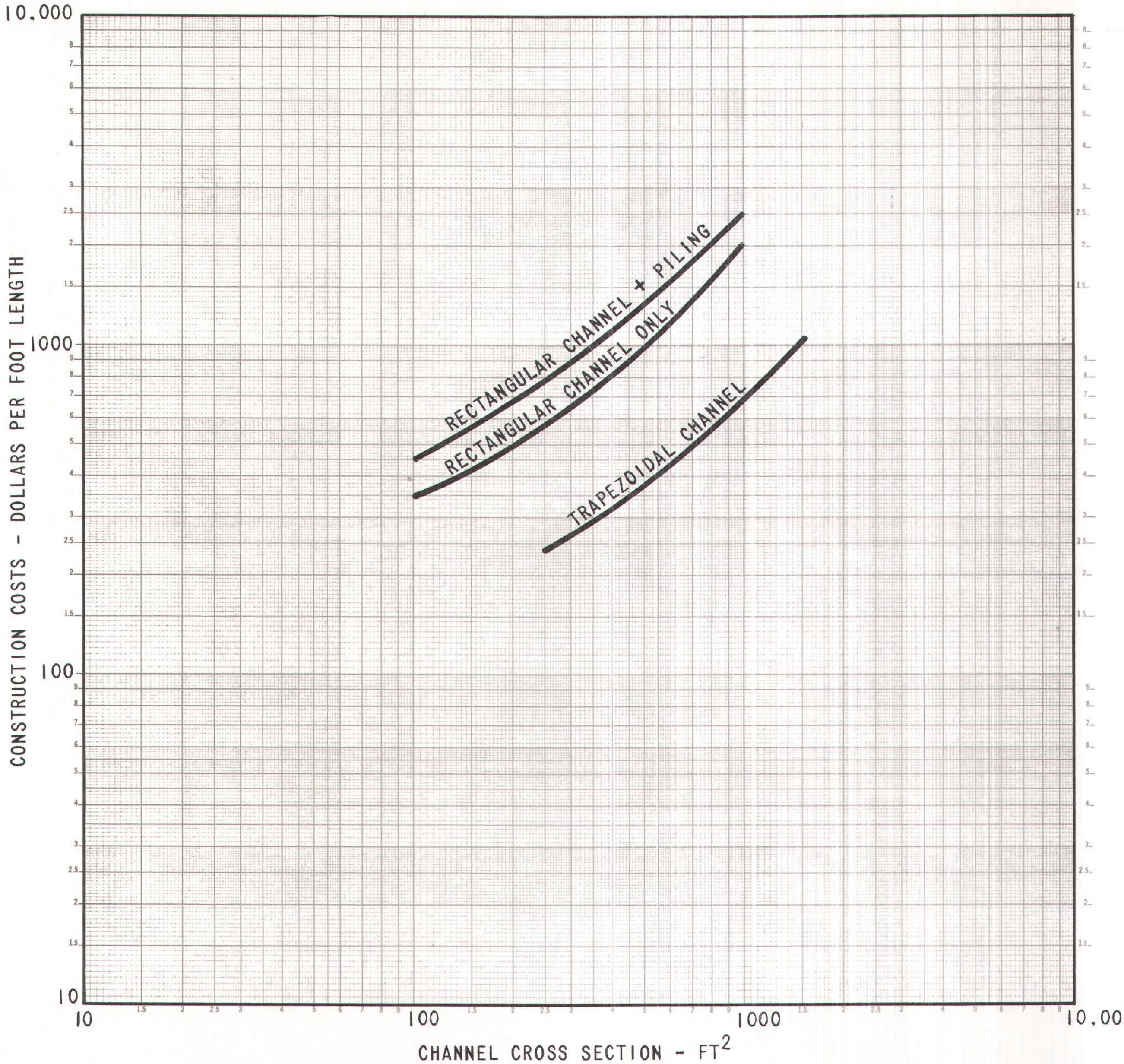
NOTE: SEWER CONSTRUCTION COSTS DEPENDENT ON LOCAL CONDITIONS. ADJUSTMENTS TO CURVE VALUES INCLUDE:

| | |
|---|---|
| SHEETING OF FULL TRENCH DEPTH | 60-65 PERCENT INCREASE |
| RESTORATION OF PAVEMENT SURFACE | 10-12 PERCENT INCREASE |

*Source: Stanley Consultants.*

### Figure B-3

### OPEN CHANNEL STORM SEWERS




NOTE:

COSTS BASED ON: RECTANGULAR CHANNELS: 10-20' DEPTH, VERTICAL CONCRETE WALLS, CONCRETE BOTTOM

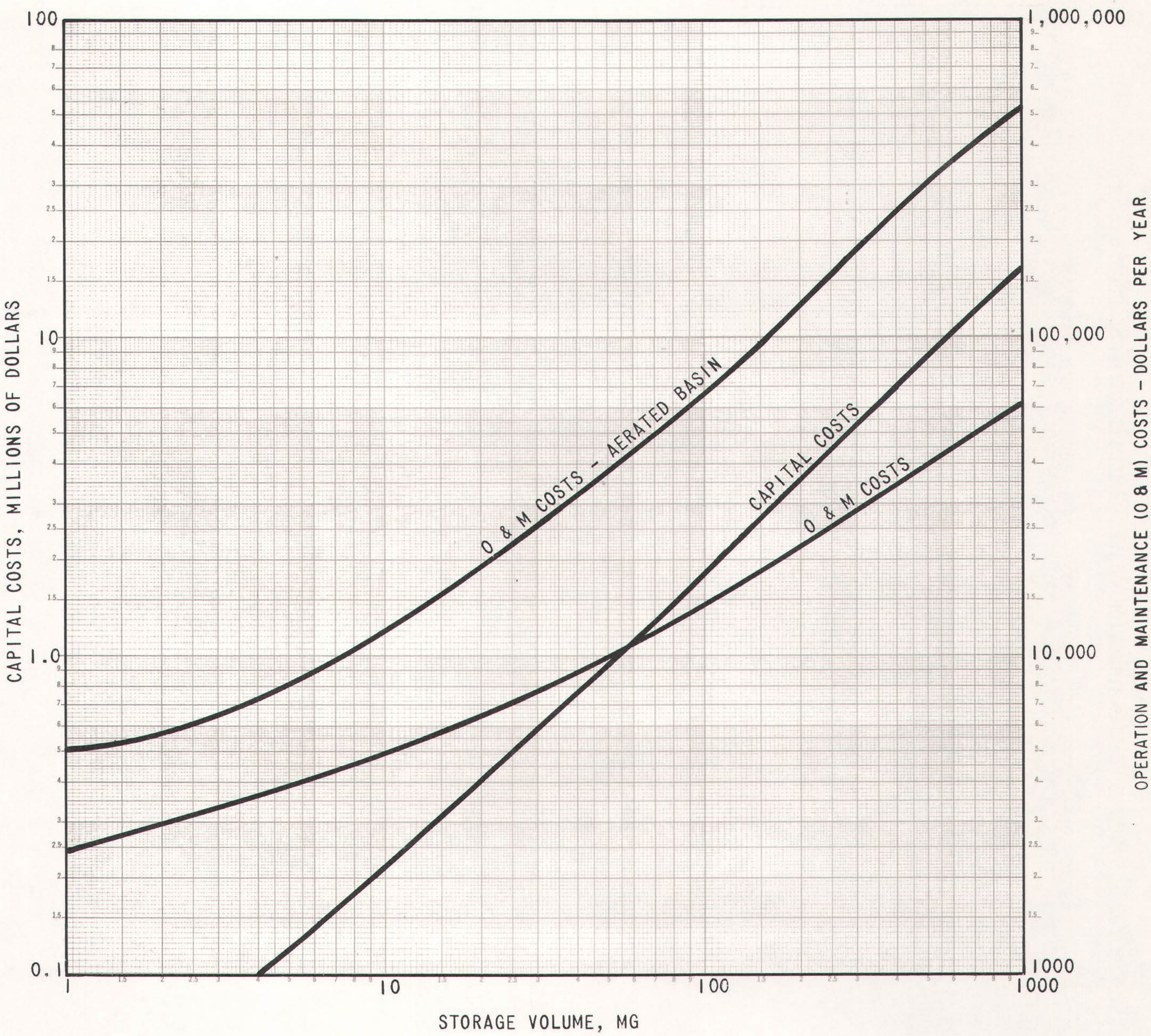
TRAPEZOIDAL CHANNELS: 10-20' DEPTH, 3:1 SIDESLOPES, GRASS LINED (CONCRETE LINING WILL ABOUT DOUBLE COST SHOWN)

ENRCCI = 2445 (AUGUST 1976)

*Source: Stanley Consultants.*

Figure B-4

SURFACE STORAGE BASINS




NOTE:

CAPITAL COSTS BASED ON AN EQUATION FROM THE STORM WATER MANAGEMENT MODEL. REFERENCE: METCALF AND EDDY, STORM WATER MANAGEMENT MODEL, JULY 1971

AERATED BASIN CONSTRUCTION COST = 1.15 - 1.20 TIMES UNAERATED BASIN COST.

COSTS DO NOT INCLUDE PROVISIONS FOR HAULING AND DISPOSAL OF REMOVED SOLIDS

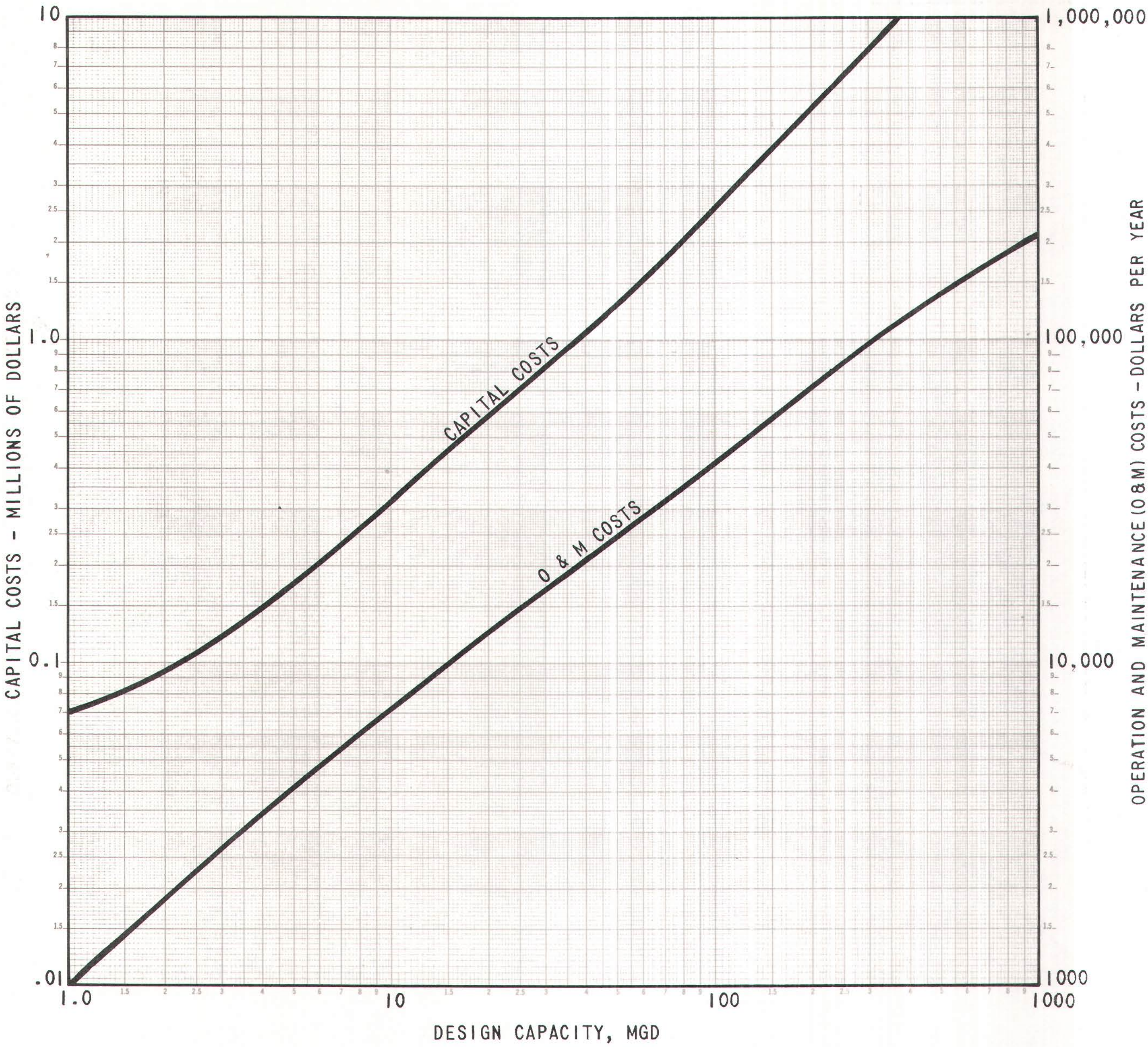
ENRCCI = 2445 (AUGUST 1976)

OTHER STORAGE COSTS HIGHLY VARIABLE

*Source: Stanley Consultants.*

Figure B-5

FINE SCREENS




NOTE:

COSTS INCLUDE: BAR RACKS, CHANNELS, PARSHALL FLUME, AND FINE DRUM SCREENS (35 MESH).

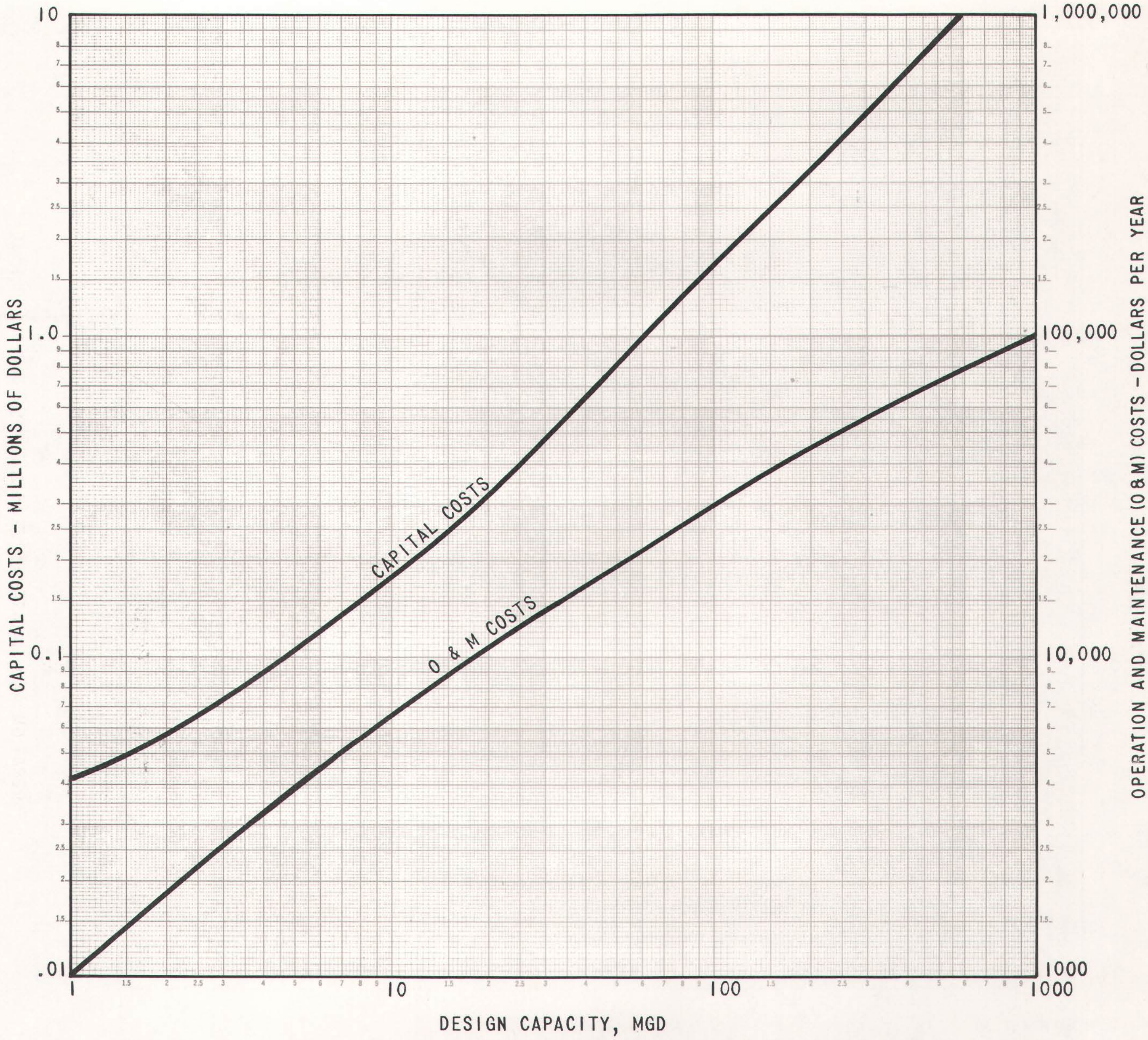
COSTS DO NOT INCLUDE PROVISONS FOR HANDLING AND DISPOSAL OF SCREENINGS

COSTS BASED ON: ENRCCI = 2445 (AUGUST 1976)

*Source: Stanley Consultants.*

**Figure B-6**

**MICROSTRAINER**




NOTE:

CAPITAL COSTS CALCULATED USING EQUATIONS FROM THE STORM WATER MANAGEMENT MODEL.

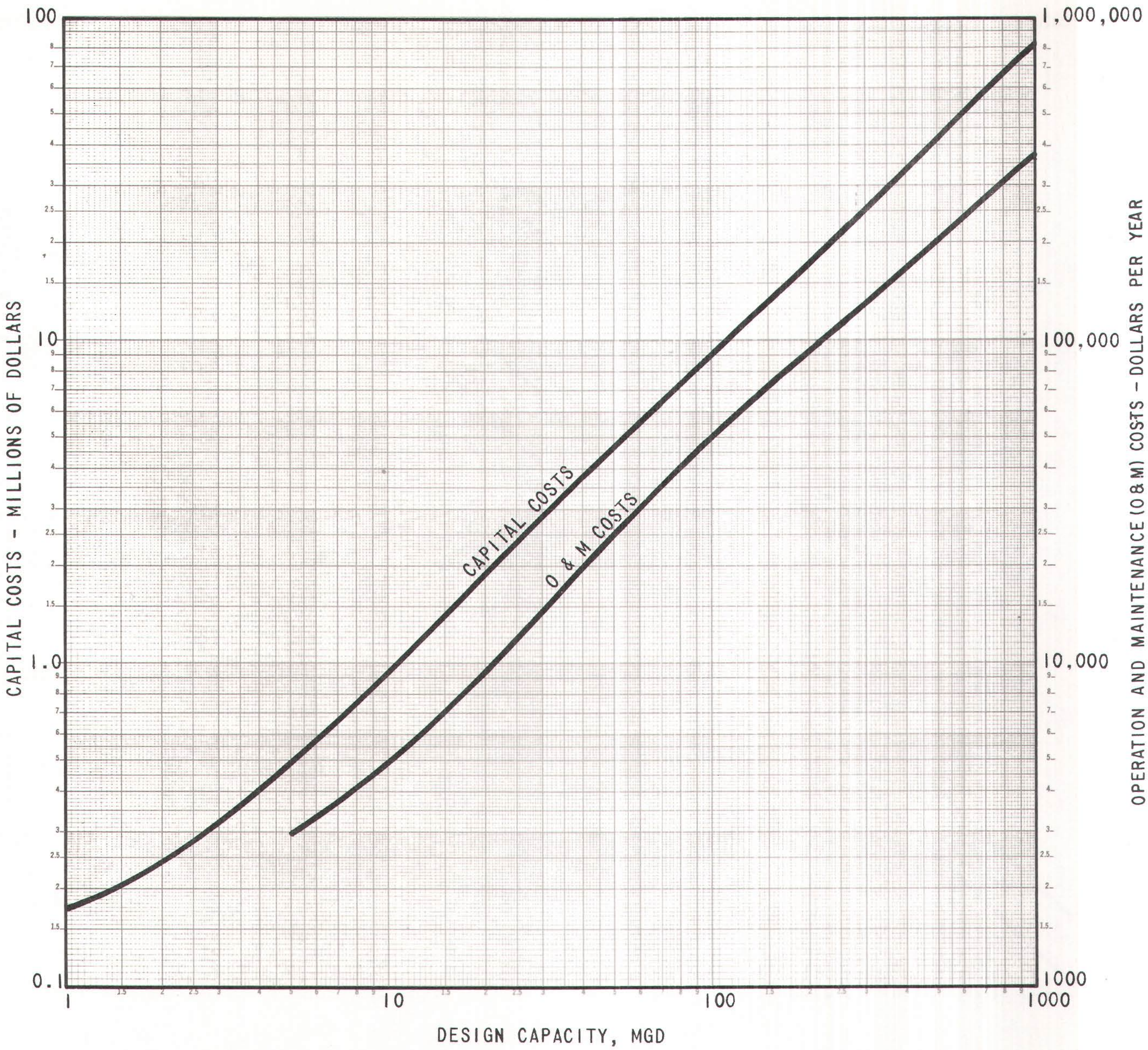
COSTS DO NOT INCLUDE PROVISIONS FOR SOLIDS HANDLING OR DISPOSAL.

ENRCCI = 2445 (AUGUST 1976)

*Source: Stanley Consultants.*

**Figure B-7**

**SEDIMENTATION TANKS**




NOTE:

COSTS BASED ON: DETENTION TIME OF 30 MINUTES AT DESIGN CAPACITY WHICH CORRESPONDS TO PEAK FLOW.

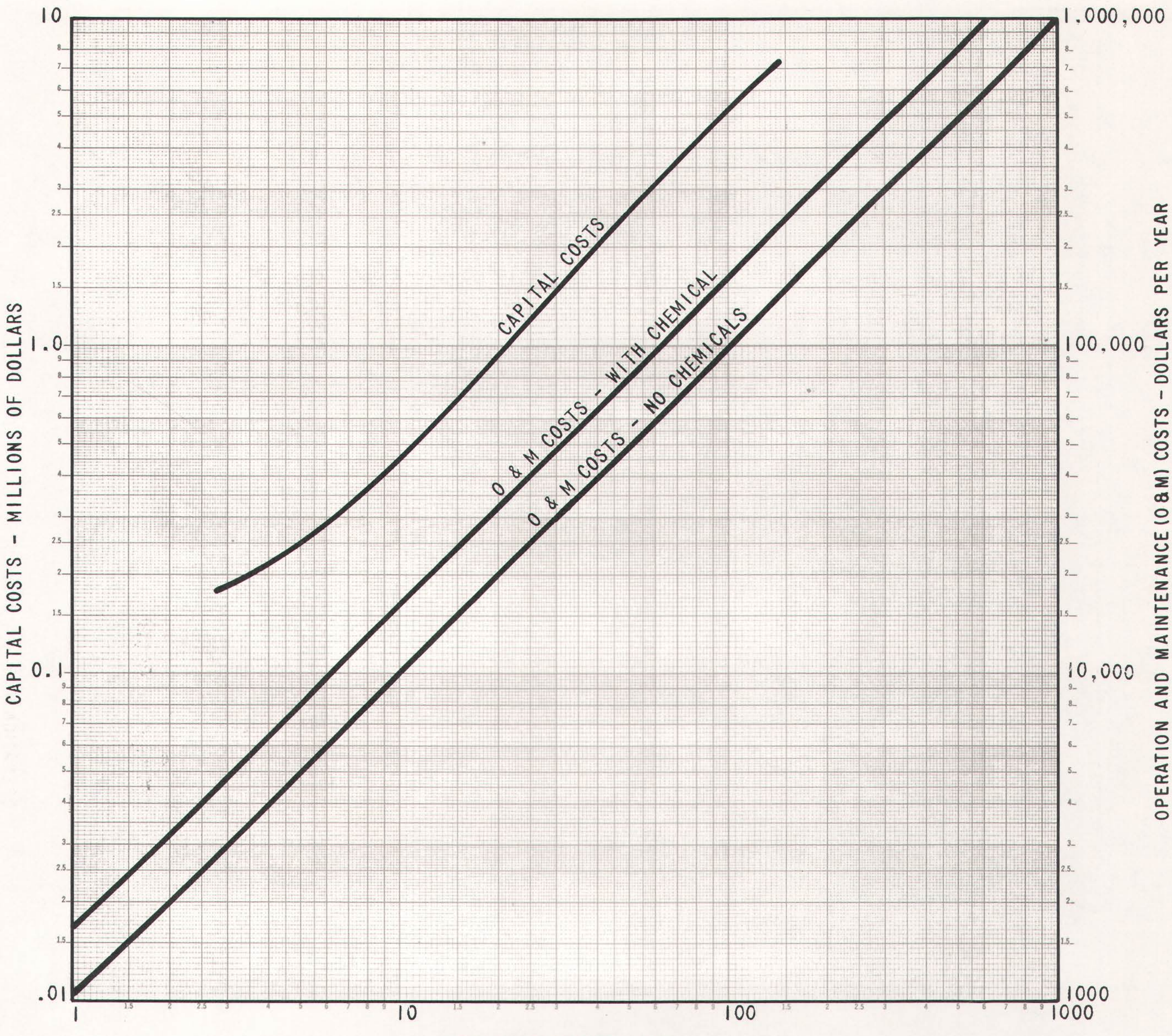
THE COSTS ASSUME A REINFORCED CONCRETE, BELOW-GRADE, SEDIMENTATION TANK. FOR CONSTRUCTION IN SPECIFIC AREAS, NOT ON TREATMENT PLANT SITE, ADDITIONAL COST FACTORS MUST BE CONSIDERED. INCREASED LAND COSTS, AESTHETICS, SECURITY, AND PUBLIC SAFETY PROVISIONS TO AVOID THE CREATION OF AN ATTRACTIVE NUISANCE MAY BE IMPORTANT.

ENRCCI = 2445 (AUGUST 1976)

*Source: Stanley Consultants.*

Figure B-8

DISSOLVED AIR FLOTATION




NOTE:

CAPITAL COSTS WERE CALCULATED USING AN EQUATION FROM THE STORM WATER MANAGEMENT MODEL. REFERENCE: METCALF AND EDDY, STORM WATER MANAGEMENT MODEL, JULY 1971.

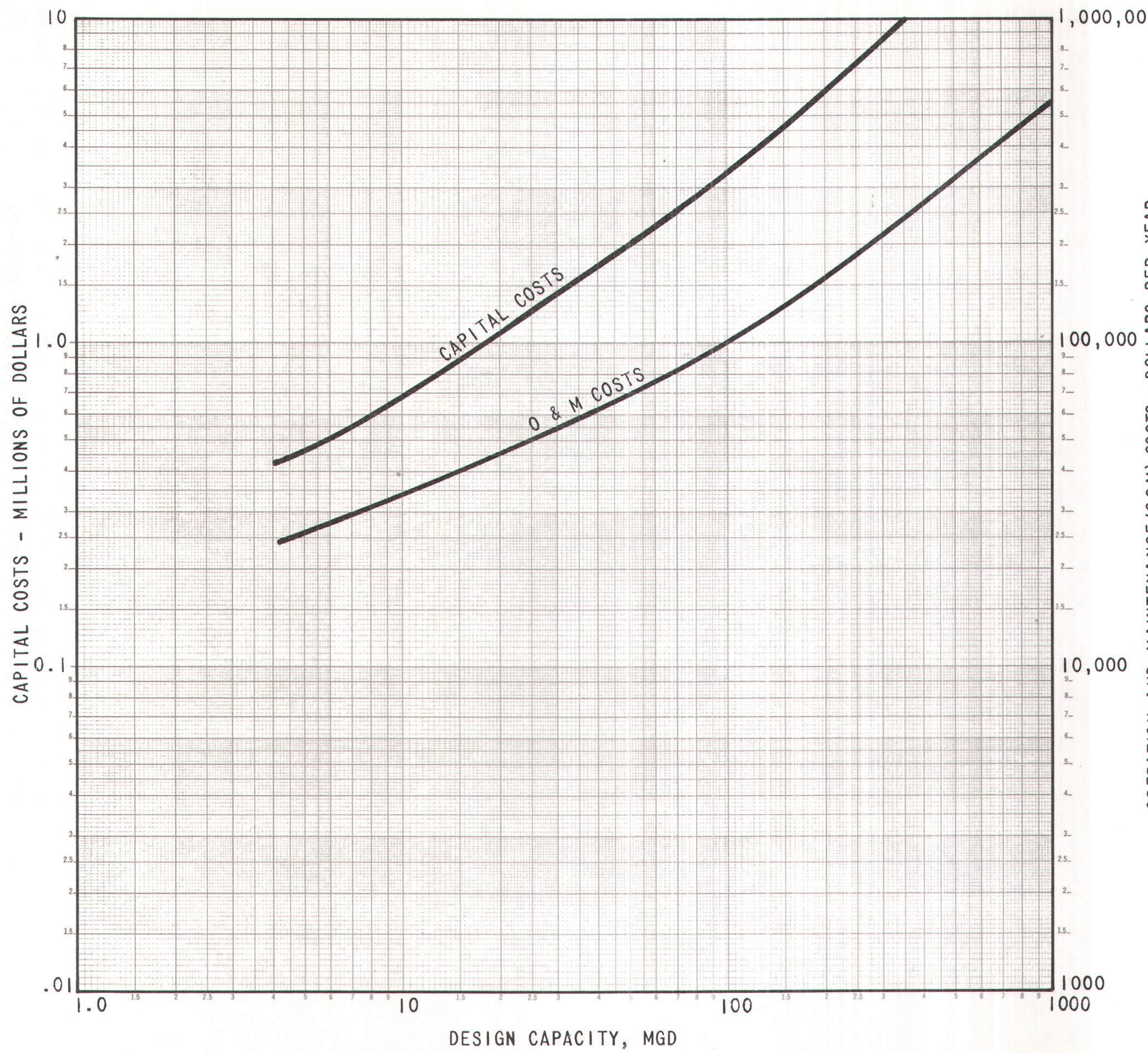
COSTS DO NOT INCLUDE PROVISIONS FOR SOLIDS HANDLING AND DISPOSAL.

ENRCCI = 2445 (AUGUST 1976)

*Source: Stanley Consultants.*

**Figure B-9**

**HIGH-RATE FILTRATION**




NOTE:

CAPITAL COSTS CALCULATED USING AN EQUATION FROM THE STORM WATER MANAGEMENT MODEL. REFERENCE: METCALF AND EDDY, STORM WATER MANAGEMENT MODEL, JULY 1971.

O & M COSTS WERE PLOTTED DIRECTLY FROM ACTUAL OPERATING COSTS, BASED ON 300 HOURS OF OPERATION PER YEAR.

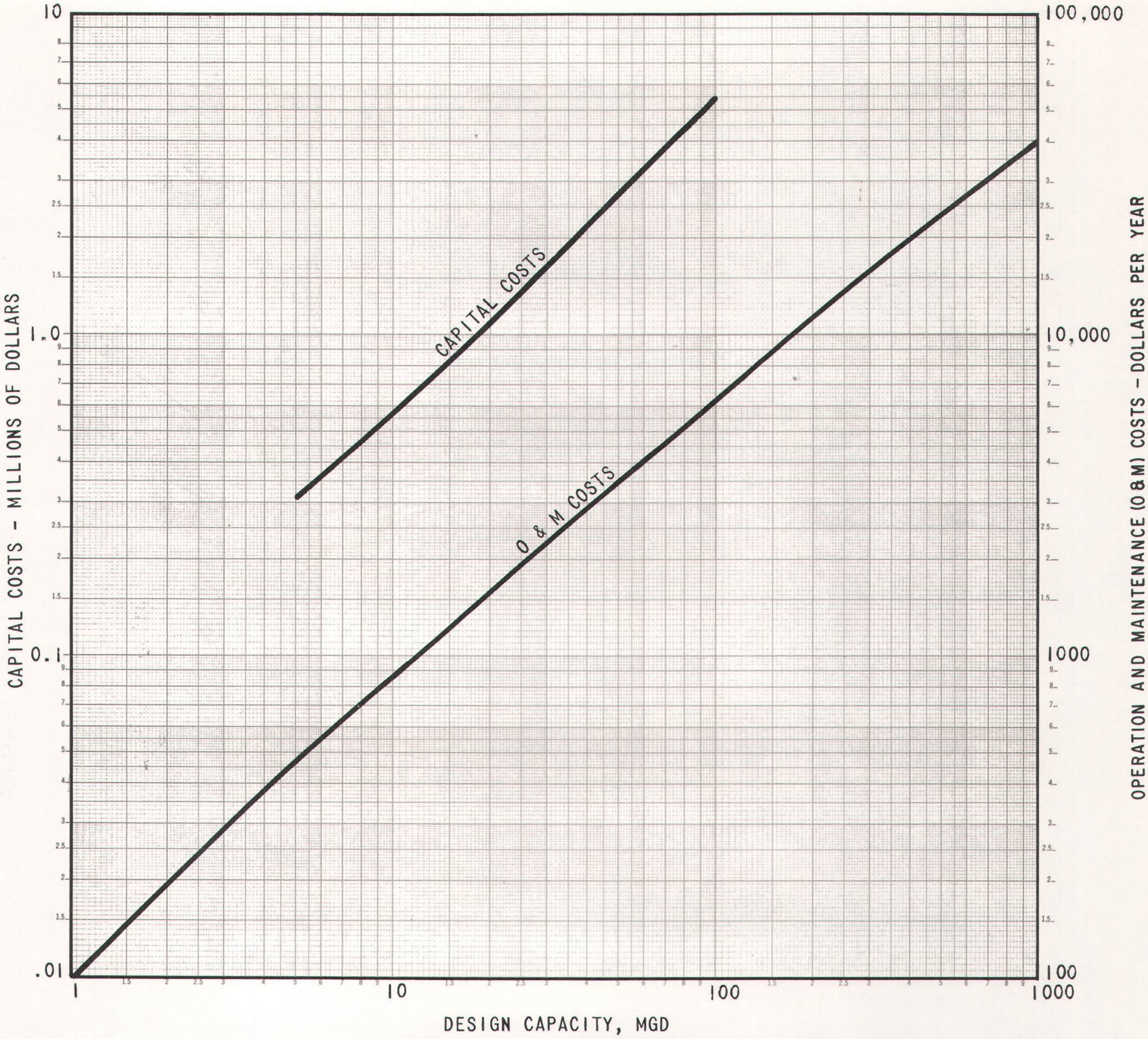
COSTS DO NOT INCLUDE PROVISIONS FOR SOLIDS HANDLING AND DISPOSAL.

ENRCCI = 2445 (AUGUST 1976)

*Source: Stanley Consultants.*

**Figure B-10**

**DISINFECTION**




NOTE:

CAPITAL COSTS CALCULATED USING EQUATIONS FROM THE STORM WATER MANAGEMENT MODEL, REFERENCE: METCALF AND EDDY, STORM WATER MANAGEMENT MODEL, JULY 1971.

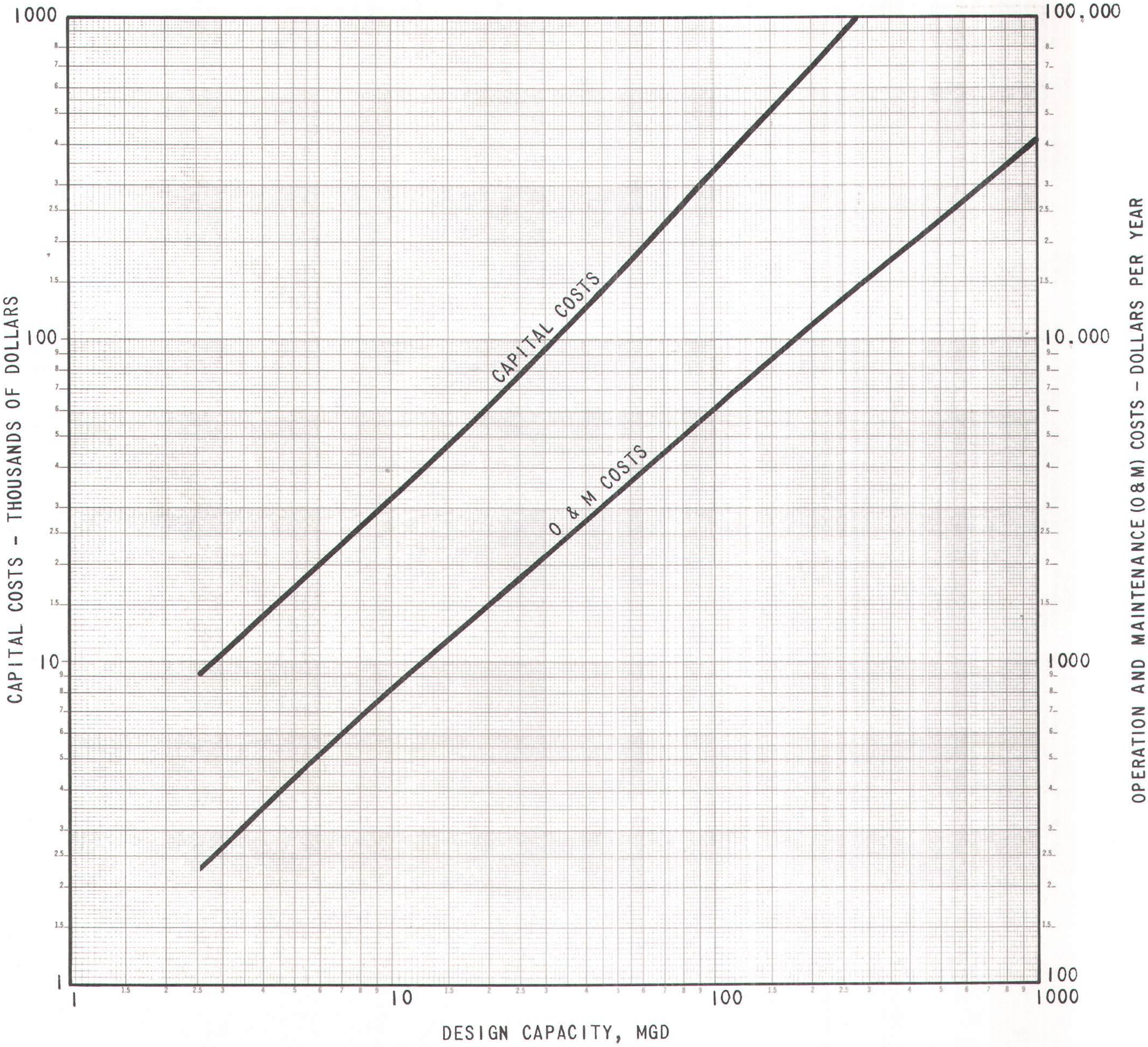
O & M COSTS WERE BASED ON 300 HOURS OF OPERATION PER YEAR AND CHEMICAL COSTS OF $0.16/LB.

ENRCCI = 2445 (AUGUST 1976)

*Source: Stanley Consultants.*

Figure B-11

HIGH-RATE DISINFECTION




NOTE:

WATER MANAGEMENT MODELING AND DECISION-MAKING. REFERENCE: HEANY ET AL URBAN STORMWATER MANAGEMENT MODELING AND DECISION MAKING, MAY 1973

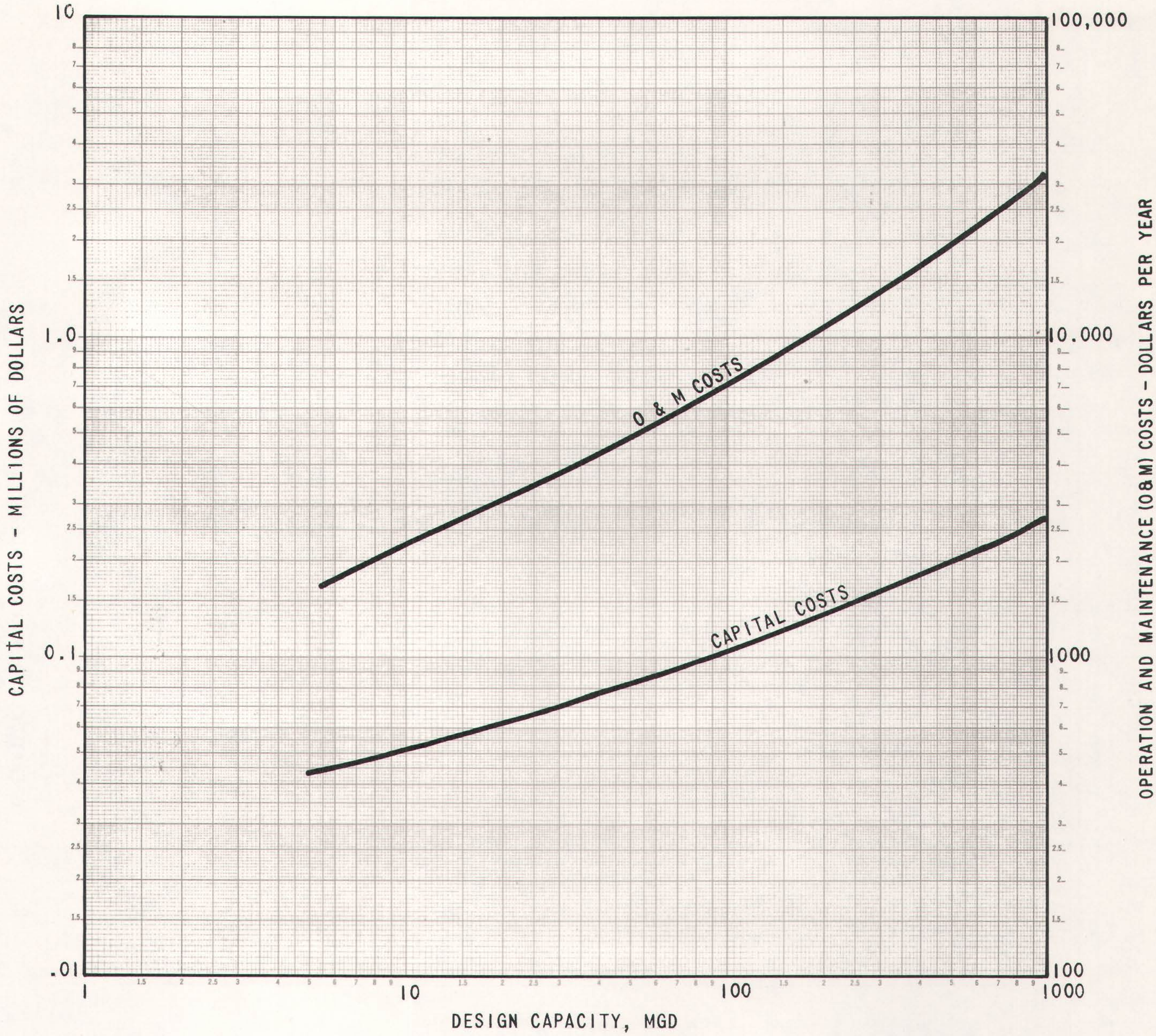
O & M COSTS WERE BASED ON 300 HOURS OF OPERATION PER YEAR AND CHEMICAL COSTS OF $0.16/LB.

ENRCCI = 2445 ( AUGUST 1976)

*Source: Stanley Consultants.*

Figure B-12

SWIRL CONCENTRATOR




NOTE:

CAPITAL COSTS WERE CALCULATED USING AN EQUATION FROM THE STORM WATER MANAGEMENT MODEL. REFERENCE: METCALF AND EDDY, STORM WATER MANAGEMENT MODEL, JULY 1971.

COSTS DO NOT INCLUDE PROVISIONS FOR SOLIDS HANDLING OR DISPOSAL

ENRCCI = 2445 (AUGUST 1976)

*Source: Stanley Consultants.*

## Appendix C

## LIST OF ABBREVIATIONS

| Abbreviation | Stands For |
|---|---|
| COD | Chemical Oxygen Demand |
| $BOD_5$ | Five-Day Biochemical Oxygen Demand |
| TSS | Total Suspended Solids |
| TS | Total Solids |
| TN or N | Total Nitrogen |
| TKN | Total Kjeldahl Nitrogen |
| $NH_3$-N | Ammonia Nitrogen |
| $NO_3$-N | Nitrate Nitrogen |
| $NO_2$-N | Nitrite Nitrogen |
| TP or P | Total Phosphorus |
| OP or $PO_4$ | Orthophosphate Phosphorus |
| mg | million gallons |
| mgd | million gallons per day |
| gpm | gallons per minute |
| ft | foot |
| yd | yard |
| $Q_D$ | Design Flow |
| $t_d$ | detention time |
| mg/l | milligrams per liter |
| mg/g | milligrams per gram |
| O&M | Operation and Maintenance |
| cu | cubic |
| sq | square |
| lbs | pounds |
| mph | miles per hour |
| min | minute |
| hr | hour |
| ml | milliliter |
| mpn | most probable number |