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ABATEMENT MEASURES FOR POLLUTION DUE TO URBAN RUNOFF

by

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ABSTRACT

Three levels of abatement of pollution due to urban runoff were investigated. Street cleaning, which represents a source control measure, was considered as a first level abatement measure. The costs and pollution abatement effectiveness of street cleaning were established. The second level abatement measures consisted of runoff storage and treatment by sedimentation. Lastly, the third level abatement measures consisted of runoff storage and advanced treatment. The effectiveness and costs of the second and third level measures were derived by modification of the data which were established by the American Public Works Association for the province of Ontario.

RÉSUMÉ

Trois niveaux de réduction de la pollution due au ruissellement des eaux urbaines ont été étudiés. Le nettoyage des rue, qui représente une mesure de lutte à la source, a été considéré comme premier niveau des mesures de réduction. On a déterminé les coûts du nettoyage des rues et l'efficacité de celui-ci à réduire la pollution. Le second niveau de mesure de réduction comprend l'emmagasinement des eaux de ruissellement et leur traitement par sédimentation. Enfin, le troisième niveau de mesures de réduction comprend l'emmagasinement des eaux de ruissellement et leur traitement tertiaire. L'efficacité et les coûts des mesures du second et du trosième niveaux ont été obtenus en modifiant les données établies par l'American Public Works Association (Association américaine de travaux publics) et en les adaptant à la province de l'Ontario.

FOREWORD: MANAGEMENT PERSPECTIVE

This report interprets available data for storm and combined sewers to provide cost estimates for the interception of polluting and nutrient material by various methods.

The data used in the analysis is rather limited but is the only data known to be available. Nevertheless, the interpretation provides the basis for the comparison of costs and efficiencies of various management strategies for the control of pollution caused by run-off in urban and developed areas. The material contained herein will be considered in context of the studies under the Pollution from Land Use Activities Reference Group (PLUARG).

T. M. Dick, Chief
Hydraulics Research Division
National Water Research Institute
29 May 1978

AVANT-PROPOS: PERSPECTIVE - GESTION

Ce rapport interprète les données connues sur les égouts pluviaux et les égouts unitaires afin de fournir des estimations des coûts pour l'interception de polluants et de matières nutrives par diverses méthodes.

Les données utilisées au cours de l'analyse sont plutôt limitées mais ce sont les seules qui existent, à notre connaisance. Néamoins, l'interprétation permet d'établir une comparaison entre les coûts et l'efficacité des diverses stratégies de gestion pour la lutte contre la pollution causée par le ruissellement dans le régions urbaines et développées. Les données figurant dans ce rapport seront étudiées dans le contexte des études menées sous l'égide du Pollution from Land Use Activities Reference Group (PLUARG) (Group de référence sur la pollution par les travaux d'utilisation des terres).

T. M. Dick, Chef
Division des recherches hydrauliques
Institut national de recherche sur l'eau
Le 29 mai 1978

1.0 INTRODUCTION

The Hydraulics Research Division has been requested by PLUARG to provide estimates of pollution loads in urban runoff and to evaluate several suitable pollution abatement measures. Annual pollutant loadings in urban runoff were presented in a preceding report [2] and their summary appears in the Appendix. The main objectives of this report are to review several levels of abatement of pollution due to urban runoff, to estimate efficiencies of various abatement measures, and to determine the associated costs. The approach taken here represents a first-cut analysis, thus maintaining about the same level of sophistication and detail as in the preceding report [2].

The abatement of pollution due to urban runoff has been extensively studied during the last ten years. During this period, new pollution abatement measures have been developed. Such measures include source controls, collection system controls, storage, and treatment. Quite often, various combinations of these basic techniques are used to achieve the most cost-effective abatement of urban runoff pollution.

Although many pollution abatement measures have been proposed and studied in the laboratory or a pilot plant, the actual experience with designing and building such abatement facilities is rather limited, particularly in Canada. This lack of hard data then contributes to relatively large uncertainties in the efficiencies and costs of the abatement measures discussed in this report.

As recommended by PLUARG, three levels of pollution abatement were considered. The first level, street cleaning, belongs to the source control category. The second level includes runoff storage and basic treatment by sedimentation. The third level combines runoff storage and advanced treatment.

Pollutant removal efficiencies and associated costs for the first abatement level were established in this report. For the second and third levels, analogous information was adopted from a recent report [4] which was prepared by the American Public Works Association (APWA) for the Urban Drainage Subcommittee. The contribution made in this report consisted in expanding the original APWA analysis for additional constituents and assuming that pollutant removals depend on the pollutant association with solid particles of certain sizes.

2.0 FIRST LEVEL ABATEMENT MEASURES

2.1 General Description

Street cleaning was considered here as a first-level abatement measure for areas served by separate sewers as well as for areas served by combined sewers. While most cities undertake some form of street cleaning for aesthetic reasons, only recently has street cleaning been recognized as a pollution control measure which reduces the pollutant loadings available for wash-off by surface runoff. There is still a relative lack of data on cost effectiveness of street cleaning and on its relation to the effectiveness of the controls which are implemented at the drainage outlet.

The most common form of street cleaning is sweeping. In general, the effectiveness of street sweeping in removal of pollutants is a function of the following factors [3] :

sweeper efficiency
number of passes
speed of equipment
pavement conditions
pollutant association with particles of certain sizes
frequency of sweeping
frequency of rainfall, and
public participation and awareness.

2.1.1 Sweeper Efficiency

A variety of street sweepers is available on the market. Two basic types are referred to as mechanical broom sweepers and vacuum sweepers. Mechanical broom sweepers are less expensive and fulfill the main objective of current street cleaning practices - aesthetics. It is well established, however, that broom sweepers are ineffective in removing fine particles which may contain high concentrations of such pollutants as phosphorus or heavy metals. Vacuum sweepers, which are more expensive, possess good removal efficiencies throughout the full range of particle sizes.

The sweeper efficiencies which were used in this report were adopted from references [3, 5]. These efficiencies are shown in Table I for various particle sizes.

TABLE I EFFICIENCY OF STREET SWEEPERS

PARTICLE SIZE mm	PERCENT OF PARTICLES REMOVED (By Weight)		
	Broom Sweepers [3]		Vacuum Sweepers [5]
	I Pass	2 Passes	
> 2	79%	95.6%	80%
0.84 - 2.00	66%	88.4%	90%
0.246 - 0.84	60%	84.0%	95%
0.104 - 0.246	48%	77.0%	
0.043 - 0.104	20%	36.0%	
<0.043	15%	27.8%	

It can be inferred from Table I that sweeper efficiencies vary with the particle size and this variation is particularly large in the case of mechanical broom sweepers. The efficiency of broom sweepers can be as low as 15% for the smallest particles and one sweeping pass.

2.1.2 Number of Passes

The removal efficiency of street sweeping can be increased by making more than one sweeping pass. This is particularly true for broom sweepers; the greater the number of passes, the greater the amount of fine particles that will be removed. For this reason, two passes were considered in this report for mechanical broom sweepers (see Table I).

2.1.3 Speed of Equipment

The majority of sweepers are designed to provide the maximum efficiency at a certain operating speed. If this speed is exceeded, the sweeper efficiency will fall significantly. The efficiencies in Table I correspond to the optimal operating speed (typically about 4-8 miles/hour).

2.1.4 Pavement Conditions

Depressions in a road surface provide hard to reach places for sweepers. In addition, further deterioration continually adds materials to the pollutant accumulations on the surface. Consequently, effective street sweeping is possible only on adequately maintained road surfaces.

2.1.5 Pollutant Association with Particles of Certain Sizes

Particle removal from the street surface is a selective process which depends on the particle size. Because pollutants tend to be nonuniformly associated with particles of certain size ranges, the removal of pollutants will also be selective. Several sources of information on pollutant association with certain particles sizes were reviewed and reference [3] was found to provide the most complete information. The basic data from reference [3], which were adopted in this report, appear in Table 2.

TABLE 2 FRACTION OF POLLUTANT ASSOCIATED WITH EACH PARTICLE SIZE RANGE (% by Weight) [3]

	PARTICLE SIZE (μ)					
	>2,000	840→2,000	246→840	104→246	43→104	<43
Total Solids	24.4	7.6	24.6	27.8	9.7	5.9
BOD	7.4	20.1	15.7	15.2	17.3	24.3
COD	2.4	4.5	13.0	12.4	45.0	22.7
Nitrates	8.6	6.5	7.9	16.7	28.4	31.9
Phosphates	0	0.9	6.9	6.4	29.6	56.2
Total Heavy Metals	16.3	17.5	14.9	23.5	27.8 (43→104 and <43 combined)	

It can be inferred from Table 2 that practically all the pollutants tend to be associated more with fine particles than with coarse particles. This tendency is particularly strong in the case of phosphates.

2.1.6 Street Sweeping Frequency and Rainfall Frequency

Particles resting on the catchment surface are removed by either surface runoff or sweeping. To quantify the pollutant removal by sweeping at a certain frequency, one has to determine the number of dry days preceding each sweeping operation. Such information was presented in reference [1] for a particular rainfall record and three sweeping frequencies. The data from reference [1] which were adopted in this report are summarized in Table 3.

TABLE 3 **POLLUTANT REMOVAL VS. SWEEPING INTERVAL [1]**

SWEEPING INTERVAL (DAYS)	POLLUTANT REMOVAL Weight Percent
30	0.146 e
15	0.296 e
7	0.463 e
e = the efficiency of sweeping (typically varies from 0.6 to 0.9)	

2.1.7 Public Participation and Awareness

Public participation is important from several points of view. Parked cars are major obstacles to efficient cleaning. The public should be informed on the need for cleaning and the need for streets to be clear of parked vehicles in order to accomplish effective cleaning.

The public also should be informed on the contributions individuals can make to reduce the amount of material that end up on a road surface.

2.2 Removal of Pollutants by Street Sweeping

The removal of pollutants by street sweeping can be determined from Tables 1-3 and the pollutant loading Table (Appendix). First, sweeper efficiencies in removing a particular pollutant were determined by applying the sweeper efficiency (Table 1), for a certain particle size, to the weight fraction of the pollutant associated with the same particle size (Table 2). The resulting pollutant removal efficiencies were then substituted into the expressions for pollutant removals for various sweeping intervals (Table 3). The final data represent pollutant removals, by sweeping at various time intervals, expressed in weight percent of the total loading. These removals are given in Table 4.

A few observations regarding the data in Table 4 are of interest. Vacuum sweepers appear to be significantly more efficient than mechanical broom sweepers. This difference is particularly marked for phosphates which tends to be associated with fine particles. The annual pollutant removals increase with an increasing frequency of street sweeping. The resulting increase in removals is not, however, linearly proportional to the sweeping frequency. This nonlinearity is caused by the climatic factors (rainfall frequency).

TABLE 4 FRACTIONS OF ANNUAL POLLUTANT LOADING REMOVED BY STREET SWEEPING

Pollutant	Type of Sweeping Operation	Fractions of Pollutant Removed [Weight Percent]		
		I[3]=30 days	I=15 days	I=7 days
BOD	B.SW.[1]-1 Pass	7.0	12.7	19.9
	B.SW.-2 Pass	9.2	18.6	29.0
	V.SW.[2]-1 Pass	13.6	27.5	43.0
N	B.SW.-1 Pass	5.0	10.2	15.9
	B.SW.-2 Pass	7.7	15.6	24.3
	V.SW.-1 Pass	13.6	27.6	43.2
P	B.SW.-1 Pass	3.2	6.6	10.3
	B.SW.-2 Pass	5.5	11.2	17.5
	V.SW.-1 Pass	13.9	28.1	44.0
SS	B.SW.-1 Pass	8.1	16.3	25.6
	B.SW.-2 Pass	11.3	22.9	35.8
	V.SW.-1 Pass	13.3	27.0	42.2
Heavy Metals	B.SW.-1 Pass	7.2	14.7	22.9
	B.SW.-2 Pass	10.3	20.9	32.7
	V.SW.-1 Pass	13.4	27.1	42.4

1 Broom Sweeper
2 Vacuum Sweeper
3 I=Sweeping Interval

Finally, the removal rates from Table 4 were applied to the annual unit loadings which were given in the Appendix, to obtain pollutant removals, by street sweeping, in weight units/acre/year. These annual pollutant removals are given in Tables 5 (a) - (c) for various land use. Note that street sweeping as well as other abatement measures are uneconomical for the land use group 4.

2.3 Cost of Street Sweeping

The costs of street sweeping are typically reported in dollars per curb mile swept. In a recent EPA report [3], these costs were found to vary as much as four times. Such a wide cost range was partly attributed to varying labour rates and labour utilization [3]. Equipment costs are also known to vary widely, with depreciation and maintenance costs varying considerably between cities. Finally, cities typically use different overhead rates and accounting procedures.

TABLE 5 POLLUTANT REMOVALS BY SWEEPING [LBS/ACRE/YEAR]
(These data apply to both separate and combined areas)

(A) MECHANICAL BROOM SWEEPERS - One Pass

Constituent	Land Use Group 1			Land Use Group 1			Land Use Group 1		
	I=30 days	I=15 days	I=7 days	I=30 days	I=15 days	I=7 days	I=30 days	I=15 days	I=7 days
BOD	2.1	3.8	6.0	5.6	10.2	15.9	2.1	3.8	6.0
N	.40	.82	1.27	.50	1.02	1.59	.35	.71	1.11
P	.045	.092	.144	.096	.198	.309	.064	.132	.206
SS	28.4	57.1	89.6	40.5	81.5	128.0	48.6	97.8	153.6
Cd	.00086	.00176	.00275	.00094	.00191	.00238	.00151	.00309	.00481
Cr	.00166	.00338	.00527	.00180	.00368	.005725	.00281	.00573	.00893
Cu	.00288	.00588	.00916	.00317	.00647	.01008	.00500	.01014	.0158
Hg	.00245	.00500	.00779	.00274	.00559	.00870	.00418	.00853	.0133
Ni	.00187	.00382	.00595	.00209	.00426	.00664	.00324	.00662	.0103
Pb	.01008	.02058	.03206	.01116	.0228	.03550	.01728	.0353	.0550
Zn	.03672	.0750	.1168	.04054	.0828	.1289	.06293	.1285	.200

(B) MECHANICAL BROOM SWEEPERS - Two Passes

Constituent	Land Use Group 1			Land Use Group 2			Land Use Group 3		
	I=30 days	I=15 days	I=7 days	I=30 days	I=15 days	I=7 days	I=30 days	I=15 days	I=7 days
BOD	2.8	5.7	8.8	7.4	15.0	23.3	2.8	5.7	8.8
N	.62	1.25	1.94	.77	1.56	2.43	.54	1.09	1.70
P	.077	.157	.245	.165	.336	.525	.110	.224	.350
SS	39.6	80.2	125.3	56.5	114.5	179.0	67.8	137.4	214.8
Cd	.00123	.00251	.00392	.00134	.00272	.00425	.00216	.00439	.00687
Cr	.00237	.00481	.00752	.00257	.00523	.00818	.00402	.00815	.01275
Cu	.00412	.00836	.01308	.00453	.00920	.01439	.00715	.01442	.0226
Hg	.00350	.00711	.01111	.00392	.00794	.01243	.00598	.01212	.01897
Ni	.00268	.00543	.00850	.00299	.00606	.00948	.00463	.00941	.01472
Pb	.0144	.0293	.04578	.01600	.0324	.0507	.0247	.05016	.0785
Zn	.0525	.1066	.1668	.0580	.1177	.1841	.0900	.1827	.2858

(C) VACUUM SWEEPERS - One Pass

Constituent	Land Use Group 1			Land Use Group 2			Land Use Group 3		
	I=30 days	I=15 days	I=7 days	I=30 days	I=15 days	I=7 days	I=30 days	I=15 days	I=7 days
BOD	4.1	8.3	12.9	10.9	22.0	34.4	4.1	8.3	12.9
N	1.09	2.21	3.46	1.36	2.76	4.32	.95	1.92	3.02
P	.195	.393	.616	.417	.843	1.320	.278	.562	.880
SS	46.6	94.5	147.7	66.5	135.0	211.0	79.8	162.0	253.2
Cd	.00161	.00325	.00594	.00174	.00352	.00636	.00281	.00569	.01018
Cr	.00308	.00623	.0106	.00335	.00678	.01187	.00523	.01057	.01823
Cu	.00536	.01084	.02417	.00590	.01192	.02671	.00925	.01870	.04113
Hg	.00456	.00921	.01611	.00509	.01030	.01781	.00777	.01572	.02756
Ni	.00348	.00705	.01272	.00389	.00786	.01399	.00603	.01220	.02162
Pb	.01876	.03794	.0615	.02077	.0420	.06784	.03216	.0650	.1047
Zn	.06834	.1382	.2421	.07544	.1526	.2663	.11712	.2369	.4117

For the purpose of this report, the costs of street sweeping were obtained from several municipalities and combined with updated data from reference [5]. The final cost data appear in Table 6.

TABLE 6 COSTS OF STREET SWEEPING [$/curb mile]

Equipment	Total Costs [$/Curb Mile]	Capital Costs [$/Curb Mile]	O & M Costs [$/Curb Mile]
Mechanical Sweepers	7.30	4.03	3.27
Vacuum Sweepers	9.80	6.09	3.71

The costs in dollars per curb mile have to be converted into annual costs per acre, in order to make these costs fully compatible with the pollutant loadings and removals given previously. Towards this end, the total curb miles swept per acre per year were first determined for various land use and sweeping intervals. The results are given in Table 7.

TABLE 7 MILES SWEPT/ACRE/YEAR

SWEEPING INTERVAL (DAYS)	MILES SWEPT/ACRE/YEAR		
	LAND USE GROUP 1	LAND USE GROUP 2	LAND USE GROUP 3
30	0.871	0.835	0.411
15	1.742	1.670	0.822
7	3.750	3.600	1.770

Finally, the annual costs of street sweeping per acre were calculated from Tables 6 and 7 and are given in Table 8. These costs (Table 8) are to be used in conjunction with the pollutant removals which were presented in Table 5.

BLE 8 **ANNUAL COSTS OF SWEEPING** [DOLLARS/ACRE]

SWEEPING OPERATION	Sweeping Interval days	ANNUAL COSTS OF SWEEPING [DOLLARS/ACRE]								
		LAND USE GROUP 1			LAND USE GROUP 2			LAND USE GROUP 3		
		Capital Costs	O&M Costs	Total Costs	Capital Costs	O&M Costs	Total Costs	Capital Costs	O&M Costs	Total Costs
Mechanical Sweepers - 1 Pass	30	3.51	2.85	6.36	3.37	2.73	6.10	1.66	1.34	3.00
	15	7.02	5.70	12.72	6.74	5.46	12.20	3.32	2.68	6.00
	7	15.11	12.27	27.38	14.51	11.77	26.28	7.13	5.79	12.92
Mechanical Sweepers - 2 Passes	30	7.02	5.70	12.72	6.74	5.46	12.20	3.32	2.68	6.00
	15	14.04	11.40	25.44	13.48	10.92	24.40	6.64	5.36	12.00
	7	30.22	24.54	54.76	29.02	23.54	52.56	14.26	11.58	25.84
Vacuum Sweepers - 1 Pass	30	5.30	3.24	8.54	5.09	3.09	8.18	2.50	1.53	4.03
	15	10.60	6.48	17.08	10.18	6.18	16.36	5.00	3.06	8.06
	7	22.84	13.91	36.75	21.92	13.36	35.28	10.78	6.57	17.35

3.0 SECOND LEVEL ABATEMENT MEASURES

The second level abatement measures are considered here as combinations of watershed storage, downstream storage, and treatment of runoff by sedimentation. Such measures are consistent with those proposed by APWA for control of urban runoff pollution in Ontario [4] and, consequently, much information from the APWA report [4] may be used in this report.

Watershed storage is understood here as runoff storage on such dual purpose sites as parking lots, roof tops, and playgrounds. As the retention period of storm runoff in such areas must be rather short, it has been assumed that no treatment takes place in these storage areas. Typically, this type of storage might be used for a maximum of several hours after the end of a storm event. There is a practical limitation to watershed storage - the total volume of storage available. This volume is likely to be limited unless it is possible to create depressions in which water can be detained. At some point, the cost of creating additional watershed storage would become excessive and that is the point when conventional storage ponds would become more economical than watershed storage. Such ponds were considered here also as primary treatment devices with average residence times in the order of a day.

To evaluate the effectiveness and costs of the first level abatement measures, data from the APWA report [4] were used. According to this source, it was assumed that these abatement measures could be characterized by a 25% control of BOD and the associated minimal costs would vary from \$8/acre/year to \$61/acre/year (an area-weighted mean cost is \$26/acre/year). Considering that particle removal by sedimentation will be governed by the particle size (for a constant specific gravity), one can use again Table 2 to estimate pollutant removals which correspond to the BOD removal of 25%. The resulting removal rates are given in Table 9.

TABLE 9 POLLUTANT REMOVALS - FIRST ABATEMENT LEVELS

	POLLUTANT				
	BOD	N	P	SS	Heavy Metals
Removal Rate [Weight Percent]	25%	14.3%	0.8%	31.6%	31.6%

The removal rates from Table 9 were applied to the annual loadings presented in the Appendix to obtain annual pollutant removals which are given in Table 10 together with the associated costs.

TABLE 10 SECOND ABATEMENT LEVEL - POLLUTANT REMOVALS AND ASSOCIATED COSTS

CONSTI-TUENT	ANNUAL POLLUTANT REMOVALS [LBS/ACRE/YEAR]					
	SEPARATE SEWERS			COMBINED SEWERS		
	Land Use #1	Land Use #2	Land Use #3	Land Use #1	Land Use #2	Land Use #3
BOD	7.5	20.0	7.5	30.0	65.5	25.0
N	1.14	1.43	1.0	4.02	4.66	4.40
P	.011	.024	.016	.073	.082	.078
SS	110.6	158.0	189.6	218.0	189.6	208.6
Cd	.0038	.0041	.0066	.0044	.0047	.0076
Cr	.0073	.0079	.0123	.0079	.0088	.0136
Cu	.0126	.0139	.0218	.0180	.0199	.0307
Hg	.0107	.0120	.0183	.0120	.0133	.0205
Ni	.0082	.0092	.0142	.0095	.0104	.0161
Pb	.0442	.0490	.0758	.0458	.0506	.0781
Zn	.1612	.1779	.2762	.1804	.1984	.3068
Total Annual Costs [$/acre/year] [1]		26.00			75.00	
Annual Capital Costs [$/acre/year] [1]		20.80			60.00	
Annual O&M Cost [$/acre/year] [1]		5.20			15.00	
Initial Capital Costs [$/acre] [1]		216.50			624.40	

[1] Weighted-mean cost adopted from the APWA report [4].

4.0 THIRD LEVEL ABATEMENT MEASURES

The third level abatement measures are considered here as combinations of watershed storage, downstream storage, and advanced treatment of runoff. As in the previous case, the main function of watershed storage is to detain runoff and therefore increase the utilization of the downstream storage and treatment facilities. These types of pollution abatement were studied by APWA, and BOD removal rates as well as the associated minimal costs were reported for Ontario [4].

Removal rates for other constituents than BOD had to be estimated for the third level abatement. Two types of estimates were produced. Firstly, a constant removal rate of 50% was assumed for all the constituents. Secondly, removal rates were assumed to be somehow affected by the particle sizes with which the pollutants tend to be mostly associated. These assumed removal rates are given in Table 11.

TABLE 11 THIRD LEVEL ABATEMENT MEASURES - REMOVAL RATES

	CONSTITUENT				
	BOD	N	P	SS	Heavy Metals
Constant Removal Rates [Weight Percent]	50%	50%	50%	50%	50%
Variable Removal Rates [Weight Percent]	50%	40%	30%	70%	60%

Finally, the removal rates from Table 11 were applied to the annual pollutant loadings (see the Appendix) and the resulting annual removals (lbs/acre/year) are given in Table 12 for both constant and variable removal rates.

TABLE 12 **ANNUAL POLLUTANT REMOVALS [LBS/ACRE/YEAR]**

(A) Constant Removal Rate of 50%

CONSTI-TUENT	ANNUAL POLLUTANT REMOVALS LBS/ACRE/YEAR					
	SEPARATE SEWERS			COMBINED SEWERS		
	Land Use #1	Land Use #2	Land Use #3	Land Use #1	Land Use #2	Land Use #3
BOD	15.0	40.0	15.0	60.0	131.0	50.0
N	4.0	5.0	3.5	14.0	16.3	15.3
P	0.7	1.5	1.0	4.55	5.1	4.85
SS	175.0	250.0	300.0	345.0	300.0	330.0
Cd	.0060	.0065	.0105	.0070	.0075	.0120
Cr	.0115	.0125	.0195	.0125	.0140	.0215
Cu	.0200	.0220	.0345	.0285	.0315	.0485
Hg	.0170	.0190	.0290	.0190	.0210	.0325
Ni	.0130	.0145	.0225	.0150	.0165	.0255
Pb	.070	.0775	.1200	.0725	.0800	.1235
Zn	.2550	.2815	.437	.2855	.3140	.4855
Initial Capital Cost [$/acre]		566.10			1998.00	
Annual Capital Costs [$/acre/year]		54.40			192.00	
Annual O&M Costs [$/acre/year]		13.60			48.00	
Total Annual Costs [$/acre/year]		68.00			240.00	

cont'd

TABLE 12 cont ANNUAL POLLUTANT REMOVALS [LBS/ACRE/YEAR]

(B) Variable Removal Rates (see Table 11)

CONSTITUENT	ANNUAL POLLUTANT REMOVALS LBS/ACRE/YEAR					
	SEPARATE SEWERS			COMBINED SEWERS		
	Land Use #1	Land Use #2	Land Use #3	Land Use #1	Land Use #2	Land Use #3
BOD	15.0	40.0	15.0	60.0	131.0	50.0
N	3.2	4.0	2.8	11.2	13.0	12.3
P	0.42	0.90	0.60	2.73	3.06	2.91
SS	245.0	350.0	420.0	483.0	420.0	462.0
Cd	.0072	.0078	.0126	.0084	.0090	.0144
Cr	.0138	.0150	.0234	.0150	.0168	.0258
Cu	.0240	.0264	.0414	.0342	.0378	.0582
Hg	.0204	.0228	.0348	.0228	.0252	.0390
Ni	.0156	.0174	.0270	.0180	.0198	.0306
Pb	.0840	.0930	.1440	.0870	.0960	.1482
Zn	.3060	.3378	.5244	.3426	.3768	.5826
Initial Capital Cost [$/acre]	566.10			1998.0		
Annual Capital Costs [$/acre/year]	54.40			192.00		
Annual O&M Costs [$/acre/year]	13.60			48.00		
Total Annual Costs [$/acre/year]	68.00			240.00		

Note: All the costs are from the APWA report [4].

5.0 DISCUSSION

Because of the limited time available for writing this report, it was necessary to rely as much as possible on the relatively scarce data which were found in the literature. In some cases, the published data, particularly the costs of abatement measures, could not be verified within the constraints of this study. Consequently, the results presented in this report contain appreciable uncertainties which must be borne in mind when interpreting these results. Detailed comments on the accuracy and reliability of results follow.

5.1 First Level Abatement Measures

Street sweeping was considered in this report as a first level abatement measure. It was assumed that the amount of pollutants removed from separate sewer areas would be identical to that removed from combined sewer areas.

Numerous uncertainties were involved in the computation of pollutant removals by street sweeping. Among the sources of these uncertainties, one could name the efficiency of sweepers, sweeping frequency, and association of pollutants with particles of certain sizes.

The efficiencies of sweepers were adopted from references [3, 5]. It would appear that the efficiency of mechanical broom sweepers was fairly well established. Only limited data were available for vacuum sweepers and these data were derived for relatively small sweepers which are used on side walks [5]. It is conceivable that the efficiency of vacuum sweepers used in street cleaning will be somewhat smaller than that given in this report. Note that according to the data from references [3, 5], mechanical broom sweepers would have to make up to three passes to achieve the same efficiency as vacuum sweepers.

The frequency of street sweeping has a pronounced effect on the removal of pollutants. In fact, one deals here with a joint probability distribution of the particle removal by either sweeping or rain. The removal rates in this report were derived by studying such joint probabilities (reference [1]) for a rainfall record from Burlington. It is conceivable that somewhat different distributions and results would be obtained at other locations. The higher the rainfall occurrence frequency, the lower the probability of particle removal by sweeping.

Since sweepers remove solid particles from the street surface rather selectively, depending on the particle size, the pollutant removal is also selective because of highly nonuniform association of pollutants with particles of various sizes. To evaluate this selective removal, the data on pollutant association with certain particle sizes were adopted from reference [3]. No other source of data was available for verification. It was felt, however, that the data from reference [3] were fairly extensive and reliable.

The costs of street sweeping were determined by making several enquiries to local municipalities. These costs are known to vary widely, depending on the local practices. Therefore, the costs presented in this report should be considered as first-cut estimates.

In the overall assessment of street sweeping, vacuum sweepers appeared to be more effective in pollution abatement than mechanical broom sweepers. This higher effectiveness more than outweighs the higher costs of vacuum sweepers. To achieve significant pollutant removals, street sweeping should be done at least once every two weeks. Even more frequent street sweeping could be considered as a higher level abatement measure.

5.2 Second Level Abatement Measures

These measures consist of watershed storage, downstream storage, and runoff treatment by sedimentation. Both removal rates and costs of these measures were adopted from the APWA report [4].

The APWA removal rates were supplemented in this report by removal rates for additional constituents. A selective removal of pollutants by sedimentation was considered using the data in Table 2 to describe the pollutant association with particles of certain sizes. Consequently, above average removal rates were obtained for suspended solids and heavy metals, below average removals were obtained for nitrogen and phosphorus. There are no experimental data to verify these assumptions.

The costs of abatement measures were adopted from the APWA report 4 and represented minimal costs which were derived for optimum combinations of storage and treatment in various cities in Ontario. Limited experience with constructing such facilities prevents any thorough verification by means of actual case histories. It would appear that the costs given by APWA and adopted here indeed represent minimal costs which would be quite often exceeded.

5.3 Third Level Abatement Measures

The third level abatement measures are similar to those applied at the second level. To achieve a higher pollution abatement, more storage capacity has to be provided and advanced treatment has to be implemented at the third level. BOD removal rates and costs were adopted from the APWA report [4].

Two kinds of removal rates were considered in this report. Firstly, identical removal rates (50%) were considered for all the pollutants. Secondly, various removal rates were assumed for the individual pollutants. These latter rates were based on an assumption that the removal rate depends on the pollutant association with certain particle sizes, however, not to the extent indicated earlier for sedimentation. Again, no experimental data were available to verify these removal rates.

The costs of abatement represent minimal costs which are likely to be exceeded under many circumstances.

6.0 CONCLUSIONS

Three levels of abatement of pollution due to urban runoff were proposed and the associated costs determined. The first level is represented by street sweeping. Vacuum sweepers employed once every two weeks were found effective in removing pollutants from the catchment surface and thus preventing their wash off by runoff. In areas served by storm sewers, the annual pollutant loadings could be reduced, by street sweeping once every two weeks, by about 27% at an average cost of about $15.23/acre/year. The same sweeping practices can be applied in the areas served by combined sewers. Because of pollutant loadings in the dry weather flow, the relative reduction in the total loading, due to street sweeping, will be lower (10%). The costs would remain the same.

In the second level, abatement schemes consisting of watershed storage, downstream storage, and runoff treatment by sedimentation were considered. Average reductions in pollutant loadings of 20% could be achieved, for both storm and combined sewer areas, at the annual costs of $26/acre/year and $75/acre/year, respectively. These abatement schemes would be practical only for combined sewer areas, since for storm sewers, better removals and economies were achieved at the first level. Under these circumstances, frequent street sweeping could be considered as a second level abatement measure for areas served by storm sewers. Weekly sweeping could reduce the annual pollutant loadings by as much as 40% at a cost of $32.78/acre/year.

The third level abatement measures were proposed as combinations of watershed storage, downstream storage, and advanced treatment of runoff. About one half of annual pollutant loadings from storm and combined sewer areas could be removed at annual costs of $68/acre/year and $240/acre/year, respectively.

7.0 RECOMMENDATIONS

A preliminary assessment of street cleaning indicates that street sweeping by vacuum sweepers is a highly cost-effective measure for the abatement of pollution due to urban runoff. It is recommended to verify this finding in the field.

8.0 REFERENCES

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3. Sartor, J. D. and Boyd, G. B. "Water Pollution Aspects of Street Surface Contaminants, Report EPA-R2-72-081, Environmental Protection Agency, Washington, D. C., November 1972.

4. Sullivan, R. H., Hurst, W. D., Kipp, T. M. Heaney, J. P., Huber, W. C., and Nix, S. "Evaluation of the Magnitude and Significance of Pollution Loading from Urban Stormwater Runoff-Ontario". A report commissioned by the Urban Drainage Subcommittee to the American Public Works Association, July 1977.

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APPENDIX

ANNUAL UNIT POLLUTANT LOADINGS (lbs/acre/year)

ANNUAL UNIT POLLUTANT LOADINGS IN LBS/ACRE/YEAR

Sewerage System	Constituent	Land Use Group 1 [1]	Land Use Group 2 [2]	Land Use Group 3 [3]	Land Use Group 4 [4]
Storm Sewers	BOD	30.0	80.0	30.0	1.0
	N	8.0	10.0	7.0	.2
	P	1.4	3.0	2.0	.04
	SS	350.0	500.0	600.0	10.0
	Cd	.012	.013	.021	.002
	Cr	.023	.025	.039	.003
	Cu	.040	.044	.069	.006
	Hg	.034	.038	.058	.005
	Ni	.026	.029	.045	.004
	Pb	.140	.155	.240	.020
	Zn	.510	.563	.874	.072
Combined Sewers	BOD	120.0	262.0	100.0	1.4
	N	28.1	32.6	30.8	1.0
	P	9.1	10.2	9.7	0.3
	SS	690.0	600.0	660.0	10.0
	Cd	.014	.015	.024	.002
	Cr	.025	.028	.043	.003
	Cu	.057	.063	.097	.008
	Hg	.038	.042	.065	.005
	Ni	.030	.033	.051	.004
	Pb	.145	.160	.247	.020
	Zn	.571	.628	.971	.080

[1] Land Use Group 1 - Low-to-medium density residential, light industry

[2] Land Use Group 2 - High density residential, commercial

[3] Land Use Group 3 - Industrial land

[4] Open land - parks, etc.

Note: For newly developed urban land, increase the SS-loadings to 1500 lbs/acre/year for all the land uses.