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Review of Alternatives for Evaluation of Sewer Flushing

Dorchester Area—Boston

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REVIEW OF ALTERNATIVES FOR EVALUATION OF SEWER FLUSHING DORCHESTER AREA--BOSTON

by

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FOREWORD

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

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

The Municipal Facilities Branch of Region I administers the grant program that provides financial assistance to communities for the planning, design and construction of wastewater treatment works to meet the objectives of the Federal Water Pollution Control Act and monitors the operation of such treatment works. It is through their sponsorship this report has been prepared.

The application of sewer flushing heavily deposited lines during dry weather periods to alleviate first flush effect and combined sewer overflows when used in conjunction with additional methods of structural control has been estimated to be a cost-effective method of urban runoff pollution abatement.

William R. Adams, Jr., Regional Administrator
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ABSTRACT

Alternatives employing sewer flushing were developed for the Dorchester Area of Boston, and their cost effectiveness compared with the decentralized combined sewer overflow (CSO) storage/treatment and disinfection facilities proposed as Eastern Massachusetts Metropolitan Area (EMMA) Alternative 1. Thirty-three alternatives were evaluated. These alternatives included sewer flushing, offline storage, in-pipe storage, storage/treatment facilities, and a combination of the above. A study objective was to determine if additional expenditures to develop sewer flushing techniques and devices were indeed appropriate.

Available information contained in the past and ongoing studies was used to obtain watershed and sewer characteristics, and to estimate rate of solids deposition in sewers. The feasibility and efficiency of sewer flushing was based on literature review including a recently completed report [4] in which extensive sewer flushing data at four small sewer segments in the Dorchester Area were obtained and interpreted.

Continuous simulation runs using 16 years (1960-1975) of hourly rainfall data from May through November were made to determine the level of CSO pollution control obtained. The Corps of Engineers' STORM program was modified to include continuous simulation of solids and organic material deposited in sewers during dry days, the removal of those deposits by dry day sewer flushing and wet-weather flow, and the storage and treatment effects of a CSO storage/treatment facility on the wet-weather discharge. STORM was also modified to do continuous simulation over a part year period instead of the entire year to allow flexibility for water quality study in areas where the recreational season may be of concern.

The study concluded that (1) the CSO storage/treatment facility, proposed as EMMA Alternative 1 designed for a one-year storm, would remove about 50 percent of the BOD and suspended solids in the CSO and is the highest cost alternative of all considered; (2) the capacity of the conveyance and pumping facilities in the original plan can be reduced by 80 percent and cost reduced by about half while maintaining the same level of pollution control; (3) sewer flushing can be an adjunct to, but can not substitute for, structural alternatives; (4) use of storage available in large sewers in conjunction with sewer flushing could reduce the cost to about 7 percent that of EMMA Alternative 1; and (5) for all alternatives considered, BOD removals equal to those of EMMA Alternative 1 could be achieved at less cost than equal SS removals. Prototype demonstrations of sewer

flushing, using automatic devices should be pursued actively, especially in large combined sewers.

This report was submitted in fulfillment of Contract No. 68-01-4617 by Clinton Bogert Associates under the sponsorship of the U.S. Environmental Protection Agency, Region I, through Anderson-Nichols, EPA's Region I Mission Contract Contractor responsible for administrative project management. Work was completed as of May, 1979.

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ACKNOWLEDGEMENTS

The support of the project by the U.S. Environmental Protection Agency, Region I, under a contract with Anderson-Nichols, Boston, an EPA Mission Contractor responsible for administrative project management, is acknowledged and appreciated.

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For Clinton Bogert Associates, this project was directed by Mr. Herbert L. Kaufman, Partner-in-charge. Dr. Fu-hsiung Lai, Associate, served as Project Engineer. Mr. Ivan L. Bogert, Partner, and Mr. John H. Scarino, Principal Associate, provided valuable criticism and review.

Dr. William C. Pisano, President, Environment Design & Planning, Inc., was most cooperative and gave generously of his knowledge and experience in computer modeling and sewer flushing. Dr. Pisano also shared freely his information on the characteristics of the Dorchester sewer system obtained during the Process Research, Inc. (PRI) study and recent EPA Demonstration Grant studies. Finally, Dr. Pisano and his staff, through an extraordinary effort, completed the draft of their report on sewer flushing in time for use in this study and made themselves fully available for discussions.

Thanks are also due Mr. John R. Elwood, Supervising Sanitary Engineer, Environmental Planning Office, the Metropolitan District Commission (MDC), the Commonwealth of Massachusetts, who assisted in providing information from various Engineers serving the MDC and provided the operation and maintenance cost data of the Cottage Farm facility. Mr. Donald G. Wood of that office was also very helpful.

Finally, the authors are grateful to Metcalf & Eddy, Inc. (M&E), Camp Dresser & McKee, Inc. (CDM), and Hydroscience, Inc., who were cooperative in providing basic data used in this study. M&E provided data related to the design of storage/treatment facilities; CDM supplied the watershed map, boundary and characteristics, and dry-weather flow metering data. Hydroscience provided a copy of the magnetic tape containing the rainfall records used in the study.

SECTION I

PROLOGUE

A report, released in September 1978 and co-sponsored by the OMB, EPA, NSF and CEQ, criticized the EMMA Alternative 1 for CSO pollution abatement as being structurally intensive. As a result, EPA Region I through Anderson-Nichols, an EPA Mission Contractor, engaged Clinton Bogert Associates to compare CSO pollution abatement techniques, including sewer flushing, "and to make this comparison and hence determine if additional expenditures to develop sewer flushing are appropriate."[a]

The comparisons were made for the Dorchester Area of Boston draining to existing CSO outfalls 49, 50 and 67 (EMMA Report, Volume 7). Included in the comparisons were capital, operating and maintenance costs totaled in terms of present worth.

Thirty-two of the more promising alternatives to EMMA Alternative 1 that were compared are described briefly in Table 1. EMMA Alternative 1, as considered for adoption by the MDC, comprises a conveying conduit and pumping station capable of delivering the peak flow from a one year return frequency storm to a combined sewage treatment plant (CSTP). The CSTP provides both primary treatment with basins (sized to allow 15 minutes detention at the peak flow) and storage when the combined sewage volume does not exceed the detention basin volume. At the end of the rainfall event, combined sewage and sludge retained in the basins would be returned to the interceptor for treatment. Five of the alternatives evaluated proposed reducing the pumping station and conveying conduit capacity by 75 to 80 percent of that proposed in EMMA Alternative 1 and achieved essentially equivalent pollutant removals. It also appears that sewer flushing can improve pollutant removals with this type of facility. Four alternatives considered the effects of sewer flushing alone at various time intervals. These alternatives indicated pollutant removals significantly lower than those achieved by EMMA Alternative 1.

Other alternatives evaluated the pollutant removals to be achieved by various amounts of storage both with and without sewer flushing and the effects of high and average sewage pollutant strengths. Finally the use of storage capacity available in existing pipes by flow routing was evaluated.

[a] from "Project Overview"

TABLE 1. PHYSICAL DESCRIPTION OF ALTERNATIVES

Case No.	Sewer Flushing Interval (dry days)	No. of Flushing Stations	Storage Capacity (mgd)	CSTP	Pumping Capacity (mgd)	Conduit Size (ft)
1	–	–	–	No	–	–
2	1	28	–	No	–	–
3	2	28	–	No	–	–
4	7	28	–	No	–	–
5	–	–	5.1	No	15.0	–
5A	1	28	5.1	No	15.0	–
6	–	–	6.8	No	15.0	–
6A	1	28	6.8	No	15.0	–
7	–	–	13.1	No	15.0	–
7A	1	28	13.1	No	15.0	–
8	–	–	7.7	Yes	497.4	10.5
9	1	28	7.7	Yes	497.4	10.5
10	–	–	5.7	Yes	100.0	5.0
11	1	28	5.7	Yes	100.0	5.0
12	–	–	7.1	No	15.0	–
13	1	28	5.1	No	15.0	–
14	–	–	7.3	No	15.0	–
15	1	28	6.0	No	15.0	–
16	–	–	7.5	No	Small	–
17	–	–	10.0	No	15.0	–
18	1	28	9.1	No	15.0	–
19	–	–	10.0	No	15.0	–
20	1	28	9.5	No	15.0	–
21	–	–	10.0	No	15.0	–
22	1	5	5.5	No	15.0	–
23	1	12	5.3	No	15.0	–
24	1	104	4.9	No	15.0	–
25	1	5	9.3	No	15.0	–
26	1	12	9.2	No	15.0	–
27	1	104	9.0	No	15.0	–
B	–	–	6.2	Yes	125.0	7.0
C	–	–	5.9	Yes	115.0	6.0
D	–	–	7.7	Yes	100.0	10.5

The effectiveness of the alternatives were measured by two criteria: obtaining (1) BOD removals and (2) SS removals equal to EMMA Alternative 1. The results of this comparison follow:

Case No.	Alternative Description	Criteria	Present Worth ($\$ \times 10^6$)
8	EMMA Alt. 1	-	46.89
10	EMMA Alt. 1 (Modified)	-	26.46
12	Storage - Strong Sewage	BOD	26.31
17	Case 12 - Strong Sewage	SS	30.58
13	Storage & Flushing[b] Strong Sewage	BOD	24.79
18	Case 13 - Strong Sewage	SS	32.04
14	Case 12 - Normal Sewage	BOD	27.03
19	Case 12 - Normal Sewage	SS	30.58
15	Case 13 - Normal Sewage	BOD	26.94
20	Case 13 Normal Sewage	SS	32.62
16	Existing Pipe Volume used for storage w/Flushing	BOD	03.30
21	Existing Pipe Volume used for storage w/Flushing	SS	14.27

[b] Flushing at 28 locations.

Further studies indicate that flushing at no more than 12 nor less than 5 locations may be cost effective.

Note: Both strong and normal sewage were considered because of their different solids deposition rates.

SECTION II

CONCLUSIONS

1. EMMA Alternative 1, as presently considered, removes about 50 percent of the BOD and SS in the Combined Sewer Overflows (CSO). It is the highest cost alternative of all considered, principally due to sizing conveying and pumping facilities for flows expected from a one-year return frequency storm.

2. EMMA Alternative 1 could be modified and its cost reduced to more reasonable levels, while maintaining its performance. This could be accomplished by reducing the capacity of the connecting conduit and pumping station to 20 percent of that considered in EMMA Alternative 1.

3. Sewer flushing alone can not match EMMA Alternative 1 in pollution abatement levels attained. Daily sewer flushing at 28 strategic locations affecting about 45 percent of the solids deposited would reduce SS discharge by about seven percent and the BOD by 17.6 percent. If flushing at a 2-dry-day interval is employed, approximately 5.2 percent of the SS and 14.1 percent of the BOD would be removed. If the flushing interval is extended to seven dry days, only about 1.2 percent of the SS and 4.0 percent of the BOD would be removed.

4. Sewer flushing, if combined with storage, should substantially reduce the cost of achieving equal SS and BOD removals as compared to EMMA Alternative 1. If compared to the modified EMMA Alternative 1 (See Conclusion 2), the combined sewer flushing and storage alternative with strong sewage should cost less for equal BOD removals. With normal sewage, this advantage is largely lost. If equal SS removals are desired, a combined sewer flushing and storage alternative does not appear cost-effective for either strong or normal sewage.

5. Use of storage made available in existing pipes in the Dorchester area by flow routing, in conjunction with sewer flushing, could reduce present worth costs to about seven percent of EMMA Alternative 1 for equal BOD removals, and to about 30 percent, for equal SS removals. If compared to EMMA Alternative 1 (modified) the respective percentages are 12.5 and 54.0.

6. Based on the locations of moderate to heavy sewer solids deposits identified in past studies by others, the maximum number of sewer flushing stations appears to be 28. These locations should affect 45 percent of the pollutants deposited during dry weather flows. Eleven are located in combined sewer segments and 17 in separate sewer segments. Additional sewer flushing stations become increasingly marginal since the solids flushed per station reduce rapidly. However, as few as five and no more than 12 stations flushing those sewer reaches with the heaviest deposits, appear to be optimum.

7. For equal flows and pipe slopes, the wall shear stress may be almost independent of the pipe size. If this is proven, it should be as feasible to flush large sewers as small sewers and would simplify greatly the maintenance required to achieve the economy in pollution abatement that appears possible with in-line storage.

8. Available prototype data was obtained from flushing 12- and 15-inch sewers. For these small sewers, flushing volumes of approximately 50 cubic feet injected at a rate of approximately 0.5 cfs would effectively flush solids in the sewers. Shear stress computations indicate a greater flow rate would be required to flush and keep pollutants in suspension in larger sewers with slopes equal to or less than 0.003. However, larger sewers generally carry greater sewage flow than the smaller sewers, therefore, solids transport capability of large sewers may be greater.

9. Trunk sewers and larger combined sewers normally follow valley bottoms, while the smaller separate and combined lateral sewers are located on the valley sides. Hence, the smaller sewers generally have steeper slopes than larger sewers. An urgent need exists to determine the optimum methods of flushing in larger sewers. Based on experience in Detroit, such a study should provide highly valuable results.

10. Sewer flushing during dry days is more effective in reducing BOD than SS in CSO. The resuspended heavier solids tend to resettle in downstream sewers. In the Boston area for the period from 1960 through 1975, the number of days with zero precipitation averaged 165 from May through November, or about two dry days in every three. To dry weather flush with the required frequency, automatic installations appear essential. If flushing devices are operated after 24 dry hours, the number of flushes would be between 165 (assuming flushing every dry day) and 70 (assuming flushing every consecutive 48 dry hours), with BOD removal ranging between 17.6 and 14.1 percent and SS removal between 7.0 and 5.2 percent. The reduction in removal efficiency is rather small. A longer interval between sewer flushing would not impact significantly on pollutants flushed by wet weather flows.

11. Sewer flushing alternatives are an adjunct to, but are not a substitute for, structural facilities to obtain the same pollutant reduction in the CSO's as EMMA Alternative 1. With a strong sewage, the same amount of BOD removal as the EMMA Alternative 1 can be achieved by (1) 7.1 million gallons of off-line storage; or (2) 5.1 million gallons of off-line storage supplemented by daily sewer flushing. The daily flushing/storage alternative has the lowest total cost of the three. The modification to the EMMA Alternative 1 would cost about seven percent more than the lowest cost alternative of sewer flushing and storage, indicating that the EMMA proposal, if optimized, could be a viable alternative.

12. With a strong sewage, the same amount of SS removal as in EMMA Alternative 1 can be achieved by: (1) 10 million gallons of off-line storage, or (2) 9.1 million gallons of off-line storage together with daily sewer flushing. Of the three pollution abatement schemes, the optimized EMMA Alternative 1 may be about 15 percent less in total cost than the storage alternative with the estimated cost of storage used herein. The sewer flushing/storage alternative appears to cost slightly more than the non-flushing storage alternative. If the sewage strength is reduced by 45 percent, sewer flushing becomes less effective and that alternative costs more to achieve the same degree of pollution control.

13. If dry-weather sewage strength is reduced by about 45 percent, the optimum EMMA proposal for the same amount of BOD removal might be less costly. However, facility planning should investigate more thoroughly the probable cost of storage.

14. The most economical alternative would be to exploit the storage in large sewers near the two outfalls. As much as 7.5 million gallons of potential storage appear to be available. This low structural alternative would require several flow regulating devices and frequent flushing of the sewer to maintain effective storage capacity. The possible savings justify the funding of a sewer flushing demonstration project for large sewers to permit evaluation of its efficacy.

15. Cost of sewer flushing based on full-scale operating experience is not available. Estimates are based on automatic flushing equipment and need verification by operation of prototype devices and field demonstration. Cost of storage, although more available, varies widely depending on the type, size and facilities included. The EMMA study report included only gross cost estimates of primary treatment facilities of known volumes. This study used the EMMA cost estimates to determine the cost of detention basin storage. These costs appear high for off-line storage and hence tend to favor the EMMA alternatives. They

should be investigated on a specific site basis in the ongoing facility planning. Storage alternatives may be economically more attractive than set forth herein.

16. The U.S. Army Corps of Engineers' STORM computer program required modification to include continuous simulation of dry day sewer solids deposition, wet day solids removal, and dry day sewer flushing effects. The output of the program indicates the amount of combined sewage quantity and quality diverted to the main treatment plant (STP) and the new CSTP, pollutants removed in the CSTP, deposited solids in sewers resuspended by combined sewage flow, and combined sewage pollutants from dry-weather flow, etc. These data are useful in the development and evaluation of alternatives.

SECTION III

RECOMMENDATIONS

1. Prototype demonstrations of sewer flushing should be pursued actively especially in large combined sewers. Sewer flushing may be a cost-effective adjunct if integrated with structural alternatives.

2. Automatic sewer flushing devices, which require minimal maintenance, should be developed and demonstrated for operational reliability. Better cost information should be developed in conjunction with field demonstrations for comparison with the cost of other viable CSO pollution abatement alternatives.

3. There is economical incentive to explore and utilize potential storage which may be available in existing large sewers. In the Dorchester area, use of this storage may be all that is required for effective CSO pollution abatement. This alternative, coupled with sewer flushing, has been demonstrated as practical in the Detroit sewer system. Flow regulating devices are available for this purpose.

4. The computer simulation model "STORM", should be further expanded to permit analysis of more than one drainage area at a time and to include additional treatment processes. This would allow the development and evaluation of pollution abatement schemes for each individual subarea of a watershed taking into consideration its particular drainage and pollution characteristics while meeting the gross objective of reducing the amount of pollutant discharged to receiving waters from the watershed.

5. Additional verification of the quantity and quality of dry weather flow deposits should be undertaken. This verification should concentrate on those sewer segments with the relatively greater deposits.

6. The use of dry-weather flow by backup and release for flushing should be confirmed as being practicable.

SECTION IV

STUDY BACKGROUND

In March, 1976, the Metropolitan District Commission (MDC) presented a comprehensive plan for Wastewater Management in its report, Wastewater Engineering and Management Plan for Boston Harbor - Eastern Massachusetts Metropolitan Area (EMMA)[1]. The report identified CSO as a major source of pollution. The plan included 13 decentralized CSO pollution abatement facilities, 10 proposed, 2 existing and one under construction. The necessary collector sewers were planned to divert wet weather flows to these facilities. The total estimated capital cost for the CSO pollution abatement facilities, at Engineering News Record (ENR) Index equal to 2200, is $279 million. The annual operating and maintenance costs is estimated at $3.9 million. While the EMMA plan appears to have represented advanced concepts at the time it was prepared, it has been criticized as being structurally intensive in light of developing knowledge. In June, 1978, U.S. EPA awarded a Step 1 construction grant to the MDC for preparation of a CSO control facilities plan in the Boston Metropolitan Area. The planning area includes about 25,000 acres and has a population of about 900,000.

The EMMA study considered three general approaches to abate CSO pollution: sewer separation, a deep tunnel plan and decentralized treatment facilities. The sewer separation alternative was not found cost-effective and probably not practical, especially in downtown Boston. The deep tunnel plan is a centralized approach and requires an early, very large capital commitment. The decentralized plan was favored because it "would continue present remedial practices". Such a plan would permit "staged implementation in accordance with criteria and needs of each immediate area and provides flexibility for inclusion of future technologies in treatment beyond that presently provided."

The EMMA study compared a totally decentralized plan (Alternative 1) with Alternatives 2 and 3 which combined the decentralized concept with the deep tunnel centralized concept. Alternative 1 had the lowest capital cost of $279 million with $299 million and $307 million, respectively, for Alternatives 2 and 3 based on the ENR Index of 2200. The annual operation and maintenance cost for the three alternatives were estimated as $3.9, $3.7 and $3.8 million, respectively. The costs for all alternatives appear to be about equal considering the range of error expected in preliminary work.

Although non-structural control, such as street sweeping and sewer flushing, were discussed in the EMMA study report, "as an important contributor to water pollution control and should be incorporated as part of any abatement program", such measures are not considered as part of an alternative. Unlike street sweeping, which is practiced in almost every urbanized area for aesthetic reasons, sewer flushing is not a common practice, although the idea is not new. As the result of several recent U.S. EPA research/development/demonstration projects [2, 3, 4] in which sewer flushing data were collected and techniques demonstrated, the possibility of sewer flushing as a viable contributor to CSO pollution abatement should be investigated. In Boston, several proposals have been made to refine computer modeling techniques, develop automatic flushing equipment, and demonstrate medium to large scale operating prototypes for sewer flushing evaluation. These proposed studies require one to two years to complete and would cost from $150,000 to $500,000. This study was undertaken, based on the state-of-the-art information, to explore the use of sewer flushing either as an adjunct to reduce the cost of structurally-oriented alternatives, or as an independent technique.

SECTION V

STUDY OBJECTIVE AND SCOPE

The major objective of this study, as directed by the U.S. EPA, Region I, was to estimate the cost of an alternative, employing sewer flushing which would provide the same degree of pollution abatement as EMMA Alternative 1 for the Dorchester Bay area. Capital and operating and maintenance costs of the selected alternative were to be compared with those for EMMA Alternative 1. The costs were to be presented at the current ENR Index.

The scope of the study included:

1. literature review on sewer flushing research, demonstrations and application;
2. pertinent data compilation and review on the Dorchester Bay area;
3. implementation of computer models;
4. evaluation of the pollution control efficiency of the EMMA Alternative 1;
5. development of alternatives employing sewer flushing and their pollution control efficiency using a computer model; and
6. development and comparison of cost estimates of alternatives.

This study uses five-day Biochemical Oxygen Demand (BOD) and Suspended Solids (SS) as the pollution abatement parameters. These two parameters can be modeled and field verified with reasonable accuracy. Coliforms have not been satisfactorily modeled for field verifications.

SECTION VI

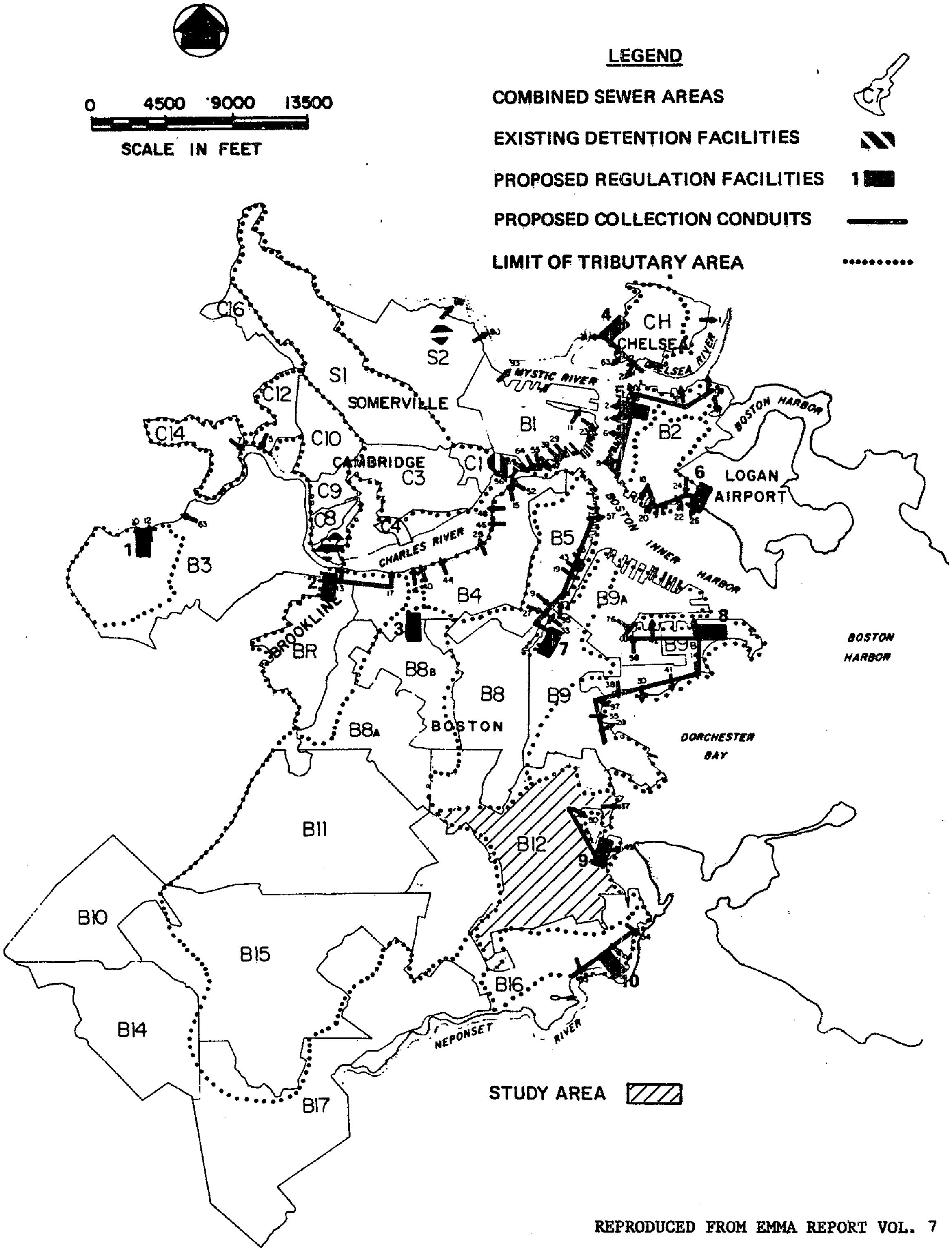
THE EMMA ALTERNATIVE 1

As shown in Figure 1, EMMA Alternative 1 consolidates combined sewer overflows into 13 groups. Sewage in each group is collected and treated prior to discharge to receiving waters. These groups include 10 proposed, 2 existing and one facility under construction. The Cottage Farm Detention and Chlorination Station and the Somerville Pretreatment Facilities are existing. The Charles River Chlorination-Detention-Pumping Station is under construction. The Cottage Farm and Charles River facilities include collection conduits, treatment and storage tanks, pumping facilities and outfalls. The Somerville facility includes screening and chlorination facilities with chlorination achieved in the outfall conduits. The proposed facilities are sized based on a storm of one-year severity and six-hour duration. Its rainfall hyetograph is shown in Figure 2. This intermediate pattern "design" storm has a total rainfall of 1.78 inches and a 10-minute peak rainfall intensity of 2.63 inches per hour. The design flow rate and volume were estimated using the Storm Water Management Model (SWMM). The model was not calibrated.

The collection conduits were sized to carry the peak design flow. The tank, which consists of two basins, receives flow from the collection conduits. Flow is delivered first to one basin. As this basin is filled, a floating scum and oil baffle rises with the water level to capture such materials. Flow may enter the second basin from the first basin or may be delivered directly to the second basin, permitting retention of the first flush in the first basin. When both basins are filled, overflows are screened before discharge to the receiving waters. The flow is chlorinated upstream of the tanks. The tank is designed to provide 15 minutes detention for the peak design flow. Each facility will have pumps, either before or after the tank, capable of pumping the peak design flow. At the end of a storm, water and solids retained in the tanks will be diverted to the main treatment plant (STP) through the existing interceptors.

Table 2 shows a summary of facilities and costs estimated by Metcalf and Eddy (M&E) for EMMA Alternative 1.

To compare the cost-effectiveness of EMMA Alternative 1 with alternatives employing sewer flushing, the area tributary to Facility No. 9 was selected since:



REPRODUCED FROM EMMA REPORT VOL. 7

Figure 1. Satellite regulation facilities and collection systems in EMMA Alternative 1

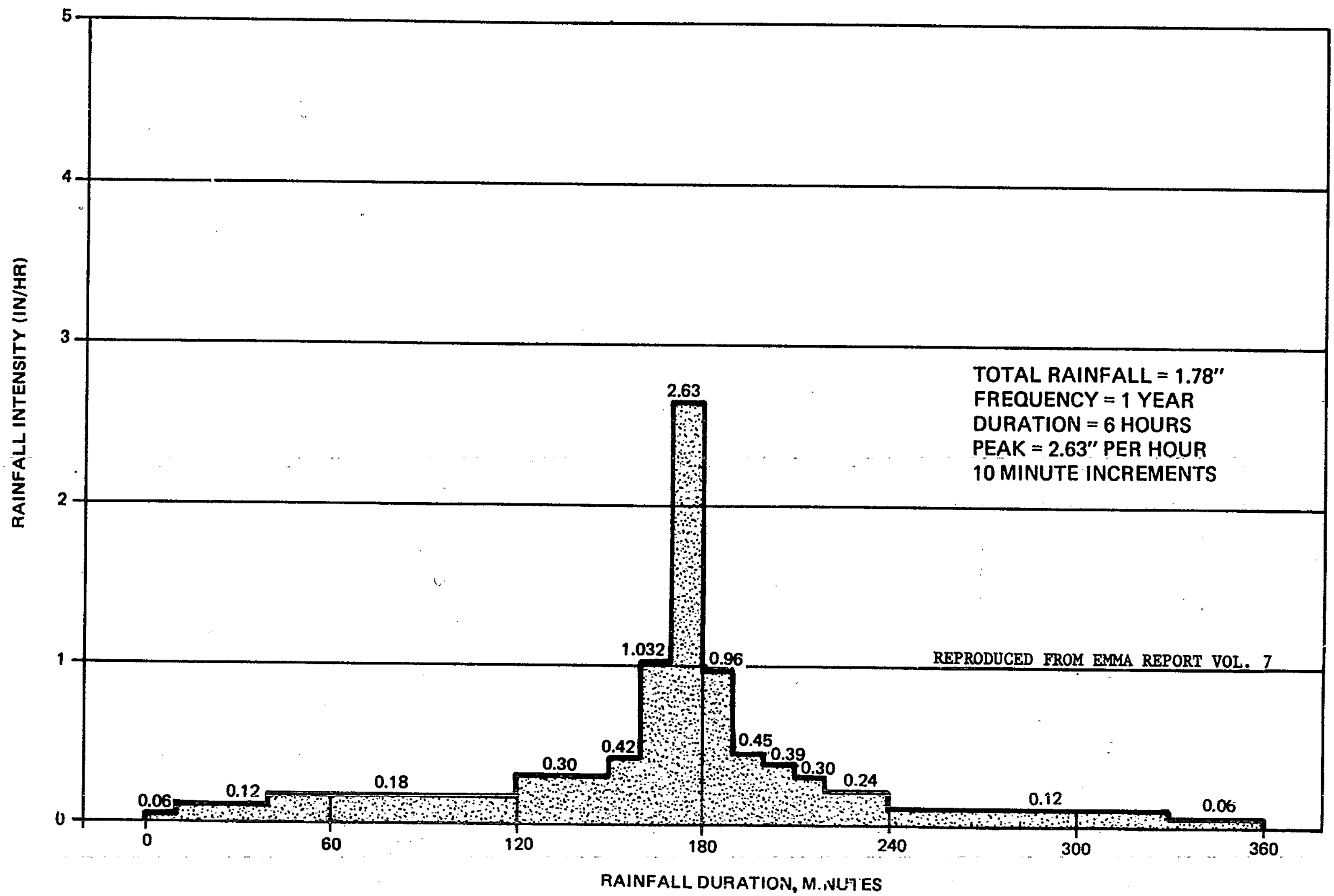


Figure 2. One year 6-hour design storm hyetograph

TABLE 2. SUMMARY OF FACILITIES AND COSTS FOR ALTERNATIVE 1 [4]

Facility No.	Location	Outfalls to be collected	Tributary area,[3] (acres)	Tank size, (million cu ft)	Construction cost (million dollars)[1]			
					Tanks	Pumping stations	Conduits	Total[2]
1	Brighton	10,12	875	0.75	13.5	10.0	0.7	24.2
2	Brookline	13,17	980	0.38	8.5	7.6	3.6	19.7
3	Back Bay Fens	16	7,550	0.75	15.3	18.3	2.5[2]	36.1
4	Chelsea	21,63,31	330	0.18	4.4	3.3	2.9	10.6
5	East Boston (North)	34,32,3,2, 4,6,8	400	0.19	4.5	4.1	8.0	16.6
6	East Boston (South)	18,20,22, 24,26	525	0.24	5.6	4.8	3.9	14.3
7	Fort Point Channel	57,45,43, 19,9,27, 33	2,960	1.00	15.0	20.0	9.8	44.8
8	South Boston	76,58,42,37, 14,41,30,38, 97,35,28	1,075	0.68	12.8	13.6	16.9	43.3
9	Malibu Beach	67,50,49	1,580	0.68	12.8	13.6	7.8	34.2
10	Granite A Avenue	54,51,53	720	0.40	9.0	9.0	4.3	22.3
	Subtotal							266.1
	Remote area projects							13.3
	Total							279.4

1. January 1975 prices (ENR 2200).
2. Includes alteration to Stony Brook Conduit and insystem chlorination.
3. Includes separate areas that discharge into combined sewers.
4. **Reproduced from the EMMA Report Volume 7.**

1. EMMA Alternative 1 is totally decentralized, i.e., each facility is independently sized with the same hydrologic and cost parameters. Study of one tributary area provides data and insight for projection to other areas while keeping the efforts required for data development reasonable;

2. the area has been fully studied in the past and most, if not all, of the necessary hydrologic, watershed and pollutional information is available; and

3. the most extensive sewer flushing data (deposition potential, flushing volume mode and effectiveness) available were obtained in the study area.

Facility No. 9 consists of a 4000-foot long, 126-inch diameter collection conduit, a pumping station with capacity of 770 cfs, a primary treatment tank with capacity of 0.68 million cubic feet (5.08 Mgal) and a 300-foot long outfall sewer. Information provided by M&E indicates the collection conduit and outfall pipe are to be supported on piles, except for 800 feet which is to be jacked.

The collection conduit connects the existing regulator near overflow No. 50 and to that near No. 49. M&E has estimated, using SWMM, that the one-year storm peak runoff rate for the area tributary to the upstream regulator is 535 cfs[21]. The additional peak runoff rate from the area tributary to the downstream regulator is 520 cfs. The collection conduit provides modulating storage which permits reducing the peak flow to the CSTP to 770 cfs. The cost of the collection conduit and outfall was estimated at $7.8 million. The costs of treatment tanks and pumping stations were estimated as $12.8 million and $13.6 million, respectively. The estimates were based on the ENR index of 2200. The total capital cost of the facility was $34.2 million. All the above costs include an allowance of 25 percent for engineering and contingencies. Land costs are not included.

SECTION VII

DESCRIPTION OF THE STUDY AREA

The tributary area to the Facility No. 9 is entirely within the boundary of Dorchester. The area is approximately bounded on the north by Columbia Road, on the west by Pennsylvania Central Railroad, on the south by Wilmington Avenue and Ashmont Street and on the east by the Dorchester Bay. Figure 3 is a map delineating the study area.

Several pollution control studies have been made in the Dorchester area; the EMMA Study by Metcalf & Eddy (M&E) in 1976[1] the Process Research, Inc. (PRI) Report in 1975,[5] and the Camp, Dresser & McKee (CDM) study of Water Quality Improvement of Tenean and Malibu Beaches in 1972[6]. CDM is preparing a CSO facilities plan for the study area. These available studies and data provided by CDM and M&E were reviewed to compile the information for this study. The PRI Report, which studied the Dorchester sewer system in detail, contained data as to solids deposition locations and rates in both the separate and combined sewer areas, dry weather flow rates, population and potential storage locations. Information in the PRI Report was adjusted or supplemented by information reported in other studies.

There are three combined sewer overflows in the study area designated as Nos. 50, 67 and 49 (Figure 1) in the EMMA study and Nos. 100, 101 and 103 respectively in the CDM study. CSO Nos. 50 and 67 serve the same drainage area. At low tide, only No. 67 functions. During high tide the capacity of the conduit connecting the Nos. 50 and 67 is reduced and both may discharge combined sewage. For this study, CSO Nos. 50 and 67 are treated as one overflow.

While the boundaries of the area described in the above reports differed somewhat, it was possible to determine the boundaries sufficiently for purposes of this report.

In CDM's ongoing CSO study, the two subareas tributary to CSO's Nos. 50 and 49 have a total area of 1,735 acres (508 and 1,227 acres, respectively). This compares to M&E's tributary area of 1,580 acres. The PRI report has 37 branch areas, 17 of which can be aggregated to form an area that is essentially equivalent to those used in the ongoing CSO study. The total sewered area of these 17 subareas is 1,613 acres, the number used in this study.

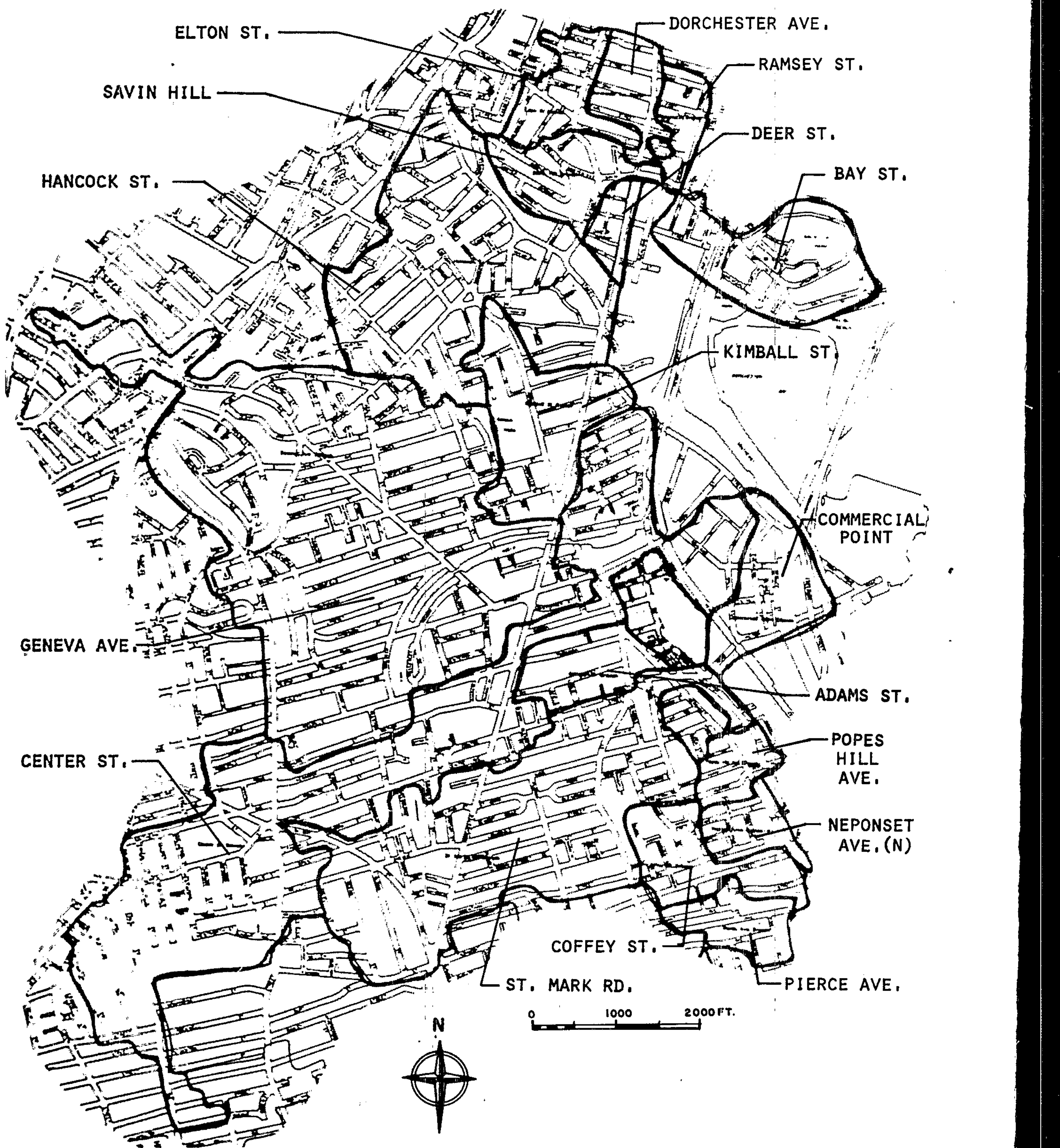


Figure 3. Dorchester Bay Branch area

Table 3 summarizes pertinent data for each branch area as obtained from the PRI report. The location of each branch area is shown in Figure 3. Of the total 1,613 acres sewered, 716 acres have combined sewers and 897 acres have separate sanitary sewers. The total population based on 1970 census data is 55,844 or 34.6 persons per acre. The dry weather flow rate is based on an average of 150 gallons per capita per day (gpcd), derived from dry weather flow monitoring during the period from February to May 1974.

The PRI report presented estimates of the daily solids deposition rate in each branch area, using a shear stress method, for every sewer pipe in the area. This estimate was based on detailed schematics and pertinent pipe characteristics such as pipe size, shape, roughness and slope obtained from street and sewer maps. The collection system was segmented into a sewer element network with each element averaged about 200 feet. The cumulative upstream sewer length for each sewer element was obtained from sewer element connectivity. Using an average population density of 19 persons per 100 feet of sewer and an average suspended solids generation rate of 0.2 lbs/capita/day, the average daily dry weather flow rate and solids loading for each sewer element was estimated. Maximum daily flow rate was related to average daily flow rate by an empirical formula with population as a variable. The daily maximum shear stress of a sewer element was computed from the maximum daily flow rate and assumed to prevail over a daily 24-hour period. The fraction of solids deposition in a given pipe element during a dry day was computed from the maximum pipe shear stress. The amounts deposited were dependent on the shear stress during peak flow and the amount deposited upstream. Applying this deposition model to Dorchester as well as to several other Massachusetts urban areas provided a data base from which Pisano [3] developed regression equations relating solids deposition potential with sewer length, slope, size and per capita water use. Recent field studies using measured sewer strengths and sewer deposit samplings [4] show a fairly good comparison between the predicted and actual deposition.

Based on a dry weather sewage with solids strength of 0.2 lbs per capita per day, the total daily deposition of dry weather flow solids was estimated as 724.6 lbs, of which 526.6 lbs was deposited in separate sanitary sewers and 198.1 lbs in combined sewers. This is equivalent to 6.5 percent of the daily solids generated.

As shown in Table 3, of the 198.1 lbs deposited daily in the combined sewers, 76.9 lbs were deposited in trunk sewers, or about 41 percent of the total. Comparatively, 119.3 lbs out of 526.5 lbs deposited daily in the sanitary sewers are found in the trunk sewers, or about 23 percent of the total. Trunk sewers receive flows from lateral sewers and convey sewage to the downstream interceptors. Trunk sewers are generally larger and laid on a flatter slope than lateral sewers.

TABLE 3. DORCHESTER BAY BRANCH DATA**

Branch	Area (Acres)		Popu-lation	Dry Weather Flow (cfs)	Total Solids Deposition* (lbs/day)		Trunk Sewer Deposition (lbs/day)	
	Separate	Combined			Sanitary Sewer	Combined Sewer	Sanitary Sewer	Combined Sewer
Adam St.	23.2	18.6	1,395	.324	8.1	2.6	0.	1.6
Bay St.	90.0	30.0	4,010	.931	15.1	5.4	2.5	3.9
Centre St.	169.0	145.9	10,514	2.440	201.8	54.0	53.8	18.6
Coffey St.	36.0	0.	1,203	.325	10.1	0.	0.	0.
Commercial Pt.	0.	41.9	1,400	.325	0.	22.4	0.	17.3
Deer St.	8.6	0.	290	.067	10.9	0.	7.6	0.
Dorchester Ave.	3.6	23.3	900	.209	0.	5.7	0.	0.8
Elton St.	10.3	18.0	946	.220	1.6	6.5	3.1	0.1
Geneva St.	213.4	146.9	12,035	2.793	133.8	7.4	36.8	2.2
Hancock St.	113.5	114.7	7,621	1.769	70.1	38.8	1.0	5.3
Kimball St.	0.	64.6	4,100	.952	0.	22.0	0.	11.5
Neponset Ave. (N)	14.7	4.7	647	.150	4.0	3.9	0.	0.
Pierce Ave.	15.7	9.0	827	.192	5.8	.2	0.	0.
Popes Hill Ave.	11.8	3.7	522	.121	.8	1.9	0.	0.
Romsey St.	0.	15.4	515	.120	0.	13.5	0.	11.4
St. Marks Road	185.1	47.7	7,776	1.805	64.4	6.5	14.5	1.2
Savin Hill Ave.	2.5	31.7	1,143	.265	0.	7.3	0.	3.0
	897.4	716.1	55,844	12.962	526.5	198.1	119.3	76.9

* Based on Loading of 0.2 lbs/capital/day
** Data obtained from the PRI Report (5)

Recent extensive field sampling in small upstream laterals in the study area [4] indicated an average solids loading of 0.56 lbs/capita/ day. The deposition model described previously implies that deposition rates are linearly proportional to dry weather solids loadings. Using the measured loading of 0.56 lbs/capita/day, the daily deposition rate in the study area becomes 2,028 lbs/day, with 1,474 lbs/day in sanitary sewers and 554 lbs/day in combined sewers. In Dorchester, practically all separate storm sewers enter combined sewers at some point.

Table 4 shows the cumulative trunk and lateral sewer lengths in the study area. PRI reports 75 percent of the daily accumulations in the Dorchester collection systems are expected in about 18 percent of the pipe components or in about 17 percent of the total pipe length. Deposition data in Table 3 shows that lateral sewers contain roughly two and a half times the deposits in trunk sewers. However, the length of lateral sewers is more than four times that of the trunk. The average solids deposition per foot in trunks is therefore greater than that in laterals. Almost all combined sewer depositions are accounted for in sewers with a deposition rate one lb/day or greater, while only about 50 percent of the deposits in sanitary sewers can be accounted for at that deposition rate. The remaining half of the solids deposition are in sewers with a lower deposition rate. Since about 75 percent of the total deposits are found in sanitary sewers, attempting to reach most of those deposits could require a very extensive flushing program.

According to the PRI Report [5], roof drains from older dwellings in Dorchester are connected to adjacent sewers. Storm runoff has been observed in sanitary sewers. Approximately 20 percent of the representative census tract areas in Dorchester selected for planimetering are covered by rooftops. This study assumed that stormwater drains directly to the adjacent sewer without loss. During a rainfall, the storm runoff entering the sanitary sewers also serves to resuspend and reduce deposited solids and associated pollutants.

TABLE 4. CUMULATIVE PIPE LENGTH OF SEWER SYSTEM (FEET)*

Branch	Trunk Sewer	Lateral Sewers			Total
		Sanitary	Combined	Storm	
Adam St.	1,090	4,530	2,144	-	7,764
Bay St.	2,175	5,980	2,450	-	10.605
Centre St.	14,017	30,272	14,213	3,454	61,956
Coffey St.	-	5,200	-	-	5,200
Commercial Pt.	3,120	-	3,025	-	6,145
Deer St.	1,310	1,800	-	-	3,110
Dorchester Ave.	2,550	-	3,695	-	6,245
Elton St.	2,180	-	4,355	-	6,535
Geneva St.	8,100	32,418	25,279	4,716	70,513
Hancock St.	4,970	11,830	19,010	-	35,810
Kimball St.	2,875	-	8,255	-	11,130
Neponset Ave (N)	-	3,345	920	-	4,265
Pierce Ave.	-	3,075	1,985	-	5,060
Popes Hill Ave.	-	2,155	1,015	-	3,170
Romey St.	1,450	-	815	-	2,265
St. Marks Road	6,176	20,416	8,566	-	35,158
Savin Hill Ave.	1,400	-	5,755	-	7,155
	51,413	121,021	101,482	8,170	282,086

* Data obtained from the PRI Report(5)

SECTION VIII

COMPUTER MODEL REQUIREMENTS

Runoff and CSO from frequent small rainfall events, when allowed to discharge freely to receiving waters, results in major pollution. Since reduction by source control, or containment and treatment of pollutants in the first flush is imperative for pollution abatement, rainfall volume is more significant than precipitation pattern. A single precipitation event cannot determine the effectiveness of pollution control for an alternative. Hence, the continuous simulation approach should be used. The effectiveness of pollution control is measured in terms of percent of runoff treated, the annual number of overflows, and the amount of pollutants discharged to receiving waters.

For a model to determine pollution abatement effectiveness, it should permit:

1. use of continuous precipitation records to obtain the overflow characteristics (both quantity and quality) of the sewer system over a period long enough to provide statistically significant information;

2. simulation of surface runoff quantity and quality using physical and land use parameters;

3. including the effect of dry weather flow quantity and quality during wet weather conditions and pollutant accumulated in the sewer during dry days;

4. evaluating the effect of street sweeping, sewer flushing, storage and treatment on the overflow quantity and quality; and

5. evaluating the pollutant removed at a CSO treatment facility.

None of the existing computer models (7) satisfied all of the above criteria. Modification of these models was required. Of these continuous simulation models, STORM(8) and the continuous version of SWMM (9) are probably the most generally used storm water management models.

SWMM can use the RUNOFF and STORAGE/TREATMENT Blocks for continuous simulation of precipitation records at hourly intervals. It produces comparable output to STORM but is about twice as expensive to run. SWMM can account for flow routing in gutters and pipes, and has better storage/treatment routines than STORM. However, these were not needed in this study. STORM was, accordingly, used as the base model for evaluation of alternative improvements.

STORM uses a simplified rainfall/runoff relationship, neglects the collection sewer system, and assumes a simple relationship between storage and treatment. The study area is characterized as a single catchment from which hourly runoff is directed to storage and treatment facilities. STORM can evaluate various storage/treatment options for stormwater runoff pollution abatement.

Figure 4 shows major processes modeled by the current version of STORM available from the Hydrologic Engineering Center of the U.S. Army Corps of Engineers. The model considers up to 21 land uses in determining runoff and the amount of street dust and dirt and associated pollutants accumulated during dry days. It can reflect the reduction in pollutant accumulation by street sweeping and determines the dust, dirt and pollutants (up to six, including suspended solids and BOD) washed from the watershed by rainfall using empirical functions. The hourly runoff volumes (including municipal sewage at the time of rainfall) less than or equal to the available capacity can be routed to treatment facilities. Excess runoff can be diverted to storage for possible treatment at a later time. Once the storage capacity is exceeded, the excess runoff becomes untreated overflow. Treatment capacity, in excess of that required for dry weather flow treatment, can be used to draw down the volume in the storage facility. The computations of the treatment, storage and overflow processes at a single outflow from the sewer system are performed by volume and pollutant mass balance. The current version of STORM does not allow routing combined sewage through a storage tank before discharge nor does it consider quality improvement in the storage facility.

In this study, STORM was modified to determine the accumulation of solids and organic material deposited in sewers during dry days, the removal of these deposits by sewer flushing and by wet weather flows, and the effect of a CSTP on the wet weather discharge. Figure 5 illustrates the processes modeled by the improved version of STORM.

IMPROVED STORM PROGRAM - FEATURES

Sewer Flushing

Solids and organic materials deposit in sewers during dry days. The amount of deposition in the sewer at the start of a rainfall event depends on the amount remaining at the end of the last rain, the frequency and efficiency of sewer flushing methods, the number of dry days since the last rain, the sewer slope, and the sewage

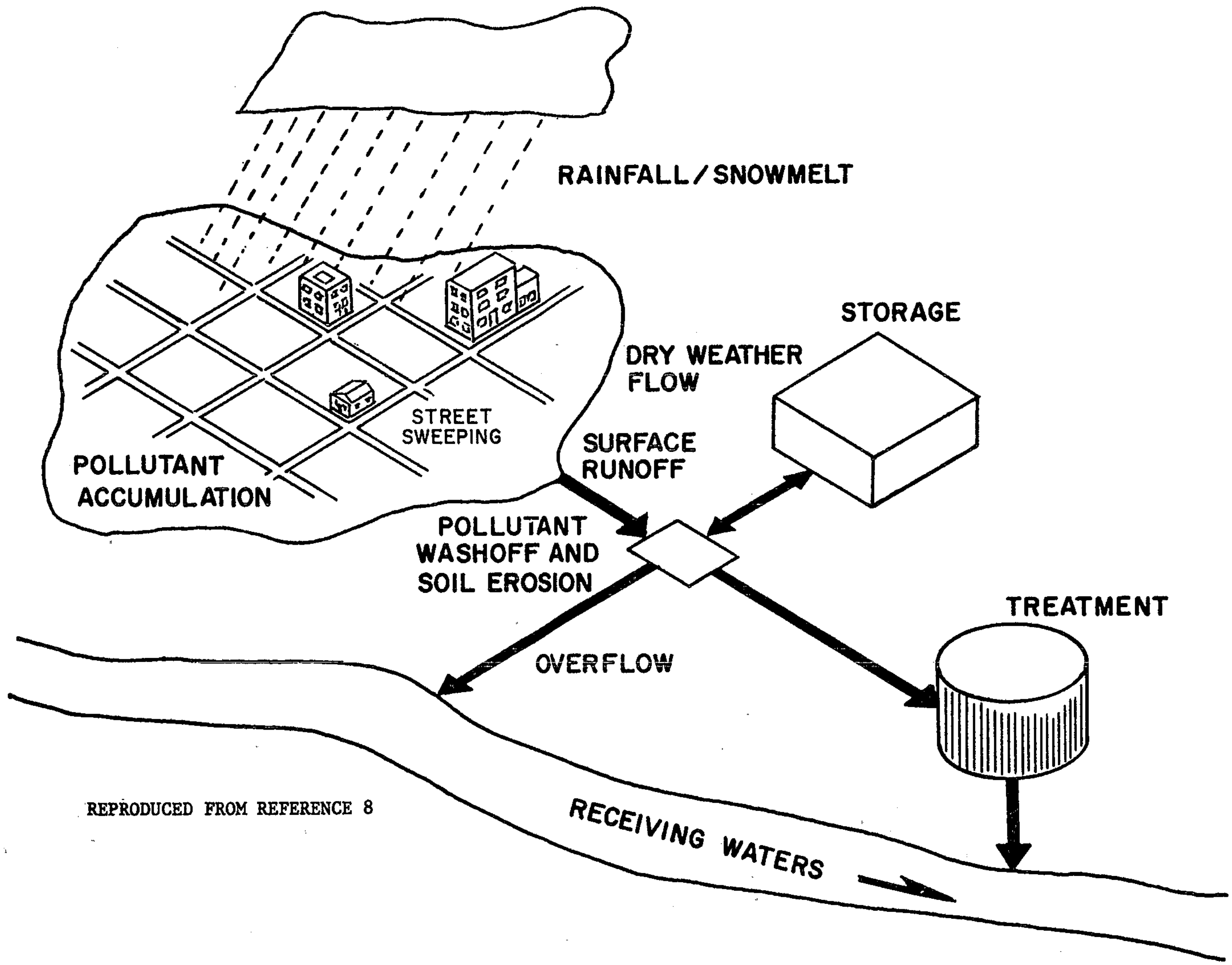


Figure 4. Major processes modelled by STORM

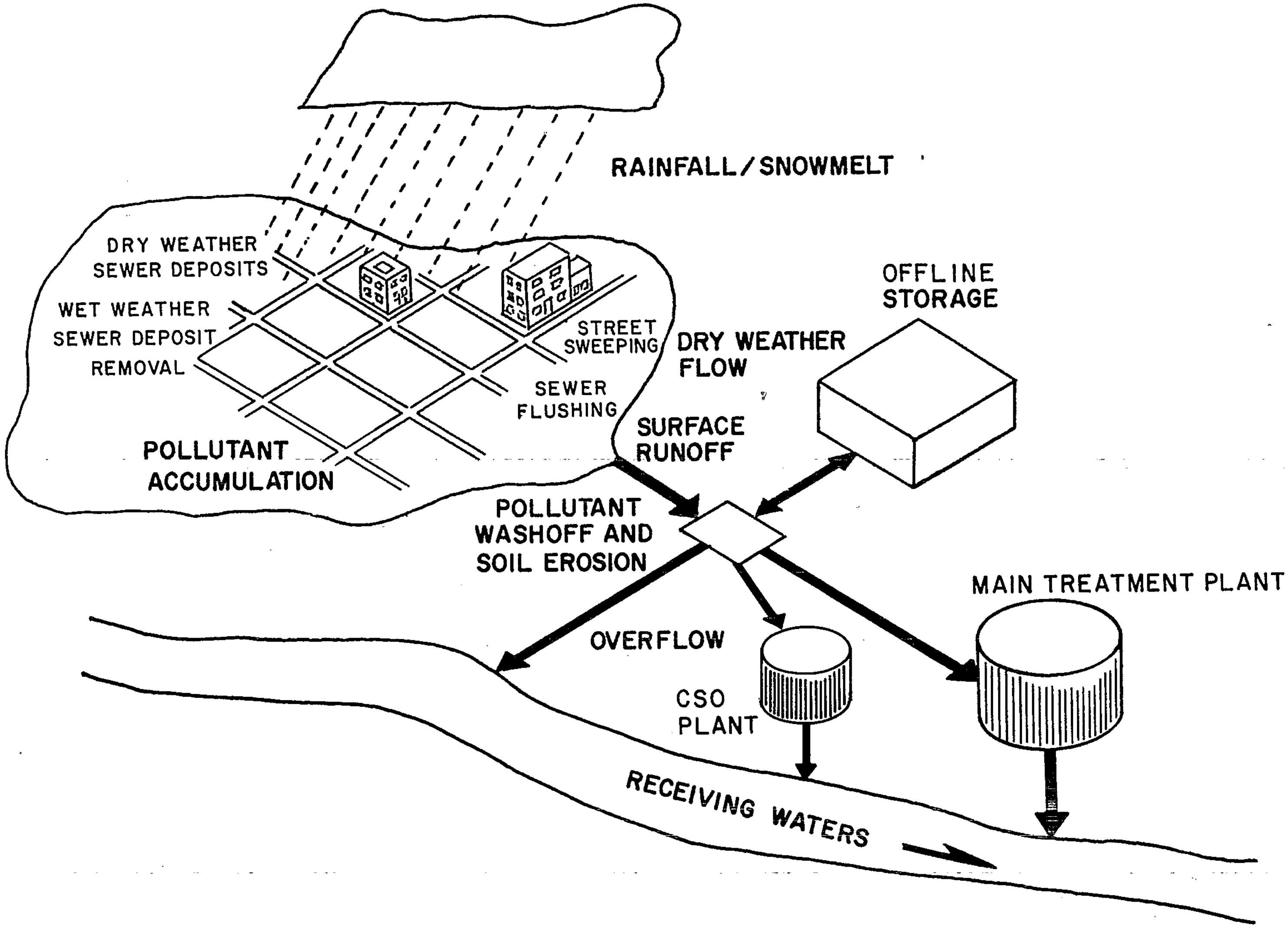


Figure 5. Major processes by the improved STORM

strength and quantity. During wet weather flows, the solids and pollutants resuspended become a part of combined sewage and the amount depends on the initial deposit mass and the driving shear stress generated by the sewer flow velocity. The daily solids deposition can be estimated from a field sampling program or by using the SWMM TRANSPORT Block or by regression equations derived from a follow-up study of the PRI Report [5]. The daily deposition rate of organic material (BOD) can be determined as a fraction of the solid deposition rate estimated from a field sampling program [4] or by calibration using field data [10]. The result of both studies shows that BOD mass equals about 40 percent of the deposited solids.

Sewer flushing methods and efficiency were recently field investigated in Dorchester under an EPA R&D grant study [4]. A solids removal efficiency of 40 percent and BOD removal efficiency of 60 percent were attained in a 12 or 15 inch sewer using a flushing volume of approximately 50 cubic feet, injected at a rate of approximately 0.5 cubic feet per second. These removals were effective for segment length of up to 1000 feet downstream of the flushing station.

The input data required to determine the effect of flushing is shown on Table 5 and includes:

1. separate sanitary sewer area;
2. combined sewer area;
3. solids deposition rate in separate sewer area;
4. solids deposition rate in combined sewer area;
5. fraction of solids deposition contributing to BOD;
6. sewer flushing interval in dry days;
7. fraction of deposition amount in separate sewer area flushed;
8. fraction of deposition amount in combined sewer area flushed;
9. removal efficiency of SS by mechanical sewer flushing;
10. removal efficiency of BOD by mechanical sewer flushing; and
11. minimum wet weather flow rate in sewers resulting in complete removal of solids.

Depression Storage Effect Analysis

STORM was improved by introducing three new variables shown on Table 6; namely, DEPRS, DETIMP and PERNIMP. DEPRS is the depression storage in inches for the pervious area, DETIMP is the same for the impervious area, and PERNIMP is the percent of impervious area that has zero depression storage. PERNIMP was used to determine the direct runoff to sewers. Table 6 also shows other input data for STORM.

Combined Sewage Treatment Plant (CSTP)

The EMMA Alternative 1 includes a new interceptor diverting combined sewage to a new CSTP. The plant provides storage, settling

TABLE 5. INPUT DATA RELATED TO CSO PLANT AND SEWER FLUSHING

```
WET-WEATHER TREATMENT CAPACITY=   497.400  MGD (1)
 TOTAL STORAGE CAPACITY OF THE PRIMARY TREATMENT TANK=     5.080  MILLION GALLONS (1)
  STORAGE CAPACITY OF THE  FIRST BASIN=     0.000  MILLION GALLONS


SIMULATION PERIOD FROM  5 (MONTH) TO 11 (MONTH)


   ***** INPUT DATA RELATED TO SEWER FLUSHING *****
         SEPARATE SEWER AREA =     897.00 ACRES
           COMBINED SEWER AREA =     716.00 ACRES
             DEPOSITION RATE (SEPARATE AREA) =   1474.00 LB/DAY(2)
               DEPOSITION RATE (COMBINED AREA) =     554.00 LB/DAY(2)
                 FLUSHING INTERVAL =  30. DAYS
                   FRACTION OF DEPOSITION IN  SEPARATE AREA FLUSHED =      .350(3)
                     FRACTION OF DEPOSITION IN COMBINED AREA FLUSHED =      .700(4)
                       FLUSHING EFFICIENCY OF SS (MECHANICAL) =      .400
                         FLUSHING EFFICIENCY OF BOD( MECHANICAL)=      .600
                           CRITICAL RUNOFF RATE FOR COMPLETE FLUSHING=      .300 IN/HOUR
                             FRACTION OF BOD/SS IN THE SEWER DEPOSITS =      .400
```

NOTE:

(1) EMMA Alternative 1
(2) Strong sewage strength containing 0.56 lbs/capita/day of solids
(3) 17 flushing stations
(4) 11 flushing stations

TABLE 6. INPUT DATA OF WATERSHED CHARACTERISTICS

WATERSHED DATA

NAMEWS	MXLG	EXPTE	REFF	TRTP	TSURC	IPACUM
BOSTON STUDY	5	2.000	.500	0.00	0.00	1

AREA	RFU	IQU	DVU	DVUMX	WU	POPULA
1613.00	1.00	0	0.00	0.00	0.00	55840.

DAILY EVAPORATION RATES FOR EACH MONTH,JAN-DEC IN INCHES/DAY
.08 .07 .11 .14 .22 .27 .33 .29 .20 .17 .09 .08

LOSSEQ	CPERV	CIMP	DEPRS	DETIMP	PERNIMP	EERC	EPRC
1	.15	.90	.250	.063	.20	0.0	0.0

INPUT DATA DESCRIBING LAND USE AND POLLUTANTS

LNDUSE	PRCNT	FIMP	STLEN	NCLEAN	DD	POUNDS POLLUTANT PER 100LB DD					BMPN/100LB DD
						SUSP	SETL	BOD	N	PO4	COLI
SINGLE	.2	50.0	300.0	10	1.50	100.000	10.000	3.000	.048	.005	59.0
MULTPL	74.0	70.0	300.0	10	3.00	100.000	10.000	3.000	.048	.005	59.0
COMMCL	12.8	80.0	300.0	10	5.00	100.000	10.000	3.000	.048	.005	59.0
INDSTL	.5	80.0	300.0	10	7.00	100.000	10.000	3.000	.048	.005	59.0
OPEN--	12.5	20.0	300.0	10	2.00	100.000	10.000	3.000	.048	.005	59.0

COMPUTED RUNOFF COEFFICIENT FOR WATERSHED IS .63780

FRACTION OF WATERSHED THAT IS IMPERVIOUS IS .6504 after its storage volume is filled, and chlorination of overflows. The plant includes two basins. The first basin can serve as a holding tank and the second as a flow-through tank or both can serve as flow-through tanks. At the end of a rainfall event, waste remaining in the basins is returned to the interceptor for treatment along with the dry weather flow.

Pollutants removed, by settling in the plant after storage was filled, was modeled after a study presented in Water and Wastewater Engineering (11). The fraction of the initial SS loading of a slug removed is a function of the detention time of that slug, as shown in Figure 6. The removal function has the following expression:

$$\% \text{ SS removal} = 0.68 \, (1 - e^{-1.2528 \times DT})$$

where DT is the detention time in hours. The older version of SWMM used this formula for estimating removal efficiency of a sedimentation tank. The new SWMM version, while using the same formula, allows coefficients to be varied. Based upon the ratios shown in Figure 6, the percent removal of BOD is taken as 55 % of the suspended solids removed. The amount of pollutant removed by settling is small, if any, compared to that removed by the storage phase. At the design detention period of 15 minutes, the theoretical removals of BOD and SS by settling are 10 and 18 percent, respectively.

An alternative formula that is used is (22)

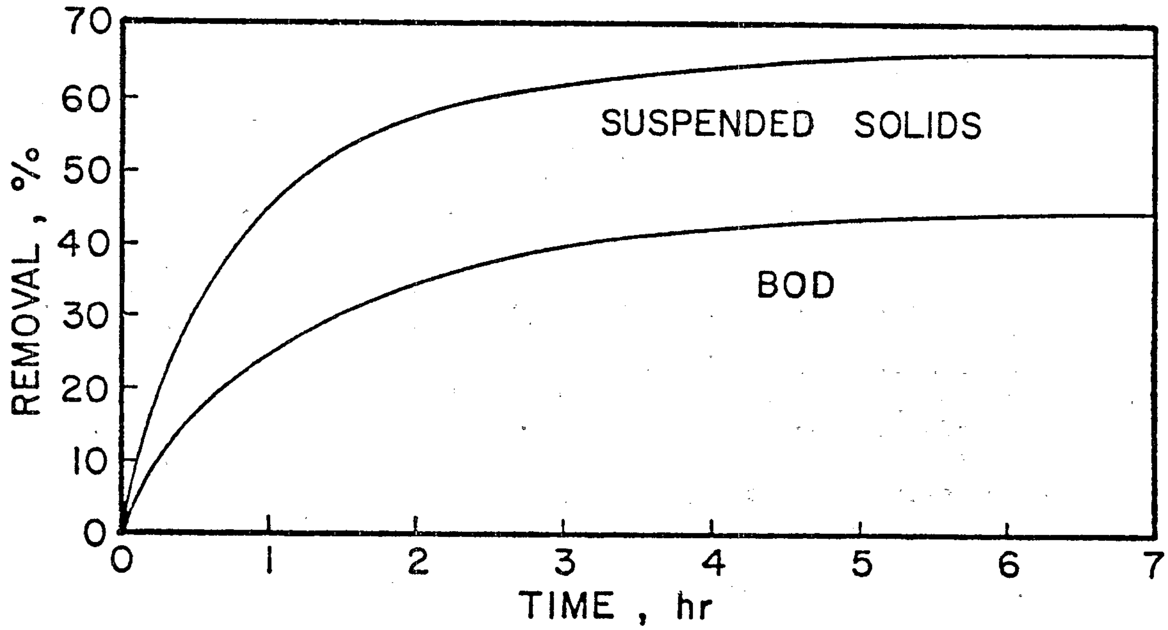
$$\% \text{ removal} = 0.82 \, e^{-\frac{\text{overflow rate}}{2780}}$$

where the overflow rate is in gallons per day per square feet. For a detention time equal to or greater than 1 hour, the difference in removal rates computed by the two formulae is small. Greater differences occur when the detention time is 30 minutes or less. However, the accuracy of any formula at such high loading rates is questionable. Further, since a smaller amount of pollutant is removed at the higher flows or shorter detention times, either formula should provide similar results using the long-term rainfall records.

The input data required relative to combined sewage treatment facilities are:

1. CSTP capacity;
2. total storage capacity of the treatment tank; and
3. storage capacity of the first holding basin.

The storage capacity of the second flow-through basin is the difference between items (2) and (3) above. By modifying the storage capacity in the two basins, the model can simulate the following conditions:



REPRODUCED FROM REFERENCE 12

Figure 6. Pollutant removal in a storage unit as a function of detention time

(i) one storage-settling tank with capacity equalling the total tank capacity; and

(ii) one storage basin and one storage-settling basin.

EMMA Alternative 1 for Facility No. 9 proposes a primary treatment plant tank capacity of 5.08 Mgal. Simulation over a 16-year continuous rainfall record indicates that, for this capacity, one storage-settling tank would result in less pollutant discharged than two basins divided equally between storage and storage-settling. This study assumed the CSTP would be operated as one storage-settling tank.

Part Year Modeling

STORM was also modified to do continuous simulation over a period equaling a part of the year instead of 12 months as in the original program. This allows flexibility for water quality studies in areas such as the Dorchester Bay where the critical period, as far as water quality is concerned, is during the recreational season. This season is from May through November (see Table 5). Statistical summaries of rainfall, runoff, and combined sewage and CSO quantity and quality are for that period.

For evaluation of alternatives, the relevant information included in the STORM output is shown on Table 7. The data are the average values over the number of simulation years. Throughout this study, the "annual" duration encompasses only the period from May through November unless otherwise specified. The additional data printed include:

1. total volume and pounds of dry weather flow contributing to combined sewage but excluding those pollutants resuspended from sewers during wet weather;

2. total volume and pounds of combined sewage diverted to the main STP;

3. total volume and pounds of combined sewage diverted to the CSTP;

4. total volume and pounds, out of (3) above, captured in the first and second basins of the CSTP for later return to the interceptor for treatment at the main STP;

5. total volume and pounds of combined sewage overflowed from the CSTP;

6. total volume and pounds of combined sewage remaining in the offline storage at the end of a rainfall event to be diverted to the main STP;

TABLE 7. AVERAGE ANNUAL STATISTICS* OF QUANTITY AND QUALITY ANALYSIS

	SUSP	SETL	BOD	N	PO4	COLI++
TOTAL POUNDS WASHOFF FROM WATERSHED AND DRY-WEATHER FLOW	3545607	223905	756038	180696	25799	270462695
TOTAL POUNDS OVERFLOW TO RECEIVING WATER	44078	6834	5758	2156	218	97538
CONCENTRATION OF POLLUTANTS IN OVERFLOW TO RECEIVING WATER (MG/L)	1130.16	175.22	147.64	55.28	5.59	5516.258
FRACTION OF TOTAL LOAD OVERFLOWING TO RECEIVING WATER	.012	.031	.008	.012	.008	.0004
FRACTION OF TOTAL LOAD INITIALLY OVERFLOWING TO RECEIVING WATER	.012	.031	.008	.012	.008	.0004
TOTAL POUNDS OF DRY-WEATHER FLOW DURING RAINFALL PERIOD	276003	6666	220854	33116	11037	268751190
TOTAL POUNDS OF POLLUTANT CAPTURED BY EXISTING STP	794906	36080	269758	46900	9778	177371539
TOTAL POUNDS OF POLLUTANTS CAPTURED BY NEW STP	2706612	180958	480468	131640	15804	92993614
TOTAL POUNDS INTERCEPTED IN THE 1ST BASIN OF STP TANK	0	0	0	0	0	0
TOTAL POUNDS INTERCEPTED IN THE 2ND BASIN OF STP TANK	1440708	0	232029	0	0	0
TOTAL POUNDS OVERFLOWED FROM NEW PRIMARY STP TANK	1265903		248439			
TOTAL POUNDS REMAINING IN THE OFFLINE STORAGE=	0	0	0	0	0	0

TOTAL WET-WEATHER FLOW CAPTURED BY EXISTING STP	=	5.806 INCHES	OR	254.31	MILLION GALLONS
TOTAL WET-WEATHER FLOW CAPTURED BY NEW PRI. STP	=	11.668 INCHES	OR	511.10	MILLION GALLONS
TOTAL DRY-WEATHER FLOW CAPTURED DURING WET PERIOD	=	3.020 INCHES	OR	132.30	MILLION GALLONS
TOTAL VOLUME CONTAINED IN THE FIRST BASIN	=	0.000 INCHES	OR	0.00	MILLION GALLONS
TOTAL VOLUME CONTAINED IN THE SECOND BASIN	=	3.999 INCHES	OR	175.17	MILLION GALLONS
TOTAL VOLUME CONTAINED IN THE OFFLINE STORAGE	=	0.000 INCHES	OR	0.00	MILLION GALLONS
TOTAL VOLUME OVERFLOWED FROM THE PRIMARY STP	=	7.669 INCHES	OR	335.93	MILLION GALLONS

TOTAL NUMBER OF FLUSHES ANNUALLY	=	0	
SS REMOVED DURING DRY-DAY FLUSHES	=	0	POUNDS
BOD REMOVED DURING DRY-DAY FLUSHES	=	0	POUNDS
SS FLUSHED DURING WET-DAY	=	389364	POUNDS
BOD FLUSHED DURING WET-DAY	=	155745	POUNDS

++ COLIFORM TOTALS IN BILLION MPN,
AND CONCENTRATION IN 10**3 MPN PER LITER

* For the period from May through November in this study

7. total number of times that sewers are mechanically flushed;

8. pounds of suspended solids and BOD removed during dry weather flushes; and

9. pounds of suspended solids and BOD in the sewer deposits resuspended by stormwater runoff and contributing to the combined sewage.

The above information identifies the principal sources of pollutant contribution. Pollution abatement strategy can be determined on a quantitative basis.

SECTION IX

MODEL INPUT DATA

Input data to STORM includes (a) meteorological data for continuous long-term rainfall-runoff simulation, (b) watershed characteristics which include parameters for surface runoff and pollutant loading computation, land use, dry-weather flow, evaporation rate, solids and associated pollutants deposition rates, and sewer flushing and street cleaning practices.

LONG-TERM METEOROLOGICAL DATA

An historical record, spanning 1960-1975, was used to develop rainfall-runoff characteristics of the study area for the period of May through November. Such records are available at the Logan Airport weather station and Blue Hill Observatory. Statistical analysis of rainfall records at these two stations were presented in the PRI Report.(5) The average antecedent dry days and the average rainfall intensity are about the same at each station and are, respectively, four days and 0.08 inches/hour. The average rainfall duration at the Blue Hill Station is 7.0 hours or 1.3 hours longer, and average rainfall per storm is 0.52 inches or 0.09 inches greater than those recorded at the Logan Airport Station. Because the Blue Hill station is closer to the study area and is about as far inland as the study area, its records were used. The ongoing CSO Facility Plans also use the Blue Hill Station records.

The amount of rainfall from May through November, averaged over the 16-year period used, is 28.26 inches. Table 8 shows the amount of annual precipitation from May through November. The period includes two record wet years (1972 and 1975) when rainfall was about 145 percent of average; two record drought years (1964 and 1965) when rainfalls were about 55 percent of average; one year (1962) when rainfall was about 122 percent of average; one year (1971) when rainfall was about 82 percent of average; and ten years when rainfall was within plus or minus 10 percent of average. Because rainfall, runoff and combined sewage overflow characteristics are affected by three extremely variable inputs, namely, the antecedent dry period, rainfall intensity and duration, the period selected for simulation should exhibit as many combinations of these random variables as possible. The period of 1960 through 1975 appears to fit this criterion well.

TABLE 8. PRECIPITATION, MAY THROUGH NOVEMBER

Year	Precipitation Inches	Percent of Average
1960	24.90	94.7
1961	28.82	109.7
1962	32.18	122.4
1963	25.68	97.7
1964	14.82	56.4
1965	13.98	53.2
1966	23.92	91.0
1967	27.66	105.3
1968	24.84	94.5
1969	25.91	98.6
1970	27.24	104.3
1971	21.57	82.1
1972	38.04	144.7
1973	27.49	104.6
1974	25.02	95.2
1975	38.40	146.1

Average = 26.28 Inches

Figure 7 shows the cumulative probability distributions of rainfall durations and antecedent dry periods as obtained from the PRI reports. These distributions were derived from the observed hourly rainfall data at the Blue Hill Station for a period of 1958 to 1972 from May through November. The same type plots for rainfall intensity and total rainfall per storm event are given in Figure 8. Using these figures, the one-year storm (Figure 2) used to design the EMMA Alternative 1 can be related to the observed rainfall data as follows:

1. The rainfall amount of 1.78 inches is exceeded about 4 percent of the time.

2. The rainfall duration of six hours is exceeded 40 percent of the time.

3. The seven antecedent dry days are exceeded about 18 percent of the time.

4. The maximum hourly intensity of 0.98 inches is exceeded less than 2 percent of the time.

A single precipitation event cannot determine the pollution control effectiveness of an alternative. Hence a facility designed using a hypothetical storm should be evaluated using a continuous

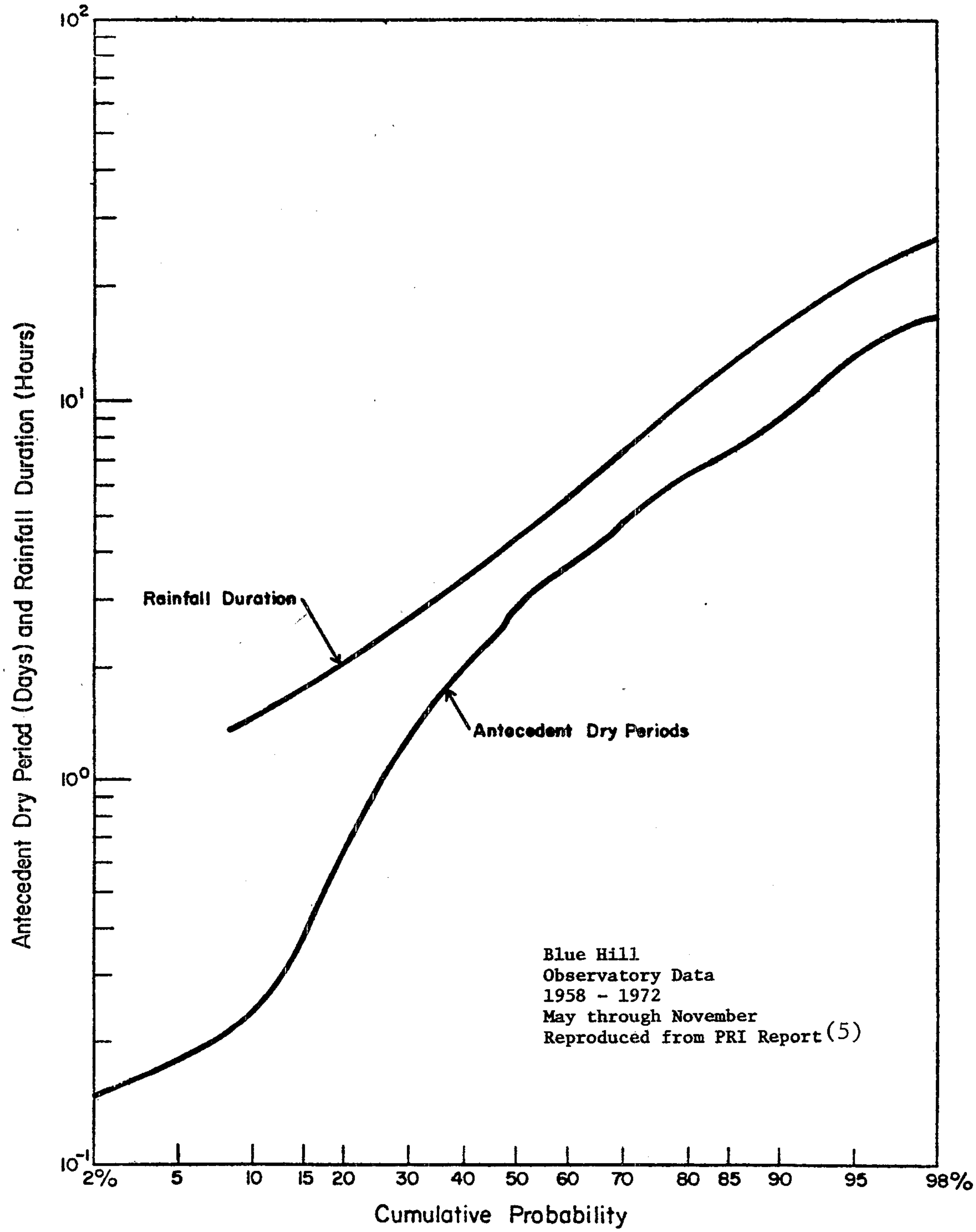


Figure 7. Cumulative probability plots of rainfall duration and antecedent dry periods

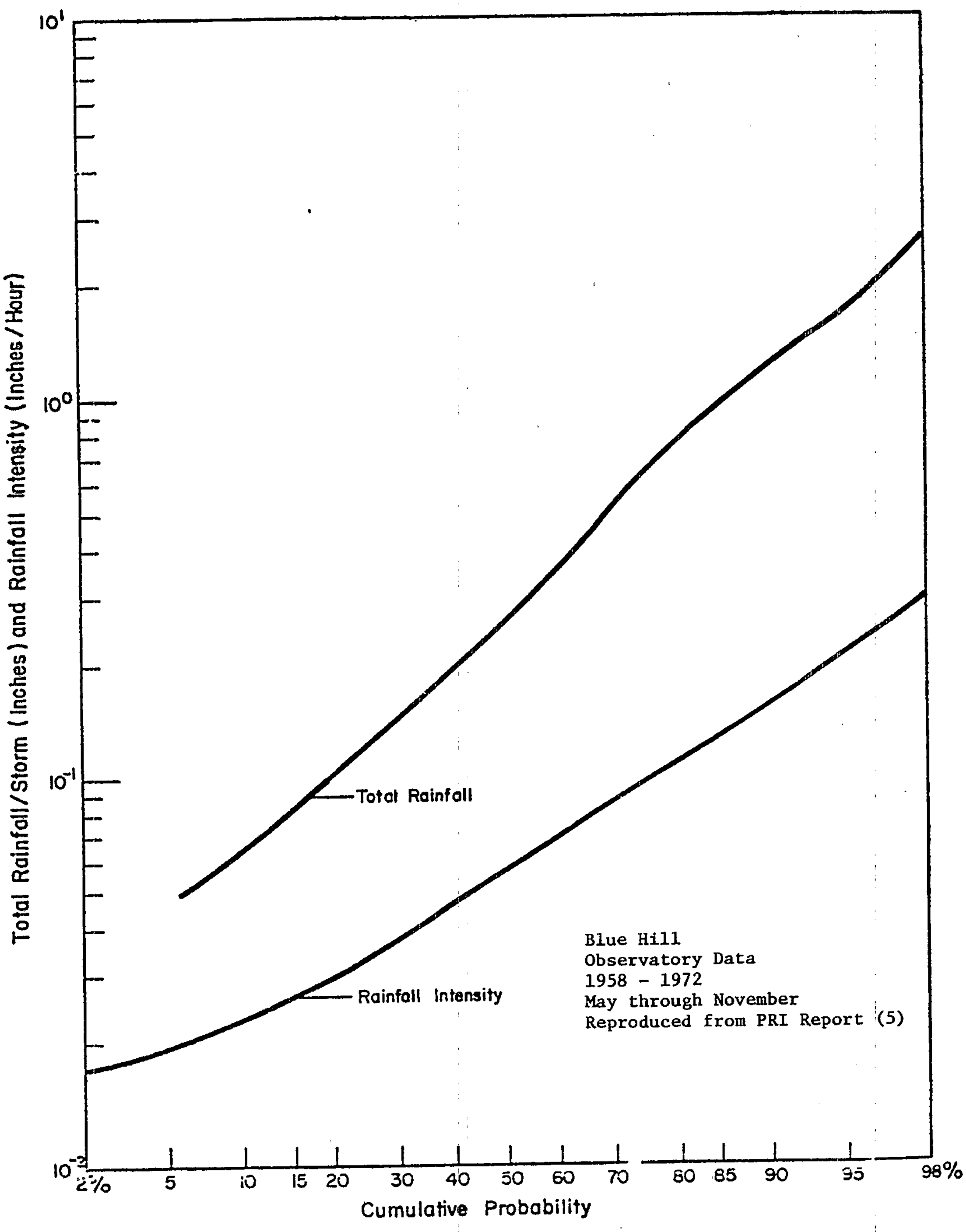


Figure 8. Cumulative probability plots of rainfall amount and intensity.

simulation model and real rainfall events. Based on such an evaluation, this design storm appears very conservative for evaluating pollution control benefits.

WATERSHED CHARACTERISTICS

STORM can now analyze only one watershed at a time. It cannot automatically transfer computed outflow quantity and quality data from an upstream to downstream watershed. For this reason, the entire study area has been considered as one watershed. Data required for STORM, therefore, should represent the gross values over the entire study area.

Data required for the STORM program, in addition to that previously described, includes:

1. <u>Land Use and Pollutant Loadings</u>

CDM furnished land use data. The area and percent distribution of land uses and percent imperviousness are summarized in Table 9 for Overflow Numbers 100 and 103, which receive drainage from the study area. The values for Overflow Number 103 were used throughout the study. These numbers are shown as PRCNT on Table 6. For comparative analyses, these numbers, if within a reasonable range, should not affect the validity of the conclusions reached. The percent imperviousness for single family, multiple family, commercial, industrial and open space are assumed to be 50, 70, 80, 80 and 20, respectively, and are shown in Table 6 under FIMP. These values appear reasonable and about 65 percent of the watershed area is impervious. In computing surface runoff by STORM only the average value is significant.

Input data required for computing pollutants generated in the watershed during dry days include density of curb length (STLEN), dust and dirt accumulation rate (DD), conversion rates to compute pollutant components from DD, street sweeping interval (NCLEAN), and street sweeping efficiency (REFF). None of the above for the Dorchester area was available at the time of this study, therefore it is necessary to make reasonable assumptions and evaluate their effects on the end result.

The density of curb length is assumed as 300 feet per acre for all land uses. This is the average value found in the ongoing CSO facilities plan study in Elizabeth, New Jersey, with a population density about the same as that in Dorchester. Compared to the national average[13], it is low for residential and commercial areas and high for industrial areas and open spaces. The dust and dirt accumulation rates and conversion factors to calculate SS and BOD in dust and dirt are also borrowed from the Elizabeth study[10]. These values were obtained from a calibration of SWMM parameters using around ten sets of rainfall-runoff quantity and quality data sampled at 7.5 minute intervals. For

TABLE 9. LAND USE AND PERCENT IMPERVIOUS FROM CDM

Overflow No. CDM	Overflow No. EMMA Study	Total Area (acres)	% Impervious	Single Family[1]	Multiple Family[2]	Commercial[3]	Industrial	Open Space[4]
100	50 & 67	508	80	-	66.7	15.7	5.9	11.7
103	49	1,227	65	0.2	74.0	12.8	0.5	12.5
Total		1,735						

(1) 1-2 dwelling units per acre
(2) >5 dwelling units per acre
(3) includes institutional land use
(4) includes parks, cemeteries, major transportation, open and public lands

Elizabeth, the SS and BOD accumulation rates are about 10 and 0.3 lbs/acre/day. The BOD rates are comparable to those reported in Milwaukee, Washington and Seattle[14], all comparable in population density. The conversion factors for settleable solids, total nitrogen, phosphate and total coliform were not calibrated in the Elizabeth study. The values shown are the default values internally assumed in both SWMM and STORM. This study considers SS and BOD in the evaluation of pollutant removal. It is assumed, based on other tests, all discharges during the recreation period will require disinfection. Other pollutants were not included.

Street sweeping interval was assumed as ten dry days. According to Figure 7, only about ten percent of the dry periods equals or exceeds ten days. This implies that the street sweeping activity is not intensive, which is typical in most old urbanized areas. The sweeping efficiency is assumed to be 50 percent which has been shown to be high considering the parked car problem and contribution of pollutants from areas other than the streets.

2. <u>Depression Storage, Recovery Rates and Runoff Coefficients</u>

The depression storage for pervious area (DEPRS) and that for impervious area (DETIMP) is assumed to be 1/4 and 1/16 inch respectively. Unlike the original STORM program, which requires a single depression storage capacity averaged over the entire drainage area, the modified program requires both DEPRS and DETIMP and computes the average storage capacity internally.

STORM allows depression storage to recover to its maximum capacity at a constant rate to account for evaporation. The recovery rates for each month were computed using the Meyer formula which expresses the evaporation rates as an empirical function of air vapor pressure and wind speed, all monthly averaged. Table 10 shows the data required for calculating recovery rates.

Runoff coefficients for the pervious area (CPERV) and for the impervious area (CIMP) are assumed to be the same as those internally assumed in STORM and are 0.15 and 0.90, respectively. The surface runoff is computed by applying these coefficients to the effective rainfall and represents all losses other than depression storage.

DRY-WEATHER FLOW AND POLLUTANT LOADING

As shown in Table 3, the average dry-weather flow is 12.96 cfs, based on an average per capita contribution of 150 gallons per day obtained from field monitoring in 1974 [5]. Both the quantity and quality of dry-weather flow generally vary with the hour of the day and the day of the week. For this study, it was assumed that hourly

TABLE 10. MONTHLY EVAPORATION RATES

Month	Mean Air Temperature (Degrees F)	Relative Humidity (Percent)	Wind Speed (mph)	Evaporation Rate (in/day)
January	27.3	55	14.5	.075
February	29.2	62	14.3	.074
March	36.8	65	14.3	.108
April	47.0	70	13.9	.163
May	56.9	76	12.8	.216
June	67.8	81	11.7	.272
July	73.3	82	11.7	.331
August	71.9	83	11.6	.289
September	64.4	84	11.4	.203
October	54.7	79	12.4	.172
November	43.7	82	12.9	.085
December	33.6	68	14.0	.082

variations are the same for any day of the week as shown in Table 11.

The hourly variations of dry-weather flow rates were derived from field data furnished by CDM. The field data were obtained in September and October of 1978 at three sampling points in Dorchester and three in South Boston, all using Manning level recorders. The sampling stations in Dorchester include Victory Road near the Dorchester Interceptor; Geneva Avenue near Tonawanda Street; and Bay Street near Maryland Street. The three stations in South Boston include Mt. Vernon near Southeast Expressway; Sidney Street near Dorchester Interceptor; and K Street near Marine Street.

The average daily concentrations of pollutants in the wastewaters adopted for long-term simulation are shown in Table 12 and are consistent with the lower sewage strength used in this report. Only suspended solids and BOD were used for evaluation of alternatives. These pollutant concentrations are classified as "medium" according to an EPA study report [15]. They are more representative of sewage strength reaching the sewage treatment plant than the sewage strength at the source of origin. Because of deposition of solids in sewers and dilution resulting from infiltration/inflow, the sewage strength may be reduced as sewage travels downstream. Recent field sampling at four upstream sewers in Dorchester [4] indicates the mean SS concentration can be as high as 1800 mg/l and mean BOD about 1000 mg/l. The average per capita suspended solids contribution of four sampling stations is 0.56 lbs/day. Using the SS strength of 250 mg/l and 150 gallons per capita per day of waste flow, the daily SS rate is 0.313 lbs/capita/day. The actual sewage solid concentration could be within these ranges. Using the SS rate of 0.313 lbs/capita/day, the daily solid deposition the study area becomes 1134 lbs/day, with 824

Table 11. DIURNAL VARIATION OF DRY-WEATHER FLOW

Hour	Flow/Average*	Flow (cfs)
1	.900	11.65
2	.865	11.20
3	.850	11.00
4	.845	10.94
5	.855	11.07
6	.885	11.46
7	.930	12.04
8	1.030	13.34
9	1.070	13.85
10	1.080	13.98
11	1.080	13.98
12	1.070	13.85
13	1.040	13.47
14	1.030	13.34
15	1.020	13.21
16	1.020	13.21
17	1.030	13.34
18	1.050	13.60
19	1.070	13.85
20	1.080	13.98
21	1.080	13.98
22	1.060	13.73
23	1.010	13.08
24	.950	12.30

*Average flow rate = 12.96 cfs

TABLE 12. AVERAGE DAILY POLLUTANT CONCENTRATION OF DOMESTIC WASTEWATER

Pollutant	Concentration
Suspended solids	250 mg/l
BOD	200 mg/l
Settleable solids	6 ml/l
Total nitrogen	30 mg/l
Total Phosphate	10 mg/l
Total coliform	5.37×10^7 MPN/100 ml

lbs/day in separate sanitary sewers and 310 in combined sewers. The effect of using the deposition rates based on 0.56 and 0.313 lbs/capita/day are evaluated.

With a sewage strength of 250 mg/l for SS and 200 mg/l for BOD, the average daily SS load is 17,458 lbs and BOD load is 13,967 lbs. These are part of input data to STORM.

Interceptor should be designed with capacity at least equal to the peak dry-weather flow of the drainage area served. For the evaluation of alternatives, interceptor capacity is assumed as equal to the peak flow. Harmon's ratio [16] is used to determine the peak flow rate:

$$\frac{M}{Q} = 1 + \frac{14}{4 + \sqrt{P}}$$

where:

M = the instantaneous peak flow
Q = the average daily domestic flow
P = the tributary population in thousands.

For an estimated population of 55,844, the ratio of peak to average flow is 2.2 and the peak dry-weather flow rate equal to 18.58 mgd.

SECTION X

DEVELOPMENT AND EVALUATION OF ALTERNATIVES

Alternatives for CSO pollution abatement can include: (1) sewer flushing; (2) storage by flow routing in pipes or in off-line basins; (3) treatment; or (4) a combination of several. The cost and pollutant removal effectiveness of the alternatives developed are compared with that of EMMA Alternative 1.

DEVELOPMENT OF SEWER FLUSHING ALTERNATIVE

From the PRI Report and recent field study report in Dorchester [4], the following is observed:

1. Seventy-five percent of sewage solids deposits in Dorchester occur in 17 percent of the sewer length.
2. Sewer flushing for pollution control purposes is effective. Beyond 1000 feet SS tend to resettle and the removal rate is greatly reduced; however, organics and nutrients are conveyed much further. Thirty-three, 50, and 60 percent of the BOD, Total Kjeldahl Nitrogen, Total Phosphorus, respectively are estimated to remain in suspension 3000 feet from the point of flush.
3. Because a significant portion (33-45 percent) of the BOD would remain in suspension after flushing, BOD removal rate is greater than SS removal rate.
4. Smaller lateral sewers may contain more deposits than the trunk sewers but have a disproportionatly greater length, thus trunk sewers have greater deposition rates per unit length.
5. Available experimental data applies to flushing 12-inch and 15-inch sewers. In these instances, flushing volumes of approximately 50 cubic feet discharged at the rate of approximately 0.5 cfs would effectively flush the sewers. Shear stress computations indicate larger flow volumes may be required to flush larger sewers. Field demonstrations in larger size sewers appear desirable.

In the Dorchester area sewer flushing, to be effective, should concentrate on moderate to heavy deposition areas. For a long lateral sewer, sequential flushing may be required to transport solids and its associated pollutants to reach trunk sewers.

In developing alternatives, flushing locations have been selected to the extent possible on the lateral sewers. Locations, however, have also been selected in some smaller sized combined sewers. Pending demonstration to define the criteria for flushing such sewers, the estimates of the benefits of flushing might be overstated. Because of the feasibility of flushing large size sewers demonstrated in Detroit (19), the amount of overstatement should not significantly effect the conclusions in this report.

Tables 13 and 14, respectively, rank sanitary and combined sewer segments with deposition rates greater than or equal to 3.0 lbs/day. Figure 9 shows both these heavy deposition segments and strategic flushing locations. There are 28 flushing locations shown; 11 in combined sewer segments and 17 in sanitary sewer segments. Flushing at 11 locations would resuspend a part or all pollutants in 14 deposition segments or at least 137.8 lbs out of 198.1 lbs of solids deposited daily in the combined sewers, or about 70 percent. Flushing at 17 sanitary sewer segments would affect 20 deposition segments or at least 172 lbs out of 526.5 lbs deposited daily, or about 35 percent of the total deposited in sanitary sewers. These deposition rates were computed based on the SS generation rate of 0.2 lbs/capita/day. At higher SS generation rates, which have been observed, sewer flushing could be proportionately more effective.

Table 15 summarizes, for both combined and sanitary sewers, the number of deposition segments, cumulative deposition rates of these segments and percent of total solids deposition segments with deposition rate equal to or greater than 2.0, 1.5 and 1.0 lbs/day. The results are plotted in Figure 10. The benefit of sewer flushing beyond 28 flushing stations becomes increasingly more marginal as the solids flushed per station reduces rapidly. For this study, the 28 flushing locations shown on Figure 9 have been used to evaluate the effects of alternatives involving sewer flushing for comparison with the EMMA Alternative 1 and storage. Flushing alternatives, with the number of flushing segments both greater and less than 28, were also considered to evaluate the cost-effective number of flushing stations for the Dorchester area.

DEVELOPMENT OF STORAGE ALTERNATIVE

STORM can consider only one storage facility at a time. STORM assumes this storage to be downstream near the interceptor system. However, the location of storage within reasonable restraints, i.e., receiving runoff from perhaps 70 percent of the watershed, is not critical.

In the PRI Report, 11 potential upstream and two potential downstream storage locations were identified. These locations are shown in Figure 11. The potential upstream storage capacity totals about 50 million gallons and the downstream storage about 17.3 million gallons. Fifty million gallons of storage is equivalent to 1.15 inches of water depth over the entire watershed and 17.3 million gallons

TABEL 13. SANITARY SEWER SEGMENTS RANK BY DEPOSITION RATE

Rank	Branch Area	Street Name	Deposition Rate (Lbs/Day)	Sewer Slope	Sewer Size (inches)	Lateral or Trunk
1	Centre St.	Norfolk	28.3	.0006	30 x 36 oval	T
2	Centre St.	Talbot	28.2	.0003	36 x 48 egg	L
3	Centre St.	Talbot	18.2	.0007	36 x 48 egg	L
4	Centre St.	Southern	16.9	.0004	12 circ.	L
5	Geneva Ave.	Park	8.9	.0019	18 circ.	L
6	Centre St.	Stanton	8.1	.0007	12 circ.	L
7	Geneva Ave.	Park	7.4	.0012	27 x 35 egg	T
8	St. Marks Rd.	St. Marks	6.7	.0010	40 x 60 egg	T
9	Centre St.	Wainright	6.4	.0008	30 x 36 oval	L
10	Geneva Ave.	Geneva	6.4	.0016	27 x 35 egg	T
11	Centre St.	Centre	4.5	.0005	26 x 48 egg	T
12	Centre St.	Wainright	4.0	.0008	30 x 36 oval	L
13	Deer St.	Dorchester	4.0	.0013	15 circ.	T
14	Geneva Ave.	Josephine	3.8	.0016	12 circ.	L
15	St. Marks Rd.	Roseland	3.8	.0019	48 circ.	L
16	Geneva Ave.	Easement	3.6	.0019	24 circ.	L
17	Centre St.	Torrey	3.3	.0019	15 circ.	L
18	Centre St.	Southern	3.2	.0016	15 circ.	L
19	Geneva Ave.	Washington	3.2	.0025	15 circ.	L
20	Coffey St.	Coffey	3.1	.0017	15 circ.	T

TABLE 14. COMBINED SEWER SEGMENTS RANK BY DEPOSITION RATE

Rank	Branch Area	Street Name	Deposition Rate (Lbs/Day)	Sewer Slope	Sewer Size (inches)	Lateral or Trunk
1	Hancock St.	Hancock	59.5	.0004	24 x 31 oval	L
2	Centre St.	Centre	11.9	.0004	36 x 48 egg	T
3	Geneva Ave.	Geneva	11.6	.0010	18 circ.	T
4	Centre St.	Washington	10.1	.0006	20 x 26 oval	L
5	Romsey St.	Sagamore	8.3	.0010	20 x 26 oval	T
6	Kimball St.	Adams	5.9	.0041	16 x 20 egg	T
7	Commercial Pt.	Freeport	5.4	.0014	15 circ.	T
8	Centre St.	Adams	4.5	.0010	32 x 42 egg	T
9	Centre St.	Washington	4.0	.0011	20 x 26 oval	L
10	Neponset Av.(N)	Boutwell	3.6	.0020	12 circ.	T
11	Centre St.	Dunbar	3.5	.0014	12 circ.	L
12	Hancock St.	East	3.4	.0018	12 circ.	L
13	Centre St.	Centre	3.1	.0006	36 x 48 egg	T
14	Kimball St.	Leedsville	3.0	.0005	12 circ.	L

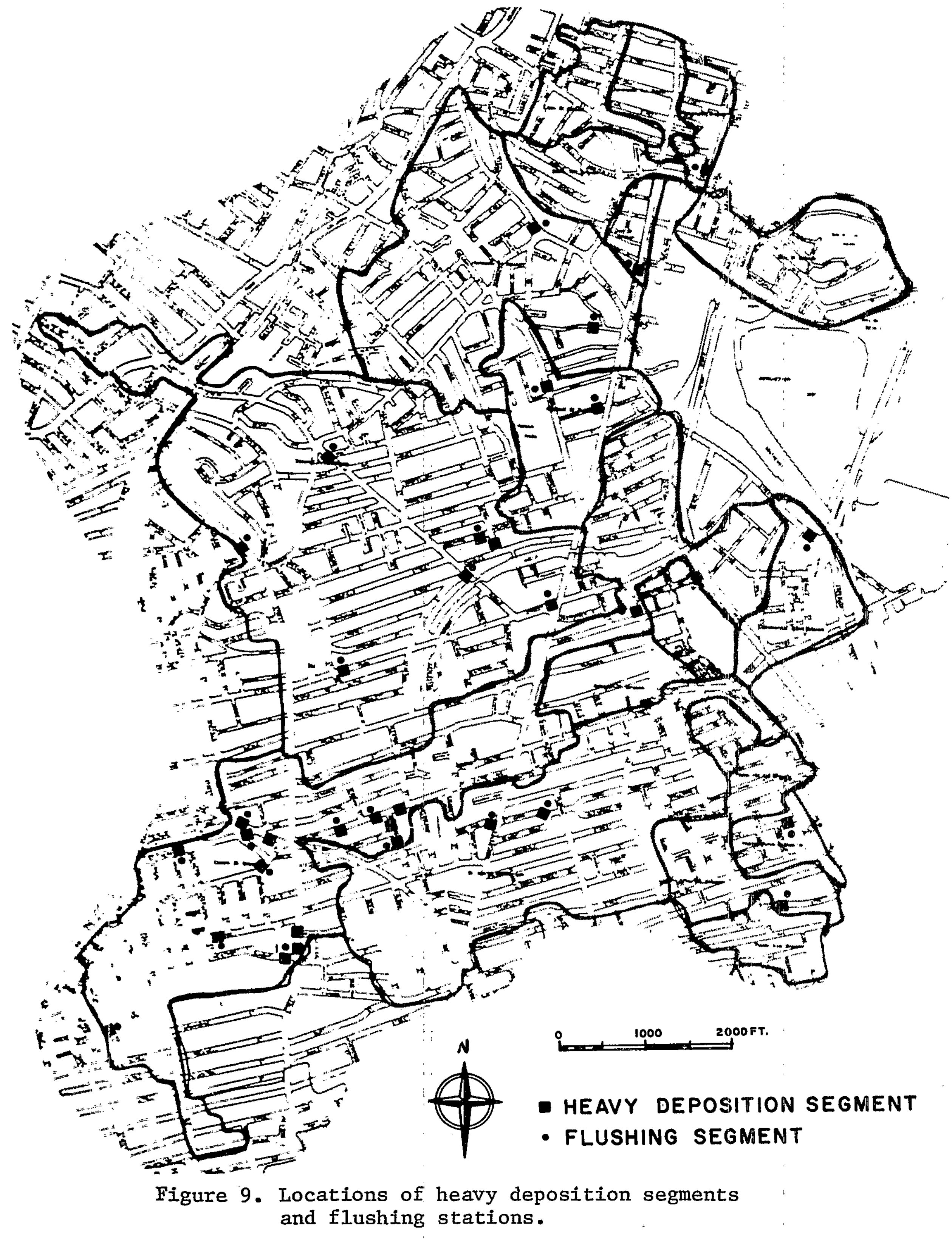


Figure 9. Locations of heavy deposition segments and flushing stations.

TABLE 15. TOTAL DEPOSITION OF SEGMENTS RANKED BY DEPOSITION RATES

Deposition Rate equal to or greater than (lbs/day)	Sewer* Type	No. of Segments	Total Deposition Rate (lbs/day)	% of** Total
3.0	C	14	138	70
2.0	C	22	156	79
1.5	C	30	169	85
1.0	C	56	198	100
3.0	S	20	172	33
2.0	S	33	203	39
1.5	S	48	229	43
1.0	S	89	278	53

* C = combined sewer
S = sanitary sewer

** Total deposition in combined sewers = 198.1 lbs/day
Total deposition in sanitary sewers = 526.5 lbs/day

equivalent to about 0.4 inches. Generally, a storage capacity of about 0.15-0.3 inches over the entire drainage area can be effective in abating combined sewage overflow pollution[20]. Consequently, storage alternatives will be considered within this range.

EVALUATION OF ALTERNATIVES

Table 16 compares the computed performance of various alternatives for a 16-year period (1960-1975). Column (1) identifies the alternative. For all cases, the maximum flow to the existing STP is equal to 18.6 mgd, the peak dry-weather flow rate. Column (2) shows the maximum combined sewage intercepting rate to the CSTP proposed in the EMMA Alternative 1 (See Figure 5). The amount of off-line storage (see Figure 5) is indicated on Column (3). In Cases 8 through 11, it equals the sum of the volume in the proposed interceptor and the CSTP. The sewer flushing interval is shown in Column (4). The 30-day flushing interval represents no sewer flushing since no dry period lasted longer than 30 days during the 16-year simulation period. Column (5) shows the average number of times from May through November the sewers would have been flushed at each of 28 flushing locations. Column (6) indicates the average number of times from May through November the combined sewage flow rate exceeded the interceptor capacity and untreated overflow to the bay occurred. Column (9) indicates both untreated overflow (Column 7) and that discharged from the CSTP after receiving primary treatment (Column 8). The amount of pollutant in the overflow also includes that untreated,

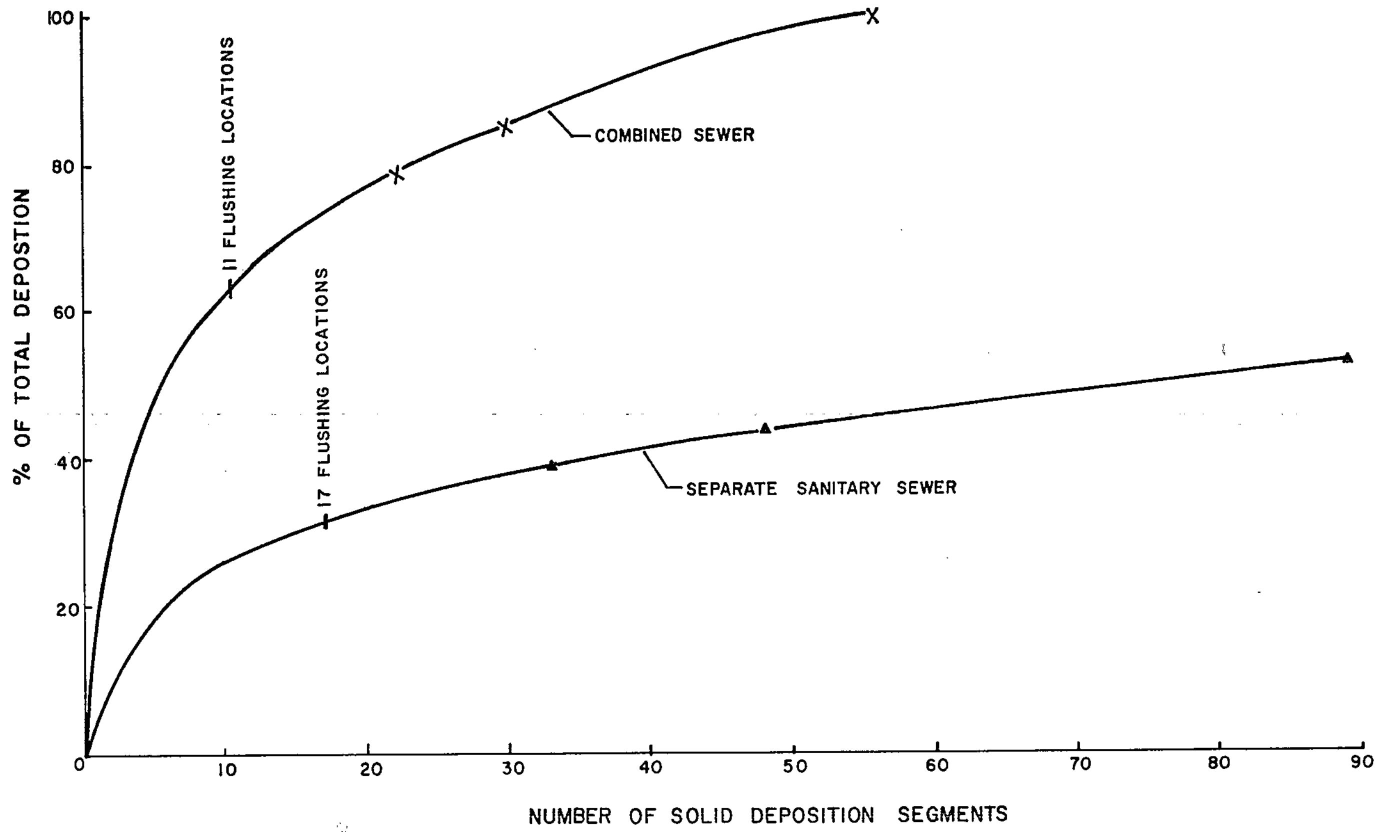


Figure 10. Total deposition versus number of segments ranked by deposition rate

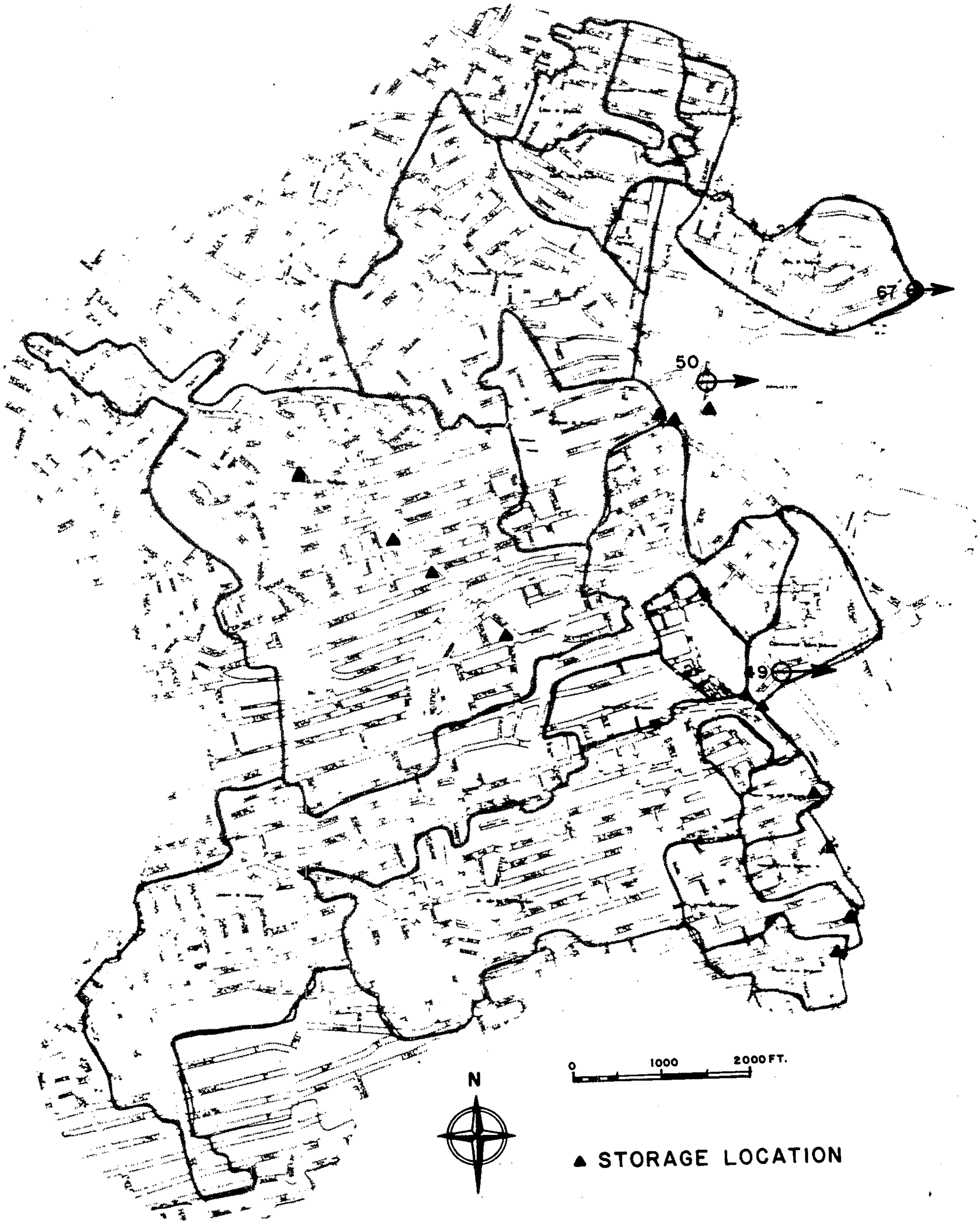


Figure 11. Potential storage locations

(Columns 10 and 14) and that treated by the CSTP (Columns 11 and 15). The total pounds of SS and BOD in the overflow are shown in Columns (12) and (16). The percent removal (Columns 13 and 17) refers to Case 1 (the existing condition) as a base. Column (18) is the volume of combined sewage and Column (19) is the amount of surface runoff included in the combined sewage. The difference represents the volume of sanitary sewage during wet-weather period. Considering the high peak flow rates of combined sewage the amount of storm water runoff routed to the STP is relatively small. The amount of wet-weather flow pollutants diverted to the main STP is shown on Columns (20) and (21). The pollutants shown in Table 16 assume a street sweeping interval of 10 dry days and sewer solids deposition rates computed with a per capita suspended solids contribution of 0.56 lbs/day. Table 17 presents information similar to that in Columns (10) through (17) of Table 16, except that solids deposition in sewers is computed assuming a per capita solids contribution of 0.313 lbs/day. In both tables, the deposition rate used for BOD is 40 percent of the SS deposition rate. Cases 2, 3 and 4 are not included in Table 17 since sewer flushing alone would not provide pollution control comparable to the EMMA Alternative 1. Cases 9 and 11 are not included since sewer flushing with the EMMA Alternative 1 is not pertinent to the conclusions of this report.

Case No. 1 represents a system in which the maximum combined sewage flow rate diverted to the main STP equals the peak dry-weather flow. Based on past studies, providing effective treatment capacity for greater flow rates is not likely to be cost-effective. Under this condition, 66 percent of combined sewage volume, 77 percent of SS and 62 percent of BOD contained in the sewage would be discharged directly to the receiving waters. On average, overflows could be expected 53 times from May through November or about once every five days. If the sewers are flushed daily at 28 locations (Case No. 2), the SS discharged would be reduced by 7 percent and the BOD by 17.6 percent. The BOD removal rate is higher than the SS removal rate since flushing efficiency is higher for BOD than that for SS. There would be an average of 165 times that sewer flushing would be performed from May through November. To achieve this condition, some form of automatic installation appears essential. Its operation would require triggering after 24 dry hours. In addition, the flushing operation at all points might have to be almost simultaneous. Case No. 3 represents flushing at a 48-hour interval. This is probably a more reasonable alternative. The flushing operation could start after 24 dry hours and would not have to be done nearly as simultaneously. The average number of flushes would be reduced from 165 to 70. Approximately 5.2 percent of the SS and 14.1 percent of the BOD would be removed. Neither Case 2 or 3 approaches the effectiveness of the EMMA Alternative 1 (Case 8). If the flushing interval is extended to 7 dry days (Case 4), only about 1.2 percent of the SS and 4.0 percent of the BOD would be removed. The number of flushing events would be reduced to 7. It does not appear that sewer flushing by itself can be considered as an effective CSO pollutant abatement technique.

TABLE 16. ALTERNATIVE DEFINITION AND POLLUTION CONTROL EFFECTIVENESS, HIGH DEPOSITION RATE++

Case* No. (1)	Intercepting Capacity to CSTP (mgd) (2)	Storage (Mgal) (3)	Flushing Interval (dry days)	No. of Flushing (5)	Overflow Events (6)	Overflow Volume (Mgal) Untreated (7)	CSTP (8) ***	Total (9)
1	-	-	30	0	53	516	-	516
2	-	-	1	165	53	516	-	516
3	-	-	2	70	53	516	-	516
4	-	-	7	7	53	516	-	516
5	-	5.1	30	0	20	358	-	358
5A	-	5.1	1	165	20	358	-	358
6	-	6.8	30	0	18	326	-	326
6A	-	6.8	1	165	18	326	-	326
7	-	13.1	30	0	12	274	-	274
7A	-	13.1	1	165	12	274	-	274
8**	497.4	7.7+	30	0	.6	5	336	341
9	497.4	7.7+	1	165	.6	5	336	341
10	100.	5.7+	30	0	16	111	229	340
11	100.	5.7+	1	165	16	111	229	340

* For all cases, the intercepting capacity to the main STP plant is equal to the peak DWF rate of 18.6 mgd

** The EMMA Alternative 1

*** CSTP has two basins with a total capacity of 5.08 million gallons

\+ Storage volume in the conduit connecting outfall Nos. 50 and 49 shown in Figure 1 plus 5.1 Mgal in the CSTP

++ Solids deposition rate computed with a sewage SS strength of 0.56 lbs/capita/day

TABLE 16 (continued)
ALTERNATIVE DEFINITION AND POLLUTION CONTROL EFFECTIVENESS, HIGH DEPOSITION RATE

	SS Overflow				BOD Overflow				Volume Routed to Main STP (mg)		Combined Sewage Pollutant Routed to Main STP (lbs)	
Case* No. (1)	Untreated (lbs) (10)	CSTP (lbs) (11)	Total (lbs) (12)	% Removal (13)	Untreated (lbs) (14)	CSTP (lbs) (15)	Total (lbs) (16)	% Removal (17)	Combined sewage (18)	Stormwater Runoff (19)	SS (20)	BOD (21)
1	2,751,200	-	2,751,200	0	486,300	-	486,300	0	268	122	823,000	292,600
2	2,557,600	-	2,557,600	7.0	400,500	-	400,500	17.6	268	122	732,100	252,200
3	2,608,200	-	2,608,200	5.2	417,600	-	417,600	14.1	268	122	756,200	260,500
4	2,717,600	-	2,717,600	1.2	467,000	-	467,000	4.0	268	122	807,400	283,700
5	1,862,700	-	1,862,700	32.3	299,900	-	299,900	38.3	520	280	1,906,900	635,200
5A	1,754,300	-	1,754,300	36.2	252,000	-	252,000	48.2	520	280	1,730,700	557,000
6	1,641,700	-	1,641,700	40.3	261,400	-	261,400	46.2	566	313	2,157,400	697,400
6A	1,549,300	-	1,549,300	43.7	220,600	-	220,600	54.6	566	313	1,965,300	612,100
7	1,018,100	-	1,018,100	63.0	159,800	-	159,800	67.1	678	404	2,823,700	833,100
7A	963,900	-	963,900	65.0	135,900	-	135,900	72.1	678	404	2,593,400	730,900
8**	44,000	1,265,900	1,309,900	52.4	5,800	248,000	254,000	47.8	429	297	2,236,000	501,800
9	42,100	1,191,700	1,233,800	55.2	4,900	206,100	211,000	56.6	429	297	2,027,300	418,800
10	883,200	463,300	1,346,500	51.1	123,400	133,100	256,500	47.3	430	297	2,201,300	501,300
11	840,500	428,300	1,268,800	53.9	104,600	108,500	213,100	56.2	430	297	1,994,500	418,500

TABLE 17. POLLUTANT REMOVAL EFFICIENCY OF ALTERNATIVES, LOW DEPOSITION RATE+

	SS Overflow				BOD Overflow			
Case No.	Untreated (lbs)	CSTP (lbs)	Total (lbs)	% Removal	Untreated (lbs)	CSTP (lbs)	Total (lbs)	% Removal
1	2,634,900	-	2,634,900	0	439,800	-	439,800	0
5	1,797,900	-	1,797,900	31.8	274,000	-	274,000	37.7
5A	1,737,300	-	1,737,300	34.1	247,200	-	247,200	43.8
6	1,586,400	-	1,586,400	39.8	239,300	-	239,300	45.6
6A	1,534,700	-	1,534,700	41.8	216,500	-	216,500	50.8
7	985,800	-	985,800	62.6	146,900	-	146,900	66.6
7A	955,500	-	955,500	63.7	133,600	-	133,600	69.6
8	42,900	1,221,600	1,264,500	52.0	5,300	225,600	230,900	47.5
10	857,900	442,200	1,300,100	50.6	113,300	119,700	233,000	47.0

+ Solids deposition rates computed with a sewage SS strength of 0.313 lbs/capita/day

Case No. 8 is the EMMA Alternative 1. Combined sewage flow at a rate of 497.4 mgd is pumped to the CSTP while 18.6 mgd is conveyed by the interceptor sewer to the main STP. The peak runoff rate of the design storm for the area tributary to the Overflow No. 50 (Figure 1) was provided by M&E as 346 mgd.[21] The peak flow rate was moderated to 152 mgd by using the storage provided in the 4000-feet long, 126-inch diameter sewer connecting outfall Nos. 49 and 50. The conduit storage behaves as off-line storage in the STORM simulation. Because of large treatment capacity and off-line storage, untreated overflow would have occurred only about ten times in 16 years. Thus the amount of unchlorinated discharges would be very small. The chlorinated overflow from the CSTP is, however, significant. Of 2,706,600 lbs of SS and 485,000 lbs of BOD entered the CSTP, 1,265,900 lbs of SS and 248,400 lbs of BOD are discharged to the receiving waters for a removal rate of 53.2 percent for SS and 48.8 percent for BOD. These removal rates are somewhat higher than the reported overall removal rates at the Cottage Farm facilities which remove 45 percent of SS and 42 percent of BOD probably due to the larger volume at the proposed EMMA Alternative 1 facility. Including untreated discharged pollutants (Columns 10 and 14 of Table 16), the percent removal with respect to the Case No. 1 is 52.4 percent for SS and 47.8 percent for BOD. This appears low considering the cost of this alternative (Table 2). The major advantage of this proposal, the elimination of practically all unchlorinated discharges, may be achieved by less costly means.

Supplementing the EMMA Alternative 1 proposal by daily flushing, Case No. 9, SS and BOD removals increase to 55.2 and 56.2 percent respectively. Sewer flushing, when integrated with other structural alternatives, such as storage, may be cost-effective. Alternatives 5, 5A, 6, 6A, 7 and 7A were developed to explore cost-effectiveness of combinations of storage and sewer flushing.

Case Nos. 5, 6, and 7 are alternatives without sewer flushing but with offline storage capacities equal to 5.1, 6.8 and 13.1 million gallons respectively. As the amount of storage increases, the number of overflow events decrease, as do the pollutants discharged to the receiving waters. In contrast to Case 8, Cases 5, 6 and 7 contemplate gravity flow to storage and pumping out of storage to deliver flows to the dry weather interceptor at much lower rates after the storm flow subsides.

Using Case 1 (no control/treatment) as the reference, Cases No. 5, 6 and 7 would remove 32.2, 40.3 and 63 percent respectively of the SS that would have been discharged under the reference case. The BOD removal rates are higher and are 38.3, 46.2 and 67.1 percent, respectively. The SS and BOD removal rates of the EMMA Alternative 1 (Case No. 8) are somewhat more than that for Case 6 and substantially less than that for Case 7. The storage provided in Case 8 is also somewhat more than that provided in Case 6 and substantially less than that provided in Case 7. The primary benefits with respect to tion abatement in Case 8 are those associated with storage rather than treatment, except for chlorination.

Case Nos. 5A, 6A and 7A supplement the offline storage alternatives with daily sewer flushing. As a result of flushing, the SS removal rates are increased to 36.2, 43.7 and 65.0 percent, respectively for Cases No. 5A, 6A and 7A, or a marginal improvement of 3.9, 3.4 and 2.0 percent over those obtained for Cases No. 5, 6 and 7. With no storage, the net improvement attributable to sewer flushing is maximum, or 7 percent. Sewer flushing is more effective in reducing BOD in the overflows. With flushing, the percent BOD removal rates are 48.2, 54.6 and 72.1 for Case Nos. 5A, 6A and 7A, respectively. The net improvements over the no-sewer-flushing alternatives are 9.9, 8.4 and 5.0 percent for storage capacities equal to 5.1, 6.8 and 13.1 million gallons respectively. With no storage, the net improvement is 17.6 percent. The net improvement decreases with increased storage capacity. The provision of flushing may permit a reduction in other pollution abatement techniques but is not likely to result in their elimination.

BOD may be a more appropriate measure of pollution control efficiency because (1) field sampling, especially in sewers, is difficult due to inaccuracies inherent in the methodology and (2) the inaccuracies most greatly affect solids with little effect on BOD, and (3) solids deposition is seldom or never discrete and non-cohesive as assumed in the models. Figure 12 compares percent SS and BOD removal versus offline storage for the no sewer flushing alternatives (Cases No. 5, 6 and 7) and daily sewer flushing alternatives (Cases No. 5A, 6A and 7A). As shown in Figure 12, an offline storage capacity of about 7.1 million gallons without sewer flushing, or a storage capacity of 5.1 million gallons with daily sewer flushing at 28 heavily deposited sewer segments, would result in the same reduction in BOD discharged between May through November to receiving waters as the EMMA Alternative 1. The ineffectiveness of EMMA Alternative 1 is graphically demonstrated in this comparison. The high pumping rate through the CSO treatment plant actually reduces efficiency as compared to simple storage and bypassing flows in excess of the storage capacity. This is not surprising since, in a major storm in areas with a high degree of imperviousness, the pollutant strength in the combined sewage decreases very greatly as the storm proceeds.

Case No. 9 is EMMA Alternative 1 supplemented by daily sewer flushing at 28 locations in the study area. The BOD removal rate is improved from 47.8 percent to 56.6 percent or by about 18 percent. The SS removal rate is improved only from 52.4 percent to 55.2 percent or by about 5 percent. Referring to Figure 12, Case 9 is equivalent to providing a storage of about 9.6 Mgal for equal BOD removal.

Case No. 10 is similar to EMMA Alternative 1 except that the conduit diameter is reduced to 5 feet instead of 10.5 feet and pump capacity to the CSTP to 100 mgd instead of 497.4 mgd. The conduit

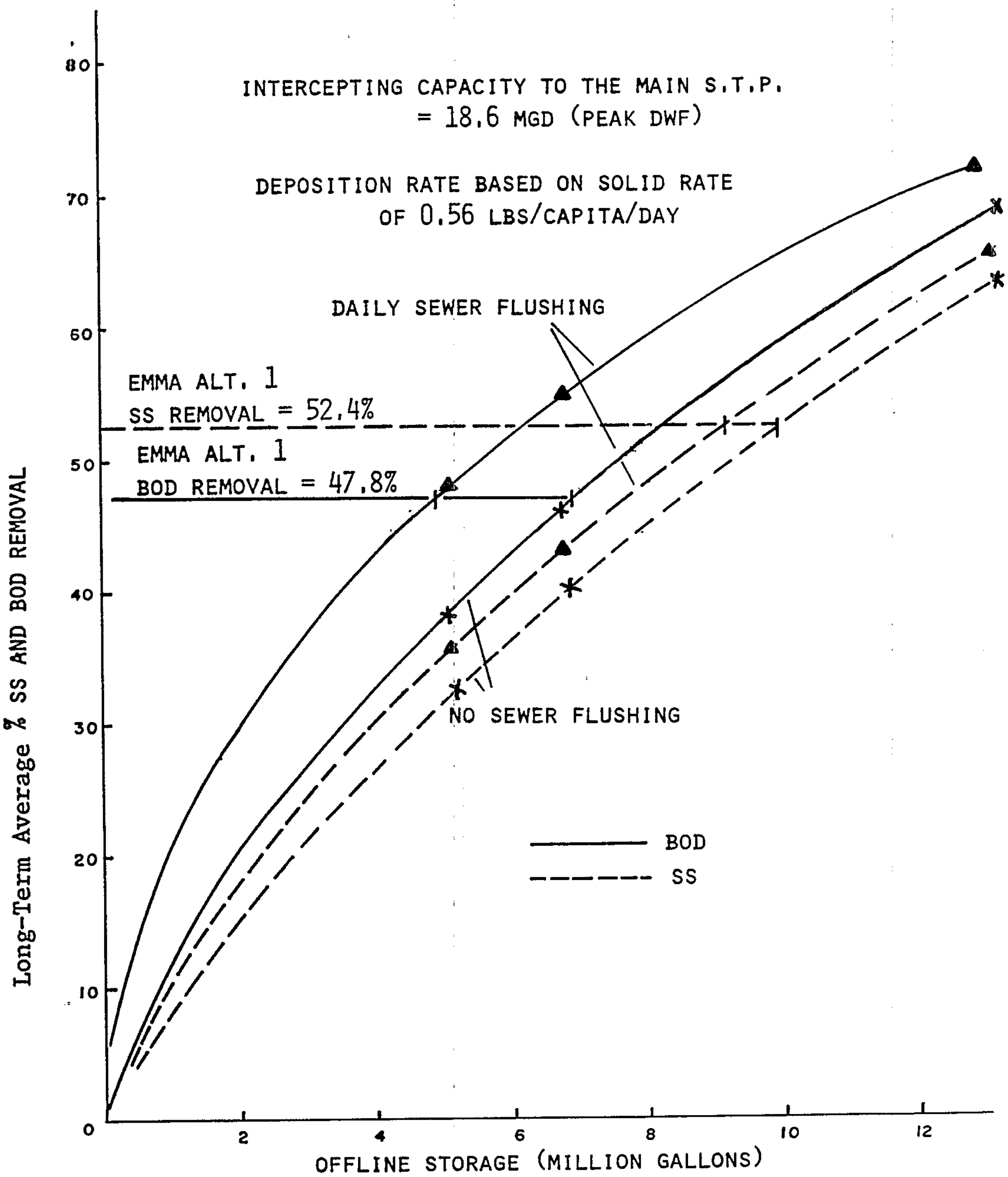


Figure 12. Effect of off-line storage on pollutant removal, high deposition rate

storage in 4000 feet of 5-foot diameter pipe is about 0.6 million gallons. This alternative would overflow untreated discharge more often (16 times during May through November versus 0.6 times for the EMMA Alternative 1), but the overall pollutants discharged to the receiving waters would be about the same. The long-term averaged SS removal rate is 51.1 percent as compared to 52.4 percent for Case 8 and the BOD removal rate, 47.3 percent as compared to 47.8 percent. Case No. 10 has obvious cost advantage as compared to Case 8. While Case No. 10 discharges more pollutant at the overflow, Case 8 discharges about the same amount more at the treatment plant. The greater pumping rate in Case 8 also reduces the effectiveness of the treatment provided. This implies that for a given storage basin capacity in a treatment plant, there is a pumping capacity and conduit size that provides the cost-effective pollution abatement. Five alternatives are compared in Table 18. Cases B, C, 10 and D are compared with Case 8. Case D would provide the greatest reduction in pollutants discharged and Case 10 the least.

Case D compares to Case 8 except the pumping capacity is reduced to 1/5 that of Case 8. It provides better pollution control and would cost less than Case 8. It appears that the cost of EMMA Alternative 1 may be substantially reduced while providing the same overall CSO pollution abatement in the Boston area. To provide a more reasonable comparison of the basic merits of storage/sewer flushing alternatives, Case No. 10 of Table 16 is cost estimated in the next chapter.

Case 11 supplements Case 10 with sewer flushing. The marginal benefit of pollution control over Case No. 10 is about the same as that of Case No. 9 over Case No. 8.

Data in Table 16 were developed for solids deposition rates in sewers calculated using a per capita solid generation rate of 0.56 lbs/day. This generation rate is based on field measurements. The calculated solids generation rate, based on the assumed 150 gpcd flow and a concentration of 250 mg/l of SS, is 0.313 lbs/capita/day. Table 17 was prepared using the deposition rate calculated with a generation rate 0.313 lbs/capita/day. Figure 13 presents percent BOD removal versus off-line storage for this lower solids generation rate. The estimated BOD removal of EMMA Alternative 1 may be achieved by providing either storage of 7.3 million gallon capacity, or storage of 6.0 million gallons supplemented by daily flushing. These alternatives are compared in Table 19, together with Case No. 10 which provides about the same degree of pollution control with less cost as the original EMMA Alternative 1.

All alternatives reduce the BOD discharged to the receiving waters about the same amounts. Case 12 assumes the wet-weather flow enters the storage basin by gravity and the storage is drained by pumps with capacity to supplement the interceptor flow so that it equals the peak dry-weather flow or 18.6 mgd. The required pump capacity has been assumed as 15 mgd to allow for a minimum

TABLE 18. OPTIMAL COMBINATION OF PUMPING AND STORAGE CAPACITIES FOR POLLUTANT REMOVAL

Case No.	Pumping Capacity (mgd)	Conduit Diameter (ft)	Conduit capacity (Mgal)	% Removal SS	% Removal BOD
8	497.4	10.5	2.60	52.4	47.8
B	125	7	1.15	54.6	49.0
C	115	6	0.85	53.4	48.4
10	100	5	0.60	51.1	47.3
D	100	10.5	2.60	55.9	50.0

interceptor flow of 3.6 mgd. To allow filling by gravity, the flow line of the storage basin was assumed at least ten feet below the ground level. This is in contrast to the EMMA Alternative 1 which pumps into the basin at a maximum capacity of 497.4 mgd and drains the basin by gravity. The storage envisioned for Case 12 could be located near Overflow Nos. 49 and 50 (Figure 1). The large sewers near the two outfalls could also be used by employing flow routing techniques to store most of the frequently occurring rainfall-runoff.

Case 13 is a daily sewer flushing/storage alternative with pumping capacity equal to 15 mgd as explained earlier. Case 10 is a less costly version of the EMMA Alternative 1, and is included to provide a more reasonable comparison with other alternatives. Cases 14 and 15 are equivalent to Cases 12 and 13, respectively, but assume the lower solid generation rate previously discussed. Case 16 utilizies storage in larger sewers near two outfalls. As much as 7.5 million gallons are potentially available.

Column 7 of Table 19 presents the volume of combined sewage to be chlorinated, excluding that disinfected at the main treatment plant. The volume includes combined sewage which bypasses either the storage basin or flows through the CSTP and should be chlorinated before discharge. For Cases 12, 13, 14 and 15, chlorination facilities can be integrated with the storage facility. For Cases 8 and 10, chlorination facilities are included at the CSTP. The capital and operating cost of the chlorination facilities would be about the same for all alternatives since the volume to be chlorinated is about the same. Consequently, for comparison of costs, the cost of chlorination can be dropped from further consideration.

Table 20 shows alternatives which reduce the amount of SS discharged to receiving waters about equally. Case No. 17, which is a

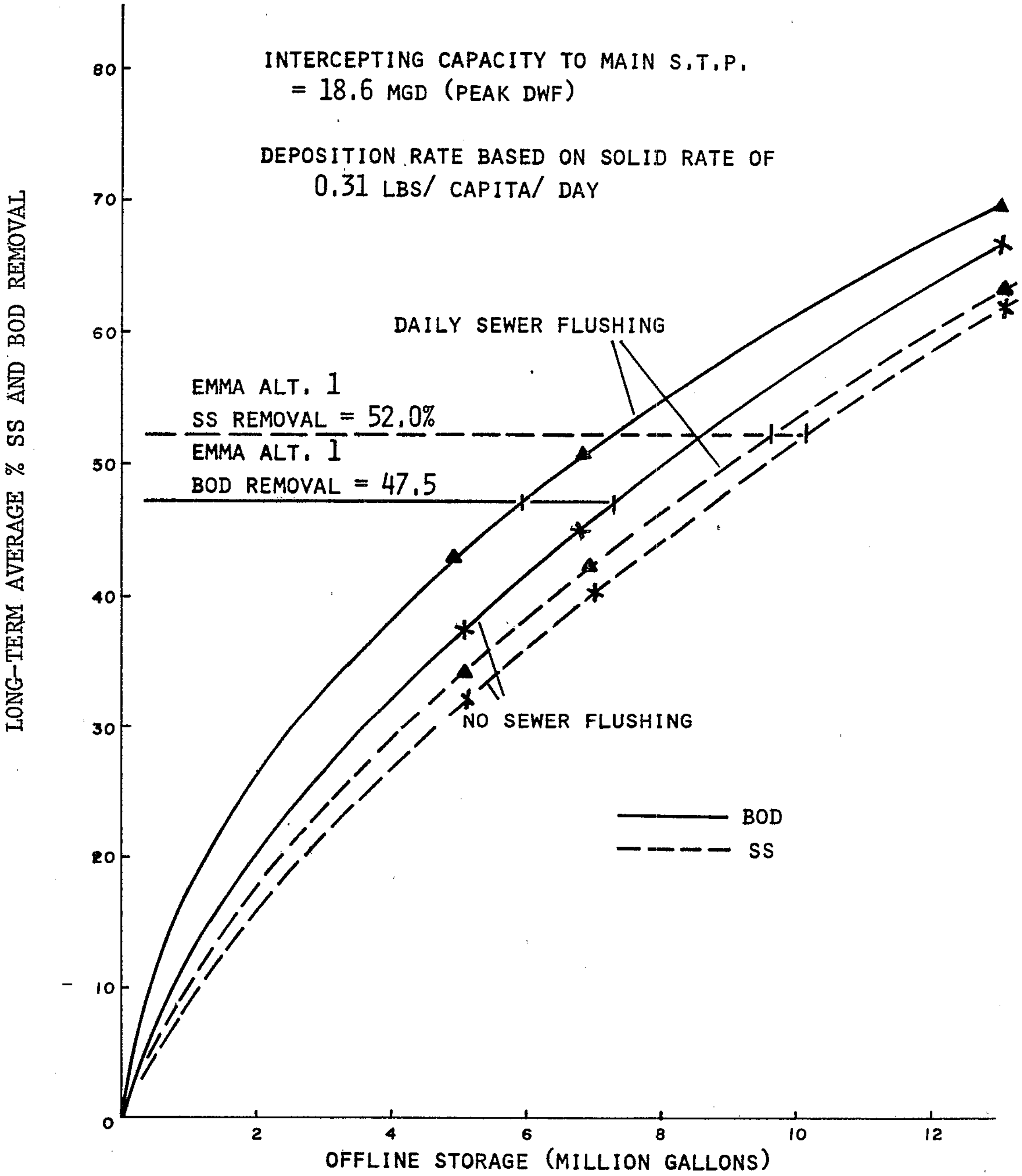


Figure 13. Effect of off-line storage on pollutant removal low depositions rate

TABLE 19. EQUIVALENT BOD ABATEMENT ALTERNATIVES

Case No. (1)	Daily Sewer Flushing (2)	Storage* (Mgal) (3)	CSTP (4)	Pumping Capacity (mgd) (5)	Conduit Size (ft) (6)	Chlorination (Mgal) (7)
12	No	7.1	No	15	-	321
13	Yes	5.1	No	15	-	358
8	No	7.7	Yes	497.4	10.5	341
10	No	5.7	Yes	100	5.0	340
14	No	7.3	No	15	-	319
15	Yes	6.0	No	15	-	337
16	No	7.5**	No	Small	-	340

* Includes off-line storage, conduit storage and storage in CSTP
** Volume of large sewers near outfall Nos. 50 and 49 (Figure 1)

TABLE 20. EQUIVALENT SS ABATEMENT ALTERNATIVES

Case No. (1)	Daily Sewer Flushing (2)	Off-line* Storage (Mgal) (3)	CSTP (4)	Pumping Capacity (mgd) (5)	Conduit Size (ft) (6)	Chlorination (Mgal)*** (7)
17	No	10.0	No	15	-	295
18	Yes	9.1	No	15	-	302
8	No	-	Yes	497.4	10.5	341
10	No	-	Yes	100	5.0	340
19	No	10.0	No	15	-	295
20	Yes	9.5	No	15	-	298
21	No	10.0**	No	15	-	295

* Not including conduit storage and 5.1 Mgal storage at the CSTP
** Includes 7.5 Mgal of pipe storage near two outfalls and 2.5 Mgal of off-line storage
*** Excluding volume disinfected at the main STP

storage alternative (as is Case No. 12), requires 10 million gallons (or greater storage than that required for the latter) to remove the same amount of SS as Case No. 8. This is because the storage in the CSTP of the EMMA Alternative 1 removes a greater proportion of SS than BOD (Figure 6). With daily sewer flushing, storage required for equivalent SS removal is reduced by 0.9 million gallons, compared to two million gallons for equivalent BOD removal (Cases No. 12 and 13). Cases No. 19 and 20, which used the deposition rate calculated with a SS generation rate of 0.313 pounds per capita per day, also show less benefit from daily sewer flushing on the storage required to achieve equal SS removal efficiency. Case 21 is equivalent to Case 16 in Table 19 except that 2.5 million gallons off-line storage is provided to supplement in-pipe storage in large sewers near two outfalls so that the total storage becomes about 10 million gallons.

SECTION XI

COST ESTIMATE AND ALTERNATIVE COMPARISONS

The cost of the alternatives includes those for sewer flushing, off-line storage, pumping facilities and conveying conduit connecting the two outfalls. The capital, operating and maintenance (O&M) costs are considered.

When possible, the unit costs reported in the EMMA study were used after updating the ENR Index from 2200 to the present value of 2800. The EMMA construction costs for conveyance systems are shown in Table 21 and for pumping stations in Figure 14. THE EMMA plan (Case 8) and the modified EMMA Plan (Case 10) also include submarine outfalls, conveying conduit connecting the two outfalls, and CSTP, none of which are required for the other alternatives identified in Tables 19 and 20. The EMMA O&M costs for interceptor, pumping station and treatment plant facilities were also discussed. The estimates of individual components were not provided. The total annual O&M cost for the 10 proposed decentralized facilities was estimated as $3.9 million (based on ENR 2200). No breakdown of this cost for each individual facility was given in the report.

This study determined O&M costs based on data found in EPA published reports. These cost data are given in curves with respect to sizes of facilities such as storage volume and pump capacity. MDC has provided, after alternatives had been cost estimated, a breakdown of O&M costs incurred in 1978 to operate the Cottage Farm Facility. For comparison, the O&M cost for the Cottage Farm Facility was estimated based on the EPA report data and was estimated at about one half of the MDC reported cost incurred. The major difference in the two cost bases is in the estimated versus actual manpower requirements. The O&M costs, if revised, would not change the conclusions of this study.

COST OF STORAGE

Table 22 is a summary of off-line storage costs compiled as of 1978. Most of the costs shown include pumping, chlorination and sludge removal facilities. Based on these costs, it would appear that a cost $1.0 per gallon would be reasonable for the tank volume above the flow line in Cases 12, 13, 14, 15 (Table 19), and 17, 18, 19 and 20 (Table 20). This volume was determined assuming a tank freeboard of 10 feet. This freeboard was assumed to insure gravity flow into the tanks. The unit cost for the tank volume above the flow line is lower than that below because it includes only a wall

TABLE 21. OPEN CUT SEWER COST ($/LINEAR FOOT)*

DIAMETER *** (IN)	AVERAGE DEPTH IN FEET 6.	8.	10.	12.	14.	16.	18.	20.	22.	24.	26.	28.	30. ***
8	49.41	64.01	78.54	92.86	113.60	129.53	164.97	181.92	209.60	*******	*******	*******	*******
10	52.38	66.83	81.50	95.69	117.15	133.07	168.80	185.46	213.15	*******	*******	*******	*******
12	55.32	69.92	82.29	98.78	120.81	151.00	172.47	189.13	*******	*******	*******	*******	*******
15	63.32	79.38	95.52	109.59	144.48	160.88	182.40	203.72	*******	*******	*******	*******	*******
18	70.23	86.33	102.53	116.66	138.08	158.01	179.91	216.16	*******	*******	*******	*******	*******
21	80.90	97.19	112.14	127.49	145.38	164.53	186.23	207.74	261.90	297.30	329.92	364.95	388.55
24	87.42	103.61	118.76	134.17	152.13	173.23	194.88	216.49	272.77	330.46	342.76	385.11	401.38
27	92.25	108.35	123.98	138.73	157.06	178.09	199.54	220.82	280.80	326.80	351.46	386.32	410.07
30	98.04	114.18	130.45	144.68	163.37	180.02	205.87	227.10	259.26	325.53	362.70	397.41	421.45
36	109.26	125.49	141.86	158.39	175.05	194.03	215.31	243.51	278.04	310.56	427.47	425.87	450.19
42	131.56	147.87	164.36	181.01	197.82	216.95	238.42	268.68	303.43	336.19	418.07	461.95	474.75
48	*******	163.65	180.25	197.02	213.98	233.28	254.92	276.75	323.81	356.80	392.13	427.64	508.27
54	*******	167.57	184.19	201.01	218.03	237.41	259.15	303.27	334.05	385.34	420.84	456.54	481.64
60	*******	187.16	203.89	220.84	238.01	257.55	279.48	308.10	358.54	391.92	447.11	483.08	508.48
66	*******	211.61	228.46	245.54	262.86	282.57	304.68	334.65	370.19	403.80	455.94	511.63	537.31
72	*******	231.79	248.75	268.12	285.59	316.27	338.56	361.11	406.66	440.51	495.06	531.58	557.55
78	*******	*******	272.77	292.28	309.89	329.94	352.42	375.17	446.14	480.23	536.77	573.56	599.83
84	*******	*******	306.25	325.89	343.66	363.87	386.53	409.49	478.09	512.42	577.28	612.19	638.75
90	*******	*******	336.95	356.72	374.63	395.02	417.87	441.03	516.05	550.62	617.89	653.08	679.93
96	*******	*******	391.96	411.87	429.94	452.65	475.69	501.22	552.99	589.96	627.26	667.04	694.18
102	*******	*******	417.24	450.24	468.47	491.35	514.58	540.31	603.11	640.32	677.88	717.94	745.38
108	*******	*******	*******	494.31	512.69	535.75	559.16	585.10	682.44	689.90	727.72	768.06	795.79
114	*******	*******	*******	533.64	564.33	577.56	599.01	625.16	697.04	743.38	781.46	819.92	852.28
120	*******	*******	*******	577.33	596.02	621.58	645.38	671.74	735.21	753.72	813.66	854.56	882.90
126	*******	*******	*******	621.67	646.99	670.57	694.57	721.13	806.43	857.59	896.19	933.05	966.01

* Reproduced from the EMMA Report Volume 2.
ENR Index = 2200

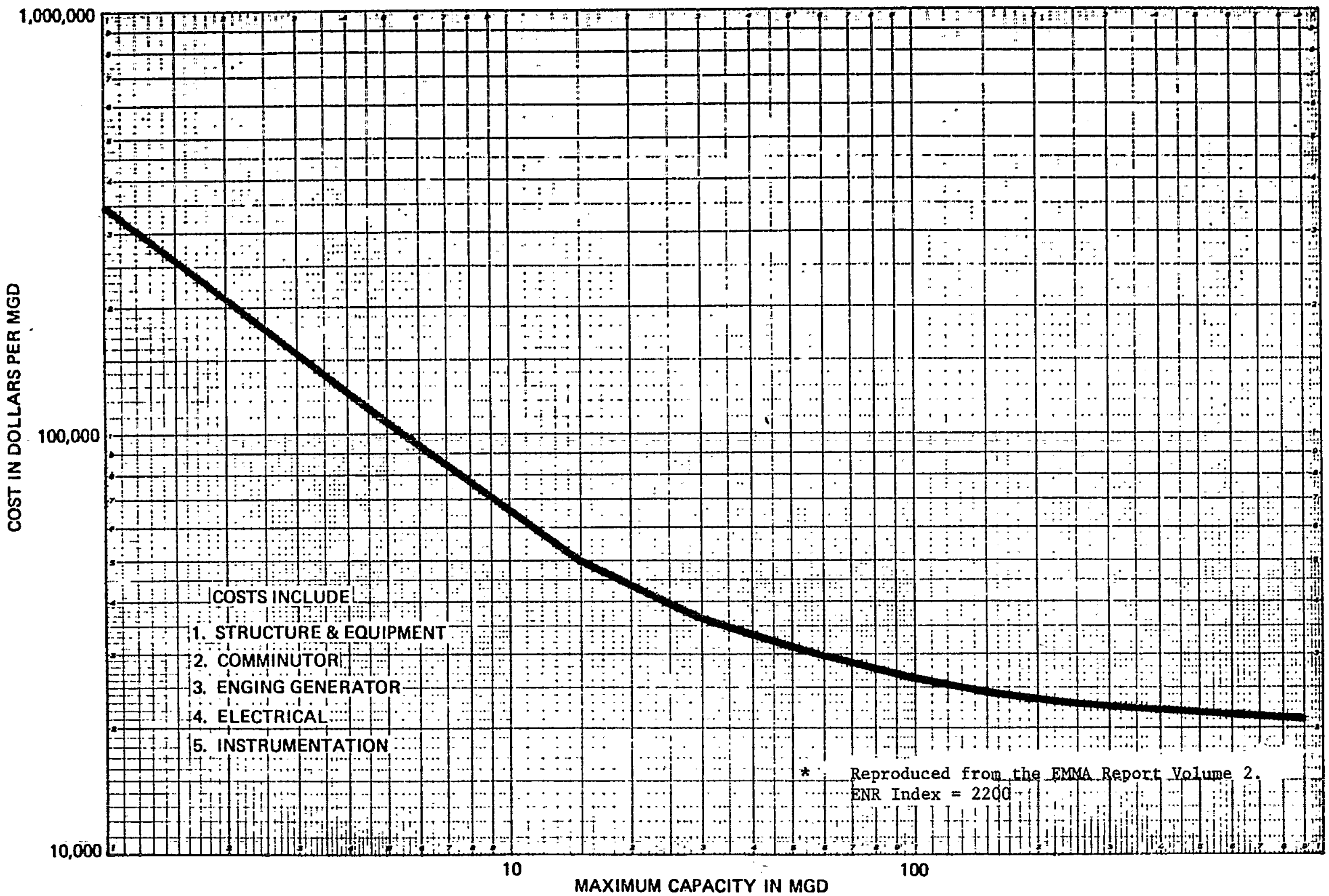


Figure 14. Pumping station construction cost

TABLE 22. SUMMARY OF OFFLINE STORAGE COSTS[a]*

Location	Storage capacity, Mgal	Drainage area, acres	Capital cost, $	Storage cost, $/gal	Cost per acre, $/acre	Annual operation and maintenance cost, $/yr
Akron, Ohio [21]	1.1	188.5	455 700	0.41	2 420	2 900
Milwaukee, Wisconsin [13]						
Humboldt Avenue	3.9	570	1 774 000	0.45	3 110	51 100
Boston, Massachusetts						
Cottage Farm Detention and Chlorination Station [17][b]	1.3	15 600	6 495 000	5.00	416	80 000
Charles River Marginal Conduit Project [19]	1.2	3 000	9 488 000	7.91	3 160	97 600
New York City, New York [22, 23, 25]						
Spring Creek Auxiliary Water Pollution Control Plant						
Storage	12.39	3 260	11 936 000	0.96	3 660	100 200
Sewer	13.00	.....	....	....	.....	....
	25.39	3 260	11 936 000	0.47	3 660	100 200
Chippewa Falls, Wisconsin [18]						
Storage	2.82	90	744 000	0.26	8 270	2 700
Treatment	....	..	189 000	....	2 100	8 000
	2.82	90	933 000	0.26	10 370	10 700
Chicago, Illinois [2, 11, 26]						
Tunnels and pumping	2,998	240 000	870 000 000	0.29	3 630	....
Reservoirs	41 315	....	682 000 000	0.02	2 840	....
Total storage	44 313	240 000	1 552 000 000	0.04	6 470	....
Treatment	......	....	1 001 000 000	....	4 170	....
	44 313	240 000	2 553 000 000	0.04	10 640	8 700 000
Sandusky, Ohio [16]	0.36	14.86	520 000	1.44	35 000	6 200
Washington, D.C. [2, 15]	0.20	30.0	883 000	4.41	29 430	3 340
Columbus, Ohio [2, 3, 12]						
Whittier Street	3.75	29 250[c]	6 144 000	1.64	210	....
Cambridge, Maryland [14]	0.25	20	320 000	1 28	16 000	14 400

a. ENR 2000.

b. Estimated values; facilities under design and construction.

c. Estimated area.

*Reproduced from EPA Report 600/8-77-017 (17)
$/acre x 2.47 = $/ha
$/gal x 0.264 = $/L
Mgal x 3785 = m^3

extension and does not include foundation slab or appurtenant works such as pumping and sludge removal facilities. This freeboard was assumed to insure gravity flow into the tanks. For the total storage cost, cost of effective tank storage obtained from Figure 15 was added to the above cost. Figure 15 was derived from the EMMA's estimates shown in Table 2. This estimated cost may be quite high and, if anything, should favor the EMMA Alternative.

COST OF SEWER FLUSHING

Verifiable costs for sewer flushing facilities, based on long-term operating experience, are not available. Pisano, et al.[4], has presented cost estimates based on a demonstration program. The costs so developed appear low for a permanent arrangement, particularly where larger sewers are involved. The preferred type of installation would probably include a new manhole structure to house a hydraulic-pneumatic control gate and a sidewalk vault to house duplicate air compressors, a compressed air tank, electrical service for heating and operation, a control system to permit operation of the gate at stated intervals, and appropriate heating and ventilating equipment. Similar installations in Cleveland to provide storage for combined sewage in 1974 were estimated to cost about $100,000. Their current cost might be $125,000. The sewers in which automatic flushing equipment is proposed would generally be smaller than those used for storage and as shown in Table 23, the construction cost per installation appears to be about $52,000 for small sewers (up to 27 inches) and increases to $63,000 for larger sewers (30 inches to 48 inches). Annual maintenance supplies and power are assumed at three percent of the equipment costs. A three-man crew should assure that the equipment is fully operational and they are provided with a truck fully equipped with safety equipment and maintenance tools and supplies. The estimated present worth, including O&M costs (20 years at 6-5/8 percent) is between $90,000 and $113,000. For purposes of estimating, a present worth value of $100,000 per module will be used.

OPERATION AND MAINTENANCE COST

Data reported in the literature has been used to estimate O&M costs. The EPA Report entitled "Cost Estimating Manual - Combined Sewer Overflow Storage and Treatment"[18] summarized the data in curves which are reproduced here.

Figure 16 shows the labor required to clean the storage reservoirs after a storm event using a spray system. The labor requirement depends upon how often the storage is used, as does the energy consumption shown in Figure 18. Miscellaneous supply costs shown in Figure 17 are arbitrarily established. The costs include repair parts, truck time, tools, insurance, janitorial supplies, gas, oil and other miscellaneous consumable products. Figures 19, 20 and 21, respectively, show the labor requirements, miscellaneous supply costs and energy requirements of a pumping facility. Labor requirements

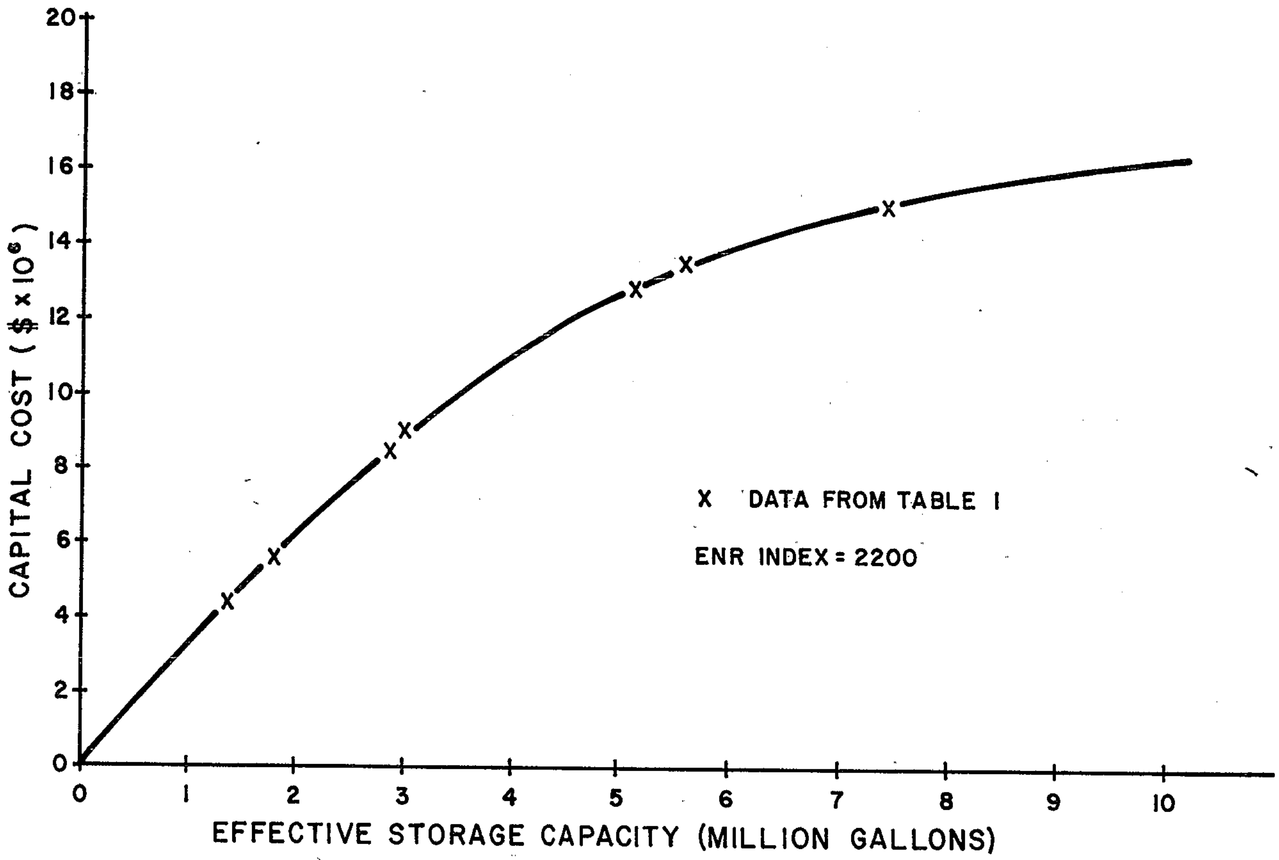


Figure 15. Capital cost of storage in EMMA study

TABLE 23. ESTIMATED COST OF AUTOMATIC SEWER FLUSHING (ENR 2800)

	Sewer Size	
Capital Cost	Small to 27"	30" to 48"
New Manhole	$ 3,000	$ 6,000
Hydraulic Slide Gate	12,000	20,000
Chamber	10,000	10,000
2 Air Compressors	4,000	4,000
Electrical Control System	10,000	10,000
Sump Pump	3,000	3,000
Contingencies	10,000	10,000
Total	$ 52,000	$ 63,000
Annual O&M Cost		
Maintenance	$ 1,500	$ 1,900
3 men @ 18,000 yr/module	1,900	1,900
Truck & Equipment - $25,000/28	900	900
Total/Module	$ 4,300	$ 4,700
Present Worth/Module (n=20 Year, i=6-5/8%)	$ 46,000	$ 50,000
Total Present Worth/Module	$ 90,000	$113,000

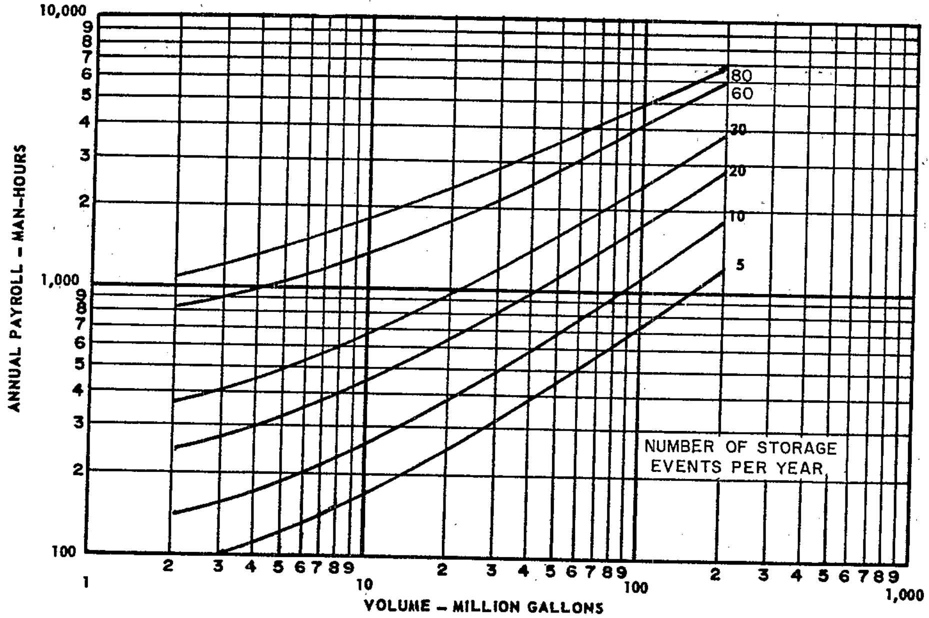


Figure 16. Storage reservoir man-hour requirements

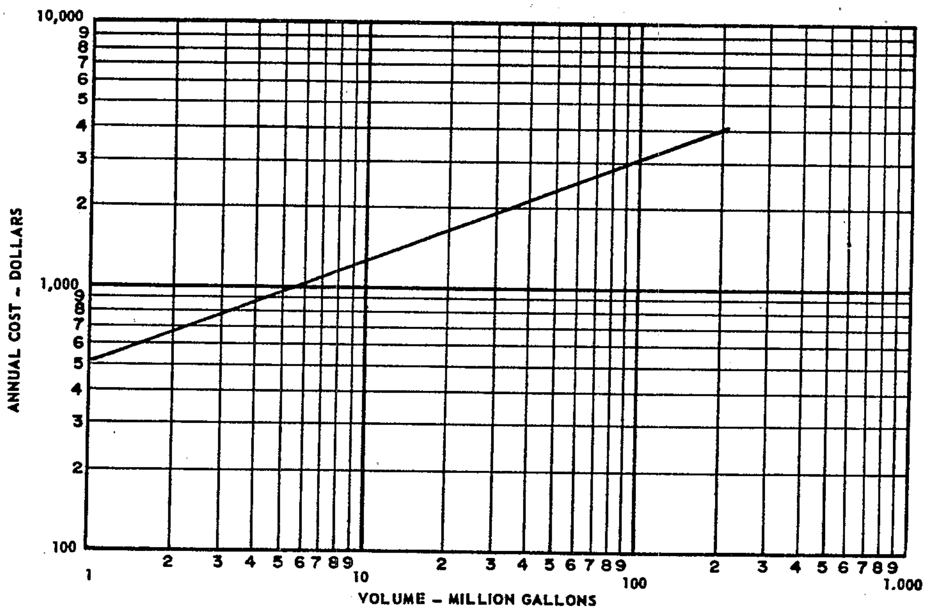


Figure 17. Storage reservoirs - miscellaneous supply cost (ENR 2200)

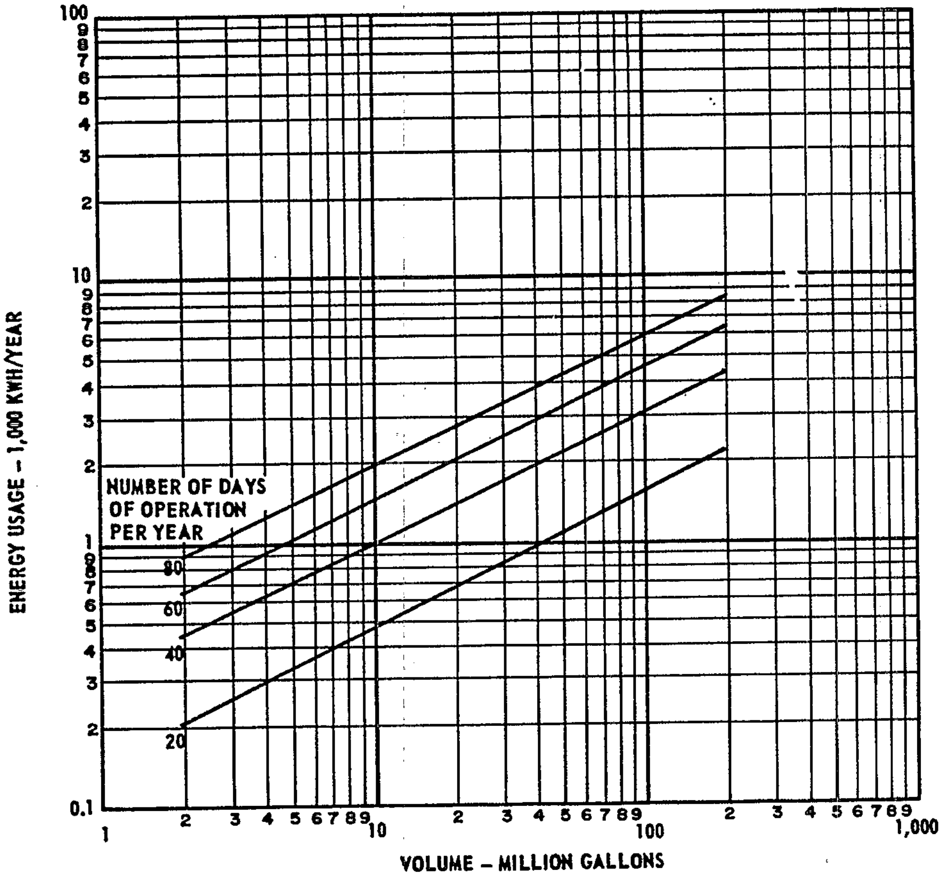


Figure 18. Storage reservoirs - energy requirements

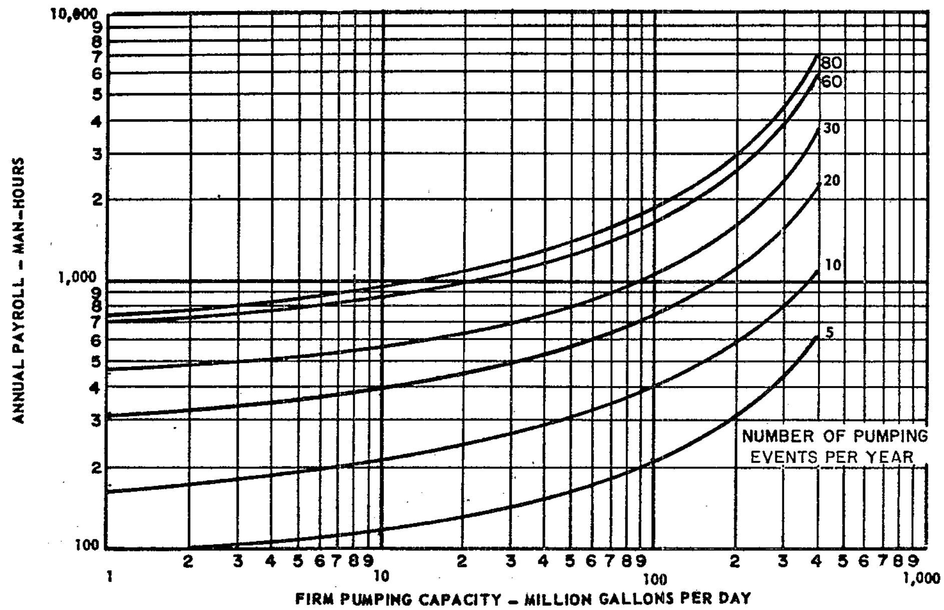


Figure 19. Raw wastewater pumping - man-hour requirements

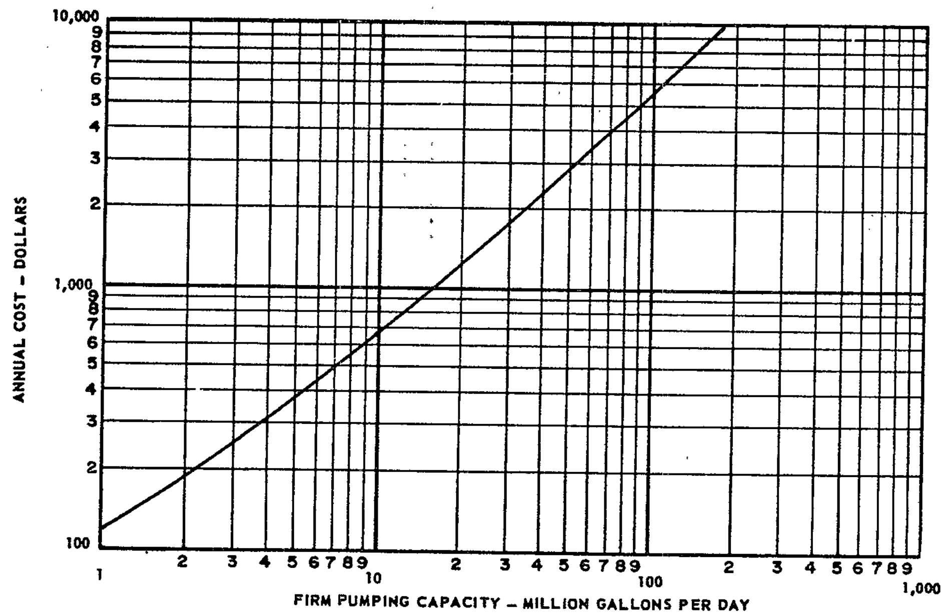


Figure 20. Raw wastewater pumping - miscellaneous supply cost (ENR 2200)

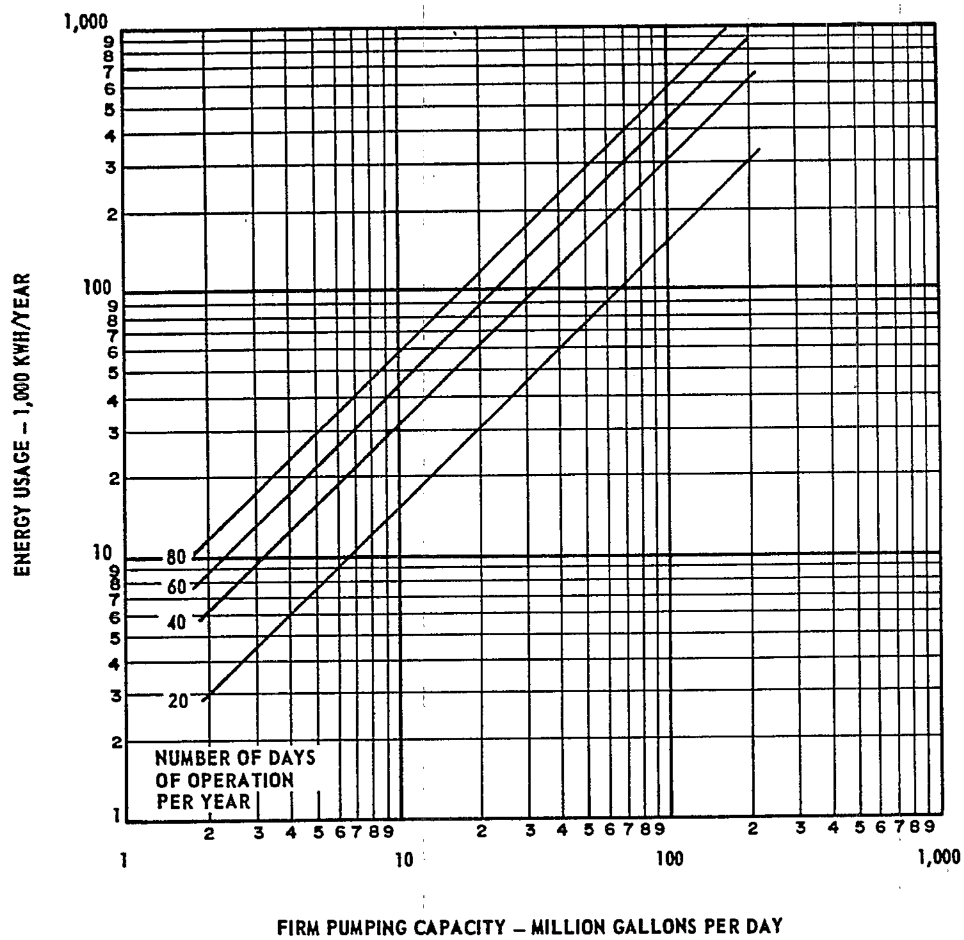


Figure 21. Raw wastewater pumping - energy requirements

are assumed to be proportional to the operating time of a pump station, with a constant requirement of eight man-hours to wash the wet well after each storm event and 24 hours per year to check and test equipment and controls between storm events. In this study, the cost of energy is assumed to be 4 cents per KWH.

COST OF ALTERNATIVES

Table 24 presents a cost summary of alternatives with the same amount of BOD removal as the EMMA Alternative 1. Costs were calculated based on the physical description of the alternatives in Table 19 and unit cost of conduit (Table 21), pumping facilities (Figure 14), storage (Figure 15) and sewer flushing (Table 23). All costs are expressed in terms of present ENR Index of 2800 applicable to Boston.

It is clear that the EMMA Alternative 1 is too expensive. Its modified version, with conveyance conduit and pump capacity reduced, by 80 percent is, however, quite comparable to other off-line storage and sewer flushing alternatives. Case 13, which is a daily flushing and off-line storage alternative, has the lowest total cost if storage available in the system is neglected. Most of the costs of Cases 12, 13, 14 and 15 are attributable to the storage cost. As mentioned earlier, these costs are perhaps too high and, therefore, the more detailed development of the costs may indicate further cost advantage compared to the EMMA Alternatives. It should be noted that the BOD removal efficiency of Case 10 is slightly lower than the other alternatives. Consequently, the actual cost of Case 10 would be somewhat higher if it is to remove the same amount of BOD discharged to receiving water as the other alternatives. Cases B and C of Table 18 would prevent more pollutants from discharging to receiving water than Case 10 but they would cost more.

The difference in costs between Case 14 and Case 15 is not as much as that between Case 12 and Case 13 since the merit of sewer flushing is reduced as the strength of wastes entering the sewers is reduced.

A storage capacity of about 7 million gallons, or a uniform runoff depth over the entire drainage basin equal to 0.16 inches, would result in the same BOD removal efficiency as the EMMA Alternative 1. A properly designed sewer system would have at least this amount of storage in trunk sewers. Such storage in trunk sewers can be utilized by installing flow regulating devices to effectively provide combined sewage pollution control. Such pipe storage is available in the study area.

It is estimated that about 3.5 million gallons or more of pipe storage is available in sewers and outfall pipes near the Outfall No. 50 (Figure 1) and about 4.0 million gallons or more near Outfall No. 49. It appears that these sewers, some of which are as large as 168-in x 138-in (horseshoe) and 144-in x 144-in (horseshoe), are above

TABLE 24. COST SUMMARY OF ALTERNATIVES WITH EQUIVALENT BOD REMOVAL(ENR 2800)

Case	Capital Cost ($ x 10^6)				Present Worth of O&M Cost *** ($ x 10^6)			Total
No.	Conduits	Storage	Pumping	Flushing	Storage**	Pumping**	Flushing	Cost ($ x 10^6)
12	-	24.79*	1.19	-	0.17	0.16	-	26.31
13	-	20.49*	1.19	1.40	0.15	0.16	1.40	24.79
8	9.88	16.25	17.25	-	0.18	3.33	-	46.89
10	5.36	16.25	4.21	-	0.16	0.16	-	26.46
14	-	25.51*	1.19	-	0.17	0.16	-	27.03
15	-	22.63*	1.19	1.40	0.16	0.16	1.40	26.94
16	-	0.50****	Small	1.40	-	Small	1.40	3.30

* All storage basins are assumed to contain an effective water depth of 15 feet. Cost includes extra depth of 10 feet above the level of effective storage at a cost of $1.0/gallon.

** Both storage and pumping station are operated 80 times a year.

*** Based on 20-year planning period and discount rate of 6-5/8%.

**** Includes four flow routing facilities at $125,000 each to utilize volume of existing large sewers for storage.

the elevation of the Dorchester Interceptor, therefore, a pumping facility may not be required. If required, it would be of small capacity, due to limitations imposed for discharge to the Dorchester Interceptor and of low head. The cost of using this pipe storage includes flow regulating devices such as an inflatable dam and routine flushing of sewers to maintain effective storage capacity. The cost could be ten percent of that of the other alternatives shown in Table 24. This pipe storage alternative of about 7.5 million gallons is designated as Case 16. The potential of this pipe storage should be explored. Such storage could replace all or most of storage required in Cases 12, 13, 14 and 15. The costs of these alternatives would then be far lower than Case 10.

Table 25 presents a cost summary of alternatives with the same amount of SS removal as the EMMA Alternative 1. The EMMA Alternative 1 is still far too expensive while its reduced scale (Case 10) becomes the lowest cost alternative when compared with off-line storage alternatives. However, as explained earlier, the cost estimates of storage for Cases 17, 18, 19 and 20 are perhaps much too conservative. Because sewer flushing is less efficient in removing SS than BOD, the advantage of daily sewer flushing/storage alternatives over only storage alternatives vanishes.

Case 21 is the alternative which supplements 7.5 million gallons of storage available in large sewers near the two outfalls with about 2.5 million gallons of off-line storage. The total storage capacity of this alternative is 10 million gallons which is comparable to Case 17. It should result in about the same amount of SS being discharged to receiving waters as other alternatives in Table 25. The cost of Case 21 is about half of the second lowest cost alternative, Case 10. The economy of Cases 16 and 21 indicates that there are definite cost incentives to explore pipe storage potential in the study area as well as other combined sewer areas in Boston.

OPTIMAL NUMBER OF FLUSHING STATIONS

The flushing alternatives described in the comparative analysis assumed 28 flushing stations. These stations would affect those sewer segments in which solids deposits equal or exceed 3.0 lbs/day. As indicated in Figure 10, 28 flushing stations are probably the maximum number that should be considered for the Dorchester area. To estimate the cost-effective number of flushing stations, alternatives using 5, 12 and 104 stations were developed. The 104 flushing station alternative would affect all of the combined sewer deposits and 43 percent of sanitary sewer deposits. The 12 flushing station alternative would affect 51.2 percent and 22.1 percent of the solids deposits in combined and sanitary sewers respectively while the 5 flushing station alternative would affect 30 and 17.4 percent. Table 26 compares costs of 8 equivalent SS and BOD abatement alternatives with daily sewer flushing assuming high sewage strength. The amounts of off-line storage required to supplement daily sewer flushing for

TABLE 25. COST SUMMARY OF ALTERNATIVES WITH EQUIVALENT SS REMOVAL (ENR 2800)

Case No.	Capital Cost ($ x 10^6)				Present Worth of O&M Cost *** ($ x 10^6)			Total Cost ($ x 10^6)
	Conduits	Storage	Pumping	Flushing	Storage**	Pumping**	Flushing	
17	-	29.03*	1.19	-	0.20	0.16	-	30.58
18	-	27.71*	1.19	1.40	0.18	0.16	1.40	32.04
8	9.88	16.25	17.25	-	0.18	3.33	-	46.89
10	5.36	16.25	4.21	-	0.16	0.48	-	26.46
19	-	29.03*	1.19	-	0.20	0.16	-	30.58
20	-	28.28*	1.19	1.40	0.19	0.16	1.40	32.62
21	-	10.0****	1.19	1.40	0.12	0.16	1.40	14.27

* All storage basins are assumed to contain an effective water depth of 15 feet. Cost includes extra depth of 10 feet above the level of effective storage at a cost of $1.0/gallon.

** Both storage and pumping station are operated 80 times a year.

*** Based on 20-year planning period and discount rate of 6-5/8%.

**** Includes four flow routing facilities at $125,000 each to utilize volume of existing large sewers for storage.

TABLE 26. EQUIVALENT SS AND BOD ABATEMENT ALTERNATIVES WITH SEWER FLUSHING

Case No.	Number of Flushing Stations	Pollution Control Parameter	Sewage Strength	Offline Storage Requirement (Mgal)	Present Worth ($ x 10^6): Total Storage Cost	Present Worth ($ x 10^6): Total Flushing Cost	Present Worth ($ x 10^6): Total* Cost
22	5	BOD	High	5.5	21.61	0.50	23.46
23	12	BOD	High	5.3	21.16	1.20	23.71
13	28	BOD	High	5.1	20.64	2.80	24.79
24	104	BOD	High	4.9	20.08	10.40	31.83
25	5	SS	High	9.3	28.19	0.50	30.04
26	12	SS	High	9.2	28.04	1.20	30.59
18	28	SS	High	9.1	27.89	2.80	32.04
27	104	SS	High	9.0	27.74	10.40	39.49

*Including pumping station cost of $1.35 million equal amounts of SS and BOD removal as the EMMA Alternative 1 are shown.

Increasing the number of flushing stations from 28 to 104 results in small savings in storage costs while sewer flushing costs increase substantially using either BOD or SS removals as a criteria. If 12 stations are used instead of 28, the total cost is reduced by about 4 percent if SS is used as the criteria and negligibly if BOD is used. The 5 station alternative appears as the least cost under either criteria. Should the cost of a sewer flushing station be $50,000 instead of $100,000 per station, the break-even number of flushing stations might be between 5 and 12.

SOLIDS HANDLING CONSIDERATION

Assuming a high strength sewage, the dry-weather flow in the study area would contain about 31,230 lbs/day of solids, of which about 2000 lbs. would settle in collection sewers and the remaining 29,230 lbs. would reach the Deer Island treatment facilities. If sewers are flushed every dry day at 28 flushing stations, about 1800 lbs., on the average, would be resuspended and eventually reach the treatment plant, assuming that the Dorchester Interceptor has adequate transporting capacity. Consequently, on a dry day, the solids transported to the treatment plant from this tributary area would be increased by about 6 percent. The increase in the plant O&M cost as the result of this 6 percent increase of solids loading should be small.

The interceptor carrying capacity was assumed as equal to the peak dry-weather flow of 18.6 mgd. Further, all pollutants reaching the interceptor were assumed to be transported to the Deer Island treatment plant. Field surveys conducted during the PRI study indicated substantial sea water intrusion into the Dorchester Interceptor as well as sediment deposits for its entire length. The deposits blocked as much as 30 percent of the flow area. The MDC has recently cleaned the Dorchester Interceptor. Unless causes of sedimentation in the Interceptor are found and corrective measures taken, it may be blocked again. Correction of problems in the Interceptor is beyond the scope of this study.

SECTION XII

FLUSHING - POSSIBLE LIMITATIONS AND ADVANTAGES

Since sewer flushing could be a valuable adjunct to reduce CSO pollution, a theoretical investigation was made to determine the relationship of wall shear stress, flow, pipe size, and pipe slope. The analysis assumed steady flow and that the Manning formula applied. The errors introduced by these assumptions could not be evaluated within the scope of this work. Figures 22, 23 and 24 present the results of analyses for sewers ranging in diameter from 12 inches to 7 feet and slopes from 0.0005 to 0.01 for flows of 0.5, 1.0 and 1.5 cfs, respectively. Pisano, et al.[(4)] have reported success in flushing sewers 12 to 15 inches in diameter by maintaining flows of 0.5 cfs for about two minutes to create a wave of celerity. This would indicate a shear stress equal to 0.04 pounds per square foot (psf) could be sufficient for effective flushing. For flushing of lighter organic particles a shear stress less than 0.04 psf may be satisfactory. This relatively small flow might not be successful in flushing larger sized pipe, unless their slope equalled 0.005 or more. At a flushing flow of 1.0 cfs, it appears that all size pipes up to 7 feet diameter with a slope of 0.003 might be flushed successfully. Further, at a flushing flow of 1.5 cfs, all pipe sizes up to 7 feet diameter and a slope of 0.002 or more, appear to be suitable candidates for flushing. For a given slope and flow, the shear stress is relatively constant. Hence, relatively large pipes may be successfully flushed with relatively small quantities of water. This, if proven, could offer significant aid in cleaning sewers of deposit after wet weather flows have been stored to permit routing combined sewage to treatment. This potential, plus possible savings in CSO pollution abatement facilities, urge strongly the continuation of investigations into the effectiveness of sewer flushing in large sewers.

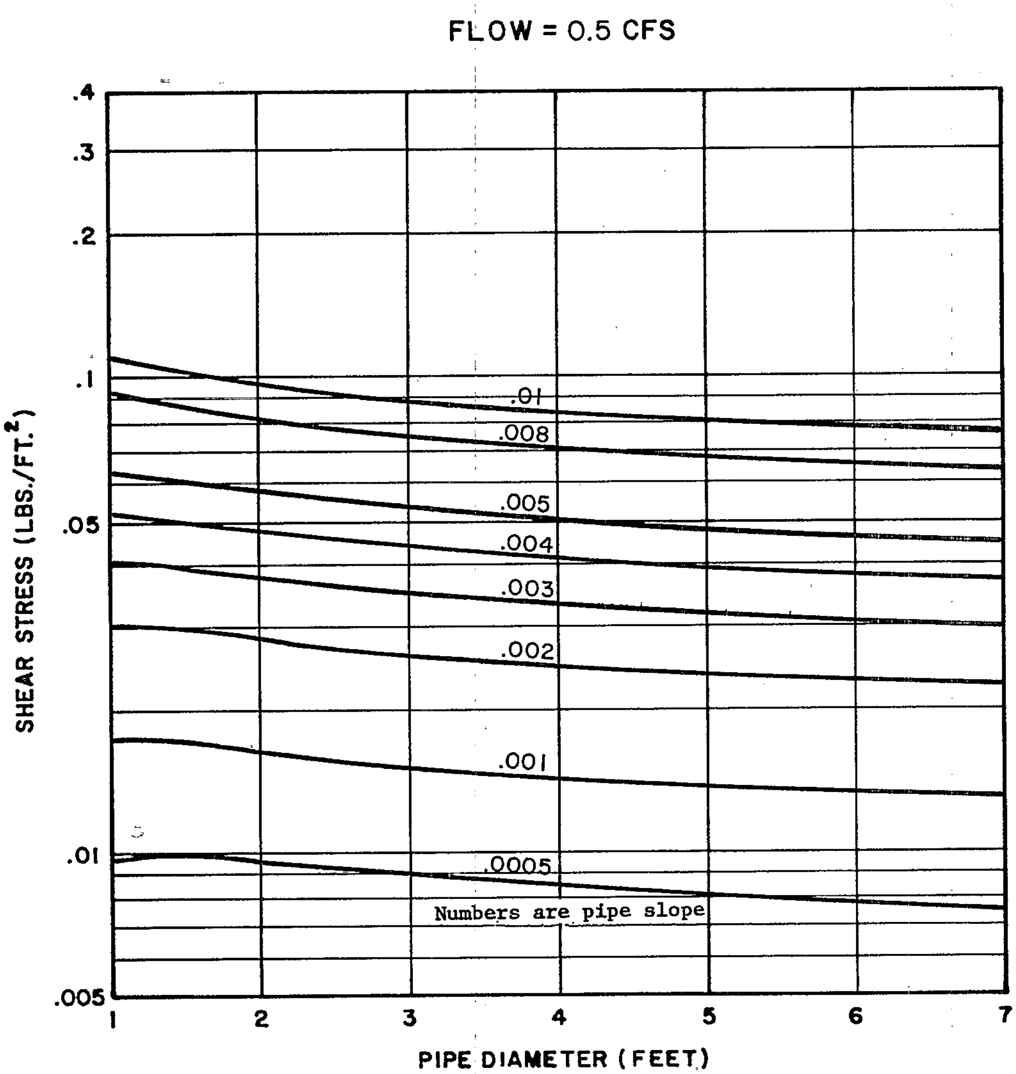


Figure 22. Wall shear stress in circular pipes, flow = 0.5 cfs

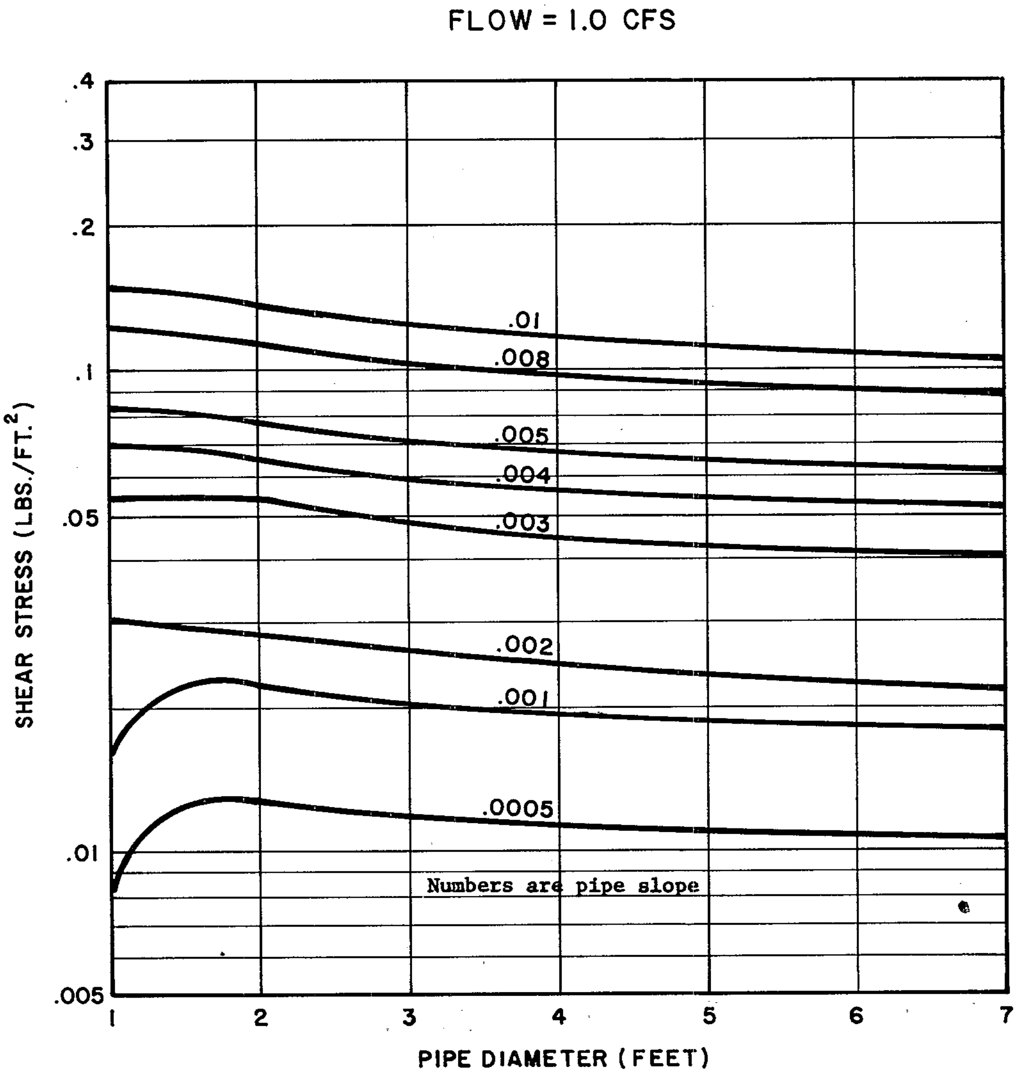


Figure 23. Wall shear stress in circular pipes, flow = 1.0 cfs

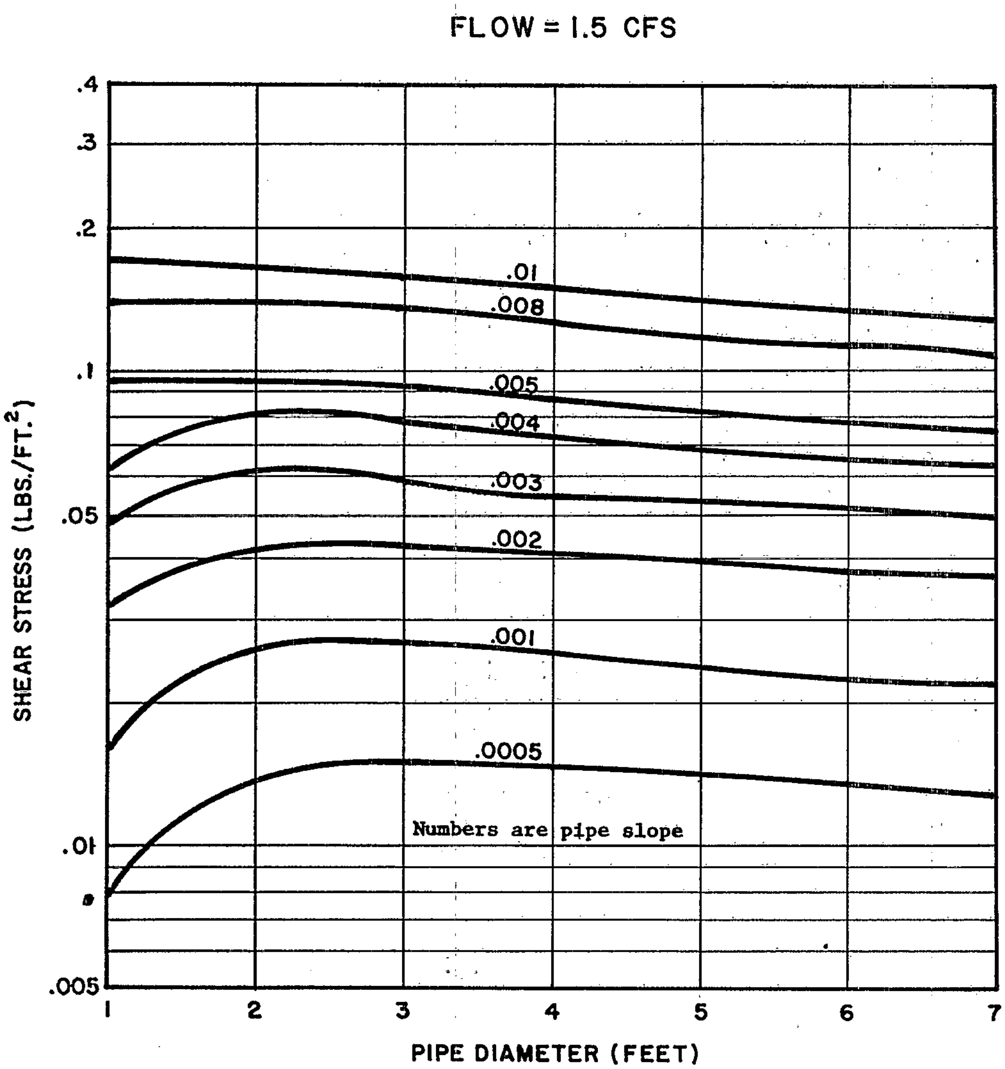


Figure 24. Wall shear stress in circular pipes, flow = 1.5 cfs

SECTION XIII

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16. ABSTRACT

Alternatives employing sewer flushing were developed for the Dorchester area of Boston and their cost effectiveness compared with the decentralized combined sewer overflow (CSO) storage/treatment and disinfection facilities proposed as Eastern Massachusetts Metropolitan Area (EMMA) Alternative 1. Thirty-three alternatives were evaluated. These alternatives included sewer flushing, off-line storage, in-pipe storage, storage/treatment facilities, and a combination of the above. A study objective was to determine if additional expenditures to develop sewer flushing techniques and devices were indeed appropriate. The feasibility and efficiency of sewer flushing was based on literature review including a report containing sewer flushing data for four small sewer segments in the Dorchester area. Continuous simulation runs using 16 years (1960-1975) of hourly rainfall data from May through November were made to determine the level of CSO pollution control obtained. The STORM program was modified to include continuous simulation of solids and organic material deposited in sewers during dry days, the removal of those deposits by dry day sewer flushing and wet-weather flow, and the storage and treatment effects of a CSO storage/treatment facility on the wet-weather discharge.

17. KEY WORDS AND DOCUMENT ANALYSIS

a. DESCRIPTORS	b. IDENTIFIERS/OPEN ENDED TERMS	c. COSATI Field/Group
*Rainfall, *Runoff, *Storm sewers, *Combined sewers, *Sanitary sewers, *Overflows, *Sewage treatment, *Cost effectiveness, *Mathematical models, Computer programs.	Combined sewer overflows, Combined sewage treatment plant, Offline storage, In-pipe storage, Sewer flushing.	13B

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