RIDEAU RIVER STORMWATER MANAGEMENT STUDY
TECHNICAL REPORT

URBAN BACTERIA SOURCES AND CONTROL BY STREET CLEANING IN THE LOWER RIDEAU RIVER WATERSHED

Ontario Ministry of the Environment

Environment Canada

Regional Municipality of Ottawa-Carleton

City of Ottawa

Nepean

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COVER PHOTO: *MOONEY'S BAY* on the Rideau River, Regional Municipality of Ottawa-Carleton.
Photograph by Ron Johnson, Ministry of the Environment, May 20, 1980.

FOREWORD

The overall goal of the RIDEAU RIVER STORMWATER MANAGEMENT STUDY is to develop a cost-effective stormwater management strategy that will enhance recreational use of the Rideau River while protecting public health and, at the same time, accommodating orderly urban development in the areas draining to the river in the Regional Municipality of Ottawa-Carleton. The Study is funded by:

- the Ontario Ministry of the Environment by way of the Provincial Lottery Trust Fund
- Environment Canada
- the Regional Municipality of Ottawa-Carleton
- the City of Ottawa
- the City of Nepean

collectively termed the "contributing partners". The Regional Municipality of Ottawa-Carleton acts as administrator for the Study. A Steering Committee has been established to direct the Study consisting of representatives from the above contributing partners, and representatives from:

- the City of Gloucester
- the Ontario Ministry of Natural Resources
- the Rideau Valley Conservation Authority
- the Ottawa-Carleton Regional Health Unit
- the National Capital Commission.

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This report was prepared under contract for the Rideau River Stormwater Management Study. Mr. G. Zukovs, Pollution Control Branch, Ontario Ministry of the Environment was the technical liaison officer. Mr. H.S. Loijens, Study Coordinator was responsible for the management of the contract and the collection of local field data summarized herein.

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REVIEW NOTICE

This report has been reviewed by the Technical Committee of the Rideau River Stormwater Management Study, and approved by the Steering Committee for publication. The views, conditions and recommendations expressed herein are those of the author(s) and do not necessarily reflect the views and policies of the participating agencies. Mention of trade names or commercial products does not constitute an endorsement or recommendation for use.

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INTRODUCTION

This report describes the activities undertaken as a supplement to the Rideau River Stormwater Management Study. The Rideau River study was a three-year program investigating ways to improve the bacteriological quality of the Rideau River. It included substantial River and test catchment urban runoff monitoring. Water quality models were also modified and verified to describe characteristics of Rideau River bacteria for a variety of conditions. It was found that separated stormwater runoff may be the most significant contributor to the existing bacteria problems. Various urban runoff control measures were therefore investigated as a means of reducing urban runoff bacteria discharges to the Rideau River. The Phase I and Phase II reports of the Rideau river study are currently available (Gore and Storrie/Proctor and Redfern, 1981b, 1981c, and 1982b), along with many related reports (including Environment Canada, 1978 and 1979; Gore and Storrie/Proctor and Redfern, 1981d, 1981e, and 1982; Loijens, 1981; Ontario Ministry of the Environment, 1982; Slack, 1982; Gietz, 1981; and Droste and Gupgupoglu, 1982).

This supplemental study investigated urban bacteria sources and relevant control measures, with particular emphasis on street cleaning in the lower Rideau River drainage area. Extensive use was made of published literature (identified by comprehensive computerized literature searches), unpublished data from various on-going studies, local Ottawa data currently and previously collected during the Rideau River Stormwater Management Study, and finally, data collected in a special field program carried out during the summer of 1981 specifically for this study.

Data from other studies was extensively used to define probable bacteria conditions in the Ottawa area, control measure effectivenesses, the effects of rains on source area contributions to urban runoff yield, and the health effects of probable Ottawa area urban runoff bacteria biotypes. The special field program conducted for this study involved collecting various dry and wet weather urban source samples (street dirt, parking lot runoff, rooftop runoff, vacant land runoff, sewerage sediments, Rideau River sediments, etc.). Most of the special samples collected were analyzed for fecal coliforms, lead, and total solids. Fecal coliforms were monitored because they are the identified problem pollutant, while total solids and lead were analyzed mostly for quality assurance. Other studies offer relatively little data for bacteria compared to data for lead and total solids from urban source areas. Local lead and total solids values allowed much of the mechanism information developed for other areas to be applied to the Ottawa area (especially source contributions). Similarly, much information is available from other areas concerning street cleaning effects on lead and total solids. Ottawa area measurements and calculations for these more common constituents were compared to other available data to confirm the accuracy of the bacteria measurements and calculations. A complete survey of street lengths, textures, and conditions was also conducted for the entire study area. A special summary of long-term Ottawa rain conditions was also provided.

The summary section describes the scope of this project along with some of the study findings.

CONCLUSIONS AND RECOMMENDATIONS

This section presents the important conclusions from this study and recommends changes to the existing street cleaning program. A control program strategy is presented, along with conclusions concerning the health effects of urban runoff bacteria. Other conclusions are included in the body of the report. These conclusions include the effects of different rain characteristics and land uses on the sources of urban runoff bacteria (Sections 1 through 4). Section 10 describes in detail how the current street cleaning program can be optimized within the current budget, or how it can be systematically expanded or reduced. Appendix A describes typical urban runoff bacteria concentrations and how the observed Ottawa data compares to data from other studies. Appendix B includes a detailed discussion of feces sample types where different bacteria biotypes were observed.

- Street cleaning may affect annual fecal coliform bacteria discharges by as much as 20 percent, but 10 percent is a more likely value for large areas. These meager improvements would only be associated with major increases in street cleaning expenditures. Street cleaning, however, can have a much greater effect in reducing the fecal coliform discharges from individual small storms. Street cleaning would have a very small effect on the bacteria discharges from the few large storms. Most of the bacteria from these large storms originate from non-street surface areas, so differences in street cleanliness would result in minor changes in runoff yields. Parking controls during periods of street cleaning also usually have a very small impact on bacteria runoff yields. These conclusions are based on specific site measurements and calculations and would be different for other areas.

- When the cost effectiveness of potential control measures are reviewed, it is recommended that the existing dog feces litter regulations be strengthened and enforced. Several cities, including New York and San Francisco, have leash laws requiring people walking their dogs to pick up any deposited feces for more appropriate disposal. Ottawa, Nepean, and Gloucester currently have dog feces regulations, but Nepean should also prohibit dog feces deposition on private property. They should all require people walking their dogs to carry containers for deposited feces and encourage dog owners to appropriately dispose of the dog feces deposited on their private property. These laws also need to be enforced. This control can be quite inexpensive, but may be associated with major social and political problems. If these regulations were effectively enforced, the fecal coliform Rideau River concentrations may be reduced by about 20 percent and about 75 percent of the urban runoff fecal coliform discharges may be eliminated. Pigeons and waterfowl (specifically ducks) probably contribute most of the fecal coliform bacteria directly to the Rideau River. Continued investigations to look for cross-connections and the elimination of the few existing combined sewer overflows should also be considered. Because of the possibility that polluted sediments may affect Rideau River bacteria concentrations, further studies examining this interaction should be carried out before more costly treatment measures are considered. If significant bacteria reductions are required (more than 75 percent) then a runoff treatment program (using unit processes) may be required.

o Modifications to existing street cleaning programs are recommended. The extensive street cleaning done now in the downtown areas is more than necessary. If the cleaning frequencies were reduced from the current nightly street cleaning to cleaning two or three times a week, substantial savings in costs would be realized. The manual litter pickup efforts, however, may have to be increased. If possible, the cleaning frequencies in the suburban areas should be slightly increased to cleaning frequencies of no more than once a week. These recommended cleaning frequencies would result in minimum street surface loadings. The cost savings from reducing the cleaning effort in the downtown areas can be used to increase the cleaning effort in the outlying areas, for a better balanced street cleaning program.

o Based on monitoring from the Rideau River Stormwater Management Study and other runoff bacteria studies, it is concluded that many potentially pathogenic bacteria biotypes can be present in the local urban runoff. Most of these patho- genic biotypes can cause health problems when ingested. Because of the low probability of ingestion of urban runoff, many of the potential human diseases associated with these biotypes are not likely to occur. The required infective doses of many of these biotypes and their relatively low concentrations in stormwater would require very large amounts of urban runoff to be ingested. As an example, Salmonella, when observed in Ottawa urban runoff and receiving waters, has been found in very low concentrations requiring the consumption of more than 20 liters of urban runoff for infections. Shigella, however, may be present in urban runoff and receiving waters and when ingested in low numbers can cause dysentery.

o The pathogenic organisms of most importance in urban runoff are usually associated with skin infections and body contact. Body contact with urban runoff is not likely. However, the Rideau River retains many of the pathogenic biotypes originating from urban runoff for a long period of time after rains. The concentrations of these specific biotypes at the swimming beaches should be investigated. The most important biotype causing skin infections is Pseudomonas aeruginosa. This biotype has been frequently detected in urban runoff at many locations in concentrations that may cause potential infections. However, there is little information relating increased infection hazards with increased Pseudomonas concentrations. Staphylococci aureus may also cause skin problems with body contact, but there is little information concerning the concentrations of this biotype in urban runoff. Various pathogenic yeasts and viruses may also be found in urban runoff, but their concentrations and infective pathways are not well enough known to establish criteria for urban runoff pollution. Therefore, the local bacteria concentration objectives based on fecal coliform concentra- tions may be unreasonable when actual potential health effects are considered.

The first phase of the recommended control plan to reduce fecal coliform population densities in the Rideau River would be to strengthen and enforce the existing dog feces regulations and to optimize the current street cleaning programs. These would be very low cost items. Effective dog feces control may eliminate most of the urban runoff fecal coliform discharges and result in important bacteria population density reductions in the Rideau River. Changes in the street cleaning program probably would not result in measurable reductions in annual bacteria discharges, but they may reduce the bacteria discharges associated with the smaller, frequent storms.

Continued studies should be made investigating the role of polluted River sediments affecting water column measurements. Even if substantial reductions in bacteria discharges to the River were made, the benefits may not be immediately noticeable because of the polluted sediments.

Further studies also need to be made concerning populations of pathogenic bacteria (specifically *Pseudomonas aeruginosa*, *Staphylococci aureus* and Shigella) in the River. Population densities of these pathogens may be related to River location, storm type, and possibly indicator (fecal coliform) bacteria densities. If adverse levels of these pathogens can be predicted, or easily and quickly measured, then they should be used as the basis for beach closures in the River.

In order to determine the sources of fecal pollution in the Rideau River, studies should be conducted to measure populaton densities of several Streptococcus biotypes. *S. bovis* and *S. equinus* are only associated with non-human animals. They are the predominant fecal strep. biotypes found in live-stock and are also common in dog, cat, rodent, and bird feces, but are not found in human feces. They also have a very rapid die-off rate, so samples would have to be obtained near the time and place of discharge. Their analyses would also have to be started immediately. *S. faecalis* is the predominant human fecal strep. biotype and usually indicates human contamination. It may also be found in feces from other animals, however. *S. mitis* and *S. salivarius* are considered more sen-sitive human indicators, but may be more difficult to analyze. Therefore, if *S. bovis*, *S. equinus*, and *S. faecalis* biotypes are monitored in a comprehensive sampling program, the presence of sanitary sewage infiltration into the River may be determined, along with an indication of the benefits of the dog feces control program.

SUMMARY

IDENTIFICATION OF PROBLEM POLLUTANTS

The first phase in designing an urban runoff control program is to identify which pollutants need to be controlled, and to what extent, based on acceptable discharge limits. The limits must consider the beneficial uses and assimilative capacities of receiving waters. The pollutants that are causing the documented problems need to be identified and appropriate control goals need to be established. The control goals can be based on legally established health limits (such as drinking water standards) or by comparing the affected reach of the receiving water with an acceptable control reach. Some of this information is included in the Phase I report of the Rideau River Stormwater Management Study (Gore and Storrie/Proctor and Redfern, 1981c).

Rideau River bacteria data is summarized in Section 7 of this report. The limited assimilative capacity of the river and how the bacteria quality decreases as the river flows through Ottawa is described. The substantial bacteria density increases during wet weather indicate an urban runoff problem and the probable lengthy duration of adverse river conditions. The bacteria quality at the beaches is also summarized. The number of observations showing bacteria densities greater than the standards indicates that Strathcona, Brantwood, and Brighton Beaches exceed the fecal coliform criteria of 100 organisms/100 mL most of the time. Mooney's Bay Beach exceeds this criteria about ten percent of the time. No significant improvement in beach bacteria quality is evident from 1976 to 1980. A limited field program was conducted during this study that found the Rideau River bottom sediments to have substantial bacteria population densities.

Appendix C is a summary of probable urban runoff bacteria biotypes and their health and sanitary significance. Most of the Appendix C information is based on an extensive literature review, but some local Ottawa data is represented. Many pathogenic bacteria biotypes may be present in urban runoff receiving waters, but only a few are likely to be present in sufficient numbers to cause potential problems: Shigella, *Pseudomonas aeruginosa*, and *Staphylocci aureus*. Shigella may cause dysentery when ingested in low numbers, while *P. aeruginosa* and *S. aureus* may cause infections by body contact. Fecal coliform population density measurements are usually poorly related to population density measurements of these pathogens of concern. The recognized problem pollutants in the Rideau River include pathogenic bacteria that are currently measured by fecal coliform indicator organism densities.

SOURCES OF PROBLEM POLLUTANTS

The second phase in designing an urban runoff control program is to determine the sources of the problem pollutants in the watershed. An understanding of where they accumulate in the catchment is needed before appropriate controls may be selected. As an example, bacteria may accumulate almost everywhere in an urban area (on rooftops from birds, and on streets, parking lots, landscaped areas, and vacant land from dogs and other urban animals) while heavy metals accumulate mostly on street surfaces and parking lots (because they mostly originate from automobiles). Original sources therefore affect a variety of potential control areas. The Rideau River Stormwater Management Plan report identified urban runoff as the major source of the problem bacteria discharges. This special street cleaning study included a limited field program which roughly identified the specific locations in the urban area where the bacteria originated. Most of this report deals with sources of urban bacteria. Appendix B (mostly from an extensive literature review) addresses the original sources of urban bacteria: soils and feces. Feces from warm blooded animals are the only sources of fecal bacteria, while soils can contain some non-fecal bacteria. The ratio of fecal coliforms to fecal strep. bacteria population densities can be used to differentiate between human and non-human sources if the samples are obtained very close to the time of discharge. Otherwise, the different survival times of the fecal strep. biotypes can radically change this ratio with time. The periodic high ratios of these two bacteria indicator groups in the Rideau River may be explained by old non-human discharges. The survival times of the different bacteria biotypes in water and soils are also discussed. Several studies were reviewed that examined the effects of waterfowl feces on water bodies. If the water bodies were small (creeks and small reservoirs), a relatively small number of birds (less than 100) were found to significantly increase various fecal bacteria biotypes in the water. However, if the water bodies were large (large bird refuges and large rivers), then large numbers of birds (as many as 100,000) did not significantly increase the bacteria population densities in the water. The water flowing from the bird refuges typically had better water quality than the inflowing water, possibly due to sedimentation in the refuge marshes. Many studies characterizing urban wildlife feces bacteria conditions were also reviewed. This information, plus wildlife population densities in the study area, was used to estimate the major bacteria sources in the basin. Dog feces are expected to contribute much of the fecal coliforms in urban runoff, while pigeons (on bridges) and ducks on the Rideau River may contribute most of the bacteria to the River. Polluted river sediments may also play an important role in contaminating river water.

Section 2 describes the test catchments, and how different rains (described in Section 1) affect the contributing areas. Small rains (less than about 15 mm) have most of their urban runoff pollutants originating from directly connected impervious areas (especially streets, parking lots, and directly connected rooftops). Pervious areas do not contribute substantial quantities of pollutants until the total rain volume exceeds about 20 mm. Streets contribute most of the urban runoff fecal coliform yield in typical Ottawa residential areas for rains less than 2.5 mm. For rains greater than ten mm, impervious areas contribute most of the fecal coliform runoff yield in residential areas. In shopping centers, parking lots always contribute most of the fecal coliforms. Therefore, street cleanliness can significantly affect fecal coliform yields from residential areas only for the small (but frequent) rains. Parking lot cleanliness in shopping centers is always important.

Appendix A summarizes urban runoff bacteria conditions for many other locations for comparison with the Ottawa runoff conditions. The overall range of observed bacteria population densities is very large, but the average urban runoff fecal coliform population density for the other studies is quite close to the observed Ottawa conditions: about 10^4 organisms/100 mL. Typical combined sewer overflow (CSO) fecal coliform population densities are about 100 to 1000 times the densities reported for separate urban stormwater.

Special street dirt samples were collected throughout the Lower Rideau River basin and analyzed for total solids, median particle size, lead, and fecal coliforms. This information is presented in Sections 3 and 6 and illustrates the importance of street texture on street surface pollutant loadings. Smooth and moderate textured streets had about one-fourth the total solids loadings as very rough streets. Very rough streets, however, had only about one-third to one-tenth the fecal coliform loadings as rough, moderate, and smooth textured streets. Most of the streets in the study area basin are of moderate texture and in good or fair condition. Only about two percent of the streets have very rough textures. The bacteria loadings on the streets before storms are usually several times greater than the total runoff bacteria yields, indicating the potential for streets to contribute all of the urban bacteria yields. Rains are therefore not capable of totally flushing bacteria from the streets. Only sub-basins having street densities greater than about 0.05 km/ha consistently have over-abundant street surface bacteria loads. Basins with street densities less than this value are least suitable for street cleaning as an urban runoff bacteria control measure. They are situated in the southernmost (upstream) portion of the study area and are mostly open areas. The areas most suitable for street cleaning have street densities greater than 0.3 km/ha, are mostly residential, and are located between Brighton Beach and Hogs Back.

Sewerage accumulations of bacteria-laden sediments are discussed in Section 5. Because of the frequent and generally low intensity rains common to Ottawa, sewerage sediments do not appear to be a major source of urban runoff bacteria pollution.

Snowmelt runoff is discussed in Section 4, and was not found to be an important contributor of urban bacteria to the Rideau River.

Section 8 is a summary of the locally observed bacteria concentrations and calculated annual bacteria yields. Urban runoff has the highest fecal coliform population densities, followed by park puddles, gutter flows, and parking lot puddles. Sewerage sediments had bacteria concentrations similar to urban runoff, while Rideau River sediments had much greater densities than anywhere. Snowmelt and sewerage sediments each contribute about ten percent, or less, of the annual urban runoff fecal coliform yield. As noted above, smooth and moderate textured streets have a much greater (about ten times) bacteria loading than is observed in the urban runoff yield.

SELECTION OF CONTROL MEASURES

The last phase in developing an urban runoff control program is to examine the different control measures that can be used to control the identified problem pollutants in the different source areas. The control measures that are available to operate at the source, accumulation areas, or outfall must be identified. Street cleaning can only operate on streets and parking lots (and possibly side-walks and driveways); construction erosion control only affects construction areas; while runoff storage and subsequent treatment can affect all sources and accumulation areas. The effectivenesses of the applicable control measures in reducing problem pollutant concentrations and yields at the outfall must be evaluated. Street cleaning is quite suitable in controlling heavy metals, but is not very suitable in controlling nutrients and organics. Runoff treatment can substantially reduce discharges of most pollutants, depending on the processes selected. When pollutants are removed from the watershed (such as by erosion control or street cleaning) much more are needed to be removed than the amount necessary to meet the discharge goal at the outfall. About 10 kg may need to be removed by street cleaning to save one kg from entering the receiving water, for areas having infrequent rains. This ratio is less for Ottawa, with its frequent rains and correspondingly lower probability for street surface particulate losses as fugitive dust.

After control measure applicability and effectiveness values are known, the urban runoff control program can be designed. In order to meet water quality objectives, a combination of several control measures may be needed. Complex decision analysis procedures may be necessary if multiple objectives are important.

This special study was conducted to examine the potential effectiveness of street cleaning efforts in controlling urban runoff bacteria discharges. A section is also included that summarizes information on the effectiveness of other control measures as presented in various literature sources. Section 9 summarizes the existing street cleaning programs in Ottawa and Nepean. Most (about 75 percent) of the total street cleaning in the Lower Rideau River basin is conducted in the downtown Ottawa area. Only about 25 percent of the existing effort is expended in the other areas. This results in quite clean downtown streets (with cleaning frequencies as high as five times a week) and somewhat dirtier residential areas (cleaning frequencies in residential areas are about once every two weeks in Ottawa and once every two months in Nepean).

Section 10 presents calculated street cleaning productivities specific for the Ottawa area. These are expressed as measures of cleaning effectiveness (expected street loadings, costs to remove street surface pollutants, amount of street surface pollutants removed, and outfall pollutant control by street cleaning) for various street cleaning programs (cleaning frequencies, parking controls, and street textures). For the common smooth and moderate textured streets and the specific Ottawa rain conditions, the optimum street cleaning frequency is about once per week. Any additional increases would result in very little improvement in street cleanliness. If parking densities are moderate (50 to 100 parked cars per curb-km), then parking controls could increase the cleaning effectiveness. Intensive street cleaning is expected to control less than 20 percent of the annual fecal coliform urban runoff discharges, but may control abut 35 percent of the fecal coliform discharges from individual very small rains. Intensive street cleaning only controls less than ten percent of the fecal coliform discharges of individual large rains (>20 mm total rain).

Section 11 summarizes bacteria control effectivenesses for other potential control measures, based on a literature review. Controls investigated include: dog feces control, bird contol (roosting on bridges), cross-connection elimination, urban runoff treatment unit processes (sedimentation, primary treatment, disinfection, and high-rate disinfection), porous pavement, catchbasin sump cleaning, and litter control. Dog feces control would be the most cost-effective control measure, with high urban runoff fecal coliform bacteria yield reductions at little cost.

REPORT ORGANIZATION

This report is organized in three parts. Part I describes specific local data affecting bacteria runoff yields in the Ottawa urban area. Part I of this report contains Sections 1 through 8. It begins with a description of the Ottawa rain conditions and is followed by descriptions of the test catchments and rain effects on yields. Sources of urban runoff pollutants (street dirt, snowmelt, and sewerage sediments) are then discussed. Receiving water conditions are then summarized and Part I ends with a summary of measured and expected bacteria population densities and yields from the different potential sources. Part I therefore contains information describing both the sources and effects of urban runoff on the Rideau River. Part II discusses current and potential urban runoff control measures, especially street cleaning. Part III includes appendices which discuss various aspects of urban bacteria, mostly derived from literature sources.

PART I
LOCAL URBAN RUNOFF AND RIDEAU RIVER BACTERIA CONDITIONS

1.0
OTTAWA PRECIPITATION CHARACTERISTICS

The most important factor affecting various urban runoff characteristics (quality and quantity) is the precipitation pattern. This section describes typical precipitation characteristics for Ottawa, especially rain totals and interevent periods. This information is used in later sections when discussing urban runoff pollutant sources and yields.

About two to three meters of snow typically fall during the winter months of November through April. Most of the snow stays on the ground throughout the winter, but winter snowmelt can occur. The major annual snowmelt usually occurs in the beginning of April. From April to November, about one-half meter of rain falls. Table 1 summarizes a nine-year rain history for the Ottawa City Hall. The total annual rain volume may range from about 300 to more than 600 mm per year. The number of rain events during these eight months can range from 50 to more than 100. June, July, and August have more rain than the other months.

Table 2 summarizes rainfall interevent periods, event durations, and rainfall volumes for the 20-year period ending in 1980 (Gore and Storrie/Proctor and Redfern, 1981c). This table includes all rains that were separated by at least six hours. The average number of all recorded rains (greater than 0.2 mm) ranged from about seven to more than 12 per month, with a total of about 80 per year. Significant rain events (those greater than about five mm are considered capable of rinsing most of the particulates off of smooth asphalt streets) occurred with a frequency from about three to more than five per month, for a total of about 30 per year. These rains occur about every three days, with a maximum reported dry period of 18 days. All of the rains lasted for an average of six and one-half hours, while the longest recorded rain lasted for 70 hours. The average rain volume per event was about seven mm, and the maximum recorded event volume during this period was 65 mm. Average rainfall intensities ranged dramatically, from less than 0.1 mm per hour to more than 30 mm per hour. The more intense rains were associated with the smaller and shorter duration rains, and were probably thundershowers.

The year 1972 was selected as a typical rain year for further analyses. During 1972, about 73 different rains occurred on 82 different days. These rains occurred from April 22 to October 28, and on about 42 percent of all days. Slightly more than one-third of these rains were greater than five mm in volume. Figure 1 is a bar graph showing the number of rain events, the rain volume, and the estimated runoff volume for the 1972 rain year. Most (about 66 percent) of the rains recorded occurred for rains in the zero to five mm volume interval. However, only about 20 percent of the total annual rain volume and less than ten percent of the total annual runoff volume occurred in this volume interval. Therefore, the small rains are very important because of their numbers, but are

Table 1. Ottawa City Hall Rain Quantities by Month (mm).

Year	April	May	June	July	Aug.	Sept.	Oct.	Nov.	total rain (mm)	number of rain events
1966	24.4	47.5	38.1	52.8	73.4	51.3	36.8	91.2	415.5	79
1967	48.5+[(1)]	66.3	128.5	74.4	98.6	106.7+	97.8	NA[(2)]	620.8+	132+
1968	22.1+	40.4	105.4	85.6	45.7	70.4	NA	NA	369.6+	78+
1969	86.9+	75.5	78.2	58.4	NA	NA	NA	NA	299.2+	62+
1970	NA	8.6+	26.9	NA	NA	NA	NA	NA	---	---
1971	10.4+	15.8	NA	63.8+	81.5	NA	52.1	NA	---	---
1972	6.9+	40.4	136.9	95.5	123.2	37.9	88.1	NA	528.9	112+
1973	40.4	111.8	126.8	61.2	160.8	22.9	45.5	NA	569.4	164+
1974	NA	96.5	70.0	71.9	31.5	NA	7.9+	NA	277.8+	110
Average	23.3+	55.9	87.9	70.4	87.9	57.9	54.6	---	448.8+	105+

(1) incomplete rain record for the month
(2) no rain data available for the month

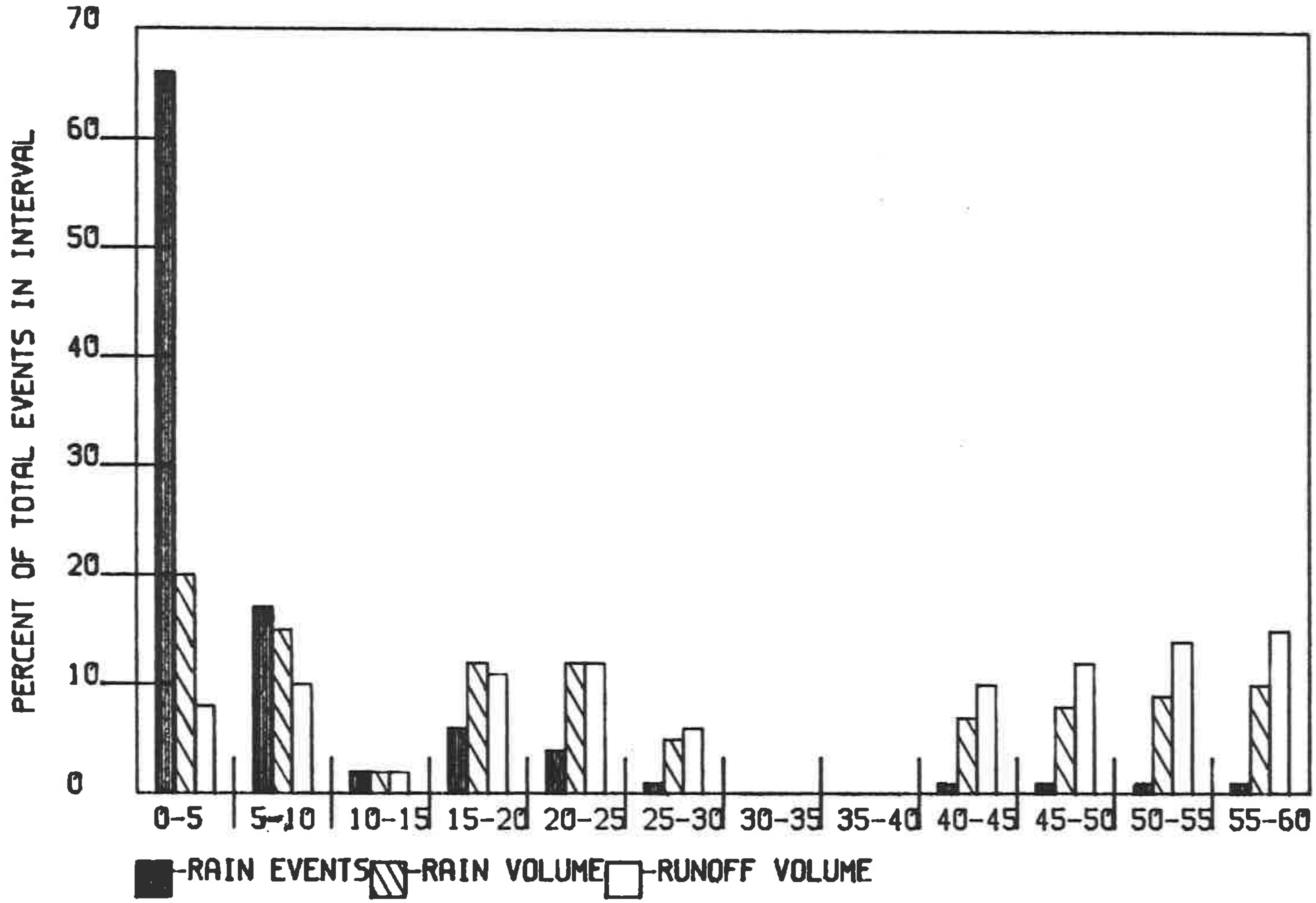
Table 2. Ottawa Rain Characteristics (CDA gauge station) for 1960 to 1980

Month	average number of storm periods/month		interevent period (days) for rains >0.2mm			interevent period (days) for rains >5mm			event duration (hrs) for rains >0.2mm			volume (mm) for rain events >0.2mm			average rainfall intensity (mm/hr) for rains >0.2mm		
	>0.2mm	>5mm	average	min.	max.	average	min.	max.	average	min.	max.	average	min.	max.	average	min.	max.
April	7.6	2.9	2.9	0.3	16.4	3.0	0.3	9.2	8.0	1	43	6.4	0.3	32.5	0.78	0.09	3.0
May	10.5	4.1	2.8	0.3	16.0	3.5	0.3	16	6.6	1	35	6.0	0.2	43.7	1.02	0.1	14.6
June	11.3	5.3	2.5	0.3	18.0	2.3	0.3	8.2	5.6	1	37	6.8	0.2	43.2	1.38	0.1	14.0
July	12.6	5.0	2.4	0.3	16.7	2.5	0.3	17	4.6	1	29	7.1	0.2	49.8	1.82	0.2	33.0
Aug.	11.1	4.3	2.6	0.3	13.7	2.8	0.3	13	5.0	1	32	7.1	0.2	60.5	1.41	0.1	9.6
Sept.	10.4	3.9	2.6	0.3	13.8	3.1	0.3	12	6.1	1	39	7.0	0.2	60.8	1.13	0.1	9.2
Oct.	9.0	3.7	3.1	0.3	18.0	3.4	0.3	18	8.0	1	70	6.5	0.2	64.9	0.81	0.08	3.4
Nov.	6.5	2.7	3.2	0.3	22.0	3.0	0.3	13	8.5	1	50	6.8	0.2	54.9	0.87	0.1	17.5
Overall	79.0*	31.9*	2.8	0.3	22.0	3.0	0.3	18	6.6	1	70	6.7	0.2	64.9	1.2	0.08	33.0

* totals

Source: Gore & Storrie/Proctor & Redfern, 1981e.

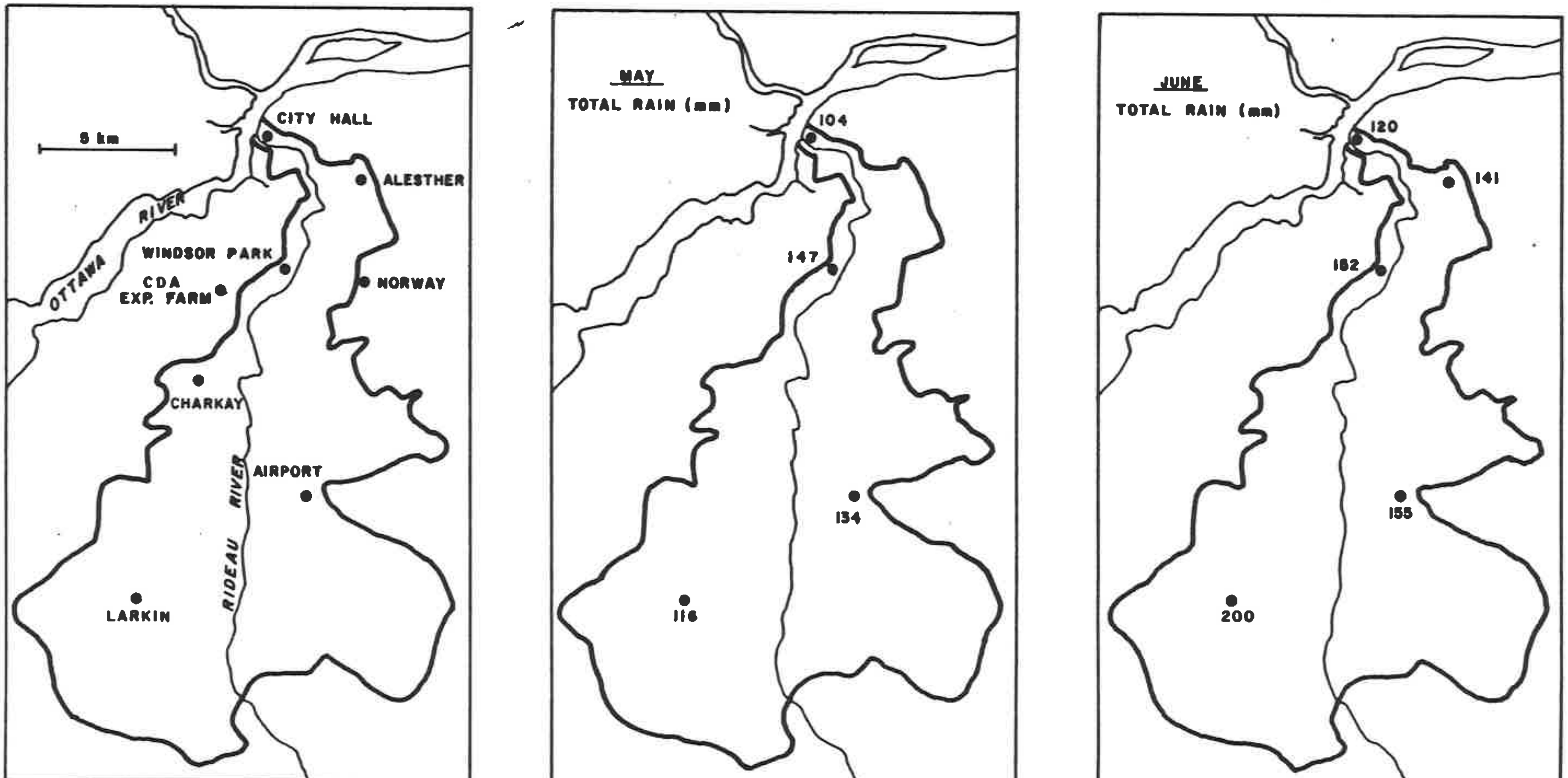
Figure 1. Ottawa Agriculture Station (CDA) distribution of the number of rain events, and rain and runoff volumes by rain interval (mm).



Source: Gore & Sorrie/Proctor & Redfern 1981e less important when rain volume and especially runoff volume is considered. The next section of this report will describe effects of different rain volumes on urban runoff quality and urban runoff pollutant yields for the Ottawa area.

A brief analysis of the available 1981 rainfall data for different lower Rideau River watershed locations was also conducted. Figure 2 shows how the observed monthly rain quantities generally increase as the monitoring stations are located further south from downtown Ottawa. The stations located closest to City Hall had a stronger linear relationship with City Hall rain data (with r^2 values from 0.80 to 0.85) while the airport and Larkin monitoring stations showed very poor linear relationships with the observed City Hall data.

Rain characteristics in Ottawa vary in both time and by location. The rain volumes can have almost a direct effect on runoff yield, as discussed in later sections. These variations must be considered when using urban runoff models and the results from field studies. The year 1972 was selected as a typical year for the calculations in this report. The specific calculation results would vary for other rain years, but the conclusions should not be significantly different.


5 km
CITY HALL
ALESTHER
NORWAY
OTTAWA RIVER
WINDSOR PARK
CDA
EXP. FARM
CHARKAY
AIRPORT
RIDEAU RIVER
LARKIN
MAY
TOTAL RAIN (mm)
104
147
134
116
JUNE
TOTAL RAIN (mm)
120
141
182
155
200

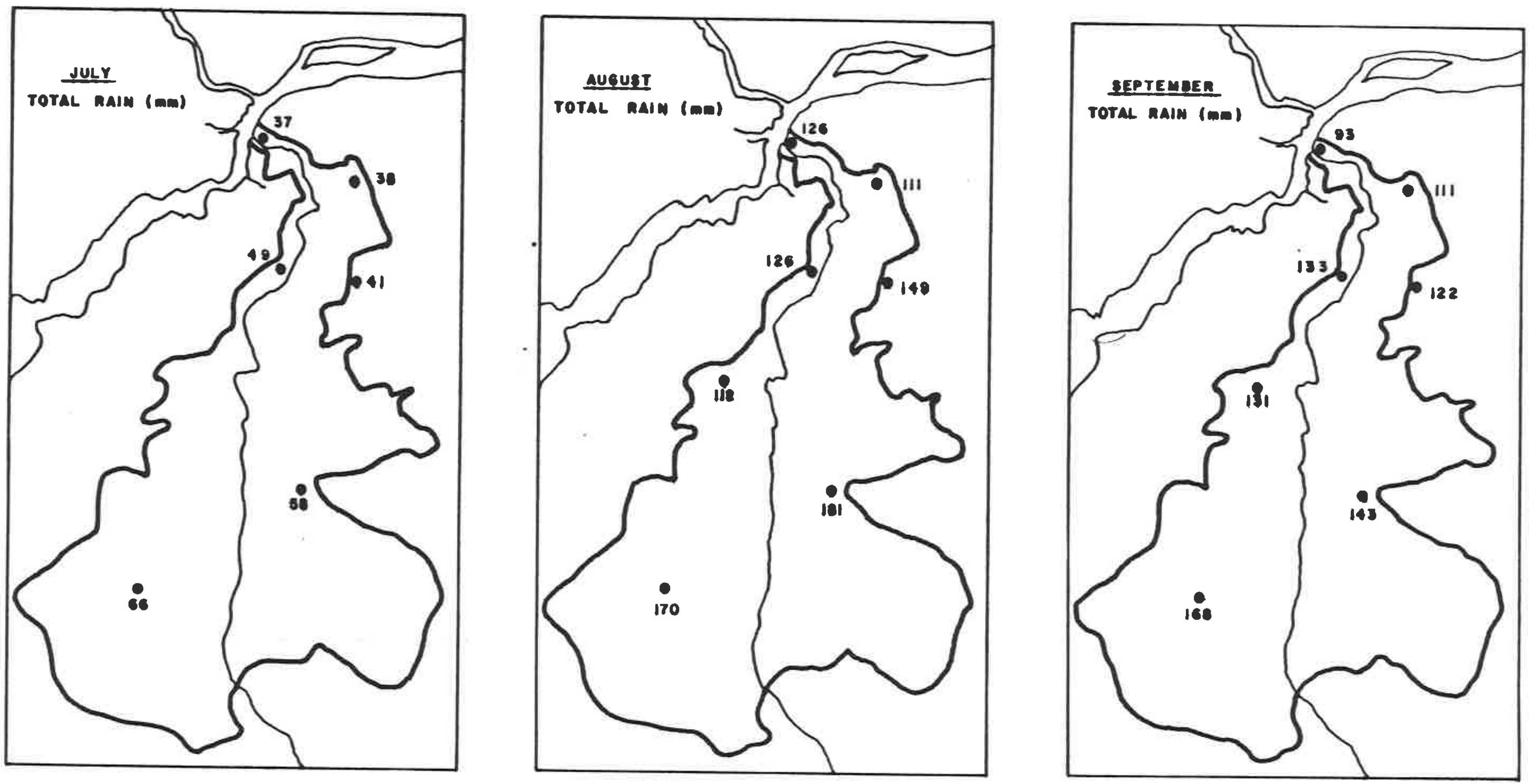


Figure 2. (Cont.) Observed rain at Rideau River Watershed sites (1981)

2.0
SMALL TEST CATCHMENT CHARACTERISTICS

The most important factor affecting the ability of street cleaning to improve runoff water quality is the relative contribution of street surface pollutants to the urban runoff yield. If street surfaces contribute only a small fraction of the problem pollutants to the runoff, then street cleaning, no matter how extensive, would not be an effective control measure. This section examines the factors that affect the relative contribution of street surface pollutants to the runoff yield.

Rainfall characteristics (especially total rain volume), land use configurations, and the sources of pollutants determine the "best" urban runoff pollutant control measures. Data from past studies that examined these factors in detail were used to develop relationships that were verified for Ottawa, using the more limited Ottawa test area data. The test catchments were selected as part of the Rideau River Stormwater Management Study because they were representative of typical Ottawa land uses, have easily-defined conditions (no known cross-connections except at Clegg St., etc.), and were relatively easy to monitor.

This section starts with a general discussion of the factors affecting street surface pollutant contributions to urban runoff. The section also discusses land use configurations and pollutant source areas, as related to rain volume. It finishes with a summary of fecal coliform bacteria population densities and yields as observed in test catchment urban runoff.

2.1 FACTORS AFFECTING STREET AREA CONTRIBUTIONS TO RUNOFF YIELD

Data from past studies can supplement the information available for Ottawa. Several past studies have involved comprehensive simultaneous analyses of street surface pollutant loadings and runoff pollutant yields. These data can identify the variables that affect the sensitivity of street cleanliness (and street cleaning) to runoff yields. The San Jose, California, street cleaning demonstration study (Pitt, 1979) along with the Castro Valley, California, Nationwide Urban Runoff Program (NURP) study (Pitt and Shawley, 1982) and the Bellevue, Washington, NURP study (Pitt, 1982) involved the simultaneous measurements of before- and after-storm street surface pollutant loadings and pollutant yields for many storms over several years of study. The San Jose study examined about six storms in the 1976 and 1977 drought years in the San Francisco Bay area while the Castro Valley study examined more than 60 complete rain events over the 1979 and 1980 rain years. The Bellevue study involved the collection of comprehensive data on more than 300 storms at two monitoring stations during the 1980 through 1982 winters. This data indicates that the amount and character of runoff pollutants from a given area depend on rain factors such as total rain volume, intensity and duration of the storm event and the length of the dry period before the rain (to allow pollutant accumulation). Castro Valley and San Jose are in areas that can have dry periods of more than 100 days in length, while the Bellevue study area was similar to the Ottawa area, with typical interevent periods of less than one week.

Large storms (those with high intensities and/or large rainfall volumes) result in smaller contributions of street surface particulates, relative to the total runoff particulate yields. This pattern is more pronounced when the inter-event periods are short. During these conditions the streets stay relatively clean because of the frequent rains. A large rain, however, will result in significant eroded materials from the adjacent saturated pervious areas that can be deposited on the streets during the rain. Areas having rains with mostly small to moderate volumes and long periods of accumulation usually have dirty street surfaces and dry adjacent pervious soils. In these areas, most of the urban run-off pollutant yield will originate from the street surfaces.

During storms having moderate to low intensities, the amount of traffic was found to have an important influence on the degree to which pollutants are transported into the storm sewerage system from street surfaces. Traffic can supply the energy needed at the street surface to loosen the particulates (there are high scour and shear velocities at the water/street interface). When light storms occur at night or at other times of low traffic, very little street dirt would be loosened and very little would be transported along the street and gutter system. Therefore, the yields from different source areas in a watershed are very site and time dependent; it is necessary to consider pavement texture and condition, interevent period, rain volume and intensity, and traffic volume.

Some of the most important information needs for urban runoff studies concern the relative contributions from different pollutant source areas in the watersheds to the total runoff yield (knowing how much of the total yield observed at the outfall is contributed by each subarea source). Sources far from the storm sewerage system inlet require considerable overland flow. Accordingly, they contribute relatively small fractions of the total pollutant yield measured at the outfall. Conversely, parking lots or street surfaces are impervious and are usually located adjacent to the storm sewerage inlets. They may be considered directly connected impervious areas. Therefore, most of the pollutants from these source areas contribute to the outfall yield and may or may not be diluted by contributions from sources further upstream.

The following subsections describe the results of some special field studies conducted in the Ottawa area to estimate subarea bacteria contributions. This site specific information was used in conjunction with the data collected from other studies to estimate the effects of street cleanliness on urban runoff bacteria yield.

2.2 TEST CATCHMENT LAND USE CHARACTERISTICS

Seven special test catchments were monitored during the Rideau River Stormwater Management Study. These included four residential areas (Alta Vista, Chesterton, Clegg Street and Leonard Avenue), one industrial site (Merivale) and two suburban shopping center sites (Billings Bridge and St. Laurent). Table 3 summarizes the land use and area characteristics of these special catchment test areas. This data was calculated using the maps and area photographs contained in the Gore and Storrie/Proctor and Redfern (1981c), Phase I Report. The percent impervious values range from about 14 for Alta Vista to 92 for the St. Laurent shopping center. These land use and subarea characteristics were used in calcu-

Table 3. Catchment Area Characteristics (fraction, unless otherwise noted)

Catchment Area	Residential Areas				Indust.	Shopping Centers	
	Alta Vista 179 ha	Chesterton 72 ha	Clegg St. 78 ha	Leonard Ave. 37 ha	Merivale 518 ha	Billings Bridge 19 ha	St. Laurent 36 ha
Vacant	0.13	0.06	0	0	0.34	0.30	0
Parks/other landscaped	0.14	0.10	0.12	0.03	0.30	0	0
Back yards	0.28	0.25	0.29	0.23	0.05	0	0.06
Front yards	0.18	0.25	0.06	0.08	0.02	0	0.02
Rooftops	0.13	0.14	0.20	0.30	0.025	0.32*	0.39*
Driveways	0.04	0.03	0.06	0.14	0.005	0	0.01
Parking lots (paved areas)	0.01	0.04	0.09	0.03	0.22	0.31	0.39
Sidewalks	0.01	0.01	0.03	0.03	0.01	0	0.01
Streets	0.08	0.12	0.15	0.16	0.03	0.07	0.12
Fraction impervious**	0.14	0.34	0.33	0.36	0.27	0.70	0.92
Fraction pervious	0.86	0.66	0.67	0.64	0.73	0.30	0.08
Number of homes in area	1,100	512	1,035	625	515	0	50
Fraction residential	0.66	0.76	0.74	0.97	0.11	0	0.06
Fraction industrial	0	0	0	0	0.54	0	0
Fraction commercial and institutional	0.03	0.18	0.26	0.03	0	0.70	0.94
Fraction open area	0.31	0.06	0	0	0.35	0.30	0

* mostly directly connected
** includes directly connected rooftops, but not other rooftops

lating the urban runoff sources in each of the test catchments and how the volumetric ratio (Rv - the ratio of runoff volume to rainfall volume) varied as a function of rain volume.

2.3 URBAN RUNOFF VOLUMETRIC RATIOS AND SUBAREA FLOW CONTRIBUTIONS

Detailed rain and runoff volume data have been obtained over a two year period of time at Bellevue, Washington (near Seattle) (Pitt, 1982). More than 300 rain and runoff data sets are available from two residential study areas which are similar in land use characteristics to the Ottawa residential areas. A power curve, relating the volumetric ratio, Rv (the portion of the rain that results in actual runoff, including urban depression storage and evaporation), to total rain was obtained for this data, with resultant r^2 values of about 0.7. The r^2 value is a measure of curve "fit"; a perfect fit would have an r^2 value of 1.0. When the data was separated into seasonal (monthly) sets, the r^2 values were much greater (approaching 0.95). In addition, limited runoff and rain volume data for Toronto were also analyzed (Ontario Ministry of the Environment, 1982). These data were used in conjunction with the rainfall and urban runoff flow measurements obtained at the Ottawa test sites to determine the variation of catchment Rv values as a function of the total rain volume. These values are summarized in Table 4. This table shows that pervious areas contribute very little runoff until a total rain quantity exceeds about 20 mm. The impervious catchment subareas contribute most of the total runoff volume for the smaller rains.

These values were developed using a variety of data sources, as described above. These values should be applicable for a variety of areas, except for seasonal changes in antecedent dry periods and soil types. The following paragraphs describe how specific land uses are used in determining the overall Rv values.

Table 5 summarizes composite runoff volumetric ratios for six catchment areas and for different rain quantities. The differences in Rv values are related to the differences in the catchment subarea compositions. Very little runoff would result from a 5 mm rain in the residential and industrial areas, but a substantial fraction of the rain would occur as runoff in the mostly paved shopping centers. The maximum values of Rv in the residential areas approach 0.6 (60 percent of the rain volume results in runoff and 40 percent would percolate into soils, evaporate, or would otherwise be "lost"). Rv values are almost 0.9 for major rains in the shopping centers. If the ground is saturated at the beginning of a rain, the Rv values would be substantially greater.

Some general conclusions from the analysis of the Bellevue data may be applicable for Ottawa conditions. In Bellevue, it was found that more than 90 percent of the Rv value could be explained by rainfall quantity only, based on a multiple regression analysis that examined total rainfall quantity, average and peak rain intensities, and the number of dry days since the last significant rain. The peak rainfall intensity explained a maximum of ten percent of the total Rv value, while the number of dry days since the last significant rain explained about five percent of the Rv value. As mentioned earlier, the month of the year was found to be very important: the winter values (November through February) had Rv values about twice those observed for the other months for rains with the same volumes. Therefore, there does not appear to be any need to adjust the Rv value for rain intensities or the interevent period. The most important factors are the

Table 4. The Variation of Catchment Subarea Runoff Coefficients as a Function of Rain Volume*

Catchment Subarea (pervious areas)

rain quantity (mm)	vacant land	land-scaped parks	back-yards	front-yards	rooftops (to front-yards)
0.25	0	0	0	0	0
2.5	0	0	0	0	0
5.0	0	0	0	0.1	0.1
10	0.05	0.05	0.05	0.2	0.1
20	0.10	0.10	0.10	0.2	0.2
40	0.15	0.15	0.15	0.3	0.3
"max"	0.4	0.4	0.4	0.4	0.4

Catchment Subarea (impervious areas)

rain quantity (mm)	rooftops (directly connected)	drive-ways	paved parking lots and other large areas	side-walks	paved streets
0.25	0.2	0.1	0.1	0.2	0.2
2.5	0.4	0.3	0.3	0.4	0.4
5.0	0.5	0.5	0.5	0.5	0.5
10	0.7	0.6	0.6	0.7	0.7
20	0.7	0.7	0.7	0.7	0.7
40	0.7	0.7	0.7	0.7	0.7
"max"	0.9	0.9	0.9	0.95	0.95

* These coefficients relate to runoff measured at the outfall, and therefore consider percolation, evaporation and storage/detention.

Table 5. Runoff Volumetric Ratio (Rv) for Test Catchments

Rain (mm)	Residential Areas			Indust.	Shopping Centers	
	Alta Vista	Clegg St.	Leonard Ave.	Merivale	Billings Bridge	St. Laurent
0.25	0.02	0.05	0.06	0.03	0.11	0.14
2.5	0.05	0.12	0.13	0.08	0.25	0.34
5.0	0.10	0.19	0.22	0.14	0.36	0.47
10	0.17	0.27	0.29	0.20	0.47	0.60
20	0.22	0.33	0.35	0.26	0.52	0.65
40	0.27	0.38	0.40	0.30	0.53	0.65
"max"	0.47	0.58	0.59	0.54	0.76	0.86

total rain quantity and the season of the year. With the evenly spaced summer rains in Ottawa, the interevent periods and corresponding soil moisture conditions are expected to have a minimal effect on the Rv values.

If runoff coefficient (k) values that change as a function of total rain quantity are known for the different catchment subareas, then calculations can be made to determine the flow contributions of each subarea to the total runoff yield. Table 6 shows estimated k values for the Ottawa test catchments. For very small rains (less than 5 mm) occurring in the residential areas, most (up to 70 percent) of the total runoff yield at the outfall originates from the street surfaces. For these small rains, no runoff is contributed from the pervious areas. As the total rain quantity increases, the percentage of the total runoff originating from the impervious areas decreases and the percentage from the pervious areas, such as vacant and landscaped areas, increases. Even for the "maximum" rains, street surfaces may contribute as much as 25 percent of the total runoff in the residential areas.

In the industrial and shopping center areas, the same general pattern is seen, but because the street surfaces make up a much smaller percentage of the total catchment area, their importance in contributing to runoff is diminished. For the industrial and shopping center areas, the directly connected rooftops contribute much of the total runoff yields. Parking lots, especially in the shopping centers, also play an important role. In the shopping centers, directly connected rooftops and the large paved parking lots contribute almost all of the urban runoff. The Merivale industrial area has substantial landscaped and residential areas. Pervious areas, such as vacant lots and landscaped areas in Merivale contribute large portions of the runoff flow, especially for the larger storms.

Figure 3 graphically shows the percentage of the runoff yield that originates from the street surfaces for these six test catchment areas. For the residential areas, the smaller storms contribute substantial portions of the total yield, but the importance of street surfaces drops off quickly for rain volumes greater than about 10 mm. Even for these larger rains, street surfaces may contribute from 25 to 33 percent of the total runoff flow. For the industrial and shopping center areas, the importance of street surface runoff diminshes because of the smaller fraction of street surface areas, but they can still contribute about 10 to 15 percent of the total runoff yield.

2.4 CATCHMENT SUBAREA URBAN RUNOFF POLLUTANT CONTRIBUTIONS

In order to determine the importance of each of the catchment subareas in contributing urban runoff pollutants, a small sampling effort was conducted to collect sheetflow and puddle water samples during two rain events. Table 7 summarizes the results of these analyses. The rooftop bacteria samples had substantially lower fecal coliform and fecal strep. bacteria concentrations than samples collected from vacant land and park puddles, parking lot puddles and street gutter flows. The rooftop samples, however, did have important bacteria concentrations, especially when compared to Rideau River bacteria concentrations above Mooney's Bay. The observed lead concentrations show that almost all of the lead originated from parking lots and street surfaces, with very little lead found in runoff from rooftops, vacant and landscaped areas and unpaved parking lots.

Table 6. Percentage of Total Runoff Yield Originating from Catchment Areas

	Rain (mm)	vacant area	parks and large landscaped areas	back yards	front yards	roof-tops	drive-ways	parking lots and other large paved areas	side-walks	streets
Alta Vista (resid.)	0.25	**					17	4	9	70
	2.5						24	6	8	62
	5.0				18	13	20	5	5	39
	10	4	4	8	21	8	14	4	4	33
	20	6	7	13	17	12	13	3	3	26
	40	7	8	15	20	14	10	3	3	20
	"max"	11	12	23	15	11	8	2	2	16
Clegg St. (resid.)	0.25						12	18	12	58
	2.5						15	24	10	51
	5.0				3	11	16	24	8	38
	10		2	6	4	7	13	20	8	40
	20		4	9	4	12	13	19	6	33
	40		5	12	5	16	11	17	6	28
	"max"		8	21	4	14	9	14	5	25
Leonard Ave. (resid.)	0.25						26	5	11	58
	2.5						33	7	9	51
	5.0				4	14	32	7	7	36
	10		1	4	6	10	28	6	7	38
	20		1	6	5	17	28	6	6	31
	40		1	9	6	22	25	5	5	27
	"max"		2	16	5	20	22	5	4	26
Merivale (indust.)	0.25					36*	2	37	6	19
	2.5					39*	2	40	5	14
	5.0				1	42*	2	40	4	11
	10	8	7	2	2	34*	2	32	3	10
	20	13	12	2	2	30*	1	29	3	8
	40	17	15	3	2	28*	1	25	2	7
	"max"	26	22	4	1	20*	1	19	2	5
Billings Bridge (shopping center)	0.25					58*		29		13
	2.5					52*		37		11
	5.0					45*		45		10
	10	3				47*		40		10
	20	6				43*		42		9
	40	9				41*		41		9
	"max"	16				38*		37		9
St. Laurent (shopping center)	0.25					54*	1	27	1	17
	2.5					48*	1	36	1	14
	5.0					42*	1	43	1	13
	10				1	45*	1	38	1	14
	20			1	1	42*	1	41	1	13
	40			1	1	42*	1	41	1	13
	"max"			3	1	40*	1	41	1	13

* mostly directly connected

** values not shown are less than 1 percent

Figure 3. Percentage of total runoff flows originating from street surfaces as a function of rain volume.

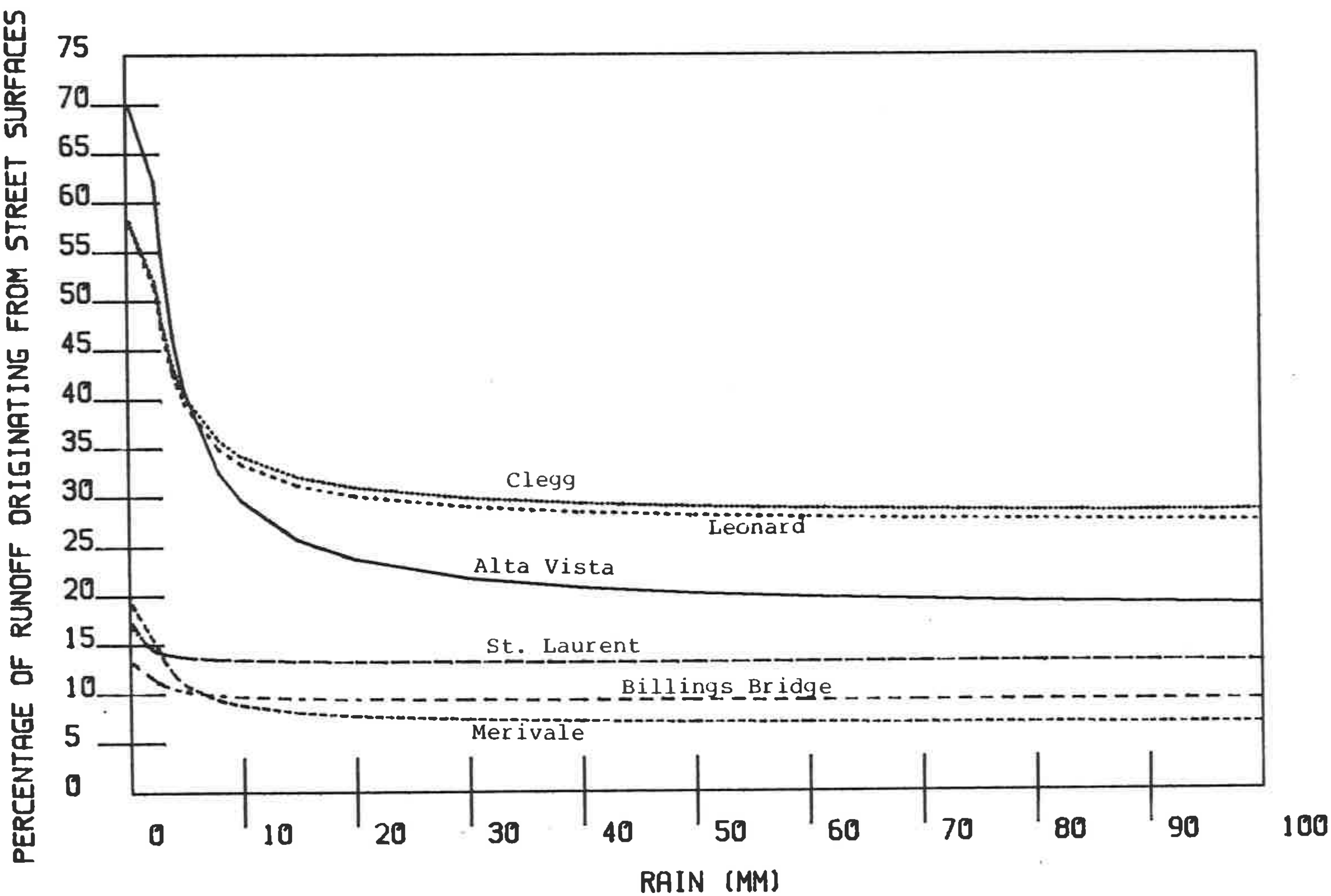


Table 7. Catchment Subarea Sheetflow Bacteria and Lead Characteristics (August 15 and September 23, 1981)

		rooftop runoff	vacant land and park puddles	parking lot puddles	gutter flow
Fecal Coliforms	geometric mean (#/100mL)	85	5,600	2,900	3,500
	min (#/100mL)	10	360	200	500
	max (#/100mL)	400	79,000	19,000	10,000
	number of observations	4	7	6	7
Fecal Strep.	geometric mean (#/100mL)	170	16,500	11,900	22,600
	min (#/100mL)	20	12,000	1,600	1,800
	max (#/100mL)	3,600	57,000	40,000	1,200,000
	number of observations	4	7	6	7

		rooftop runoff	vacant land, parks and unpaved parking lot puddles	paved parking lot puddles	gutter flow
Lead	mean (mg/L)	0.03	0.03	0.35	0.32
	min (mg/L)	0.01	0.02	0.29	0.07
	max (mg/L)	0.05	0.04	0.40	0.70
	number of observations	2	4	2	4

These observed subarea bacteria concentrations were much greater than those observed in a similar sampling program in San Jose, California, (Pitt and Bozeman, 1982). In San Jose, the observed fecal coliform gutter and parking lot sheetflow sample concentrations were much greater than elsewhere in the San Jose study areas, and were from several hundred to about 1000 organisms/100 mL. Rooftop runoff and landscaped area runoff fecal coliform concentrations were less than ten and less than 50 organisms/100 mL., respectively. The San Jose sheetflow fecal strep. concentrations were closer to the observed Ottawa concentrations. An early Ottawa study reported by the Regional Municipality of Ottawa - Carleton (1972) measured rooftop runoff bacteria concentrations. The runoff from a roof at an experimental farm that was frequented by many birds had coliform concentrations greater than 10,000 organisms/100 mL. Street surface and parking lot runoff showed total coliform concentrations in the hundreds of thousands of organisms/100 mL.

Tables 8, 9 and 10 show the resultant percentage contributions for bacteria and lead from each of the catchment subareas. These values are calculated from the observed sheetflow and puddle pollutant concentrations and from the calculated urban runoff flow contributions from each subarea. It is interesting to note the differences in the subarea contributions for fecal coliforms, fecal strep. and lead. The differences in bacteria yields from street surfaces when comparing large rains with small rains are much more dramatic than the differences observed for lead. The bacteria yields from the street surfaces decrease much more for the larger rains because of the high bacteria concentrations observed in non-street surface sheetflows. These tables are an estimate of the relationship between street surface cleanliness and runoff yields. Even if all of the street surface bacteria was removed from the streets, a maximum reduction of about 60 to 70 percent in outfall bacteria yields would be achieved, and only for the runoff from residential areas and for the smallest rains. For the largest rains, and if all of the fecal coliform bacteria was removed from the streets, only about 10 to 25 percent bacteria reductions would be observed at the outfall. If sidewalks and driveways were cleaned, a greater fraction of the bacteria could be controlled. If the shopping center parking lots, along with the streets, were cleaned, then a substantial portion of the urban runoff lead and much of the bacteria in these areas could also be controlled and for almost all storms.

2.5 TEST CATCHMENT FECAL COLIFORM BACTERIA QUALITY AND YIELD

Five to eleven storms were completely monitored for fecal coliform concentrations at four of the test catchments from 1978 to 1981. Table 11 summarizes these observations for the 34 monitored storms. The resultant calculated catchment bacteria runoff yields expressed in millions of organisms per hectare per day are shown in Table 12. Approximately 1.5×10^8 fecal coliforms per hectare per year and about 3.7×10^8 fecal strep. organisms per hectare per year are the estimated bacteria yields for the Ottawa six month runoff season.

Table 8. Percentage of Fecal Coliform Runoff Yield Originating from Catchment Areas

	rain (mm)	pervious areas (yards, vacant land and parks)	roof-tops	parking lots	sidewalks and driveways	streets
Alta Vista (resid.)	0.25	*		3	26	71
	2.5			5	32	63
	5.0	30		4	26	40
	10	52		3	16	29
	20	61		2	14	23
	40	70		2	11	17
	"max"	78		1	8	13
Clegg St. (resid.)	0.25			15	25	60
	2.5			21	26	53
	5.0	6		23	28	43
	10	20		17	22	41
	20	28		16	20	36
	40	37		15	18	30
	"max"	52		11	13	24
Leonard Ave. (resid.)	0.25			4	37	59
	2.5			6	42	52
	5.0	7		7	45	41
	10	18		5	37	40
	20	21		5	39	35
	40	29	1	5	34	31
	"max"	38	1	5	28	28
Merivale (indust.)	0.25		2**	51	14	33
	2.5		2**	60	13	25
	5.0	3	2**	63	11	21
	10	42	1**	36	7	14
	20	55	1**	29	5	10
	40	65	1**	23	3	8
	"max"	78		14	3	5
Billings Bridge (shopping center)	0.25		4**	62		34
	2.5		3**	71		26
	5.0		2**	77		21
	10	10	2**	68		20
	20	18	2**	63		17
	40	24	2**	58		16
	"max"	39	1**	46		14
St. Laurent (shopping center)	0.25		3**	52	5	40
	2.5		2**	64	4	30
	5.0		2**	69	4	25
	10	3	2**	63	4	28
	20	6	2**	63	4	25
	40	6	2**	63	4	25
	"max"	11	2**	60	4	23

* values not shown are less than 1 percent
** mostly directly connected

Table 9. Percentage of Fecal Strep. Runoff Yield Originating from Catchment Areas

	rain (mm)	pervious areas (yards, vacant land and parks)	roof-tops	parking lots	sidewalks and driveways	streets
Alta Vista (resid.)	0.25	*		2	27	71
	2.5			3	33	64
	5.0	16		3	31	50
	10	34		3	22	41
	20	42		2	21	35
	40	52		2	18	28
	"max"	63		1	14	22
Clegg St. (resid.)	0.25			10	26	64
	2.5			14	28	58
	5.0	3		16	31	50
	10	11		13	26	50
	20	17		13	25	45
	40	23		13	24	40
	"max"	34		10	20	36
Leonard Ave. (resid.)	0.25			3	38	59
	2.5			4	43	53
	5.0	4		4	48	44
	10	10		4	42	44
	20	11		4	45	40
	40	16		4	42	38
	"max"	24		4	36	36
Merivale (indust.)	0.25		1**	41	17	41
	2.5		1**	49	17	33
	5.0	2	1**	54	15	28
	10	30	1**	36	11	22
	20	45		31	8	16
	40	54		26	6	14
	"max"	68		18	5	9
Billings Bridge (shopping center)	0.25		2**	53		45
	2.5		1**	63		36
	5.0		1**	70		29
	10	7	1**	63		30
	20	12	1**	62		25
	40	18	1**	57		24
	"max"	29	1**	48		22
St. Laurent (shopping center)	0.25		1**	42	6	51
	2.5		1**	53	6	40
	5.0		1**	60	5	34
	10	2	1**	54	5	38
	20	4	1**	56	5	34
	40	4	1**	56	5	34
	"max"	7	1**	54	5	33

* values not shown are less than 1 percent

** mostly directly connected

Table 10. Percentage of Lead Runoff Yield Originating from Catchment Areas

	rain (mm)	pervious areas (yards, vacant land and parks)	roof-tops	parking lots	sidewalks and driveways	streets
Alta Vista (resid.)	0.25	*		4	26	70
	2.5			7	31	62
	5.0	2	2	8	34	54
	10	6	1	7	30	56
	20	8	3	7	32	50
	40	11	3	8	31	47
	"max"	16	3	6	29	46
Clegg St. (resid.)	0.25			19	23	58
	2.5			26	25	49
	5.0		1	30	26	43
	10	2	1	25	25	47
	20	2	2	27	25	44
	40	3	2	28	25	42
	"max"	5	2	26	24	43
Leonard Ave. (resid.)	0.25			6	37	57
	2.5			8	41	51
	5.0		1	9	47	43
	10	1		8	43	47
	20	2	2	9	45	42
	40	2	3	9	45	41
	"max"	4	3	9	42	42
Merivale (indust.)	0.25		5**	57	11	27
	2.5		6**	63	10	21
	5.0		6**	68	9	17
	10	3	6**	64	9	18
	20	6	6**	63	8	17
	40	8	6**	63	7	16
	"max"	14	5**	58	9	14
Billings Bridge (shopping center)	0.25		11**	63		26
	2.5		9**	72		19
	5.0		7**	77		16
	10		8**	75		17
	20	1	7**	77		15
	40	2	7**	75		16
	"max"	3	6**	74		17
St. Laurent (shopping center)	0.25		9**	55	4	32
	2.5		7**	67	3	23
	5.0		6**	71	3	20
	10		7**	67	3	23
	20		6**	70	3	21
	40		6**	70	3	21
	"max"	1	6**	69	3	21

* values not shown are less than 1 percent
** mostly directly connected

Table 11. Catchment Runoff Fecal Coliform Bacteria Observations

	Alta Vista	Chesterton	Leonard	St. Laurent	Overall
geometric mean* (#/100mL)	14,100	12,300	21,700	4,580	10,200
min. (#/100mL)	5,900	720	11,500	540	540
max. (#/100mL)	38,000	96,600	64,100	31,400	96,600
number of storms	11	7	5	11	34
study period	1980,81	1978,79,81	1980,81	1980,81	1978-81

* geometric mean of flow-weighted averaged concentrations for storms

Table 12. Catchment Bacteria Runoff Yields (10^6 organisms/ha/day)

Catchment	Fecal Coliform mean	Fecal Coliform range	Fecal Strep. mean	Fecal Strep. range
Alta Vista	0.5	(0.3 to 1.1)	1.3	(0.8 to 3)
Chesterton	0.6	(0.4 to 1.5)	1.5	(1 to 4)
Leonard	1.4	(0.7 to 3)	3.5	(2 to 8)
St. Laurent	0.6	(0.3 to 1.4)	1.5	(0.8 to 4)
Average.........	0.8×10^6 FC org/ha/day (1.5×10^8 FC org/ha/yr)(1)		2×10^6 FS org/ha/day (3.7×10^8 FS org/ha/yr)(1)	

(1) assuming a 6-month "runoff" season

3.0
STREET DIRT POLLUTANT CHARACTERISTICS AND ITS CONTRIBUTION TO RUNOFF YIELDS

3.1 STREET SURFACE PARTICULATE CHARACTERISTICS

Field work was also conducted during the summer of 1981 to characterize the street surfaces throughout the lower Rideau River watershed and to determine local street dirt pollutant concentrations. Typical street dirt pollutant loadings were then compared to observed urban runoff yields as an indication of the sensitivity of street surface bacteria loadings to urban runoff bacteria yields. Table 13 summarizes the observed street surface total particulate loadings for the three main classifications of street texture. Street texture has been found in previous studies (especially Pitt, 1979, and Sutherland and Pitt, 1982) to be the determining factor affecting street surface pollutant loads. Rough textured streets are usually many times dirtier than smooth streets. Street cleaning and rains also do not clean rough streets as well as smooth streets. All streets have a reservoir of particulates that seems to reside in the cracks and depressions of the street surface. Street cleaning and rains cannot remove these particulates, but the sampling procedures used in this study can remove them. Some soluble and mobile pollutants, possibly including bacteria, may be "leached" from this reservoir during rains. It is therefore important to consider the distribution of street textures in the study area when examining street cleaning practices.

Street surface particulate samples were collected and analyzed using procedures developed by Pitt (1979). As a summary, the river basin study area was divided into several test areas representing the different street textures and conditions. Ten curb-to-curb strips, about 15 cm wide, were thoroughly vacuumed in each of these areas. The resultant samples were then dried, weighed, and analyzed for total solids loadings and lead concentrations. The samples were separated into eight particle size fractions and their median particle size was calculated. Fecal coliform and fecal strep. densities were measured from specially collected samples. Samples were collected in the third week of August and again in the third week of September, 1981. Field notes were also made describing the land uses; street surface types, conditions, and textures; gutter and curb types and conditions; the estimated parking density; the estimated traffic volume and speed; landscaping conditions; and the recent precipitation and street cleaning histories. This information is presented in a separate Rideau River Stormwater Management Data Report (Slack, 1982).

Table 14 summarizes the street lengths in the watershed test area by texture and condition categories (smooth and moderate combined, rough, and very rough). Table 15 presents the observed street dirt loadings by these categories. The smooth and moderate street texture category had loadings of about 100 grams per curb meter, while the rough street texture category had loadings of about 250 grams per curb meter, and the very rough street surface texture category had loadings of about 400 grams per curb meter. The average accumulation period for these samples was about three days; the short-term constant accumulation rate (equal to the deposition rate), for the short period of time since a rain, was estimated to be about 20 grams per curb meter per day. This accumulation rate is assumed to be equal for all three street surface textures; but the initial loads

Table 13. Ottawa Street Surface Particulate Loadings (August 19-21 and September 14-17, 1981)

Total Solids (gram/curb-meter)*

street texture	mean	min.	max.	number of observations
smooth and moderate	100	31	259	12
rough	250	230	278	2
very rough	400	367	428	2

* The average accumulation period was 3 days (ranged from 1 to 5 days). The linear accumulation rate for all street types is estimated to be 20 grams/curb-meter/day. The initial loads (at the beginning of an accumulation period, immediately after a significant rain) are estimated to be 40,200 and 320 grams/curb-meter for smooth, rough and very rough streets, respectively.

Table 14. Street Lengths by Texture and Condition in the Lower Rideau River Watershed

street texture	street condition	street types in all 27 catchments length(km)	percent	estimated particulate loading* (g/curb-m)
smooth	excellent	30.2	2.2	100
smooth	good	193	14.0	100
smooth	fair	153	11.1	100
moderate	excellent	100	7.3	100
moderate	good	599	43.3	100
moderate	fair	235	17.0	100
rough	good	41.0	3.0	250
rough	fair	28.9	2.1	400
total (weighted average):		1,380	100.0	100

* assuming a three-day accumulation period

Table 15. Ottawa Street Surface Particulate Bacteria, Lead and Particle Size Characteristics (Aug. 19-21 and Sept. 14-17, 1981)

street texture	mean	min.	max.	number of observations
Median Particle Size (u)				
all textures	310	156	400	10
Lead (mg lead/kg total solids)				
smooth & mod.	1,000	120	2,690	10
rough	400	370	370	1
very rough	250	230	297	2
Fecal Coliforms (organisms/gram total solids)				
smooth & mod.	350*	24	31,000	12
rough	70*	48	100	2
very rough	15*	8	23	2
Fecal Strep. (organisms/gram total solids)				
smooth & mod.	1,900*	24	16,000	8
rough	900*	670	1,200	2
very rough	3,400*	1,700	6,800	2

* geometric mean

(the street surface loading values right after a significant rain or street cleaning) varied significantly for each street texture. This initial load represented the quantity of material that is tied up on the streets and not available for removal by rains or street cleaning under normal conditions. These initial loading values were estimated to be 40 grams per curb meter for smooth and moderate street texture conditions, 200 grams per curb meter for rough street texture conditions, and 320 grams per curb meter for very rough street surface texture conditions. The very rough street surfaces have greater opportunities to retain particulates and, therefore, pollutants on the streets which are not subject to normal removal.

Table 14 summarizes the distribution of street textures and conditions throughout the lower Rideau River basin. About 1380 km of streets are in this study basin, and about 94 percent of these streets have typical storm sewage systems. About five percent of the streets do not have any storm drainage systems, while about one percent of the streets have ditch drainage systems. The most common category of street texture and condition is moderate textured streets in good condition, which makes up about 43 percent of the total street length in the area. Moderate textured streets in fair condition make up about 17 percent of the streets, while about 25 percent of the streets have smooth surfaces in good or fair condition. Streets with rough textures in fair condition are classified as very rough and are most common in the most southerly watershed areas.

Table 15 summarizes the observed particle sizes, and lead and bacteria concentrations observed for the street surface particulate samples. The median particle size was about 300 microns and did not vary significantly for the different textures. This particle size range was very similar to the street surface particle sizes observed in the San Jose study (Pitt, 1979) but was smaller than observed in the Castro Valley and Bellevue NURP studies. The smaller median particle sizes would typically reflect higher concentrations of most street surface pollutants. The fecal coliform and lead concentrations were much greater for the particulates found on the smooth streets, while the very rough street particulates had the greatest fecal strep. concentrations.

These observed lead concentrations were well within the ranges reported in earlier studies (Sartor and Boyd, 1972; Pitt and Amy, 1973; Pitt, 1979). Bacteria concentrations are much more difficult to compare with the previously recorded data because of the extreme ranges involved. Past reported fecal coliform concentrations in street dirt ranged from ten to more than 100,000 organisms per gram of total solids, with a U.S. mean value estimated to be about 10,000 organisms per gram, or substantially greater than the mean values reported for Ottawa.

Table 16 shows the calculated daily street surface particulate loading values for total solids, lead, fecal coliforms, and fecal strep. bacteria. These values consider both the reported particulate pollutant concentrations and the observed loadings of total solids on the streets for the different street textures. As noted earlier, the very rough streets had greater particulate loadings; however, all of the street textures had similar unit lead loadings, while the smooth, moderate, and rough streets had similar bacteria loadings. The very rough streets had lower fecal coliform loadings but much greater fecal strep. loadings. When these loadings are compared to values presented by Sartor and Boyd (1972), the observed fecal coliform loading values appear to be similar. Sartor and Boyd reported a range of about 4000 to more than ten million fecal coliform organisms per curb meter in seven cities throughout the United States. Most of

Table 16. Estimated Daily Street Particulate Loading Values

Days of Accumulation	Total Solids (grams/curb-meter)			Lead (grams/curb-meter)		
	smooth and moderate	rough	very rough	smooth and moderate	rough	very rough
0	40	200	320	0.04	0.08	0.08
1	60	220	340	0.06	0.09	0.09
2	80	240	360	0.08	0.10	0.09
3	100	260	380	0.10	0.10	0.10
4	120	280	400	0.12	0.11	0.10
5	140	300	420	0.14	0.12	0.11
6	160	320	440	0.16	0.13	0.11
7	180	340	460	0.18	0.14	0.12

Days of Accumulation	Fecal Coliform Bacteria (organisms/curb-meter)			Fecal Strep. Bacteria (organisms/curb-meter)		
	smooth and moderate	rough	very rough	smooth and moderate	rough	very rough
0	14,000	14,000	5,100	76,000	180,000	1,100,000
1	21,000	15,000	5,400	110,000	200,000	1,200,000
2	28,000	17,000	5,700	150,000	220,000	1,200,000
3	35,000	18,000	6,000	190,000	230,000	1,300,000
4	42,000	19,000	6,300	230,000	250,000	1,400,000
5	49,000	21,000	6,600	270,000	270,000	1,400,000
6	56,000	22,000	6,900	300,000	290,000	1,500,000
7	63,000	24,000	7,300	340,000	310,000	1,600,000

the loadings were in the range of 1000 to 10,000 fecal coliform organisms per curb meter. Because the Ottawa values are based on a limited sampling program and street surface particulate loading values are known to vary on a seasonal basis, these values should only be considered applicable for the period of observation. The sampling procedures, however, do ensure that the observed concentrations are reasonable for the study area during the period of sample collection and are probably within 25 to 50 percent of the true values.

3.2 STREET DIRT CONTRIBUTIONS TO URBAN RUNOFF YIELD

The observed street surface bacteria loading values were compared to the expected urban runoff yields for the different catchments in Table 17. This table shows that there were from two to seven times the fecal coliform organisms on the streets before a storm than were observed in the urban runoff yields. The ratios for fecal strep. were much greater and ranged from about three to 35 times for the different catchments. Urban runoff bacteria yields are therefore not source limited, but are more controlled by the ability of the rain event to dislodge and transport the bacteria from the source areas to the outfall. This was also noted by Gupta, et al (1981) in their study of highway runoff throughout the United States. They found that a runoff-producing rainfall event will not cleanse a highway right-of-way surface free of indicator bacteria for even a very short period of time. As noted earlier, a substantial fraction of the total street surface particulate and pollutant loadings remain on the streets even after large rain events. Another factor influencing this high ratio of street surface loads to urban runoff yields may be the method of bacteria analysis. If the street surface particulate bacteria has aged since the deposition of feces, the feces material would be decomposed and the bacteria would be diffuse. However, if the runoff washes off more recently deposited feces (and the turbulence of the runoff does not break up the feces material), a single organism reported by the laboratory may actually represent quite a large number of original discreet organisms that were still clumped together before the analysis.

Table 17. Ratio of Bacteria Loadings on Streets to Runoff Yields (for 0 to 7 days interevent periods and 5 to 9mm rains)

Catchment	Fecal Coliform		Fecal Strep.	
	mean	range	mean	range
Alta Vista	4	(1 to 5)	35	(8 to 44)
Clegg	7	(2 to 8)	15	(4 to 17)
Leonard	3	(1 to 3)	7	(2 to 8)
Merivale	2	(0.3 to 2)	3	(0.6 to 4)
Billings Bridge	2	(0.4 to 2)	3	(0.8 to 4)
St. Laurent	2	(0.6 to 2)	5	(1 to 5)

4.0 SNOWMELT QUALITY AND ITS CONTRIBUTION TO URBAN BACTERIA DISCHARGES

This section presents a rough estimate of the annual bacteria contributions associated with urban snowmelt. These calculations were made to compare the snowmelt bacteria contributions to contributions from other sources, especially from urban runoff. Local Ottawa data was used for both snowfall quantities and snowmelt bacteria quality.

As noted in Section 1, a substantial quantity of snow falls in the Ottawa area and remains on the ground throughout several months. Most of the mechanisms that contribute to bacteria deposition still occur (but possibly at a slightly reduced rate when compared to the summer months, due to smaller active wildlife populations and reduced wandering of domestic pets). Snow is capable of accumulating large amounts of urban pollutants and contributing these to the receiving waters during snowmelt periods. A simple mass balance was conducted to estimate the magnitude of snowmelt on urban bacteria discharges.

Table 18 lists the snow disposal sites which receive snow from streets and parking lots in the lower Rideau River watershed area. Most of these locations are in the watershed area itself and the snow disposal practices would have very little effect on the snowmelt mass balance. They do play an important role in removing contaminated snow from the directly connected impervious areas (street surface and parking lots) and placing the contaminated snow further upstream in the watershed subjecting them to less efficient yields (as described in Section 2). These ten snow disposal locations total about 400 hectares and stored about 1.5 million cubic meters of snow during the 1971 and 1972 winter. Table 19 shows the estimated quantities of snow that would be removed in the lower Rideau River watershed for different frequencies of winter snowfall. These snow removal quantities are about 0.005 of the total snowfall in the total area, but are a much greater portion of the total snowfall occurring on the roadways.

Qureshi and Dutka (1979) monitored several snowmelt events in the southern Ontario region. In December of 1975, they monitored a rain that occurred on frozen snow covered ground. They found high concentrations of indicator bacteria in all of the runoff samples collected. They found also that initial flushing had little effect on the bacteria quality of stormwater runoff during snowmelt events. They concluded that snow and slush in urban areas can have high concentrations of microorganisms, especially bacteria from animal fecal material. Much of this bacteria can reach storm sewers and receiving waters. Sparrow, Davenport, and Gordon (1978) studied the survival abilities of fecal indicator bacteria in very cold and ice covered rivers in Alaska. They found that these bacteria were able to survive for long periods during these low temperature conditions. Toxopeus, et al (1978) also monitored snowmelt runoff quality at two catchment basins in Ottawa in 1977. Table 20 summarizes his results which shows small concentrations of indicator bacteria in snowmelt. This table also shows estimated bacteria snowmelt yields per hectare per meter of snow, based on these snowmelt concentrations.

Table 18. Lower Rideau River Watershed Snow Disposal Sites

Location	Area (ha)	Volume Deposited in 1971-72 (m^3)	Density (m^3/ha)
Riverside	12	567,000	47,300
Mann	6.1	315,000	51,600
Brewer	2.6	205,000	78,900
Champagne	3.3	119,000	36,100
Alta Vista	3.3	118,000	35,800
Chapel	2.3	78,700	34,200
Range Road	2.4	75,000	31,300
Smyth	4.3	47,700	11,100
Walkley	2.9	34,200	11,800
Mooney's Bay	0.6	5,310	8,900
Total	40	1,600,000	39,000(average)

Source: McNeely Engineers, 1980; and J.L. Richards and Assoc./ Labrecque Vezina and Assoc., 1972

Table 19. Snow Removal Efforts in Rideau River Watershed

frequency (years)	winter snowfall (mm)	winter snowfall (m^3/ha)	average "removal" (m^3/ha)(1)	total removal (1,000m^3)(2)
100	4,450	44,500	215	840
50	3,480	34,800	170	650
20	3,180	31,800	150	590
10	2,970	29,700	140	550
5	2,720	27,200	130	500
2	2,210	22,100	100	400

(1) this represents a "removal" of about 0.5% of the total snowfall

(2) for Ottawa and Nepean within the lower Rideau River Watershed Study Area

Source: McNeely Engineers, 1980

Table 20. Snowmelt Runoff Quality (measured at 2 catchbasin inlets on 3/29/77)

Organism	geometric means(1) (organisms/100mL)	minimum (organisms/100mL)	maximum (organisms/100mL)	mean yields per ha per 1,000mm snow(2)
Total Coliform	15	<2	240	$1.5x10^{8}$
Fecal Coliform	<2	<2	4	$<2x10^{7}$
Fecal Strep.	2	<2	4	$2x10^{7}$
SPC,20°C	6,200,000	11,000	170,000	$6.2x10^{13}$
Pseudomonas aeruginosa	4	2	13	$4x10^{7}$

(1) Roadway samples were much greater than parking lot samples for total coliform (120/100mL versus 2/100mL) and for 20°C SPC's (100,000/mL versus 29,000/mL).

(2) assuming a snowmelt factor of 0.1 (1,000mm snow is equivalent to 100mL water).

Source: concentrations from Toxopeus, et al., 1978

Even though the concentrations of bacteria in snowmelt are low, the yield of bacteria from snowmelt can be surprisingly high. Table 21 summarizes estimated snowmelt runoff yields expressed in organisms per hectare per year, for different snowfall return frequencies. Section 8 compares these estimated yields with other urban area source bacteria yields.

Table 21. Snowmelt Runoff Yield (organisms/ha/yr)

frequency(yr)	2	5	10	20	50	100
snowfall(mm)	2,210	2,718	2,973	3,175	3,480	4,446
Total Coliform	3.3×10^{8}	4.1×10^{8}	4.5×10^{8}	4.8×10^{8}	5.2×10^{8}	6.7×10^{8}
Fecal Coliform	$<4\times10^{7}$	$<5\times10^{7}$	$<6\times10^{7}$	$<6\times10^{7}$	$<7\times10^{7}$	$<9\times10^{7}$
Fecal Strep.	4.4×10^{7}	5.4×10^{7}	6.0×10^{7}	6.4×10^{7}	7.0×10^{7}	8.9×10^{7}
SPC	1.4×10^{14}	1.7×10^{14}	1.8×10^{14}	2.0×10^{14}	2.2×10^{14}	2.8×10^{14}
Ps. aeruginosa	8.8×10^{7}	1.1×10^{8}	1.2×10^{8}	1.3×10^{8}	1.4×10^{8}	1.8×10^{8}

5.0
SEWERAGE BACTERIA ACCUMULATIONS

The accumulation of bacteria in sewerage sediments and water (catchbasin sumps and the drainage conduits) may be a substantial fraction of the total urban runoff bacteria yield. The cleaning of storm sewer conduits and/or catchbasin sumps may be an effective control measure if substantial portions of the urban runoff pollutant yield are in the sewerage sediments and removed before subsequent rains. This accumulation does not affect the annual mass balance of the bacteria unless, of course, it is removed and appropriately disposed. It can, however, greatly affect the storm to storm mass yields. Small storms may move many particulates from the street surface and into the sewerage inlets. The flows from small storms, however, may not be sufficient to transport the particulates through the sewerage system and out the outfall. Therefore, the particulates would accumulate in the catchbasin sumps or in the sewerage as sediment. Depending upon the storm characteristics and the design of the sewerage system, these particulates may accumulate and reach a general steady state level or they may be periodically flushed.

Toxopeus, et al (1978) examined catchbasin sump sediments during a special program that investigated the effectiveness of a catchbasin control device (HydroBrake). They found that the sumps which were located in the Ottawa area were not always full. There was, on the average, about 0.3 cubic meter of water and about 0.05 cubic meter of sediment in each catchbasin sump. The sediment volumes found varied substantially from site to site and with time. They found that most of the sediments were flushed out after almost every storm. They concluded that the washout of catchbasin sediments during rains may cause significant degradation of stormwater quality in terms of suspended solids, nutrients, and sometimes bacteria.

In September of 1981, several sewerage sediment samples were obtained from different locations in the Ottawa residential test catchments. The observed fecal coliform and fecal strep. concentrations of these samples are shown in Table 22. Tables 23 and 24 summarize the bacteria quality of catchbasin sump samples collected by Toxopeus, et al (1978) in Ottawa. The sewage sediment samples collected as part of this study had bacteria concentrations that were much greater than the catchbasin sump sediments sampled by Toxopeus. Table 25 shows the estimated catchbasin sump bacteria yields on a per catchbasin per flushing storm basis. More than one million fecal coliform bacteria and ten million fecal strep. bacteria may be flushed from each catchbasin during each flushing storm. Assuming one catchbasin sump per ten hectares and 35 flushing storms per year, about six million fecal coliform and 30 million fecal strep. bacteria organisms may be flushed from catchbasins per hectare per year. The catchbasin sediment accumulations may be about one cubic meter per hectare per year (sediment and water). About 80 percent of this material would be water. Those estimated yields are compared with yields of other urban bacteria sources in Section 8.

Table 22. Observed Storm Sewerage Sediment Bacteria Concentrations(1)

Sewerage Location(2)	Fecal Coliform (#/gram)	Fecal Strep. (#/gram)	FC/FS (ratio)	depth of sediment (mm)
Alta Vista	9,800	7,800	1.3	100
Coventry	3,600	13,000	0.28	25 to 150
Leonard	9,000	41,000	0.22	100

(1) samples collected on September 25, 1981, 2 days after a 29mm rain

(2) all residential areas

Table 23. Catchbasin Sump Bacteriological Quality

	total coliforms	fecal coliforms	fecal strep.	FC/FS ratio	standard plate count (20°C)	Pseudomonas aeruginosa
Water Conc. (#/100mL)						
geo. mean	3,300	57	260	0.21(mean)	$2.4x10^7$	26
standard dev.	820,000	91,000	22,000	---	$2.8x10^8$	3,700
# of samples	100	100	100	74	100	100
Sediment Conc. (#/gram)						
geo. mean	350	22	130	0.35(mean)	$4.4x10^6$	13
minimum	<10	<10	<10	0.02	$2.5x10^5$	0.9
maximum	150,000	8,900	39,000	1.1	$5.8x10^7$	90
standard dev.	49,000	2,500	10,000	---	$1.7x10^7$	30
# of samples	15	15	15	6	15	15

Source: Toxopeus, et al., 1978

Table 24. Catchbasin Sump Water and Sediment Accumulations

	Observed Depths (mm)(1)			Observed Volumes (m^3)		
	average	minimum	maximum	average	minimum	maximum
water	170	25	350	0.3	0.04	0.6
sediment	25	0	130	0.05	0	0.25

(1) Source: Toxopeus, et al, 1978

Table 25. Estimated Catchbasin Sump Bacteria Yields
(yields per catchbasin per storm)

	total coliforms	fecal coliforms	fecal strep.	standard plate count (20°C)	Pseudomonas aeruginosa	volume of material (m^3)
water	3.3×10^{7}	5.7×10^{5}	2.6×10^{6}	2.4×10^{11}	2.6×10^{5}	0.3
sediment	1.9×10^{7}	1.2×10^{6}	7.2×10^{6}	2.4×10^{11}	7.2×10^{5}	0.05
total	5.2×10^{7}	1.8×10^{6}	9.8×10^{6}	4.8×10^{11}	9.8×10^{5}	0.35
annual yield (organisms/ha/yr)(1)	1.8×10^{8}	6.3×10^{6}	3.4×10^{7}	1.7×10^{12}	3.4×10^{6}	$1.2 m^3$/ha/yr

(1) assuming 0.1 sump per ha. and 35 "flushing" storms per year

6.0
STREET SURFACE BACTERIA CONTRIBUTIONS TO URBAN RUNOFF YIELDS IN LARGE DRAINAGE BASINS

This report section examines the sensitivity of street surface bacteria contributions to runoff bacteria yields in the large catchments that make up the lower Rideau River drainage basin. Figure 4 shows the general locations of the 27 large catchments in the lower Rideau River basin, along with the seven small test catchments. Table 26 summarizes the street surface and land use characteristics of all of these catchments, and compares them to the small test catchments. Most of the streets have smooth or moderate textures. Typical street densities are about 0.2 km of street per hectare. The street densities are significantly less in the southern catchments, further from the Ottawa metropolitan area. The percent impervious values vary from about ten to 50 percent for the northern urbanized catchments, but is typically less than ten percent for the southern catchments. These large southern catchments are mostly open areas (croplands and recreation areas).

Table 27 and Figures 5 and 6 were calculated based on the actual street lengths in each basin and their land use configuration. Specific Ottawa street surface bacteria loads (as shown in Section 3), total catchment bacteria yields for different land uses (as shown in Section 2), and total basin yields as used by Gore and Storrie/Proctor and Redfern (1981c) were used to estimate the total basin bacteria yields and the portion originating on the streets.

Table 27 compares the estimated typical street surface particulate bacteria loadings (based upon the test catchment data and street densities) to estimated runoff bacteria discharges (assuming an average three days accumulation period and the different land use configurations). Most of the catchments through number 20 would have more bacteria residing on the streets than would be present in typical urban runoff. The less urbanized areas have important nonstreet surface bacteria sources. Similar trends are shown for fecal strep. bacteria, but the street loading to runoff yield ratios are almost ten times greater than for fecal coliforms. Figures 5 and 6 graphically show the relationships between catchment street densities and street bacteria loads to runoff yield ratios.

These figures show that the street density is directly related to the street load to runoff yield ratio for the large basins. The test catchment values varied from this straight-line relationship because of their smaller size, and the corresponding greater probability of irregularities (such as local erosion sources, differences in pet populations and litter clean-up practices, etc.) not averaging out.

Figure 5 shows that basins having street densities less than 0.05 km/ha have more non-street fecal coliform bacteria sources than street sources. These basins (numbers 14, 18, and 21 through 27) would be least suitable for street cleaning as a fecal coliform bacteria urban runoff control measure. Table 27 can be used to set priorities for intensive street cleaning for these basins. The highest priorities could be set for catchment numbers 9, 20, 11, 10, 13, and 15. These basins are expected to have more of their urban runoff fecal coliform bacteria originating on the streets than any of the other basins. Street cleaning would therefore be most effective in these basins.

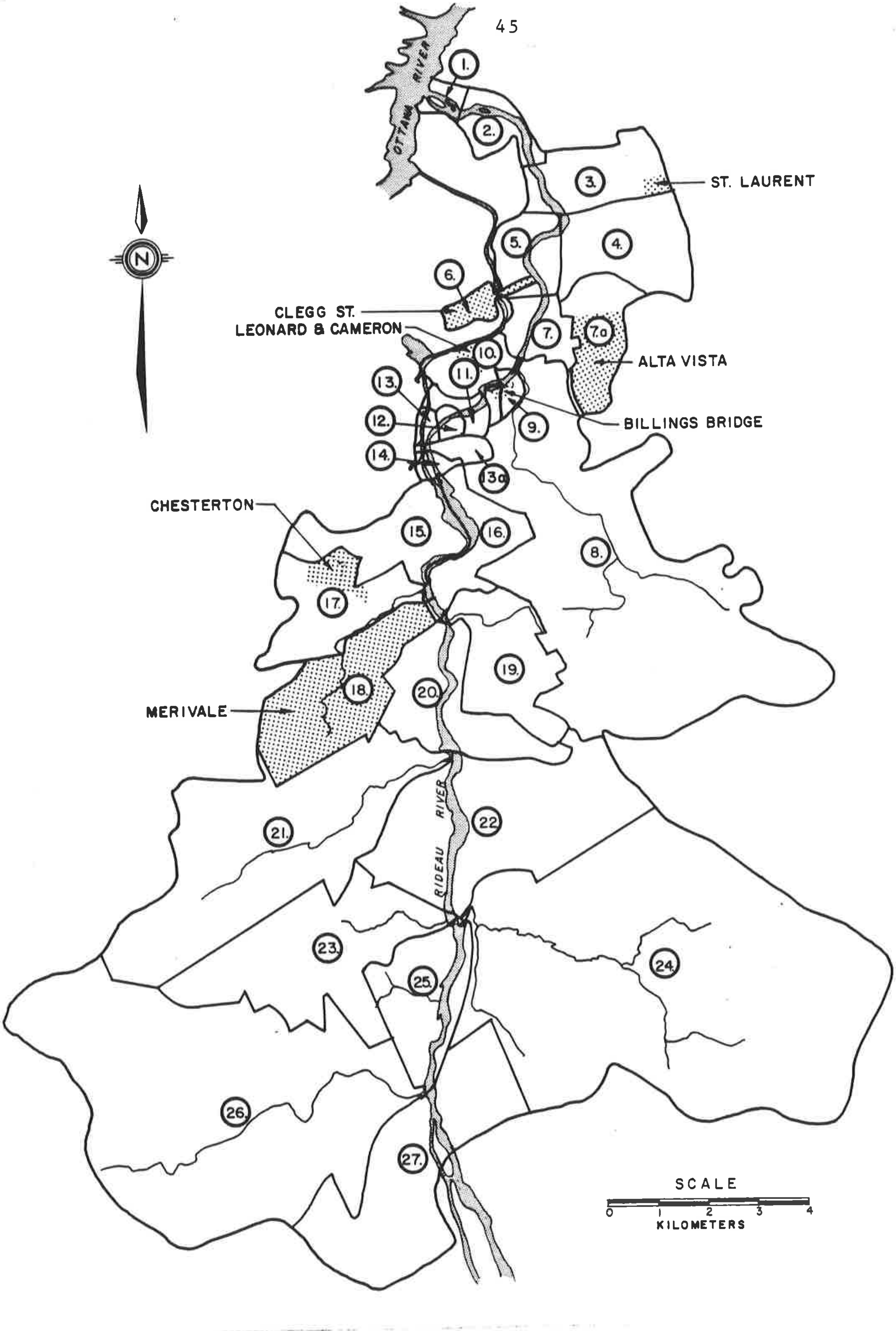


Figure 4. Test and large catchment locations

Table 26. Catchment Characteristics

Catchment	Area (ha)	street length(km)-texture			street length to area ratio (km/ha)	percent imper-vious (%)	land-use(%)				
		smooth and moderate	rough	very rough			resid.	commerc.	indust.	open*	other
3.	340	65		3	0.20	17	50	6	—	39	5
4	370	42			0.11	11	10	—	10	79	1
5	120	14			0.12	24	8	8	—	72	12
7	200	40			0.20	30	74	5	—	11	10
8	2,300	430			0.19	18	34	10	5	50	1
9	35	15			0.43	50	20	26	—	43	11
10	110	32		3	0.29	35	53	10	—	31	6
11	83	26			0.31	38	—	24	—	68	8
12	34	3			0.09	21	—	12	—	76	12
13	28	8			0.29	46	—	29	—	53	18
13a	55	14			0.25	36	—	35	—	64	1
14	20	1			0.05	20	—	5	—	80	15
15	280	75	10		0.30	19	80	5	—	13	2
16	340	57			0.17	16	36	—	—	44	20
17	390	26	5	3	0.09	6	27	6	1	57	9
18	420	11	3	1	0.04	3	11	8	23	55	3
19	400	87			0.22	19	7	—	42**	51	—
20	500	180	17		0.39	24	16	2	40**	35	7
21	1,600	37			0.02	2	7	1	1	90	1
22	1,200	7		6	0.01	4	—	—	24**	76	—
23	940	41			0.04	4	16	1	—	82	1
24	3,800	27			0.01	0	—	—	—	100	—
25	440	1		7	0.02	0	10	—	—	75	15
26	3,000	20	5	1	0.01	2	6	—	—	92	2
27	830	5	2	5	0.01	0	—	—	—	97	3
Alta Vista	180	11		6	0.09	14	66	3	0	31	0
Clegg	78	12			0.15	33	74	26	0	0	0
Leonard	37	5	1		0.16	36	97	3	0	0	0
Merivale	520	17			0.03	27	11	0	54	35	0
Billings Bridge	19	1			0.05	70	0	70	0	30	0
St. Laurent	36	2			0.06	92	6	94	0	0	0

* includes cropland, recreation areas, etc.
** mostly airport

Table 27. Ratio of Street Surface Particulate Bacteria Loadings to Runoff Bacteria Discharges (3 days accumulation)

Catchment	Fecal Coliform	Fecal Strep.
3	3.3	23
4	2.0	12
5	2.0	13
7	3.5	23
8	3.2	21
9	7.5	48
10	5.2	40
11	5.5	35
12	1.3	9
13	5.1	34
13a	4.6	30
14	1.0	8
15	5.0	32
16	2.9	19
17	1.2	10
18	0.5	4
19	3.9	25
20	6.4	44
21	0.4	3
22	0.1	2
23	0.7	5
24	0.1	1
25	0.1	3
26	0.1	1
27	0.1	2

Figure 5. Fecal coliform street surface particulate loadings and runoff yields compared.

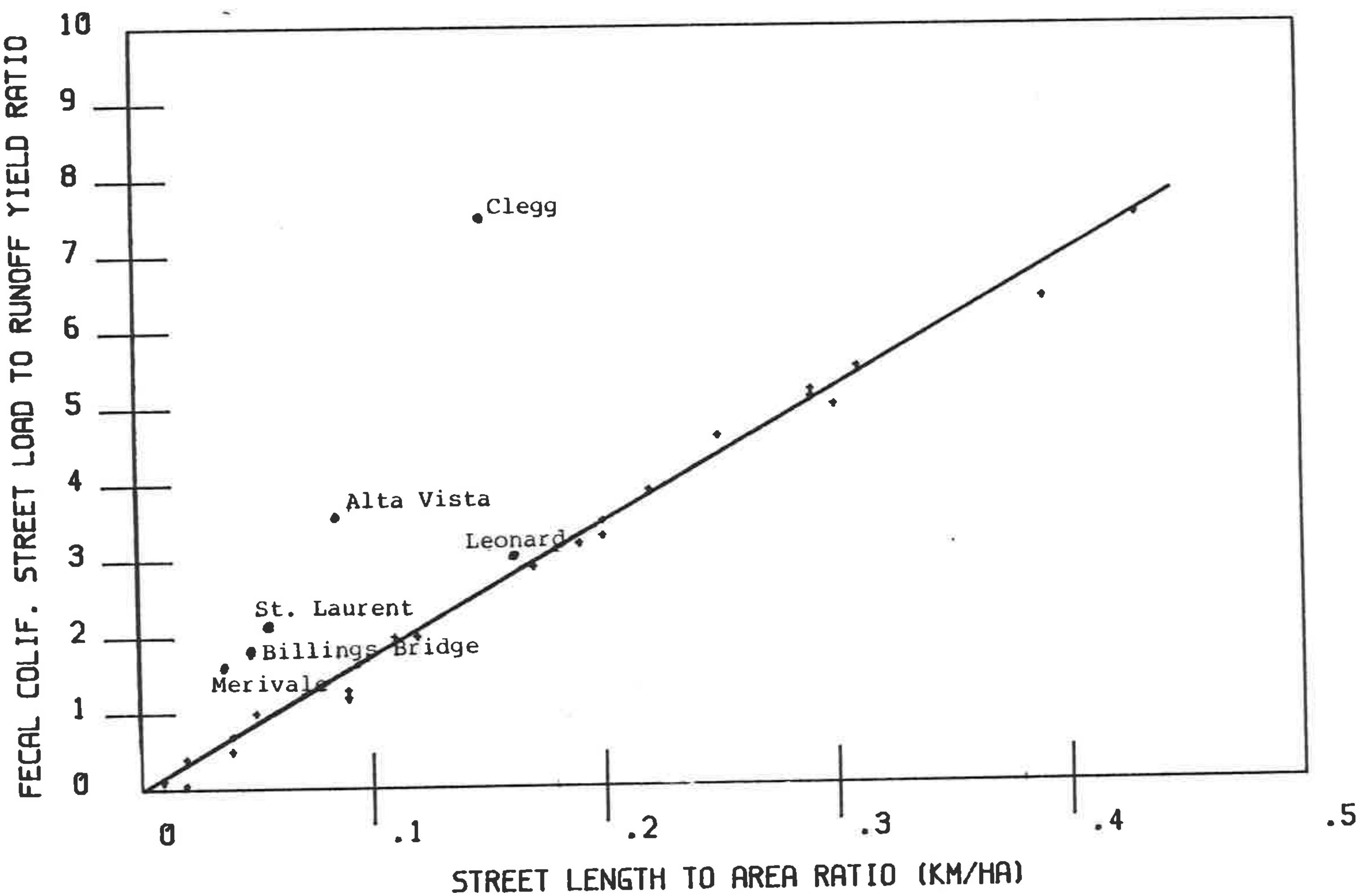
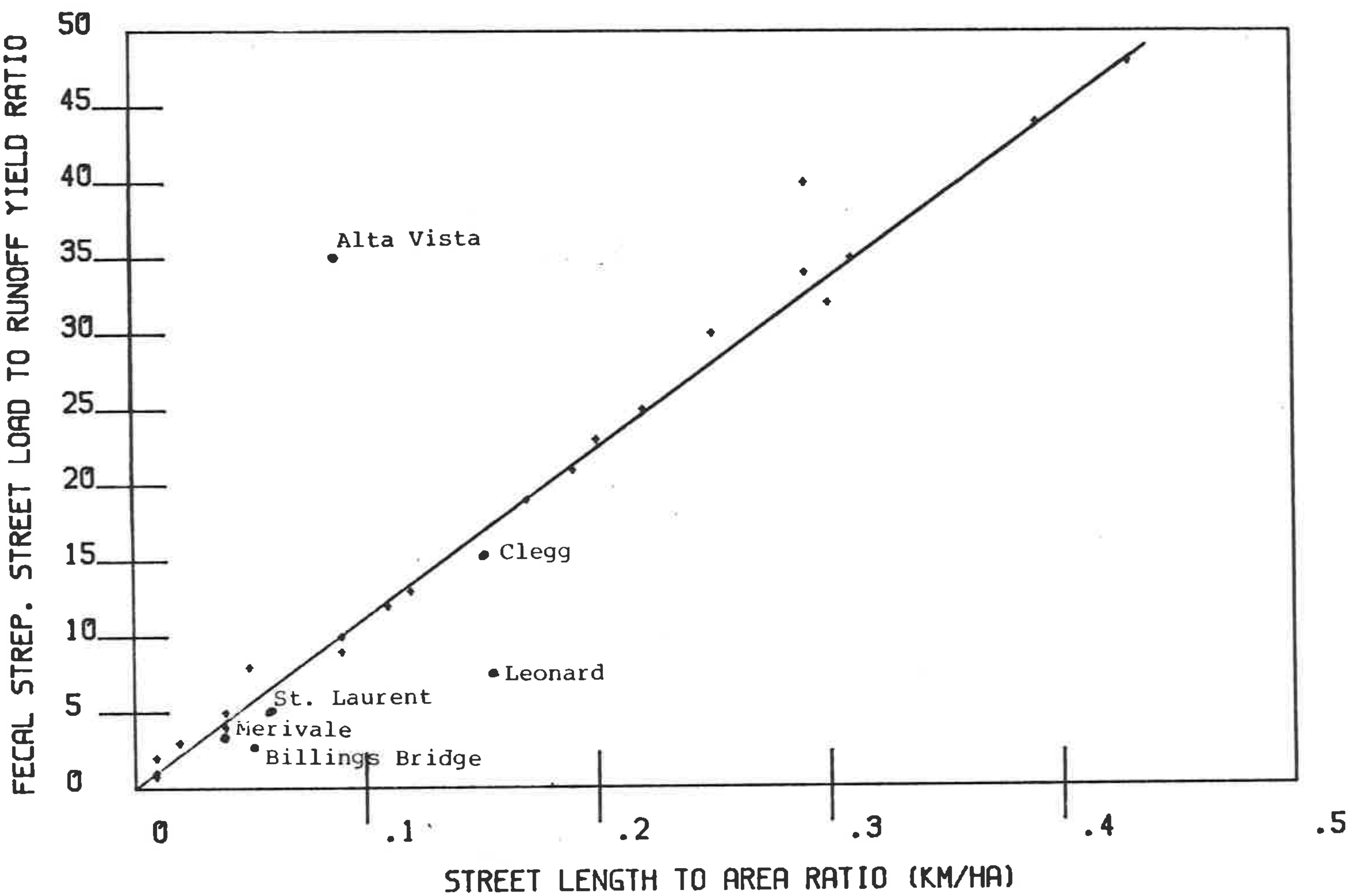


Figure 6. Fecal Strep. street surface particulate loadings and runoff yields compared.



7.0
RIDEAU RIVER BACTERIA QUALITY

7.1 RIDEAU RIVER CHARACTERISTICS AFFECTING BACTERIA TRANSPORT AND DILUTION

The average summertime flow of the Rideau River is about 10 to 20 cubic meters per second with velocities of about five to 20 cm/sec. Gore and Storrie/Proctor and Redfern, (1981c) stated that thermal and chemical stratification can occur in deeper reaches of the river. This stratification effectively reduces the river cross-sectional area available for the assimilation of pollutants. Therefore, the Rideau River during the summertime rain period is an effectively small receiving water. The resultant dilutant capabilities and the assimilative capacity is quite small for a river basin of its size.

7.2 RIDEAU RIVER BACTERIA QUALITY

Loijens (1981) stated that the fecal coliform levels in the reach downstream of Hog's Back are a result of area-wide stormwater runoff and poor mixing and dispersion characteristics. He concluded that there is not sufficient assimilative capacity for fecal coliform bacteria downstream of Hog's Back.

Figure 7 shows Rideau River sectors corresponding to reported bacteria concentrations. This figure also shows the locations of four swimming beaches along the Rideau River. An extensive investigation of bacteria concentrations in the Rideau River was carried out from 1978 through 1981 as part of the Rideau River Stormwater Management Study. Table 28 summarizes the observed bacteria and suspended solids concentrations for these river sectors for the 1978 and 1979 sampling season. As mentioned previously, there is a substantial difference in fecal coliform and fecal strep. concentrations above Hog's Back (Sectors D and E) as compared to the downriver stretches near the urbanized area. The mean suspended solids concentrations did not vary significantly, although the variations (standard deviations) in most of the downstream reaches were larger than in the upstream regions. The lead concentrations in the river noticeably increased in a downstream direction but not to the same extent as the increases in the fecal coliform and fecal strep. concentrations.

Table 29 summarizes the ratios between wet weather to dry weather bacteria observations for each Rideau River sector and for the Jock River. Wet weather fecal coliform values were about 1.5 to 2.4 times the dry weather concentrations; while the fecal strep. concentrations for wet weather were about three to four times the dry weather concentrations. The effects of wet weather on Rideau River bacteria concentrations has been noted in many reports. Environment Canada (1980) stated that the fecal coliform counts in the downstream sectors consistently exceeded the Ontario recreational objective of 100 fecal coliform organisms per 100 mL. The urban sector of the river is considered marginally polluted and much more sensitive to stormwater pollution than the upstream suburban section.

The flow characteristics of the Rideau River and Ottawa rain characteristics combine to make wet weather bacteria impacts very important. As mentioned previ-

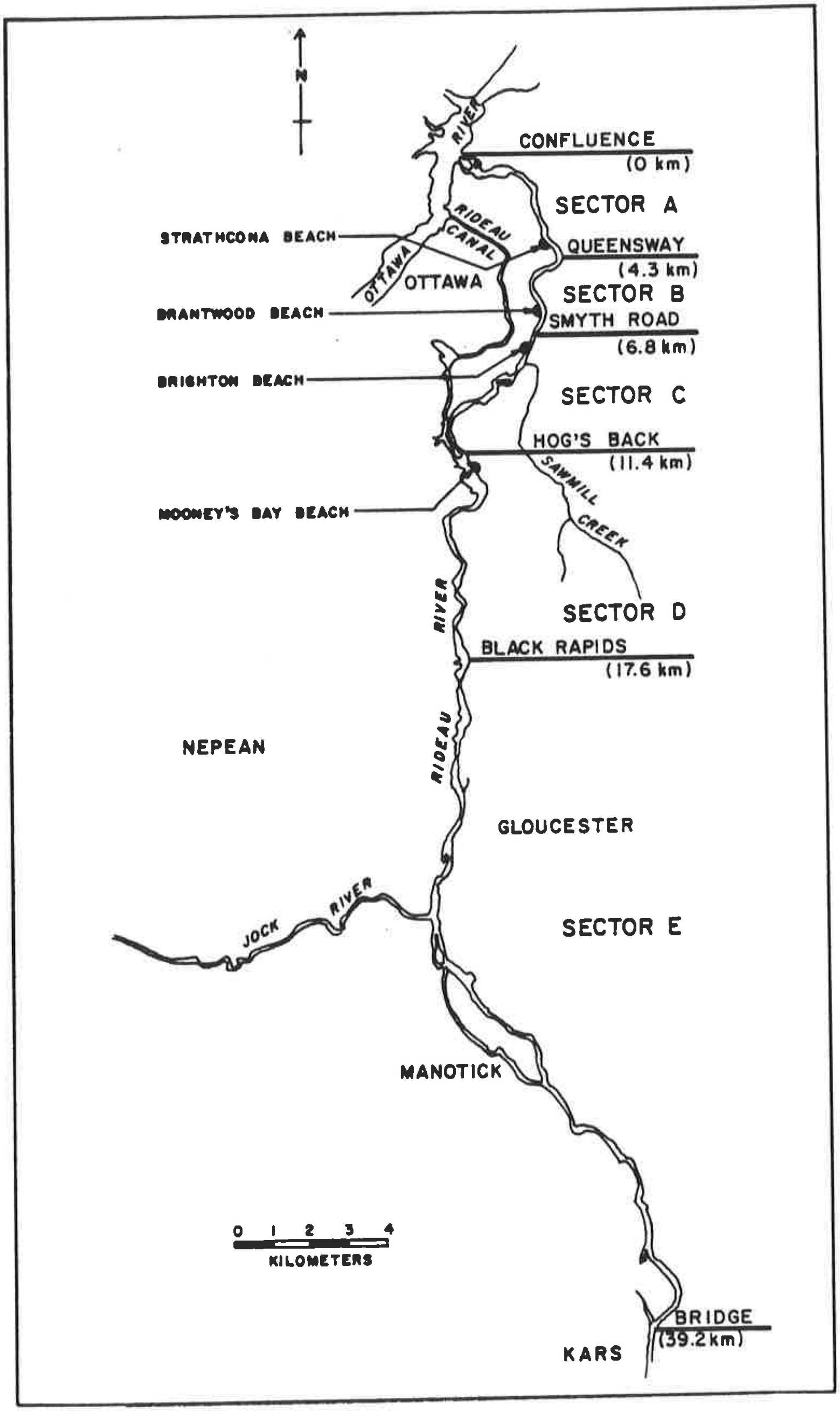


Figure 7. Rideau River sector locations

Table 28. Rideau River Water Quality Observations (June to August, 1978 and June to August, 1979)*

Sector	mean	standard deviation	number of observations
Suspended Solids (mg/L)			
A	5.1	9.4	125
B	5.5	7.5	42
C	4.6	2.7	139
D	3.9	2.7	155
E	4.7	3.4	103
Lead (mg/L)			
A	0.027	0.01	40
B	0.045	0.09	23
C	0.023	0.02	64
D	0.017	0.02	29
E	0.016	0.01	28
Total Coliforms (organisms/100mL)			
A	16,900	49,200	116
B	1,370	2,490	47
C	950	195	220
D	770	4,760	77
E	210	320	85
Fecal Coliforms (organisms/100mL)			
A	760	1,040	261
B	310	280	86
C	170	310	301
D	36	180	203
E	34	43	194
Fecal Strep. (organisms/100mL)			
A	620	940	261
B	530	1,150	86
C	370	620	301
D	68	180	203
E	34	64	194

* wet and dry weather period observations combined

Source: Gore & Storrie/Proctor & Redfern, 1981c

Table 29. Ratio of Wet to Dry Weather Bacteria Densities (1979)

Rideau River Sector	ratio of wet to dry weather bacteria geometric means: fecal coliform	fecal strep.	Pseudomonas aeruginosa
A	2.4	3.0	3.9
B	1.5	2.7	3.6
C	1.8	2.9	2.1
D	2.1	4.9	2.0
E	1.7	2.7	2.0
Jock River	2.3	4.1	2.8

Source: Environment Canada, 1980

ously, the pollutant transport in the river is very slow and the frequency of rain events at Ottawa is relatively high. Gore and Storrie/Proctor and Redfern (1981c) concluded that the river seldom recovers from rain events before the next event occurs; the river requires a long dry period to recover completely from each rain. Measurements of instream bacteria concentrations during dry weather usually are affected by previous rain events. These rain effects on Rideau River bacteria concentrations had been known for some time. Gore and Storrie/Proctor and Redfern (1981c) stated that high bacteria levels were seldom encountered except during major rain storms.

The Regional Municipality of Ottawa - Carleton (1972) stated that many cross-connections were found and corrected, but that the bacteria levels continued to increase above the recreation objectives during heavy rains. Four swimming beaches on the Rideau River have been closed permanently in Sectors A, B, and C since 1970. Mooney's Bay (Sector D) Beach is usually kept open, but is intermittently closed when fecal coliform concentrations exceed 100 organisms per 100 mL.

7.3 RIDEAU RIVER SWIMMING BEACH BACTERIA CONCENTRATIONS

Table 30 summarizes the indicator bacteria concentrations observed at four of the swimming beaches along the Rideau River in each of the A, B, C, and D river sectors. These data, covering the sampling periods of 1976 to 1980, show that the annual geometric means at Mooney's Bay Beach were all less than the criteria. However, the maximum observed fecal coliform concentrations at all of the beaches exceeded the criteria. Almost all of the samples collected at Strathcona Beach in sector A exceeded the fecal coliform criteria, while less than ten percent of the samples at Mooney's Bay Beach exceeded the criteria. Again, these samples were collected during both wet and dry weather.

7.4 RIDEAU RIVER SEDIMENT BACTERIA CONCENTRATIONS

Contaminated sediments may significantly affect water column bacteria concentrations (see Appendix B). The resuspension of contaminated sediments during high flows may elevate Rideau River concentrations more than wet weather discharges by themselves and could prolong the periods of time when high concentrations are present in the water column. In order to examine the potential for resuspended sediments affecting Rideau River bacteria concentrations, a few samples were collected during August of 1981. Table 31 shows the results of this limited sampling effort. The water fecal coliform concentrations were about 400 organisms per 100 mL, while the bottom sediment concentrations were more than 20,000 organisms per 100 mL. After the sediment was gently disturbed by the diver who was collecting the samples (by waving his hand near the bottom), the near bottom water concentrations increased to 2000 organisms per 100 mL. This does show the potential effects that minimal disturbance and resuspension of bottom sediments can have on instream water quality.

Gore and Storrie/Proctor and Redfern (1981c) stated that they did not find correlations between high suspended solids concentrations and elevated levels of fecal coliforms in the Rideau River. They therefore concluded that high coliform concentrations were not associated with resuspended bottom sediments. However, this may not be a logical conclusion; the bottom sediments have much greater bacteria concentrations than the solids from most other particulate sources. The quantity of runoff solids coming into the River during a rain would be much greater than the amount of sediment solids resuspended from the river sediments. Because the river sediments have a much higher concentration of bacteria than the incoming solids, the relationship between river suspended solids and bacteria may not be indicative of the bacteria sources.

Table 30. Bacteria Population Observations at Swimming Beaches (number of organisms/100mL)*

Beach	year	Total Coliforms geom. mean	Total Coliforms min.	Total Coliforms max.	Total Coliforms # of obs.	Fecal Coliforms geom. mean	Fecal Coliforms min.	Fecal Coliforms max.	Fecal Coliforms # of obs.	Fecal Strep. geom. mean	Fecal Strep. min.	Fecal Strep. max.	Fecal Strep. # of obs.	% of all TC obs. >1,000	% of all FC obs. >100
Strathcona (Sector A)	1976	1,219	144	11,700	80	309	49	1,697	80	103	<10	2,654	52	56%	85%
	1977	646	39	9,640	75	263	19	1,975	75	78	<10	1,372	46	25	93
	1978	754	135	6,417	25	289	115	782	25	183	26	2,098	25	40	100
	1979	1,041	121	11,000	53	426	79	1,142	53	237	49	774	21	42	96
	1980	630	171	9,440	66	302	40	2,973	66	72	6	1,975	24	33	83
Brantwood (Sector B)	1976	574	57	11,700	80	130	<10	728	80	55	<10	1,932	52	35	70
	1977	254	10	>8,000	75	92	<10	2,700	75	33	9	3,382	46	8	44
	1978	317	98	7,890	25	120	10	1,011	25	84	16	1,272	25	8	64
	1979	346	26	10,000	53	130	15	3,590	53	77	12	2,311	21	15	68
	1980	154	17	9,390	67	68	12	390	67	23	7	490	24	6	33
Brighton (Sector C)	1976	637	95	22,200	80	138	13	857	80	57	<10	2,213	52	50	37
	1977	316	20	>8,000	74	112	<10	3,200	74	32	<2	1,740	46	16	54
	1978	467	180	4,980	25	150	9	1,220	25	130	13	1,000	25	12	72
	1979	379	28	3,390	53	127	13	504	53	67	10	434	21	28	68
	1980	192	27	2,205	67	72	13	427	67	46	6	1,181	24	7	34
Mooney's Bay (Sector D)	1976	152	37	3,088	77	19	5	475	77	10	2	214	78	8	6
	1977	54	9	554	76	12	1	526	76	6	1	65	78	0	5
	1978	117	12	2,642	50	24	2	493	50	15	2	95	20	16	16
	1979	86	6	2,780	75	23	5	659	75	25	3	1,100	21	4	9
	1980	62	1	624	71	16	3	389	71	8	2	26	24	0	7

* wet and dry period observations combined

Source: Rideau River Stormwater Management Study, 1981

Table 31. Rideau River Sediment Fecal Coliform Concentrations (#/100mL)[1]

Sampling Location	water column	near-bottom water after sediment disturbance	sediment
Between Smyth Rd. Bridge and Bank St. Bridge	390[2]	2,200[3]	22,000[4]
Smyth Rd. Bridge	---	---	20,000[5]

(1) samples collected on August 26, 1981.

(2) Five water samples were obtained; FC concentrations ranged from 320 to 480/100mL.

(3) Two samples were obtained; 2,000 and 2,500 FC/100mL.

(4) Two samples were obtained; 21,000 and 24,000 FC/100mL.

(5) Two samples were obtained; one was 20,000 FC/100mL, but the other was suspected of being contaminated directly by bird feces and was 270,000 FC/100mL.

8.0
SUMMARY OF OBSERVED CONCENTRATIONS AND YIELDS

8.1 OBSERVED BACTERIA CONCENTRATIONS

Tables 32 and 33 summarize the bacteria concentrations observed for the different samples collected in the Ottawa urban area and the estimated annual bacteria discharges for different sources in the lower Rideau River basin. Except for rooftop runoff, the catchment subarea sheetflow concentrations all approach the concentrations of the urban runoff. The urban runoff bacteria concentrations are slightly greater than the river concentrations below Mooney's Bay. The catchment area sheetflow fecal strep. concentrations, again except for rooftop runoff, are all substantially greater than the river concentrations.

The population densities of the bacteria in the particulates (sediments) appear to increase when going from the upper catchment subareas to the river sediment. This may possibly indicate the contamination of the particulates as they migrate through the catchments and sewerage systems before they are deposited as river sediments.

8.2 ESTIMATED UNIT AREA BACTERIA YIELDS

The urban runoff fecal coliform unit area yield is more than a factor of ten greater than the snowmelt yield, and about a factor of ten greater than the sewerage and catchbasin sump yields. Therefore, snowmelt and sewerage accumulations probably do not appreciably affect the total annual yields, but they may significantly affect individual snowmelt and storm event concentrations and yields. The street surface particulate fecal coliform and fecal strep. accumulations are as much as one to two orders of magnitude greater than the total urban runoff bacteria discharges. Again, bacteria urban runoff yields do not appear to be source-limited in that substantial quantities of bacteria reside on the street surfaces that are not washed off by rain. A large quantity of bacteria is associated with particulates that are trapped in the street textures and may be subject to significant die-off during periods of dry weather. The many other sources of bacteria in the urban area would further increase this overabundance of bacteria sources for urban runoff.

This overabundance is common for many other urban runoff constituents and is usually associated with the resuspension and subsequent deposition of contaminated particulates further away from the directly connected impervious areas. As an example, street dirt can be resuspended naturally by winds or by turbulence caused by automobile traffic. Much of this resuspended street dirt settles out within 100 meters downwind from the road surface where it contaminates soils or other surfaces. These particulates are much less effectively washed off of these pervious surfaces during rains than from the street surfaces. Some past studies have measured near-street surface atmospheric deposition rates and have added these rates to the source area contributions. This typically results in artificially high atmospheric deposition contributions for urban runoff (assuming atmospheric deposition should only consider larger scale phenomenon). The speci-

Table 32. Typical Bacteria Population Densities

	Total Coliforms	Fecal Coliforms	Fecal Strep.
water samples (organisms/100mL)			
Rideau River			
below Mooney's Bay	7,000	1,000	500
above Mooney's Bay	500	50	50
Urban Runoff	---	10,000	---
Snowmelt	3,000	<2	2
Catchbasin Sump	---	50	300
Gutter Flows	---	4,000	20,000
Parking Lot Puddles	---	3,000	10,000
Vacant Land and Park Puddles	---	6,000	20,000
Rooftop Runoff	---	100	200
sediment samples (organisms/gram solids)			
Rideau River Sediments (urban area)	---	20,000	---
Sewerage Sediments	---	8,000	20,000
Catchbasin Sump	400	20	100
Street Dirt			
smooth and moderate texture	---	400	2,000
rough texture	---	100	1,000
very rough texture	---	10	3,000

Table 33. Summary of Annual Bacteria Discharges (organisms/ha/yr)

	Total Coliforms	Fecal Coliforms	Fecal Strep.
Urban runoff	---	10^8	10^8
Snowmelt	10^8	$<10^7$	10^7
Sewerage and catchbasin sumps	10^8	10^7	10^7
Street dirt			
smooth and moderate texture	---	10^9	10^9
rough texture	---	10^8	10^9
very rough texture	---	10^7	10^{10}

fic processes that may be involved in transporting bacteria in the urban area are not well-defined, but die-off and after-growth of bacteria after the feces are deposited play an important role.

Appendix A presents information on urban runoff bacteria collected at many different locations. Appendix B summarizes possible urban bacteria sources affecting urban runoff bacteria concentrations, including the contamination of soils by feces and bacteria survival. Appendix B also includes a rough estimate of bacteria feces sources form different animals in the Ottawa area. Appendix C describes the different bacteria types and their significance in urban runoff.

PART II
LOCAL CONTROL MEASURES FOR URBAN RUNOFF BACTERIA CONTROL

9.0
CURRENT STREET CLEANING EFFORTS IN THE LOWER RIDEAU RIVER WATERSHED

The cities of Ottawa and Nepean conduct street cleaning activities in the lower Rideau River watershed. Tables 34 through 36 summarize this effort. Ottawa currently uses about ten mechanical or vacuum-assisted mechanical street sweepers. This is supplemented with some road flushers. They report a cost of about $58 per hour for city-owned equipment and about $27 per hour for contractor-owned equipment. This results in curb-kilometer costs of about $21 and $10, respectively. The 1981 Ottawa street cleaning work force had been reduced substantially from the 1975 level (currently 15 to 20 people from a previous level of 75 to 80 people). Ottawa also uses about 25 people in the downtown area for manual street cleaning. The residential and industrial areas are cleaned mechanically about once every two weeks and are flushed about once a month. The Central City streets are cleaned one to five times per week. The cleaning speed is about nine km per hour. The major reported problem for the Ottawa street cleaning program is the poor condition of the streets (many of the streets need overlays). Ottawa also has a substantial nighttime cleaning program which includes manual and mechanical cleaning of Central City sidewalks five times a week. Most of the Ottawa street cleaning effort is used for the Central City's streets and sidewalks. About 25 percent of the total Ottawa street cleaning effort is used in day mechanical and day flushing activities in the non-central city areas.

The city of Nepean uses three pieces of street cleaning equipment. Their goal is to clean once every two months or about three times per summer. Their largest stated problem is cleaning in areas currently under construction.

Table 34. City of Ottawa Street Cleaning Program

- Types of equipment available:
  - 7 Vacu-Sweeps (2 are contractor operated)
  - 3 Wayne 3-wheel mechanical sweepers
  - some flushers also
  - equipment is 2 to 12 years old with a 50% downtime
  - the mechanical sweepers are used in colder weather and for heavier loads, but have more downtime
  - City costs are $58/hr, while contractor costs are $27/hr ($21/curb-km and $10/curb-km, respectively)

- Numbers of personnel:
  - 15 to 20 during 1981 (reduced from 75 to 80 during 1975) for mechanical cleaning
  - 20 to 30 people are used for manual cleaning in the downtown area having heavy parking conditions

- Roads cleaned:
  - 882 km mechanically cleaned (daytime)
  - 728 km flushed (most of above area) (daytime)
  - 472 km central city nighttime mechanically cleaned
  - 197 km central city nighttime flushed
  - 259 km central city nighttime manually cleaned
  - 31 km central city sidewalks cleaned

- Cleaning frequency:
  - residential/industrial areas once every two weeks mechanically cleaned (flushed once per month)
  - central city one to five passes per week mechanical, flushing and manual
  - cleaning speed is 5 to 7 mph (8 to 11 km/hr)
  - city wide parking restrictions during street cleaning enforced on high volume streets

- Debris disposal:
  - 1 to 2 day interim storage at maintenance yards before landfilling

- Problems:
  - many streets need overlays (potholes are corrected, most streets are asphalt with some slurry sealed)

- Other activities:
  - extensive spring cleanup (March 15 to May 1) every year
  - 750 litter baskets (mostly central city) are emptied from once or twice a week to three to four times a day
  - catchbasins are cleaned once per year
  - 14,000 tons sand and salt applied over 500 km of streets for deicing
  - special leaf removal operations

Table 35. Ottawa Street and Sidewalk Cleaning Effort*

	start of cleaning	cleaning frequency	curb length (km)	total cleaned per cleaning season (km)
ALL AREAS				
Day Mechanical	7 am	once every two weeks	882	10,590
Day Flushing	7 am	once per month	728	4,370
Total			1,610	14,960
CENTRAL CITY STREETS				
Night Mechanical				
city	9 pm	one to five passes per week	255	14,380
contract	9 pm	one to two passes per week	217	9,340
Night Flushing	9 pm	one to three times per week	197	7,420
Manual Street	---	once per week	259	6,220
Total			928	37,360
CENTRAL CITY SIDEWALKS				
Mechanical Sidewalk	---	five times per week	24	2,870
Manual Sidewalk	---	five times per week	3	400
Hand Flushing of Sidewalks	9 pm	twice per week	4	200
Total			31	3,470

* assuming a 6 month cleaning season (April 22 to October 22)

Table 36. City of Nepean Street Cleaning Program

- Types of equipment available:
  - 2 Vacu-Sweeps (about 7 years old)
  - 1 mechanical sweeper (used for intersections)
- Numbers of operators: 3 to 4
- Roads cleaned:
  - 118 km urban roads
  - 35 km collector streets
  - mostly residential (about 10% industrial)
- Cleaning frequency:
  - goal is once every 2 months (3 times per summer)
  - about 150 to 200 tons of street dirt removed per summer
  - cleaning speed is 5 to 7 mph (8 to 11 km/hr)
  - some parking restrictions during street cleaning
- Debris disposal:
  - on and near street interim storage (about 2 weeks)
  - most disposed in landfills
- Problems:
  - construction areas
- Other activities:
  - catchbasins are cleaned about once per year
  - no special residential leaf removal practices
  - deicing application of sand and salt is about 25% of older application rates

10.0
CURRENT AND AVAILABLE STREET CLEANING PRODUCTIVITY IN THE LOWER RIDEAU RIVER WATERSHED

This section presents the results of a numerical analysis used to define the effectiveness of mechanical street cleaning operations in the lower Rideau River watershed. Previous urban runoff projects that evaluated the effects of street cleaning were instrumental in this analysis. These projects (the San Jose demonstration project, Pitt, 1979; the Castro Valley NURP project, Pitt and Shawley, 1982; and the Bellevue NURP project, Pitt, 1982) involved hundreds of street cleaning tests for a variety of street surface characteristics, particulate loading values, different types of street cleaning equipment and climatic conditions. Preliminary test results from other street cleaning productivity tests conducted in Reno, Nevada (Sutherland and Pitt, 1982) and NURP projects located in Milwaukee, Wisconsin, Champaign-Urbana, Illinois, and Winston-Salem, North Carolina, were also reviewed.

These street cleaning productivity tests required sampling street dirt in test areas in a similar manner as the special street surface particulate loading tests conducted in Ottawa, as described in Section 3. Immediately after initial, or "before", street surface loading samples were obtained, the streets were cleaned in a controlled manner using street cleaning equipment that operated under a specific set of operating conditions. A residual, or "after", street surface particulate sample was then collected within several hours after the streets were cleaned, using the same sampling procedures, but at locations slightly different than the initial samples.

The most useful description of street cleaning productivity was found by calculating a straight line equation between the initial street surface loading values and the residual loading values. The resultant equations, which were determined for specific test areas and operating conditions, had quite high r^2 values (most were greater than 0.8, with some approaching 0.95). Statistical analyses were also conducted to determine the important test and operating characteristics that affected the resultant equations. The most important factor was the street surface texture. Other factors of importance included the presence of parked cars and parking controls (if the parked cars were removed during the street cleaning activities). These straight line equations were much more meaningful than simply expressing the productivity as a percentage removal. In all cases, the percentage removals were substantially greater when the initial street loadings were high, as compared to when they were low. These percentage removals could easily vary from negative values for very low initial loadings (the residual loading values were actually greater than the initial values) to percentage removal values approaching 65 percent for high initial loadings for the same operating conditions and test area. The negative removal values were found to be caused by the action of the street cleaner on very clean streets actually eroding part of the street surface material. Streets in very poor condition had much lower street cleaning productivities than streets in smooth condition. This is due to the inability of street cleaning equipment to remove material that is trapped in cracks or within the actual texture of the rougher streets.

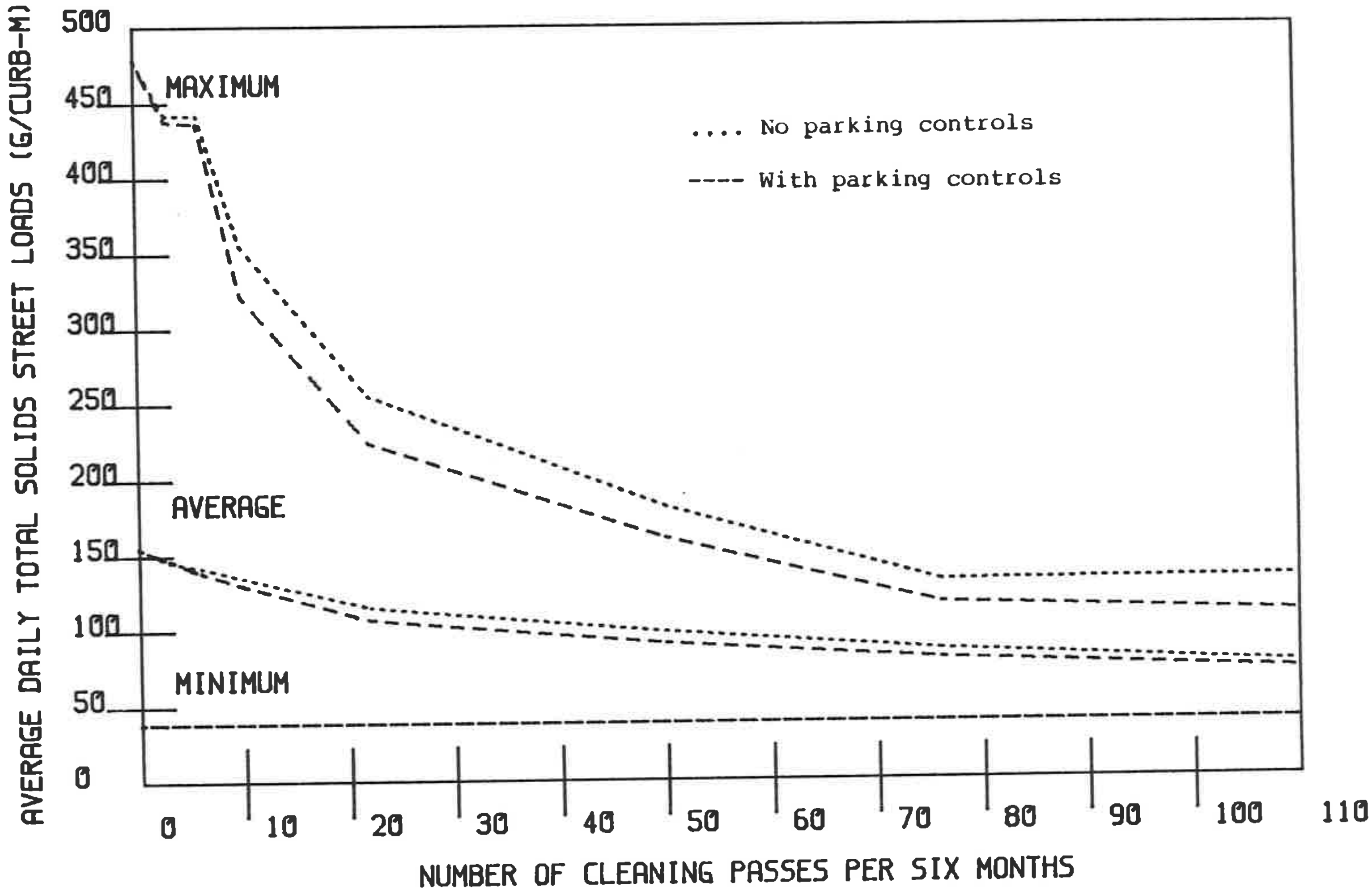
As street cleaning equipment moves around parked cars, it misses the typically higher street dirt loadings near the curbs. For smooth streets having light to moderate parking conditions, the presence of parked cars can substantially reduce street cleaning productivity. However, when there is extensive parking (greater than 80 percent of the curb length occupied by parked cars) or rough textured streets, much of the street dirt is away from the curb, so that the removal of parked cars for street cleaning actually decreases street cleaning productivity. This is a common problem in downtown areas.

A computer program has been developed by Pitt that utilizes these productivity relationships, site specific street surface particulate accumulation rates and the rain history to summarize the expected long-term street cleaning productivities for a variety of cleaning programs. The accumulation and removal mechanisms are subjected to the specific rain history by the computer program to calculate average daily street loadings; initial and residual loadings, amount removed, and percent removed for each day of street cleaning; and loading values immediately before rain events. If the necessary information is available, the urban runoff yields for each rain event based upon the sensitivity of street dirt loading values to runoff yields, is also estimated. The amount of street surface particulates that is lost to the air as fugitive dust is also calculated on a daily basis. All of these values are summarized on a monthly and an annual (or study period) basis.

Figure 8 (along with Figures D-1 through D-5 in Appendix D) summarizes the results of these computer calculations. They show the effects of different street cleaning programs (number of passes with and without parking controls) for different street textures and parking conditions. The minimum and maximum expected street surface particulate loadings for a constant cleaning program during the cleaning season is also shown in addition to the average values. These figures show a substantial improvement in street cleanliness when going from a current program which has a very low frequency of street cleaning to one that is more intense. If the existing street cleaning frequency is about 20 to 30 passes per six months (about one pass per week), increases in street cleaning would have very little effect on the average street surface loading values. Maximum loading values are much more sensitive to street cleaning changes than average loading values. This is important when one is concerned about the potential street surface loading values before rains. Reducing the maximum probable loading value that may occur before a small volume rain may substantially reduce the corresponding urban runoff yield. As described in Section 1, the Ottawa rain pattern is quite evenly spaced during the six month summer street cleaning season. None of those months would justify a different street cleaning program based on the rain pattern.

Table D-1 (of Appendix D) summarizes the changes in average daily street surface loadings due to changes in the cleaning frequency. These ratios are expressed as the new load divided by the old load and are shown for three different base cleaning frequencies (about once every two weeks, once every two months and no street cleaning). The effects of parking controls are also shown for these three base frequencies. Three different street surface texture conditions are also shown with a combination of light, medium and extensive parking. The new street cleaning frequencies vary from no cleaning to cleaning five times a week. Very little change in street loadings due to parking controls is noted for these conditions, except for smooth and moderate textured streets with medium parking. Under this case, a maximum 21 percent improvement may occur for cleaning frequencies of three times per week. For other parking densities or other street

Figure 8. The effects of cleaning frequency and parking controls on street loadings for smooth/moderate textured Ottawa streets having light parking densities.



surface textures, the presence of parking controls has little effect on street cleaning productivity. Medium parking densities are defined as the condition when about 40 to 80 percent of the curb length is occupied by parked cars (about 50 to 100 parked cars per curb-km). Under these parking conditions about 90 percent of the street surface particulates are within 2.5 meters of the curb (the actual street cleaning path) for smooth asphalt streets. For rough asphalt streets, the percentage of material in this cleaning width is reduced to about 75 percent and for very rough streets, only about half of the total street surface particulates are within this sweeping width.

For the conditions shown, a maximum increase in street surface loadings of about 15 percent is noted if the street cleaning program was entirely eliminated. For certain conditions (smooth and moderate textured streets) the street surface particulate loadings can be reduced by as much as 50 percent by changing to very intensive street cleaning programs (about two passes per week appears to be best). With rough textured streets, a maximum improvement seems to be about 33 percent while for very rough textured streets, a maximum improvement appears to be about 10 to 15 percent. Extremely intensive street cleaning programs (several times a week) are not that much more effective than more moderately intensive programs (about once a week). Two passes per week should probably be considered the maximum cleaning effort that should be used under most conditions. More intensive street cleaning programs may be warranted for unusual conditions.

These calculations are all extremely site specific and relate to the specific rainfall patterns of the 1972 rain year. In those areas having different rain patterns (especially other interevent times between significant rains) the results could be substantially different. However, it is very rare when street cleaning programs of more than two or three passes per week can be justified by street cleanliness or water pollution control objectives. Most street cleaning programs are designed based upon the land uses of the service areas. As shown here, a much more reasonable procedure for designing street cleaning programs relates to street textures and parked car conditions.

Figures 9, 10, and 11 (along with Figures D-6 through D-20 of Appendix D) summarize the street cleaning unit productivity for various street texture and parking conditions. These figures show an increase in the total amount of street particulates removed as the cleaning frequency increases. The average removal of street surface particulates per street cleaning pass generally decreases as the cleaning intensity increases, while the removal unit cost (dollars per kilogram removed) generally increases. A low point in unit removal cost occurs at about 20 passes per six months (about once a week cleaning). The unit removal cost does not vary significantly when going from very little cleaning effort to about one pass per week. After this point, however, it steadily rises. The shapes of these curves are similar for different street textures, parking conditions and parking controls, while the absolute differences in values between different programs do vary.

Another computer program was developed to use the Ottawa total solids street cleaning productivity values and the relative contributions of street surface contaminants to the runoff yields, as described in Section 2. As an example, Table 8 shows the percentage of the fecal coliform total runoff yields that originate from street surfaces for the different test catchments. For the Alta Vista area, the street surface bacteria contributions range from 13 to 71 percent, depending upon the specific rain event characteristics (total rain volume). Table D-1 shows how the street surface loading values can be changed by

Figure 9. Total street dirt removal for smooth/moderate textured Ottawa streets having light parking densities.

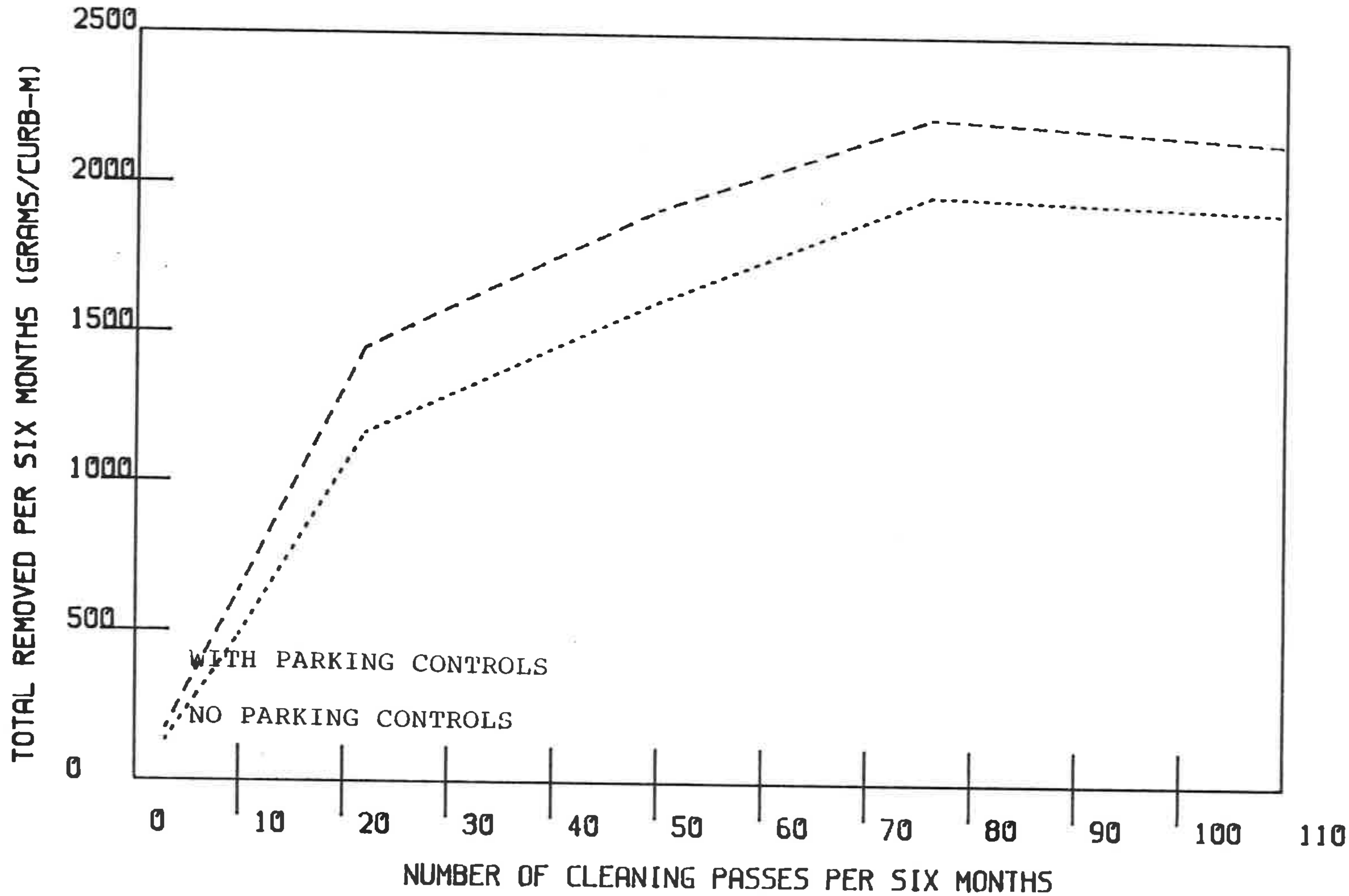


Figure 10. Average street dirt removal per pass for smooth/moderate textured Ottawa streets having light parking densities.

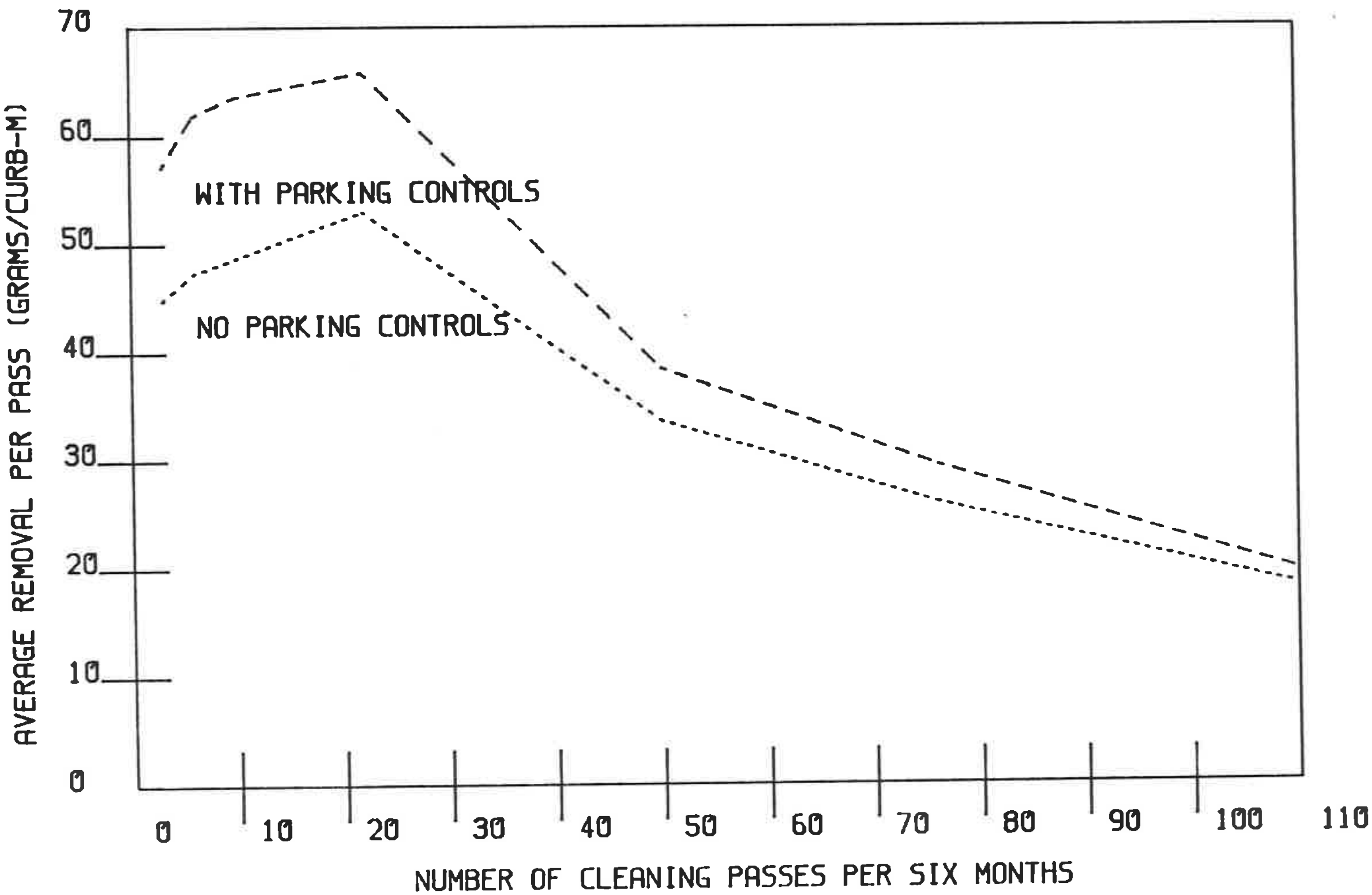
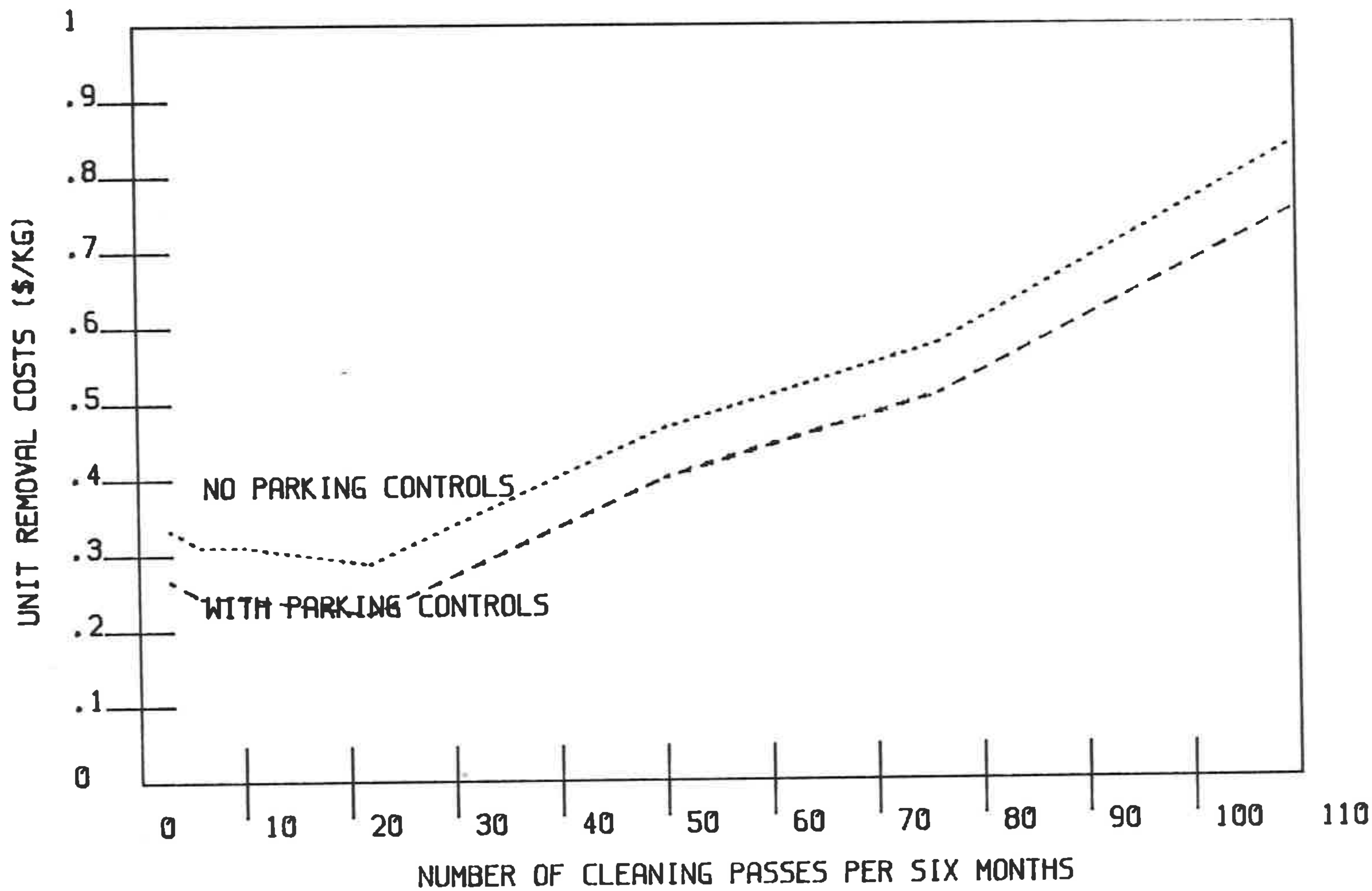


Figure 11. Unit removal costs for smooth/moderate textured Ottawa streets having light parking densities.



different street cleaning programs. The street dirt loading values are roughly proportionate to the street surface bacteria loading values. Therefore, when these two sets of values are multiplied together, the effects of a different cleaning program on the urban runoff pollutant yield can be estimated. If the street dirt (and bacteria) loading value can be reduced by 50 percent, as shown in Table D-1, by a new street cleaning program, the urban runoff bacteria yield would be reduced by less than 50 percent because of other bacteria sources. If the street surface contributes 50 percent of the total basin fecal coliform yield, then this 50 percent reduction in street surface fecal coliform loadings would result in a 25 percent reduction in fecal coliforms in the total runoff yield.

All of these conditions were considered in Table 37 and Figure 12. These two illustrations and Tables D-2 and D-3 and Figures D-21 and D-22 summarize the effects that street cleaning program changes may have on outfall fecal coliform, fecal strep. and lead yields. These tables and figures assume a base cleaning program of one cleaning pass about every two months with no parking controls. The new program also does not consider any parking controls. The Clegg and Leonard residential areas were combined for the analyses along with the Billings Bridge and St. Laurent shopping center areas.

Table 37 shows that a maximum control of about 15 percent is possible for fecal coliforms in the Clegg and Leonard residential areas if the street cleaning program is changed to maximum values. Fecal strep. and lead changes in runoff yield are more sensitive to street cleaning program changes, and a maximum control of about 20 to 24 percent at the outfall may be obtained for these pollutants.

These figures consider the complete rain history for the six month time period. Figure 12 shows how fecal coliform control made possible by street cleaning is highly dependent on the specific rain characteristics and, therefore, the combinations of the different rains during the study period. Almost 35 percent of the individual rain runoff yield can be controlled by intensive street cleaning programs (greater than three passes per week) for very small but frequent rains. However, changes in street cleaning activities have little effect on fecal coliform runoff yields for large rains (greater than 40 mm rain). These large rains, however, are quite rare in the Ottawa area. Fecal strep. outfall yields for these large rains may be controlled as much as 10 percent by increasing the street cleaning activities. Maximum reductions of lead outfall concentrations may be close to 20 percent for these large rains and for intensive street cleaning efforts.

Street cleaning may have a limited but possibly important effect on the control of bacteria in Ottawa urban runoff, based on limited local studies and street cleaning productivity relationships measured at other locations. Maximum urban runoff bacteria control of 20 percent may be possible for intensive street cleaning programs and favorable street surface and parking conditions. More reasonable maximum controls that may be expected from increased street cleaning efforts might be closer to 10 percent. When the discharges from individual storms are considered, changes in street cleaning may affect the indicator bacteria yields for small storms by as much as 35 percent. This may be important in reducing the number of violations at the swimming beaches if the small storms currently contribute to the bacteria degradation in the river. Section 11 summarizes the effectiveness of other urban runoff bacteria control options, based upon a limited literature review.

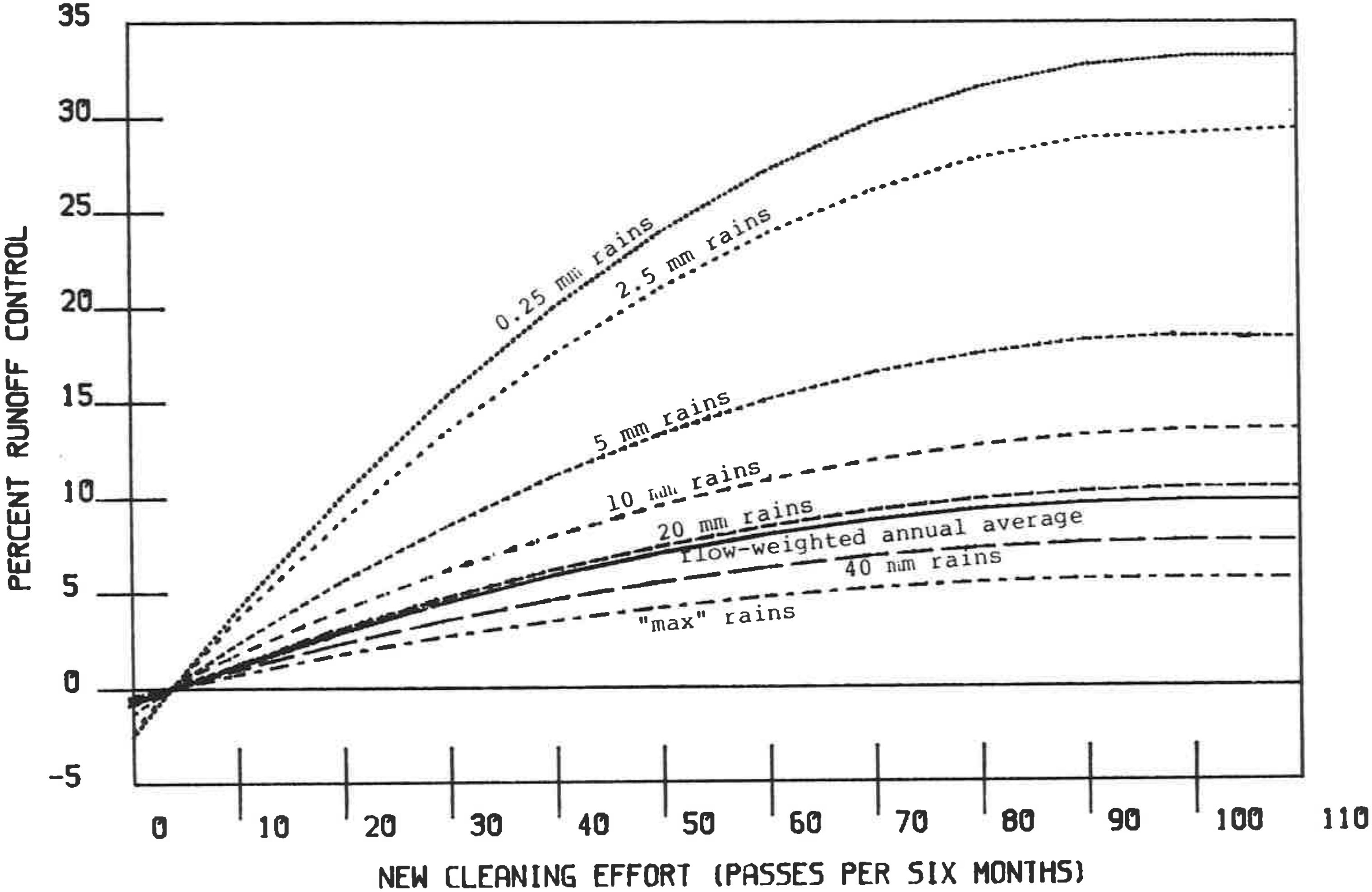
Table 37. Effects of Street Cleaning on Fecal Coliform Annual Discharges (percent removal)*

Study Areas	Street Texture	Parking Conditions	New Cleaning Effort (# passes per 6 months) 110	76	50	22	10	6	3	0
Alta Vista	smooth and mod.	light	10	9	7	4	1	0	0	-1
	smooth and mod.	medium	9	7	5	3	1	0	0	-1
	smooth and mod.	extensive	9	7	5	3	1	1	0	-1
	rough	light	7	6	5	4	1	1	0	-1
	rough	medium	6	5	4	2	1	0	0	-1
	very rough	light	3	2	1	1	0	0	0	0
Clegg and Leonard	smooth and mod.	light	16	14	11	7	2	1	0	-2
	smooth and mod.	medium	14	10	7	4	2	1	0	-1
	smooth and mod.	extensive	14	11	8	5	2	1	0	-1
	rough	light	11	10	8	6	2	1	0	-2
	rough	medium	10	8	6	3	1	1	0	-1
	very rough	light	4	3	2	1	0	0	0	0
Merivale	smooth and mod.	light	5	4	3	2	1	0	0	-1
	smooth and mod.	medium	4	3	2	1	0	0	0	0
	smooth and mod.	extensive	4	3	2	1	0	0	0	0
	rough	light	3	3	2	2	1	0	0	0
	rough	medium	3	2	2	1	0	0	0	0
	very rough	light	1	1	1	0	0	0	0	0
Billings Bridge and St. Laurent	smooth and mod.	light	10	9	7	4	1	0	0	-1
	smooth and mod.	medium	9	6	5	3	1	0	0	-1
	smooth and mod.	extensive	9	7	5	3	1	1	0	-1
	rough	light	7	6	5	4	1	1	0	-1
	rough	medium	6	5	4	2	1	0	0	-1
	very rough	light	3	2	1	1	0	0	0	0

* The base program is 3 passes/6 months with no parking controls. The new program also does not have parking controls.

Some recommendations to optimize the current street cleaning program are evident. If the most intensive downtown street cleaning programs are reduced to about two passes per week, a substantial savings could be realized. These savings, however, could be put to good use by slightly increasing the cleaning frequency in the other areas of the watershed. Of course, those people who are currently receiving extensive street cleaning services will not be pleased when learning that their services are being reduced. This would require a public education program, especially for the downtown merchants and office people. The current extensive litter pickups and litter basket programs may be sufficient to keep the litter at acceptable levels, even with reduced street cleaning. However, it may be necessary to slightly increase these manual efforts to compensate for any reduced mechanical street cleaning.

Figure 12. Fecal coliform bacteria runoff control by street cleaning.*



* This example is for the Alta Vista test catchment, which has smooth/moderate textured streets and light parking. The base cleaning effort is three passes per six months with no parking controls. The new program also does not have parking controls.

11.0 OTHER URBAN RUNOFF BACTERIA CONTROL OPTIONS

Several urban runoff treatment studies have been conducted in the Ottawa area, as described by Ayers (1972), Hauck (1976), Gietz (1981), and the Regional Municipality of Ottawa - Carleton (1981). These studies have involved cross-connection eliminations, disinfection of creek waters, and impounding urban runoff in detention structures. The information presented in this section is based on many studies (as referenced) and is an attempt to summarize the performance of alternative urban runoff treatment systems for comparison with street cleaning controls.

11.1 SELECTION OF CONTROL MEASURES

The most effective urban runoff control measures are probably those that can reduce the loadings or concentrations of the problem constituents at convenient source areas (or concentration areas) in the urban watershed. As an example, street cleaning can only be applied to those impervious areas that street cleaning equipment has access to (specifically streets and parking lots and possibly driveways and sidewalks). Catchbasin and storm sewerage cleaning only affects the material that can accumulate in them (mostly from adjacent street surfaces and erosion material from constructions sites). Although treatment of the urban runoff at the outfall is capable of affecting pollutants originating from all of the urban runoff sources, in most cases a much greater amount of the material must be removed at the source area to affect the same amount of material at the outfall. This is due to transport and accumulation of urban runoff pollutants in locations that are not readily affected by rainfall (such as uptake by plants and soils). In past studies, it has been found that about ten pounds of street surface particulates must be removed to control one pound of the particulates at the outfall. This is also shown in the calculations presented in Section 10, where the intensive street cleaning programs remove much more bacteria from the streets than are actually removed from the resultant runoff water. The additional particulate removals from street surfaces result in reduced fugitive dust losses to the air. Fugitive dust losses can be significant and intensive street cleaning programs also have the added benefit of reducing particulate air pollution.

Another problem with most of the control measures considered for use in urban areas is that each one is only suitable for a few of the urban runoff pollutants. In addition, the total magnitude of control available (total pollutant mass or yield that can be "removed") by any one control method may not be sufficient to satisfy the runoff treatment goals. Therefore, even if a potential problem is confined to a single pollutant (such as fecal coliform bacteria in Ottawa), a combination of control measures will probably be needed.

Unit cost effectiveness (dollars required to control a unit of the pollutant at the outfall) must be calculated for the alternative control measures and for their different degrees of utilization. The total control possible for each level of utilization of the control measures must also be known. When this data is available, it may be a matter of simply selecting those control measures having the lowest unit costs. Again, if a single control measure and utilization level (such as street cleaning twice a week or dog feces litter control) is not adequate to meet the total discharge reduction goals, more expensive control measures may be necessary. This type of procedure ensures the maximum utilization of the least-cost controls. However, if there are other objectives besides urban runoff control that must be considered (such as public relations, safety, or air pollution), or there is the need to control more than one pollutant, a much more sophisticated decision analysis procedure, such as described by Pitt (1979) would be needed.

Gore and Storrie/Proctor and Redfern (1981c) summarized the need for urban runoff bacteria control in Ottawa by stating that the urban community has a significant negative impact on river water quality and stormwater management measures should be employed to minimize this impact on local river quality. In summarizing the sources of bacteria contamination, they stated that stormwater loads along the river are acting as uniformly distributed loads instead of point sources. Therefore, effective control measures must be implemented on an area-wide scale rather than in just a few catchments. Qureshi and Dutka (1979) also found that urban stormwater runoff was a major factor in nonpoint source pollution of receiving waters in southern Ontario. They said that it would be illogical to disinfect specific portions of the runoff as pathogenic organisms are likely to occur throughout the runoff event; control measures for urban runoff bacteria need to be applied over large areas for complete runoff events.

Olivieri, Kruse, and Kawata (1977b) concluded that there is little justification, based upon benefit-risk considerations, for large scale disinfection programs of urban storm runoff in Baltimore, Maryland. They felt it was more important to decrease the sources of bacteria through control of the amount of combined sewer overflows by increasing the carrying capacities of sanitary sewers. However, Ottawa has already completed the separation and upgrading of most of their sanitary sewage system thereby eliminating almost all overflows into the Rideau River.

Another factor that confuses the issue concerning the need for stormwater runoff control is the great variability in stormwater quality from location to location. Field and Struzeski (1972) stated that stormwater quality variability has made it difficult to adapt existing wastewater treatment technology for the treatment of urban runoff, especially for biolgical treatment systems. Geldreich, et al, in 1968 listed the most effective urban runoff bacteria control measures for Cincinnati; prohibit cats and dogs on public beaches and adequate garbage collection programs to discourage rodent populations. They also stated that storm drainages should be directed away from beaches and reservoirs, or at least be allowed some minimal mixing before these wastewaters enter public use areas. If stormwater cannot be diverted from the receiving water of interest, Geldreich stated that treatment methods able to handle the large volumes of stormwater may be necessary.

11.2 DOG CONTROL

Appendix B quantifies the sources of feces affecting urban runoff. A very important source of urban runoff bacteria is domestic pets, especially dogs. Schillinger and Stuart (1978) recommended that domestic animals should be fenced away from stream banks and that dog kennels should not be installed along the banks of receiving waters. Marron and Senn (1974) described their experience in enforcing dog leash and dog feces littering laws. They stated that explaining the provisions of the city code to offending pet owners in a formal manner has been quite successful and that followup field visits were necessary in less than 20 percent of the complaint cases.

Ottawa, Nepean, and Gloucester all have dog control laws regulating the deposition of dog feces. Ottawa, in its bylaw number 196-81 (passed June 17, 1981), requires that dog feces be removed immediately when deposited on city streets, public parks, other public property, and private property (except that of the dog's owner or custodian). Ottawa also prohibits dogs running at large.

Nepean passed bylaw number 32-79 on March 27, 1979, which prohibits dog feces on streets, unless immediately removed. This bylaw does not prohibit dogs defecating on other property, including private property.

Gloucester's bylaw number 108 of 1980 prohibits dogs running at large and dog feces deposited on streets or bridges, town property, or public property (except with authority from the property owner or occupant). Any dog feces deposited on these areas must be immediately removed.

If these regulations were enforced, and the Nepean bylaw prohibited dog feces deposition on private property, much of the urban runoff fecal coliform discharges would be eliminated. Dog owners should also be encouraged to properly dispose of dog feces deposited on their property. Proper disposal would include placing the feces in a garbage can (properly wrapped) for garbage collection or composting in specially designed sub-surface units that are commercially available. People walking their dogs should be required to carry devices to pick up and carry dog feces.

11.3 BIRD CONTROL

Appendix B summarizes the Rideau River Stormwater Management Study investigations of the potential direct bacteria effects from birds on the Rideau River. The results were somewhat conflicting, but do point out that direct bird feces contamination may be an important source of bacteria in the Rideau River. Several methods to discourage birds from roosting on the structures over water (specifically road bridges) have been tried. During this study, netting was suspended under the bridges to seal off convenient roosting locations and any remaining birds were trapped and moved elsewhere in the area. This procedure seemed to be quite effective, but it did require periodic maintenance to repair holes in the netting and to remove trapped birds. The number of captured birds did decrease with time. Unfortunately, the misplaced birds spent a considerable period of time in the adjacent residential areas before giving up on their bridge roosting area. The problem of the misplaced birds roosting in nearby residential areas may occur for all nonlethal bird control methods, except for trapping and transporting to distant locations.

Fennell, James, and Morris (1974) studied the effects of birds on a reservoir. A part of their study involved removing the roosting gulls. They selected bird scaring fireworks, which were set off around the edges of the reservoir when the gulls were returning from their feeding area. The fireworks were used every evening for three weeks with a dramatic effect on the bird population. There was an immediate drop in their numbers and in the concentrations of Salmonella and E. coli in the water; these organisms were common before the birds were diverted. When the fireworks were stopped, the gulls reappeared and higher bacteria counts were noted. They had to resume the use of the fireworks until the birds had departed to breeding sites away from the reservoir.

Another alternative for controlling birds on bridges or other architectural structures is to use strips of pointed metal spikes that are mounted directly on the structure. One such device is marketed by Nixalite (1981). This material, which would cost about $5 per foot, reportedly does not detract esthetically from the structure. However, installation, especially on the underside of a bridge, could be time consuming and costly. These needle strips have a reported service life of many years and would probably be less expensive in the long run and more pleasing to the eye than bird netting.

11.4 CROSS-CONNECTION AND COMBINED SEWER OVERFLOW CONTROL

The Regional Municipality of Ottawa - Carleton (1981) reported that more than 40,000 homes had been dye tested since 1971 in the search for cross-connections. Many cross-connections of sanitary sewage into the storm drainage system were found and corrected. A preliminary method for finding cross-connections, without the use of dyes was also used: continuous sampling and plotting of bacteria concentrations in a storm sewer for a 24-hour period of time. If this 24-hour plot of dry weather bacteria concentrations in the dry weather urban runoff flows showed small increases following meal times, then they were quite certain of finding cross-connections, and dye testing was used. Environment Canada (1980) stated that there are currently few known cross-connections affecting the Rideau River. These result in occasional overflows from the sanitary systems and the exfiltration of sanitary sewage during low river flows from collector sewers. Additional investigations and abatement of these cross-connections is planned.

Schillinger and Stuart (1978) recommended that bacteria testing or flourescent dye tracer studies be made wherever a sanitary sewage line passes beneath a water body to ensure no leakage.

11.5 URBAN RUNOFF TREATMENT PROCESSES

Many physical processes have been studied for stormwater and combined sewer overflow treatment. These studies have included facilities ranging in size from small pilot plants to large, full scale treatment facilities. Table 38 summarizes the unit processes that have been tested to control bacteria concentrations in stormwater or combined storm overflows. Much of this data was developed for treating combined sewer overflows, but because of the highly variable flows and chemical and bacteria characteristics common to both stormwater and combined sewer overflows, similar results should be obtainable when treating stormwater only (Field and Struzeski, 1972, Field and Tafuri, 1973 and 1976). Several of these studies did investigate unit processes with stormwater only. These processes included: sedimentation (usually just detention facilities in the form of small urban ponds or lakes); primary treatment that used sedimentation with chemical additions to aid settling; and primary treatment that included sedimen-

Table 38. Urban Runoff Treatment Unit Processes

Process and Description (stormwater and combined sewer overflow treatment)

Sedimentation

location	detention time	removal - notes	ref.
The Woodlands, TX	12 hours	Total coliform, fecal coliform and fecal strep. remained in suspension	2
Toronto, Ontario	9 to 50 hours	No bacteria reduction noted	5
New Jersey	32 hours	Greater than 90% reduction	7
Tucson, AR	3 days	Effluent total coliform concentration reduced to 70 to 3200 org./100 mL.	6
Texas	long (small lake)	Appreciable reductions for most storms, except for total colif.	1

Primary Treatment (sedimentation with chemical addition to aid setting)

location	chemical addition	removal - notes	ref
Tucson, AR	polyelectrolytes only	Very little improvement	6
Tucson, AR	alum (3 to 10 grains/gal.)	90% reduction ("economical and convenient", but variable alum need	6

Primary Treatment (sedimentation with disinfection)

location	chemical addition	removal - notes	ref.
Toronto, Ontario	NaOCl (5 mg/L avail. chlorine)	Effluent fecal coliform to less than 10 org/100 mL (no regrowth, but chlorine demand varied widely)	5

Disinfection

location	chemical addition	removal - notes	ref.
Texas	chlorine (8 mg/L)	Adequate reduction (fecal coliform effluent conc. 10 org/100 mL)	2
Texas	ozone (32 mg/L)	Adequate reduction (fecal coliform effluent conc. 10 org/100 mL)	2
Toronto, Ontario	chlorine (residual of 1 mg/L to 5 mg/L) and 30 min. contact time	Total coliforms reduced to <100 org/100 mL and fecal coliforms reduced to <10 org/100 mL	5

High Rate Disinfection

location	chemical addition	removal - notes	ref.
Texas	chlorine (5 mg/L)	Coliforms reduced by 99.99%, fecal coliform effluent to <10 org/100 mL	2
----	chlorine (10 mg/L) for 120 sec.	99.99% reduction for total and fecal coliforms (irrespective of pretreatment)	4
Rochester, NY	ClO_2 (18 mg/L) for 7 min.	99.99% reduction	3
	Cl (12 mg/L) for 11 min.	99.99% reduction	3

References:
1 Casserly and Davis, 1979
2 Davis, 1979
3 Drehwing, 1979
4 Field and Tafuri, 1973
5 Ontario Ministry of the Environment, 1982
6 Resnick and DeCook, 1980
7 Whipple and Hunter, 1981

tation with separate disinfection processes, different types of chemicals, and contact times.

Sedimentation in urban lakes or ponds can result in important bacteria reductions. Davis (1979) stated that the settling of stormwater suspended solids is closely associated with bacteria reductions in the water. Very large bacteria kills (on the order of 99 percent reductions) are not possible without separate disinfection processes (Field and Tafuri, 1973). Bacteria reductions greater than 90 percent by sedimentation alone has been noted for special cases (Whipple and Hunter, 1981).

Primary treatment (controlled sedimentation with chemical additions to improve settling) may also result in about 90 percent reductions of urban runoff bacteria levels. Resnick and DeCook (1980) found that addition of alum was both economical and convenient.

When primary treatment was used in conjunction with disinfection, effluent fecal coliform concentrations were typically less than ten organisms/100 mL (Ontario Ministry of the Environment, 1982). Chemical flocculation before disinfection was not essential. No bacteria regrowth was noted for up to two days after disinfection but the chlorine demand varied widely.

Field and Struzeski (1972) stated that disinfection of stormwater in combined sewer overflows is difficult because of the highly varying characteristics of the stormwater component. The design and operation of a disinfection facility must be capable of responding to rapid quality changes. Varying temperatures of stormwater causes changes in disinfection efficiency. As an example, the contact time to obtain a 99 percent kill was five times longer at 5°C. as compared to 30°C. In addition, the disinfectant demand (a combination of influent physical, chemical, and bacteria conditions) also varies. Most stormwater disinfectant operations use more disinfectant than would be necessary if disinfectant demands could be more closely monitored.

Davis (1979) reported that chlorine and chlorine dioxide are the most effective disinfectants for stormwater and in many cases were found to be the least expensive options. Chlorine dosages necessary to disinfect stormwater may be as high as eight mg/L, while necessary ozone dosages may be greater than 30 mg/L. When high suspended solids are present in stormwater, greater concentrations of disinfectant are necessary. They noted some regrowth of total coliform bacteria after disinfection, but found that fecal coliform, fecal strep., and some pathogenic bacteria concentrations remained at low levels (less than ten organisms/100 mL) for up to eight days after disinfection.

Bench-scale disinfection studies were carried out in Toronto (Ontario Ministry of the Environment, 1982). As in other studies, they found that chlorine demand varied with the stormwater characteristics and with the degree of treatment prior to disinfection. A dosage of sodium hypochloride (NaOCl) of five mg/L total available chlorine, reduced the total and fecal coliform concentrations to less than 100 organisms/100 mL and to less than ten organisms/100 mL, respectively. They also did not find any regrowth of the indicator bacteria within two days after disinfection. Field and Struzeski (1972) noted that the Sewerage and Waterboard of New Orleans participated in a demonstration project using sodium hypochloride for the disinfection of storm flows as high as 300 cubic meters/second.

High rate disinfection (relatively high dosages of disinfectant in very turbulent contact chambers for short contact periods) has been shown by Drehwing (1979) to be more cost effective than conventional disinfection. The use of high rate chambers can significantly reduce the capital equipment costs because of the reduced contact time. The high bacteria kill rates in these devices are attributed to the very high turbulence during the contact time. Field and Tafuri (1973) stated that it may be possible to achieve a suitable bacteria kill with high chlorine dosages within certain types of solids removal devices so that no separate contact chambers would be required. They reported a 99.99 percent bacteria kill rate in stormwater with chlorine dosages of ten mg/L and two-minute contact times. The flow rates in this test chamber were about 75 liters per minute. The three-minute chlorine demand during these tests was quite uniform and was slightly more than three mg/L in the raw stormwater.

Drehwing (1979), in their studies of high rate disinfection at Syracuse, New York, found that chlorine dioxide was the preferred disinfectant in stormwater when compared to free chlorine, because chlorine dioxide was less reactive with the organic materials present in the stormwater. With chlorine dioxide, rapid bacteria kills were obtained within the first 30 seconds of contact; but little kill was attained with additional exposure. They concluded that a two-stage disinfection process using initial dosages of free chlorine followed by chlorine dioxide after an initial contact time of 15 to 30 seconds resulted in the largest bacteria kills. In all cases, the mixing was shown to be very important in all disinfection tests. They concluded that high rate disinfection appeared to be more cost effective than conventional disinfection for the treatment of combined sewer overflows. High rate disinfection facilities have high operating costs but low capital costs. Because treatment facilities that treat combined sewer overflows or stormwater would remain idle for much of the year, operating costs would be much smaller than for a similar plant that would treat sanitary sewage.

11.6 POROUS PAVEMENT

Porous pavement is a class of material that can be used to support the weight of vehicles and still allow water infiltration to reduce or eliminate runoff. Porous pavement can take the form of special porous asphalt pavement mixtures placed over a drainage base, or may simply be perforated concrete blocks set on sand (possibly with grass growing through the holes in the concrete). The asphalt forms of porous pavement have been used with some success on parking lots, while concrete blocks are more suitable for seldom-used access roads (such as garbage truck routes across lawn areas). Porous asphalt pavements have not been successful for applications where heavy traffic occurs. Open asphalt mixtures may also be unsatisfactory in areas of substantial freezing weather. Any successful form of porous pavement can reduce the number of overflows in a combined sewer system, or reduce the amount of runoff originating from the parking lot areas to the storm drainage system. There are no published results concerning the effectiveness of porous pavements in controlling urban runoff pollution, but their use would remove water from the surface runoff regime and reduce the introduction of source area pollutants into the receiving waters (Diniz, 1980).

The clogging of porous pavement surfaces by street dirt would reduce the effectiveness of the porous pavement. Various procedures (possibly vacuum cleaning and flushing) may restore the permeability of the pavement.

Other runoff reducing procedures should also be considered for areas of new construction. These may include more extensive use of landscaping, less surface paving, the use of roof and parking lot ponding with subsequent discharges to pervious areas, and the use of specially constructed catchbasins or gutter systems that are perforated to allow infiltration. As shown in Section 2, pollutant transport is severely restricted when the runoff is allowed to infiltrate.

11.7 CATCHBASIN SUMP CLEANING

Toxopeus, et al (1978) found that in the Ottawa area, catchbasin sump material accumulated during one storm but was flushed out partially or completely by following storms. Therefore, in order to control runoff pollutants by catchbasin cleaning, very frequent cleaning to remove water and sediments would be necessary. Section 8 shows that the amount of bacteria associated with catchbasin sump waters and sediments is about ten percent of the total annual urban runoff bacteria yields. Therefore, even if all of the sump material in Ottawa was eliminated after each storm, the urban runoff bacteria yields would only be reduced by about ten percent. This conclusion is highly dependent on site specific rain patterns.

Catchbasin cleaning was found to be very effective in controlling many urban runoff pollutants in Castro Valley, California (Pitt and Shawley, 1982). In Castro Valley, long periods of dry weather in the summer (up to three months) allow sufficient time to clean the catchbasins before the major storms of the following fall and winter. The amount of pollutants in the catchbasins at any one time was a significant fraction of the annual runoff yield. Much of the material in the catchbasins would be semi-permanent, and would only be flushed out during infrequent, very large storms. These large storms occur about once every year or two. Under these situations, cleaning catchbasins about every two or three months could have a noticeable and cost effective effect on urban stormwater pollutant discharges.

11.8 LITTER CONTROL

Litter control may not have a direct effect on urban runoff bacteria yields. Litter control, in the downtown area especially, would lessen the problems associated with reducing the street cleaning operations as recommended in Section 10. Litter control would also reduce rodent populations and their feces bacteria contributions.

11.9 SUMMARY

Table 39 lists various control measures and gives their relative costs and estimated control effectiveness for controlling fecal coliforms in urban runoff. Litter control and catchbasin cleaning are expected to have potentially low control effectiveness (probably resulting in less than a ten percent reduction in bacteria discharges). Bridge bird control may reduce fecal coliform

Table 39. Summary of Urban Bacteria Control Measures

Control Measure	Control Effectiveness* (for fecal coliforms)	Control Cost (relative, or $/yr)
Litter control	low	low/moderate
Bridge bird control	moderate (to 50%)	low/moderate
Catchbasin cleaning	low (<10%)	moderate/high ($10,000 to $100,000/yr)
Street cleaning	low/moderate (to 20%)	very high ($100,000 to $3,000,000/yr)
Dog feces control	moderate (to 35%)	very low
Cross connection elimination	high (if exist)	moderate/high
Runoff treatment	can be very high (to >75%)	can be very high (>$500,000/yr)

* Values shown are for fecal coliform bacteria reductions in the Rideau River. Urban runoff bacteria reductions could be much greater.

concentrations in the River by as much as 50 percent. Street cleaning may have a low to moderate effect by reducing fecal coliform discharges up to 20 percent. The control of dog feces could have a large effect in reducing fecal coliform concentrations in urban runoff, and help to reduce fecal coliform concentrations in the River by about 35 percent. The elimination of any existing cross-connections would be very important and highly effective. Runoff treatment can result in the highest levels of bacteria reductions in the runoff.

One control measure not listed in this table is dredging bacteria-polluted sediments from the Rideau River. It is not known how extensive the polluted sediments are, or how much they affect the water column bacteria concentrations. Many studies have shown the importance of sediment/water bacteria interactions; the presence of polluted sediments in the river would tend to mask, or at least slow down, any noticeable improvements associated with urban runoff control. This would be especially important for an urban runoff treatment control measure that would be very effective at the outfall. Many years may be required before the polluted sediments are naturally scoured from the channel or the bacteria dies off in situ.

The costs of these control measures vary widely. Dog feces control, bridge bird control, and litter control all have low to moderate expected costs. Dog feces control costs could be very small, as this could simply entail a public education campaign and enforcement of required policies. Catchbasin cleaning could be moderately expensive, ranging from about $10,000 to $100,000 per year, while effective street cleaning could be very high, ranging from about $100,000 to several million dollars per year. The costs of runoff treatment could have a very wide range, depending upon the availability of land for treatment facilities, and could range from more than $500,000 per year to many millions of dollars per year.

Because of its low cost and potentially moderate to high effectiveness, it is recommended that a dog feces control program be seriously considered. In addition, the continued investigation of cross-connections and the elimination of the few existing combined sewer overflows should be considered. Further studies investigating the role of polluted sediments in the river and how they interact with the water column should be carried out before more costly treatment measures are considered. Runoff treatment may be the only possible control measure if very significant bacteria reductions are necessary (more than 75 percent reductions).

As mentioned in Section 10, it is recommended that the current street cleaning programs be optimized by reducing the intensive street cleaning effort in the downtown areas and slightly increasing the cleaning frequency in the dirtier residential areas. The owners of private parking lots (especially at large shopping centers) should also be required to clean their parking lots at least once per week. These changes in the street cleaning programs would probably have a very small effect on the urban runoff bacteria conditions, but much more expensive intensive street cleaning programs throughout the basin may not result in satisfactory bacteria reductions. However, these changes would result in a more efficient street cleaning effort and may result in somewhat fewer bacteria violations per year, especially for the smaller storms.

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PART III
APPENDICES

APPENDIX A
OTHER URBAN RUNOFF BACTERIA DATA

There have been many studies in the United States and Canada that examined the bacteria quality of urban runoff. Many of these studies also examined significant factors affecting the bacteria concentrations. This appendix will summarize some of these data.

Lager, et al (1977) summarized the results of a study conducted in Tulsa, Oklahoma, which looked at the precipitation and land use factors that affected pollutant concentrations in urban stormwater. The only two factors that had a significant effect on fecal coliform concentrations were the interevent period and the intensity of the rain event. The amount of rain and the street density also affected the total coliform concentrations. Seidler (1979) in a semi-rural watershed in Oregon also found that bacteria concentrations during storm events were more related to the length of the dry period before the storm than the season of the year or the actual amount of precipitation. Qureshi and Dutka (1979) found little relationship between intensity and the amount of rain versus the presence of indicator and pathogenic microorganisms in southern Ontario stormwater runoff. Olivieri, Kruse, and Kawata (1977a) found that the density of fecal coliforms in Baltimore, Maryland, urban runoff appeared to be independent of the instantaneous flows and the length of time since the last rainfall. Gupta, et al (1981) also found that flow did not have a significant effect on the instantaneous bacteria concentrations.

In contrast to these studies, another series of studies found some relationships between bacteria densities and the urban runoff flows. The concentrations of bacteria were normally high during periods of high flows and lower during other times in these studies (Evans and Owens, 1972; Casserly and Davis, 1979; Pontius, 1977; Davis, 1979; and Siedler, 1979). The concentrations of bacteria in urban stormwater have been found to vary during storms, sometimes as a function of various observed factors and sometimes independent of observed factors. The important factors varied from site to site. Most of these studies consisted of relatively few completely monitored storms but many samples were usually included within the few storms monitored. The variable nature of bacteria deposition, accumulation, transport, and die-off makes it very difficult to identify consistent influencing factors.

The most reasonable approach in characterizing urban runoff bacteria conditions is to study as many storms as possible in the watersheds of concern. Statistical analyses can then be used to help identify probable concentrations and yields. As noted earlier, the concentrations of bacteria in Ottawa urban stormwater did not appear to follow a specific pattern. However, the bacteria yields were dependent on total storm runoff volume.

The current Nationwide Urban Runoff Program (NURP) projects being conducted at many locations in the United States are obtaining urban runoff bacteria conditions for a variety of test sites. Table A-1 describes the characteristics of 70 test catchments in the NURP program that are currently monitoring urban runoff bacteria quality. These test catchments range in size from less than one acre to more than 10,000 acres. Most of these catchments are of residential land uses but almost all land uses in urban areas are included (commercial, industrial, open space, etc.). Table A-2 summarizes the total coliform, fecal coliform, and fecal strep. bacteria concentrations available for these catchments, as of October, 1981. Also included on this table are total lead and total solids concentrations. More than 1,600 fecal coliform urban runoff observations had been made by the NURP projects by this time, with an overall observed range of ten to 270,000 organisms/100 mL. The average of the site means was about 20,000 fecal coliform organisms/100 mL.

Table A-3 summarizes various bacteria ratios to help determine possible urban area source contributions. Several of the test sites had fecal coliform to fecal strep. ratios greater than four, indicating potential sanitary sewage influences. These data only represent part of the total NURP bacteria data base. These data are only for small urban catchments that were known to be free from gross sanitary sewage influences. Many other NURP sites are also monitoring bacteria, but they involve sampling locations situated on receiving waters that are also receiving sanitary wastewater effluent and agricultural drainages. These data were for samples collected from 1978 to 1981, with most of the data from samples collected in 1980. Almost 220 NURP monitoring stations had reported information to the STORET computer files by October, 1981, and almost one-half million analyses had been made.

Table A-4 summarizes the results from about 25 other reported studies that monitored coliform bacteria in urban runoff. These represent many stations throughout the United States with some locations in Canada and Europe.

The overall NURP reported average fecal coliform concentration was about 2.2 x 10^4 organisms/100 mL. The average from the other studies was about 3 x 10^4 fecal coliform organism/100 mL. The estimated Ottawa average fecal coliform urban runoff concentration is about 1 x 10^4 organisms/100 mL. These average concentration values are all surprisingly close. However, the overall observed range is quite high, ranging from not detecting any fecal coliforms to as high as 10 x 10^7 organisms/100 mL.

As a comparison, Table A-5 presents some typical combined sewer overflow bacteria concentrations, as reported in the literature. The fecal coliform concentrations in combined sewer overflows are seen to range from about 2 x 10^4 to a high of about 2 x 10^7 fecal coliform organisms/100 mL. The separate stormwater fecal coliform bacteria observations are at the low end of this reported range. Typical combined sewers can therefore have 100 to 1,000 times the fecal coliform concentrations as separate stormwater. A study by Burm and Vaughan (1966) in Detroit and Ann Arbor, Michigan, found that the total coliform densities in the combined sewers were always about three to 15 times greater than those found in urban runoff. The fecal coliform densities in the combined sewers were about 90 times the stormwater values. They found that the fecal coliform to fecal strep. ratios in the combined sewers was always greater than three, while this ratio was equal to or less than one in the stormwater. They concluded that the bacteria densities for the combined sewer overflows were at least ten times greater than those reported for the stormwaters alone. This stresses the importance of finding and correcting any cross-connections and eliminating the known combined sewer overflows discharging into the river.

Table A-1. NURP Urban Catchment Land Use Data*

NURP City, State	Monitoring Site	Area (acres)	Pop. Den. (people/ acre)	Major Land Use
Durham, NH	Shop/Save parking lot	0.9	0	commercial parking lot
Lake Quinsigamond, MA	Jordan Pond	110	9.5	resid.
	Rt. 9	340	6.8	resid./commer.
	Locust St.	150	11.0	resid.
	Fitz. Brook at Anne St.	600	9.1	resid./park-open
	Coal Mine Bk. at Convent	100	1.0	commer./open-park
	Tilly Brook	1,700	1.7	open-park/resid.
Long Island, NY	Huntington	39	0	parking lot
	Laurel Hollow	100	1.2	resid.
	N. of Belmont L.	NA**	NA	NA
	N. of Belmont L.	NA	NA	NA
	Massapequa Pond influent	300	32.0	resid.
	Massapequa Pond effluent	300	32.0	resid.
Irondequoit Bay, NY	East Rochester	380	18.0	resid.
	Southgate	180	1.5	shopping center

Table A-1 (cont.). NURP Urban Catchment Land Use Data

City, State	Monitoring Site	Area	Pop. Den.	Land Use
	Cranston Rd.	170	5.4	resid.
	Baird	18,000	1.4	resid.
Wash., D.C.	Stedwick	NA	NA	NA
	Stedwick	NA	NA	NA
	Stedwick	NA	NA	NA
	Lakeridge	NA	NA	NA
	Lakeridge	NA	NA	NA
	Stratton Woods	NA	NA	NA
	Westleigh Rt. 28	41	NA	resid.
	Fairidge	19	NA	resid.
Winston-Salem, NC	into Tar Branch	23	0	CBD
	into Burke Branch	320	5.7	resid.
Knoxville, TN	Clinton Plaza	NA	NA	strip commer.
	Union Ave.	NA	NA	CBD
Milwaukee, WI	Wood Center	45	12	strip commer./resid.
	N. Hastings	32	17	resid.
	North Burbank	63	15	resid.
	State Fair	29	10	strip commer./resid.
	Rustler	12	0	shop. ctr./park. lot
	Post Office	12	0	shop. ctr./park. lot
Austin, TX	NW Austin into Woodhollow Dam	380	9.3	resid.

Table A-1 (cont.). NURP Urban Catchment Land Use Data

City, State	Monitoring Site	Area	Pop. Den.	Land Use
	from Woodhollow Dam	380	9.3	resid.
	Rollingwood	60	3.3	resid.
Denver, CO	Big Dry Trib.	33	19	resid.
	Asbury Park (inflow to HIG)	120	9.2	resid./commer.
	Asbury Park (outflow from HIG)	130	9.3	resid./commer.
	North Ave. (inflow to HIG)	69	9.2	open/resid./commer.
	North Ave. (outflow from HIG)	80	7.9	open/resid./commer.
	Cherry Knolls	57	24	resid.
	116th & Claude	170	14	resid.
	Villa Italia	74	0	commer.
Salt Lake City, UT	No. Temple	NA	NA	NA
	8th So.	NA	NA	NA
	1300 So.	NA	NA	NA
	1300 So.	NA	NA	NA
	South	NA	NA	NA
	90th So.	NA	NA	NA
Rapid City, SD	Meade St.	2,000	NA	resid./open
Bellevue, WA	Lake Hills	100	12	resid./instit.
	Surrey Downs	95	8.6	resid.
	148th Ave.	about 1	NA	resid. street

Table A-1 (cont.). NURP Urban Catchment Land Use Data

City, State	Monitoring Site	Area	Pop. Den.	Land Use
Eugene, OR	Polk St.	NA	NA	NA
	A-3/Wallis Rd.	NA	NA	NA
	A-3/Bertelsen	NA	NA	NA
	A-2/Golden Gardens	NA	NA	NA
	Q St.	NA	NA	NA
	72nd St.	NA	NA	NA
	So. Branch Q St.	NA	NA	NA
	N. Branch Q St.	NA	NA	NA
	Q St. at 2nd St.	NA	NA	NA
	Q St. at Garden Way	NA	NA	NA
	Q St. at Skipworth	NA	NA	NA
	Marcola Rd.	NA	NA	NA
	Springfield Mill Race	NA	NA	NA
	Eugene Mill Race	NA	NA	NA

* in STORET as of 10/1/81
** NA = not available

NURP City, State	Monitoring Site	Total Coliforms mean** value (#/100mL)	Total Coliforms # of obs.	Fecal Coliforms mean value (#/100mL)	Fecal Coliforms # of obs.	Fecal Strep. mean value (#/100mL)	Fecal Strep. # of obs.	Total Lead mean value (ug/L)	Total Lead # of obs.	Total Solids mean value (mg/L)	Total Solids # of obs.
Durham, NH	Shop/Save parking lot	7,800	7	480	7	1,100	7	260	48	100	51
Lake Quinsigamond, MA	Jordan Pond	180,000	33	24,000	25	---	---	220	47	170	117
	Rt. 9	750,000	17	110,000	17	---	---	470	44	260	134
	Locust St.	850,000	18	230,000	18	---	---	240	27	350	134
	Fitz. Brook at Anne St.	340,000	20	33,000	18	---	---	160	36	220	131
	Coal Mine Bk. at Convent	39,000	19	280	11	---	---	220	42	270	100
	Tilly Brook	900,000	32	110,000	32	---	---	250	32	170	40
Long Island, NY	Huntington	47,000	23	23,000	23	62,000	23	54	42	---	---
	Laurel Hollow	16,000	24	6,000	24	76,000	24	34	47	---	---
	N. of Belmont L.	150,000	16	41,000	16	45,000	16	200	2	---	---
	N. of Belmont L.	12,000	41	4,300	41	46,000	41	280	4	---	---
	Massapequa Pond influent	74,000	224	19,000	206	74,000	224	115	84	---	---
	Massapequa Pond effluent	54,000	210	3,800	203	42,000	210	25	81	---	---
Irondequoit Bay, NY	East Rochester	---	---	4,800	22	---	---	16	14	---	---
	Southgate	---	---	8,700	22	---	---	31	20	---	---

Table A-2 (cont.). NURP Urban Catchment Runoff Data

City, State	Monitoring Site	Total Coliforms		Fecal Coliforms		Fecal Strep.		Total Lead		Total Solids	
	Cranston Rd.	---	---	4,800	14	---	---	14	16	---	---
	Baird	---	---	5,500	23	---	---	22	35	---	---
Wash., D.C.	Stedwick	2,400	1	3	1	3	1	100	25	---	---
	Stedwick	240,000	1	9,300	1	2,400	1	100	6	---	---
	Stedwick	240,000	1	46,000	1	2,400	1	110	19	---	---
	Lakeridge	1,800	4	120	4	120	4	150	35	---	---
	Lakeridge	1,900	4	70	4	170	3	120	27	---	---
	Stratton Woods	240,000	1	46,000	1	2,400	1	100	4	---	---
	Westleigh Rt. 28	1,500	4	720	4	1,200	4	100	16	---	---
	Fairidge	240,000	1	9,300	1	2,400	1	100	11	---	---
Winston-Salem, NC	into Tar Branch	---	---	17,000	95	---	---	550	396	470	385
	into Burke Branch	---	---	13,000	66	---	---	300	416	300	415
Knoxville, TN	Clinton Plaza	---	---	1,600	1	2,000	1	20	1	---	---
	Union Ave.	---	---	10	1	200	1	21	1	---	---
Milwaukee, WI	Wood Center	---	---	16,000	1	9,800	1	680	29	510	29
	N. Hastings	---	---	26,000	4	85,000	4	78	19	150	18
	North Burbank	---	---	270,000	4	280,000	4	100	18	300	18
	State Fair	---	---	36,000	2	37,000	2	240	8	240	8
	Rustler	---	---	8,900	3	5,700	2	120	23	270	22
	Post Office	---	---	4,000	1	6,500	1	260	39	230	38
Austin, TX	NW Austin into Woodhollow Dam	61,000	4	15,000	8	---	---	210	9	370	64

City, State	Monitoring Site	Total Coliforms		Fecal Coliforms		Fecal Strep.		Total Lead		Total Solids	
	from Woodhollow Dam	37,000	2	8,600	10	---	---	71	17	410	39
	Rollingwood	---	---	730	1	---	---	200	13	440	23
Denver, CO	Big Dry Trib.	---	---	6,200	39	---	---	170	63	---	---
	Asbury Park (inflow to HIG)	---	---	3,800	9	---	---	470	16	---	---
	Asbury Park (outflow from HIG)	---	---	31,000	10	---	---	440	19	---	---
	North Ave. (inflow to HIG)	---	---	2,700	44	---	---	310	85	---	---
	North Ave. (outflow from HIG)	---	---	5,900	24	---	---	270	43	---	---
	Cherry Knolls	---	---	6,300	29	---	---	160	56	---	---
	116th & Claude	---	---	25,000	45	---	---	310	63	---	---
	Villa Italia	---	---	6,800	34	---	---	200	70	---	---
Salt Lake City, UT	No. Temple	150,000	1	7,100	12	21,000	11	330	12	---	---
	8th So.	---	---	120,000	3	6,000	3	200	13	---	---
	1300 So.	---	---	6,600	5	53,000	5	270	12	---	---
	1300 So.	---	---	480	1	52,000	2	170	12	---	---
	South	1,200	5	730	9	1,300	9	140	10	---	---
	90th So.	24,000	4	26,000	6	23,000	6	120	16	---	---
Rapid City, SD	Meade St.	---	---	94,000	16	---	---	390	9	4,100	26
Bellevue, WA	Lake Hills	---	---	3,300	97	---	---	210	197	97	2
	Surrey Downs	14,000	7	3,300	97	7,300	7	190	180	180	2
	148th Ave.	---	---	560	68	---	---	310	140	180	6

Table A-2 (cont.). NURP Urban Catchment Runoff Data

City, State	Monitoring Site	Total Coliforms		Fecal Coliforms		Fecal Strep.		Total Lead		Total Solids	
Eugene, OR	Polk St.	---	---	31,000	12	---	---	30	13	210	11
	A-3 at Wallis Rd.	---	---	1,900	25	---	---	20	23	200	28
	A-3 at Bertelsen	---	---	1,500	25	---	---	14	26	180	30
	A-2 at Golden Gds.	---	---	190	13	---	---	8	9	160	12
	Q St.	---	---	10	1	---	---	---	---	---	---
	72nd St.	---	---	620	6	---	---	9	6	100	6
	So. Branch Q St.	---	---	1,700	9	---	---	46	13	250	13
	N. Branch Q St.	---	---	56	7	---	---	8	9	80	9
	Q St. at 2nd St.	---	---	9,700	23	---	---	24	21	150	24
	Q St. at Garden Way	---	---	2,100	16	---	---	23	16	140	20
	Q St. at Skipworth	---	---	230	10	---	---	9	6	150	9
	Marcola Rd.	---	---	10	1	---	---	160	6	1,300	6
	Springfield Mill Race	---	---	2,400	16	---	---	14	15	64	18
	Eugene Mill Race	---	---	1,000	7	---	---	13	7	57	7
overall number of observations:			724		1,655		620		2,939		1,995
overall minimum:		1,200		10		120		8		57	
overall maximum:		900,000		270,000		280,000		680		4,100	
average of site means:		170,000		22,000		32,000		170		370	

* in STORET as of 10/1/81
** arithmetic mean values

Table A-3. NURP Urban Catchment Pollutant Ratios*

NURP City, State	Monitoring Site	FC/FS	FC/Pb #/100mL / ug/L	FC/TS #/100mL / mg/L	TC/TS #/100mL / mg/L	FS/TS #/100mL / mg/L	Pb/TS ug/mg or ppb
Durham, NH	Shop/Save parking lot	0.43	1.9	4.7	76	11	2.5
Lake Quinsigamond, MA	Jordan Pond	---	110	140	1,000	---	1.3
	Rt. 9	---	230	410	2,900	---	1.8
	Locust St.	---	960	670	2,500	---	0.69
	Fitz. Brook at Anne St.	---	210	150	1,500	---	0.72
	Coal Mine Bk. at Convent	---	1.2	1.0	140	---	0.81
	Tilly Brook	---	420	620	5,300	---	1.5
Long Island, NY	Huntington	0.37	430	---	---	---	---
	Laurel Hollow	0.08	180	---	---	---	---
	N. of Belmont L.	0.91	200	---	---	---	---
	N. of Belmont L.	2.8	16	---	---	---	---
	Massapequa Pond influent	0.26	160	---	---	---	---
	Massapequa Pond effluent	0.09	150	---	---	---	---
Irondequoit Bay, NY	East Rochester	---	300	---	---	---	---
	Southgate	---	280	---	---	---	---

Table A-3 (cont.). NURP Urban Catchment Runoff Pollutant Ratios

City, State	Monitoring Site	FC/FS	FC/Pb	FC/TS	TC/TS	FS/TS	Pb/TS
	Cranston Rd.	---	340	---	---	---	---
	Baird	---	250	---	---	---	---
Wash., D.C.	Stedwick	1.0	0.03	---	---	---	---
	Stedwick	3.9	93	---	---	---	---
	Stedwick	19	430	---	---	---	---
	Lakeridge	1.0	0.84	---	---	---	---
	Lakeridge	0.41	0.61	---	---	---	---
	Stratton Woods	1.9	460	---	---	---	---
	Westleigh Rt. 28	2.1	7.2	---	---	---	---
	Fairidge	3.9	91	---	---	---	---
Winston-Salem, NC	into Tar Branch	---	30	35	---	---	1.2
	into Burke Branch	---	44	44	---	---	1.0
Knoxville, TN	Clinton Plaza	0.82	82	---	---	---	---
	Union Ave.	0.06	0.48	---	---	---	---
Milwaukee, WI	Wood Center	1.6	24	32	---	19	1.3
	N. Hastings	0.31	340	180	---	570	0.52
	North Burbank	0.96	2,600	910	---	940	0.35
	State Fair	0.97	150	150	---	150	1.0
	Rustler	1.6	72	33	---	21	0.47
	Post Office	0.62	15	17	---	28	1.1
Austin, TX	NW Austin into Woodhollow Dam	---	69	40	170	---	0.6

Table A-3 (cont.). NURP Urban Catchment Runoff Pollutant Ratios

City, State	Monitoring Site	FC/FS	FC/Pb	FC/TS	TC/TS	FS/TS	Pb/TS
	from Woodhollow Dam	---	120	21	88	---	0.17
	Rollingwood	---	3.7	1.7	---	---	0.45
Denver, CO	Big Dry Trib.	---	35	---	---	---	---
	Asbury Park (inflow to HIG)	---	8.1	---	---	---	---
	Asbury Park (outflow from HIG)	---	70	---	---	---	---
	North Ave. (inflow to HIG)	---	8.7	---	---	---	---
	North Ave. (outflow from HIG)	---	22	---	---	---	---
	Cherry Knolls	---	39	---	---	---	---
	116th & Claude	---	81	---	---	---	---
	Villa Italia	---	34	---	---	---	---
Salt Lake City, UT	No. Temple	0.34	21	---	---	---	---
	8th So.	20	580	---	---	---	---
	1300 So.	0.13	25	---	---	---	---
	1300 So.	0.01	2.9	---	---	---	---
	South	0.57	5.4	---	---	---	---
	90th So.	1.2	220	---	---	---	---
Rapid City, SD	Meade St.	---	250	23	---	---	0.09
Bellevue, WA	Lake Hills	---	15	34	---	---	2.2
	Surrey Downs	0.45	17	18	86	41	1.1
	148th Ave.	---	1.8	3.0	---	---	1.7

Table A-3 (cont.). NURP Urban Catchment Runoff Pollutant Ratios

City, State	Monitoring Site	FC/FS	FC/Pb	FC/TS	TC/TS	FS/TS	Pb/TS
Eugene, OR	Polk St.	---	1,000	150	---	---	0.14
	A-3 at Wallis Rd.	---	94	9.4	---	---	0.1
	A-3 at Bertelsen	---	100	8.1	---	---	0.1
	A-2 at Golden Gds.	---	24	1.2	---	---	0.05
	Q St.	---	---	---	---	---	---
	72nd St.	---	73	6.2	---	---	0.1
	So. Branch Q St.	---	36	6.7	---	---	0.2
	N. Branch Q St.	---	7.0	0.7	---	---	0.1
	Q St. at 2nd St.	---	400	66	---	---	0.16
	Q St. at Garden Way	--	89	15	---	---	0.17
	Q St. at Skipworth	---	26	1.6	---	---	0.06
	Marcola Rd.	---	0.06	0.01	---	---	0.12
	Springfield Mill Race	---	170	37	---	---	0.22
	Eugene Mill Race	---	78	18	---	---	0.23
overall minimum:		0.01	0.03	0.01	76	11	0.09
overall maximum:		20	2,600	910	5,300	940	2.5
average of site means:		2.3	180	110	1,400	200	0.7

* in STORET as of 10/1/81

Table A-4. Urban Runoff Bacteria Population Densities Reported for Previous Studies (number of organisms/100 mL)

City, Province/State	site/station/ land use	Total Coliforms geo. mean	Total Coliforms min.	Total Coliforms max.	Total Coliforms # of obs.	Fecal Coliforms geo. mean	Fecal Coliforms min.	Fecal Coliforms max.	Fecal Coliforms # of obs.	Fecal Streptococci geo. mean	Fecal Streptococci min.	Fecal Streptococci max.	Fecal Streptococci # of obs.	Ref*
Burlington, Ontario	Aldershot Plaza	$2.3x10^5$	$2.9x10^3$	$2.2x10^7$	8	$6.3x10^2$	$1.0x10^2$	$7.5x10^3$	8	$7.5x10^2$	$1.6x10^2$	$5.5x10^3$	8	19
	Malvern Rd.	$3.5x10^2$	3	$5.3x10^3$	10	57	1	$1.8x10^3$	10	89	13	$9.0x10^2$	10	19
Toronto, Ontario	Brucewood	---	100	$1.1x10^4$	---	---	10	$1.9x10^4$	---	---	---	---	---	17
	Guelph-North	---	$<10^4$	$8.3x10^5$	---	---	$<10^3$	$7.1x10^4$	---	---	---	---	---	17
	Windsor-A	---	200	$1.2x10^6$	---	---	100	$2.0x10^4$	---	---	---	---	---	17
	NA (not available)	$6.1x10^5$	$7.0x10^4$	$3.2x10^6$	18	$1.1x10^4$	$3.0x10^3$	$2.7x10^4$	18	$2.9x10^4$	$1.3x10^3$	$7.1x10^4$	18	17
	NA	$2.0x10^4$	---	---	---	$5.0x10^3$	---	---	---	---	---	---	---	24
Milwaukee, WI	highway site-794	---	$3.0x10^3$	$6.0x10^5$	---	---	10	$>10^5$	---	---	40	$4.3x10^3$	---	13
	highway site-45	---	$4.5x10^3$	$7.9x10^6$	---	---	$4.9x10^2$	$3.0x10^5$	---	---	$1.3x10^3$	$3.0x10^5$	---	13
Cinncinnati, OH	residential	---	---	$5.0x10^5$	---	---	---	$8.0x10^4$	---	---	---	$1.0x10^5$	---	25
	residential street	---	---	---	---	$1.4x10^3$	50	$4.7x10^4$	?	$1.9x10^4$	$2.2x10^3$	$1.5x10^5$	?	12
	suburban bus. area	---	---	---	---	$8.7x10^3$	$2.5x10^3$	$4.0x10^4$	?	$3.2x10^4$	$1.3x10^4$	$5.6x10^4$	?	12
Ann Arbor, MI	NA	$2.1x10^6$	$1.2x10^5$	$3.4x10^7$	22 storms	$1.2x10^5$	$7.4x10^3$	$7.5x10^5$	22 storms	$2.1x10^5$	$3.1x10^4$	$6.7x10^5$	22 storms	6
Harrisburg, PA	highway site	---	10^2	$1.8x10^5$	---	---	<1	$>10^5$	---	---	$6.4x10^2$	$2.0x10^5$	---	13
Washington, DC	NA	---	$1.2x10^5$	$3.2x10^6$	---	---	$4.0x10^4$	$1.3x10^6$	---	---	---	---	---	14
Baltimore, MD	NA	$1.2x10^5$	---	---	---	$2.4x10^4$	---	---	---	$1.7x10^5$	---	---	---	16
	Stoney Run	---	$5.4x10^3$	$1.6x10^6$	17	---	$1.3x10^3$	$5.4x10^4$	17	---	$5.3x10^2$	$3.0x10^5$	17	11
	Glen Ave.	---	$7.9x10^3$	$1.6x10^6$	17	---	$1.4x10^3$	$2.3x10^5$	17	---	$9.2x10^3$	$2.8x10^6$	17	11
	Howard Park	---	$4.9x10^3$	$2.8x10^7$	17	---	$2.3x10^3$	$2.9x10^6$	17	---	$<10^3$	$1.4x10^6$	17	11
	Jones Falls	---	$3.3x10^4$	$>2.4x10^6$	17	---	$5.0x10^3$	$>1.6x10^6$	17	---	$2.6x10^3$	$8.0x10^5$	17	11
	Bush Street	---	$7.9x10^3$	$2.4x10^6$	17	---	$1.7x10^3$	$2.4x10^6$	17	---	$2.5x10^3$	$1.9x10^6$	17	11
	Northwood	---	$1.3x10^3$	$1.7x10^5$	14	---	80	$7.9x10^4$	14	---	$1.7x10^3$	$3.0x10^5$	14	11
Durham, NC	NA	---	---	---	---	$2.5x10^5$	$3.0x10^3$	$1.9x10^6$	37	---	---	---	---	5
	NA	---	---	---	---	$2.3x10^2$	1	$2.0x10^3$	---	---	---	---	---	7
Nashville, TN	highway site	---	$1.7x10^3$	$2.9x10^6$	---	---	$1.5x10^2$	$2.6x10^5$	---	---	$3.9x10^3$	$3.5x10^6$	---	13
Knoxville, TN	Plantation Hills suburban	---	---	---	---	$2.0x10^4$	$6.7x10^2$	$7.0x10^5$	40	---	---	---	---	3

Table A-4 (cont.). Urban Runoff Bacteria Population Densities Reported for Previous Studies

City, State	Land Use	Total Coliforms				Fecal Coliforms				Fecal Streptococci				Ref.
Atlanta, GA	4 suburban sites, combined	---	---	---	---	$6.3x10^3$	10	10^5	53	---	---	---	---	4
Miami, FL	parking lot	$5.0x10^4$	---	---	---	$5.0x10^4$	---	---	---	10^3	---	---	---	23
	residential	$5.0x10^3$	---	---	---	$4.0x10^3$	---	---	---	$7.0x10^2$	---	---	---	23
	residential	$2.0x10^4$	---	---	---	$2.0x10^4$	---	---	---	10^3	---	---	---	23
Oklahoma City, OK	15 areas combined	---	---	---	---	$4.0x10^2$	0	$4.7x10^5$	358	---	---	---	---	2
Houston, TX	Westberry Square, residential	$3.0x10^7$	---	10^7	---	$2.0x10^4$	---	10^4	---	10^4	---	10^4	---	8
Denver, CO	highway site	---	0	$>10^5$	---	---	0	$2.7x10^3$	---	---	0	$>10^5$	---	13
Boulder, CO	snowmelt	$5.0x10^6$	$2.3x10^3$	$11.0x10^6$	1 "storm"	$<5x10^6$	$<2x10^2$	$<11x10^6$	1 "storm"	---	---	---	---	18
	urban stream-base flow	---	$4.0x10^3$	$6.0x10^3$	---	---	$6.0x10^2$	10^3	---	---	---	---	---	18
	semi-urban/rural	---	$9.3x10^2$	$4.6x10^4$	---	---	$9.3x10^2$	$9.3x10^3$	---	---	---	---	---	15
	urban	---	$9.3x10^2$	$2.4x10^5$	---	---	$4.3x10^2$	$9.8x10^4$	---	---	---	---	---	15
Seattle, WA	street gutters	---	---	$1.6x10^4$	---	---	---	---	---	---	---	---	---	22
Tucson, AZ	High School	10^7	---	---	---	10^5	---	---	---	10^5	---	---	---	20
	Arcadia	10^6	---	---	---	10^5	---	---	---	10^5	---	---	---	20
	Railroad	10^6	---	---	---	10^4	---	---	---	10^5	---	---	---	20
San Diego, CA	Tecolote Creek	---	---	---	---	$1.5x10^4$	$5.8x10^3$	$4.1x10^4$	33	---	---	---	---	21
Sacramento, CA	NA	---	---	---	---	---	$2.4x10^4$	10^7	---	---	---	---	---	9
Stockholm, Sweden	streets and parks	$4.0x10^3$	---	$2.0x10^5$	---	---	---	---	---	---	---	---	---	1
nationwide	urban streams	---	---	---	---	$6.0x10^3$	$2.0x10^2$	$2.0x10^6$	---					10
overall minimum:			0				0				0			
overall maximum:				$3.0x10^7$				10^7				$3.0x10^6$		
average of site means:		$3.0x10^6$				$3.0x10^4$				$6.0x10^4$				

Table A-4 (cont.). Urban Runoff Bacteria Population Densities Reported for Previous Studies

* References for Table A-4

1. Akerlinch, 1950
2. AVCO, 1970
3. Betson, 1976
4. Black, Crow, and Edisness, Inc., 1975
5. Bryan, 1972
6. Burm and Vaughan, 1966
7. Colston, 1974
8. Davis, 1976
9. Envirogenics Co., 1971
10. Field and Struzeski, 1972
11. Field, et al., 1976
12. Geldreich, 1976
13. Gupta, et al., 1981
14. Lager and Smith, 1974
15. McElroy and Bell, 1974
16. Olivieri, Kruse, and Kawata, 1977a
17. Ontario Ministry of the Environment, 1982
18. Pontius, 1977
19. Qureshi and Dutka, 1979
20. Resnick and DeCook, 1980
21. Setmire and Bradford, 1980
22. Sylvester, 1960
23. Lager, et al., 1977
24. Waller and Novak, undated
25. Weibel, et al., 1964

Table A-5. Selected Combined Sewer Overflow Bacteria Data from the Literature (approximate bacteria densities: organisms/100mL)

City (reference)	Total Coliforms	Fecal Coliforms	Fecal Strep.
Ottawa (Rideau R. Stormwater Management Study, 1982)	---	$5x10^5$-$9x10^6$	---
Toronto (Ontario Min. of the Envir., 1982)	10^7	10^6	---
Detroit (Geldreich, 1976)	---	10^6-10^7	10^5
Selected Data (Field & Struzeski, 1972)	$2x10^4$-$9x10^7$	$2x10^4$-$2x10^7$	$2x10^4$-$2x10^6$

APPENDIX B
URBAN BACTERIA SOURCES

The Regional Municipality of Ottawa-Carleton (1972) recognized the importance of rooftop, street surface, and field runoff in contributing bacteria contaminants to surface waters in the Ottawa area. More recently, Gore and Storrie/Proctor and Redfern (1981c) have investigated various urban bacteria sources affecting the Rideau River. They examined dry weather continuous coliform sources, the resuspension of contaminated river bottom sediments, exfiltration from sanitary sewers, and bird feces. These sources were all considered in an attempt to explain the relatively high dry weather coliform bacteria concentrations found in the river. They concluded, however, that stormwater runoff is the most probable source for the wet weather and continuing dry weather bacteria Rideau River concentrations. As noted earlier, the slow travel time of the river water usually does not allow the river to recover completely from one rainstorm before another begins. They found that the Rideau River reach between the Bank Street and Smyth Road bridges has the largest fecal coliform loadings during both wet and dry weather.

The Regional Municipality of Ottawa-Carleton (1972) noted the early Ottawa activities in correcting stormwater and sanitary sewage cross-connections. Since that time, many combined sewer overflows have also been eliminated from the Rideau River. Loijens (1981) stated that as a result of sewer separation activities, only one overflow currently remains active (Clegg Street). During river surveys in 1978 and 1979 in the vicinity of this outfall, increased bacteria levels were not found. Gore and Storrie/Proctor and Redfern (1981c) stated that there is currently no evidence that combined sewer overflows are causing the elevated fecal coliform bacteria levels in the river. Environment Canada, (1980) however, stated that high, dry weather bacteria density levels, especially when considering the fecal coliform to fecal strep. ratio, constitutes presumptive evidence of low volume sporadic inputs of sanitary sewage from diverse sources into the downstream Rideau River sectors.

B.1 GENERAL BACTERIA SOURCES

Street surfaces have been identified as potential major sources of urban runoff bacteria in other locations. Pitt and Bozeman (1982) found that parking lots, street surfaces, and sidewalks were the major contributors of indicator bacteria in the Coyote Creek watershed in California. Gupta, et al (1981) found high concentrations of fecal coliforms at a highway runoff site in Milwaukee. This site was entirely impervious and located on an elevated bridge deck. The only likely sources of fecal coliforms at this site were bird droppings and possibly feces debris falling from livestock trucks or other vehicles.

Several studies have found that the bacteria in stormwater runoff in residential and light commercial areas were from predominantly nonhuman origins (Oureshi and Dutka, 1979). They found that there may be an initial flush of animal feces when runoff first develops. However, the most important bacteria source for runoff is the feces bacteria that have been distributed generally in the soils and on the surfaces of the drainage area. Geldreich and Kenner (1969) stated that the fecal coliforms in stormwater are from dogs, cats, and rodents in city areas, and from farm animals and wildlife in rural areas. The most important source, however, may be feces bacteria that are distributed in the soil and not the fresh feces washing off the impervious surfaces.

Some studies have investigated vegetation sources of coliform bacteria. For example, Geldreich (1965) found that the washoff of bacteria from vegetation does not contribute significant bacteria to the runoff. They also found that most of the bacteria on vegetation is of insect origin.

Geldreich, et al (1980) found that recreation activities in water bodies also increase the fecal coliform and fecal strep. concentrations. These organisms of intestinal origin will concentrate in areas near the shore or in areas of stratification.

Fennell, James, and Morris (1974) found that open dumps containing domestic refuse can be a reservoir of Salmonella bacteria that can be spread to nearby water bodies by foraging animals and birds.

When a drainage basin has much of its surface paved, the urban runoff bacteria concentrations can be expected to peak near the beginning of the rainfall event and then decrease as the event continues. Initial high levels of bacteria may be associated with direct flushing of feces from paved surfaces. These feces are from dogs defecating on parking lots and street areas and from birds roosting on rooftops. When a drainage area has a lot of landscaped areas or open land, relatively high bacteria concentrations in the urban runoff may occur throughout the rain event.

B.2 FECAL COLIFORM TO FECAL STREP. BACTERIA RATIOS

Geldreich (1965) found that the ratio of fecal coliform to fecal strep. bacteria concentrations may be indicative of the probable fecal source. In fresh human fecal material and domestic wastes, he found that the fecal coliform densities were more than four times the fecal strep. densities. However, this ratio for livestock, poultry, dogs, cats, and rodents was found to be less than 0.6. These ratios must be applied carefully, because of the effects of travel time and various chemical changes (especially pH) on the die-off rates of the component bacteria. As a generality, he stated that fecal coliform to fecal strep. ratios greater than four indicate that the bacteria pollution is from domestic wastes, which are composed mostly of human fecal material, laundry wastes, and food refuse. If the ratio is less than 0.6, the bacteria is probably from livestock or poultry in agricultural areas or from stormwater runoff in urban areas. He found that agricultural and stormwater runoff can be differentiated by studying the types of fecal strep. bacteria found in the water samples (see Appendix C). Geldreich and Kenner (1969) further stressed the importance of carefully using this ratio. They stressed that samples must be taken at the wastewater outfalls. At these locations, domestic wastes, meat packing wastes, stormwater discharges, and feedlot drainage contain large numbers of fecal organisms recently discharged from warm blooded animals. Once these organisms are diffused into the receiving stream, however, water temperature, organic nutrients, toxic metals, and adverse pH values may alter the relationship between the indicator organisms. This ratio should only be applied within 24 hours following the discharge of the bacteria.

Feachem (1975) examined how these ratios could be used with bacteria observations taken over a period of time. Because the fecal coliform and fecal strep. bacteria die-off rates are not the same, the ratio gradually changes with time. He found that bacteria is predominantly from human sources if the FC/FS ratios are initially high (greater that four) and then decrease with time. Non-human bacteria sources would result in initially low fecal coliform to fecal strep. ratios (less than 0.7) which then rise with time.

Table B-1 summarizes the observed fecal coliform to fecal strep. bacteria population ratios in the Rideau River study area. These ratios are separated into source area sheet-flow and puddle samples, Rideau River water samples and water samples collected at the swimming beaches. The source area sheet-flow and puddle samples contain the most recent pollution, while the river segment and beach samples contain "older" bacteria. The initial source area samples all have ratios of less than 0.7. However, the river averages range from 0.5 to 1.2 and the beach samples (which may be "older" than the river samples) range from 1.7 to 2.8. These ratios are seen to start with values of less than 0.7 and increase with time. Based on Feachem's (1975) work, this would indicate that the major bacteria sources in the Rideau River are from non-human sources. This substantiates the previous conclusions as presented in the Phase I Rideau River Stormwater Management Report. Periodic high bacteria ratios in the river and at the beaches could be caused by the greater die-off rate of fecal strep. as compared to fecal coliform. The observed periodic high Rideau River FC/FS ratios (which can be greater than four) may therefore be from old, non-human fecal discharges and not from fresh human fecal discharges.

B.3 WATER BODY SEDIMENT BACTERIA SOURCES

Matson, Horner, and Buck (1978) studied the effects of river and lake sediments as a source of bacteria to the water column in Connecticut. They found that resuspended sediments in shallow waters can elevate the water column bacteria concentrations significantly. They stated that the physical resuspension of shallow water sediments is increased by elevated river discharges, wind induced turbulence, dredging, motorboats, swimming, walking, and wading and normal activities of aquatic microorganisms. The magnitude of sediment resuspension varies with the intensity of the mechanisms involved, and the water depth to the sediment. They stated that during stable river flows, the water bacteria populations are relatively constant, but during periods of high flows, sediment organisms can be scoured from the benthic surfaces and mixed into the water column. After peak discharges, water borne microorganisms resettle downstream, which increases those sediment bacteria populations. Geldreich, et al (1980) also studied bacteria interactions between sediment and water. They found that the sediment-water interface of a water body is an attractive habitat for a variety of different bacteria involved in different biochemical processes. Shallow bottom sediments attract a variable bacteria population because of the physical and chemical requirements that can be satisfied there, in contrast to the more limited conditions available in the water or buried in the sediments.

Davis (1979) stated that bacteria contamination of waterways during and following storm events is a function of the stream sediment bacteria concentrations, the concentrations of bacteria in soils adjacent to the stream (and source

Table B-1. Fecal Coliform to Fecal Strep. Bacteria Population Ratios in Study Area

Source Areas	FC/FS (ratio)
rooftop runoff	0.5
vacant land puddles	0.3
parking lot puddles	0.2
gutter flows	0.2
average........................	0.3
Rideau River Segment	
A	1.2
B	0.6
C	0.5
D	0.5
E	1.0
average........................	0.7
Beaches	
Strathcona	2.8
Brantwood	2.3
Brighton	2.1
Mooney's Bay	1.7
average........................	2.2

areas in an urban watershed), and the stream velocities. Davis further stated that stream sediments can contain greater densities of coliform bacteria on a number per unit weight or volume basis than the water body itself; the concentrations of bacteria in the top two inches of mud can be 100 to 1,000 times greater than the concentrations of the bacteria in the water. He reported fecal coliform sediment concentrations up to 100 organisms per gram of sediment and that the suspended sediments can be a major source of bacteria contamination. Geldreich, et al (1980) stated that sediment bacteria concentrations can be as high as 3,000 to 15,000 organisms per square meter of particulate surface. Pitt and Bozeman (1979), in a study of an urban lake in Oakland, California, found fecal coliform sediment concentrations that ranged from one to 35,000 organisms per gram and averaged about 1,000. McSwain (1977) found that in a rural study in North Carolina, total and fecal coliform concentration increases were more related to bottom sediment disturbances than to stream bank flushing.

B.4 SOIL BACTERIA SOURCES

Van Donsel, Geldreich, and Clarke (1967) stated that soil bacteria pollution may occur from direct defecation by livestock, pets, and wild animals, by malfunctioning or overflowing septic tank systems or by flooding of sewerage systems. Much of the total coliform indicator bacteria organisms in urban areas, however, are not from these sources. Geldreich, et al (1968) found that in a Cincinnati urban runoff study, direct fecal contamination accounted for less than 10 percent of the total coliform bacteria present in the stormwater. The remaining coliforms (which were non-fecal in origin) were assumed to be contributed from soil erosion. Therefore, soil can contain large numbers of both non-fecal and fecal coliform bacteria. Because rain water contains very small bacteria concentrations, urban runoff becomes contaminated with bacteria when the rain water contacts contaminated surfaces. In wilderness areas, runoff has very little fecal coliform bacteria, while runoff from agricultural areas or urban areas can have varying amounts of fecal coliform bacteria. Seidler (1979) found that the movement of fecal coliform bacteria in saturated soils was extremely rapid. Soil can add appreciable fecal and non-fecal coliform bacteria to rain runoff. Casserly and Davis (1979) found that coliform types in urban soils were the same as those found in urban runoff, indicating a strong interaction between polluted soils and contaminated urban runoff. Davis (1979) found that irrigated soils, with high humic content, can yield greater amounts of bacteria. Evans and Owens (1972) found that the concentrations of *E. coli* and Enterococci in stormwater runoff were affected by the soil bacteria concentrations.

Evans and Owens (1973) reported that bacteria was more likely to erode than the particulate matter in the soil. Davis (1979) found that the leaching action of rain on soil bacteria was quite erratic. The most important factors affecting bacteria concentrations in runoff were found to be the concentrations of the bacteria in soils. They reported total coliform concentrations in soils ranging from 200 to more than 500,000 total coliform organisms per gram. Fecal coliform soil concentrations ranged from less than 20 to about 300 organisms per gram and fecal strep. soil concentrations ranged from less than 20 to about 1,000 organisms per gram.

B.5 SURVIVAL OF BACTERIA IN SOIL

Because of the importance of soil bacteria as a source of urban runoff bacteria, their survival in the soil after deposition is important. If an area has long interevent times between rain events, soil bacteria survival would have to be quite long in order for the soil to be a significant urban runoff bacteria source. However, in areas having frequent rains, soil bacteria survival is less important (assuming that it is greater than the interevent period). Many site conditions have been reported to influence soil bacteria survival. Van Donsel, Geldreich, and Clarke (1967) found that sunlight, temperature, rainfall, soil moisture, pH, organic matter, and the presence of other microorganisms all affect the survival of total coliforms, fecal coliforms, and fecal strep. soil bacteria. They also reported that feces bacteria deposited on dry soils are relatively immobilized and subject to the specific site conditions. After-growth of soil bacteria (increasing populations without new deposition) may account for some of the seasonal variations in runoff bacteria counts. If the soil has not been recently contaminated, the runoff would have an immediate supply of microorganisms from the soil. Contamination of the receiving waters would be out of proportion to the true sanitary history of the area. They also stated that non-fecal coliforms reappeared after fecal organisms declined. They were also present in much higher concentrations after fecal bacteria die-off than before the soil was contaminated.

Both after-growth and decline of bacteria in soils have been reported. Soil coliforms can exhibit after-growth following rainstorms and exhibit rapid declines during freezing weather. If very warm weather follows a rain, a very large increase in soil coliform bacteria was noted, while the increase was much less if cool weather followed a rain. They also found declining bacteria soil populations if the soil was dry. Alternate freezing and thawing at exposed winter sites caused significant mortality of soil coliform bacteria. Evans and Owens (1972) reported that E. coli and Enterococci showed 90 percent reductions after about two to three months in soils. Van Donzel, Geldreich, and Clarke (1967) reported prolonged persistence of other bacteria types. Various strains of Salmonella were found to exist for long periods of time (nine months for S. typhimurium). It is not uncommon for soil bacteria to survive for up to 200 days after innoculation.

B.6 BACTERIA SURVIVAL IN STORMWATER

The survival of urban runoff bacteria in receiving waters is an important issue. Very little direct consumption or contact of urban runoff usually occurs. However, when the runoff is discharged into a larger receiving water, consumption or contact may occur after the rain event has ended. The Rideau River Stormwater Management Study has examined the die-off of fecal coliform bacteria in the Rideau River (Droste and Gupgupoglu, 1982; Environment Canada, 1980; Gore and Storrie/Proctor and Redfern, 1981b and 1981c). They found that the 90 percent die-off for Rideau River fecal coliforms was about two days. Again, because of the long travel time on the Rideau River and short interevent times of rains in the area, the effects of bacteria discharges from stormwater from one storm can affect the river concentrations during the next storm. The persistence of fecal coliforms and the slow river velocities cause downstream beach bacteria concentrations to seldom, if ever, regain true low background bacteria concentration levels. Environment Canada (1980) reported significant increase in coliform concentrations in recently excreted moist feces. These factors significantly affect any attempts to estimate bacteria mass balances, to identify potential fecal discharges, and to estimate resultant river bacteria concentrations.

Seidler (1979) stated that the sources of Salmonella bacteria can determine their survival. This is probably true for most types of bacteria because the different bacteria sources usually determine the specific bacteria biotypes found in the feces (see Appendix C). Different bacteria types can have quite varying die-off rates.

Factors affecting urban runoff bacteria survival in stormwater have been found to be quite variable and site specific. Geldreich, et al (1968) found that no significant differences in survival of urban runoff bacteria could be related to the chemical constituents present. Water temperature, however, did have a strong influence on urban runoff bacteria survival. Geldreich, et al (1980) found in a Kentucky study that when copper sulfate was applied as an algicide in a reservoir, sharp declines in fecal coliform densities occurred. The standard plate count densities, however, sharply increased. They found that the survival of urban runoff bacteria was longer near the bottom of the reservoir than in shallower waters. They also found that reduced dissolved oxygen concentrations near the sediments was not detrimental to bacteria survival. Faust and Goff (1978) found that clay concentrations in the Rhode River in the Chesapeake Bay area extended the survival of fecal coliform bacteria.

Many studies reported the effects of temperature on urban runoff bacteria die-off. Geldreich, et al (1968), in a series of lab tests, found that stormwater bacteria persisted at higher concentrations under winter water temperature conditions (10°C) than they did for summer water temperature conditions (20°C). There were some differences in survival for the various specific types of stormwater bacteria, but this trend seemed typical. Van Donzel, Geldreich, and Clarke (1967) found that fecal strep. did not survive as long as fecal coliform bacteria during the summer months, while in the autumn there was little difference in their survival times. In the winter and spring, the fecal strep. survived much longer than the fecal coliforms. Seidler (1979) found that Salmonella survived for longer periods of time in colder water temperatures. McSwain (1977) reported that coliform bacteria were able to multiply in bottom sediments at a rate regulated by stream temperature. They reported another study that found significant enteric bacteria concentration increases at temperatures above 16°C, but that little or no growth occurred below 10°C. The conditions affecting bacteria survival in water appear to be site and bacteria specific. Many of the differences are probably associated with the specific bacteria biotype present and with the water temperature. Chemical constituent concentrations do not appear to be a factor, except when they are present at very low concentrations.

Table B-2 summarizes reported 90 day die-off rates for different stormwater bacteria types. Fecal coliform die-off values varied from less than one day to about 13 days, but can be considered quite fast. Fecal strep. die-off values, however, were longer than the fecal coliform die-off rates. Some of the Streptococcus bacteria types had long survival rates, while others had short survival rates. The forms likely to be associated with agricultural activities (*S. bovis* and *S. equinus*) all are shown to have much shorter survival times than more common urban Streptococcus types (*S. faecalis*).

Table B-2. Stormwater Bacteria Survival

Bacteria Type	Description	Days Survival before 90% Dieoff	Reference
Fecal Coliform	Rideau River - Summer	2	8
	Cincinnati - Stormwater at 10°C	10	3
	Cincinnati - Stormwater at 20°C	2	3
	Oakland, CA - Bird feces into lake	rapid	6
	Stormwater - Summer	3	1
	Stormwater - Autumn	13	1
Fecal Strep.	Oakland, CA - Bird Feces into lake	>30	6
	Stormwater - Summer	3	1
	Stormwater - Winter	20	1
Streptococcus faecalis	Cincinnati - Stormwater	>14	3
S. faecalis var. *liquifaciens*	Cincinnati - Stormwater at 10°C	>14	3
	Cincinnati - Stormwater at 20°C	6	3
S. bovis	Cincinnati - Stormwater at 10°C	<1	3
	Cincinnati - Stormwater at 20°C	1	3
S. equinus	Cincinnati - Stormwater	<1	4
Salmonella	Rural Oregon Creek	>6	7
S. typhimurium	Cincinnati - Stormwater at 10°C	7	3
	Cincinnati - Stormwater at 20°C	2	3
Shigella flexneri	Baltimore - Stormwater	>8	2
Enterobactor aerogenes	Cincinnati - Stormwater at 10°C	5	3
	Cincinnati - Stormwater at 20°C	4	3

References:

1. Van Donsel, Geldreich, and Clarke, 1967
2. Field, et al., 1976
3. Geldreich, et al., 1968
4. Geldreich and Kenner, 1969
5. Gore & Storrie/Proctor & Redfern, 1981c
6. Pitt and Bozeman, 1979
7. Seidler, 1979
8. Droste and Gupgupoglu, 1982

B.7 EFFECTS OF BIRDS ON WATER BODY BACTERIA CONCENTRATIONS

Several studies have been conducted which examined the effects of large migratory or permanent waterfowl populations on the bacteria quality of water bodies. A study at the Montezuma Bird Refuge in New York (Have, 1973) found inconsistent relationships between the bird populations and total coliform, fecal coliform, and fecal strep. counts. Peak populations of 70,000 geese and 100,000 ducks frequent this 1,000 acre refuge. In fact, they found that the concentrations of the non-pathogenic bacteria in the two major streams flowing into the refuge were greater than in the water flowing out of the refuge. The specific conductance of the inflowing water was also greater than the outflowing water. The effluent did have higher concentrations of phosphorous and nitrogen. They concluded that the settling effect of the quiet waters in the refuge may help explain the improvement in the quality of water leaving the refuge.

Brierley, Brandvold, and Popp (1975) studied the Rio Grande Bird Refuge in New Mexico. This refuge supports bird populations of more than 10,000 Sandhill cranes, 2,000 Canada geese, more than 8,000 snow geese, and more than 25,000 ducks from October to early March along ten miles of river channel. The water flowing into this bird refuge area along the Rio Grande River has high concentrations of suspended sediment and bacteria. The bacteria concentrations seem to correlate directly with the high sediment concentrations. The presence of the large number of birds apparently does not affect the concentrations of the bacteria that were investigated (total heterotrophic bacteria, fecal and total coliforms, and Enterococci). Most of the birds use a single large pond as their winter habitat. The draining of this pond at the end of their season did not seem to significantly change the bacteria population of the receiving channel water. The bird habitat pond, in fact, had decreased concentrations of bacteria during and following the period of maximum use. They concluded that the bacteria originated in upstream areas before it reached the refuge.

In a study at Lake Wingra in Wisconsin (Geldreich, 1980), intermittent high fecal coliform counts during the late summer and early fall were found to be due to a combination of wastes from mallard ducks and the local weather. They reported that fecal coliforms in the sand due to duck defecation multiplied during the first week after deposition and then die-off occurred. Bacteria in these near-lake sands were transported into the water primarily by stormwater runoff erosion and by the foot traffic of bathers when going into the water.

Oplinger (1977) studied the effects of waterfowl populations on the water quality of a small creek park in Pennsylvania. They felt that increasing waterfowl populations and the declining water quality were related and threatened the health and welfare of both the waterfowl and the human watershed users.

Figley and Vandruff (1974), in a study of suburban parks in New York state, noted that mallard ducks are especially attracted to suburban lagoon developments. They felt that urban concentrations of semi-wild ducks may be detrimental, by serving as the focal points for outbreaks of infectious avian diseases and as a reservoir of diseases that could be transmitted to migrating wildfowl.

A study by Fennell, James, and Morris (1974) examined the effects of about 500 roosting gulls on a one million cubic meter storage reservoir. Salmonella were usually found in the reservoir waters but never in the incoming water. They also found close correlations between the number of gulls and the degree of bacteria contamination. The sources of Salmonella appeared to be household and other refuse from dumps where the gulls were foraging. When the gulls left, after bird scaring fireworks were used, the Salmonella and other bacteria concentrations almost immediately decreased. The bacteria concentrations remained at low levels for a period of five weeks until the fireworks were stopped; the birds were allowed to return, and the bacteria concentrations in the reservoir immediately increased.

It is evident that birds can have varying effects on the bacteria concentrations in waterbodies. Large refuges do not seem to be severely affected by the wildlife populations. In fact, the ponding of waters in refuges appears to improve the water quality through sedimentation. Waterfowl frequenting smaller bodies of water, especially creeks and small lagoons, appear to have the potential for substantially increasing the water bacteria concentrations.

Gore and Storrie/Proctor and Redfern, (1981a) summarized the results of studies made to determine the effects of birds roosting on bridges over the Rideau River on river bacteria concentrations. They found that the birds on the bridges could have a statistically significant impact on fecal coliform concentrations, especially during the low summer flows. Measured concentration increases of fecal coliform bacteria downstream from the Queensway Bridge was found to be about 300 fecal coliform organisms/100 mL.

B.8 URBAN WILDLIFE FECES BACTERIA CONCENTRATIONS

The last subsections of this appendix summarize reported bacteria concentrations in fecal samples from wild and domestic animals, their potential populations in urban areas, and their estimated annual bacteria yields for the lower Rideau River watershed.

Table B-3 lists samples (mostly from mammals and birds with some soil, sediment, and river samples) where specific bacteria types were not generally found. This table, of course, is not complete; there are obviously other samples where these bacteria types are not found. The presence or absence of certain bacteria types in environmental samples can be a very important factor in identifying the bacteria sources (feces from which animals). As an example, Streptococcus bovis and S. equinus have not been found in human feces by several projects. (These types, however, are the predominant fecal strep. type found in livestock feces.) Their absence in a sample indicates the probable absence of livestock feces contamination.

Table B-4 lists the feces samples in which different bacteria types were found, along with their relative concentrations. Geldreich and Kenner (1969) stated that the absence of fecal strep. bacteria indicates the absence of warm blooded fecal pollution. The presence of Streptococcus faecalis indicates human fecal contamination. S. faecalis far outnumbers S. inulinaceus in sewage and in sewage polluted waters, even though S. inulinaceus is in great abundance in fresh feces (Bartley and Slanetz, 1960). S. faecalis var. liquefaciens is ubiquitous as it is present in almost all samples tested (Geldreich and Kenner, 1969; Bartley and Slanetz, 1960). S. mitis and S. salivarius are considered sensitive indicators of human pollution when they are found (Seidler, 1979). S. bovis and S. equinus are nearly ideal non-human mammal fecal indicators (Seidler, 1979). They have rapid die-off rates (much faster than fecal coliform die-offs) and are the most sensitive bacteria in the fecal strep. category. Their presence indicates

Table B-3. Test Samples Where Specific Bacteria Types Were Not Generally Found

Bacteria types	Organisms that tested negative	Reference
Aerobactor	Pine Squirrel feces	Drake, et al, 1961
Escherichia	Pine Squirrel feces Pocket Gopher feces	Drake, et al, 1961
Pseudomonas aeruginosa	not normally found in lower animals' feces	Cabelli, et al, 1976
	not usually found in non-human feces	Olivieri, Kruse, and Kawata, 1977b
Salmonella	rare in Texas stream sediments, soils and lake sediments	Davis, 1979
	negligible contamination of Oregon surface waters by livestock grazing	Seidler, 1979
	not found in Ottawa storm-water outfalls	Environment Canada, 1980
S. agona	rare in Rideau River waters	Environment Canada, 1978
S. haardt	rare in Rideau River waters	Environment Canada, 1978
S. saint paul	rare in Rideau River waters	Environment Canada, 1978
Fecal Streptococci	very little in remote streams and soils	Geldreich and Kenner, 1969
	not permanent in fish intestines (only present when food or water is contaminated)	Geldreich, 1965
Streptococcus faecalis	not found in most domestic animals	Bartley and Slanetz, 1960
S. faecalis var. liquefaciens	not found in duck feces	Geldreich and Kenner, 1969
Atypical S. faecalis	not found in human feces	Geldreich and Kenner, 1969
	not found in cow feces	"
	not found in pig feces	"
	not found in sheep feces	"
	not found in duck feces	"
	not found in chicken feces	"
	not found in turkey feces	"
	not found in insects	"
	not found in agric. soils	"
S. bovis/ S. equinus	not found in human feces	Geldreich, 1965 Geldreich & Kenner, 1969 Seidler, 1979
	none found in 3,100 Cinncinnati stormwater bacteria strains	Geldreich, et al, 1968
S. zymogenes	none found in reptiles	Mundt, 1963
Enterococci	very few on vegetation and litter	Seidler, 1979
	generally not found in strongly herbivorous or subsurface ground dwellers	Mundt, 1963

Table B-4. Test Samples Where Specific Bacteria Types Were Found

Bacteria types	Samples that tested positively (relative abundance)	Reference*
Aerobactor	Chipmunk feces (33% positive)	6
	Ground squirrel feces (40% positive)	6
	Pocket gopher feces (100% positive)	6
	Cottontail rabbit feces (33% positive)	6
	Jackrabbit feces (75 to 100% positive)	6
	Deer mice feces (50% positive)	6
	Meadow mice feces (40% positive)	6
Escherichia	Chipmunk feces (67% positive)	6
	Ground squirrel feces (0 to 50% positive)	6
	Cottontail rabbit feces (67% positive)	6
	Jackrabbit feces (25 to 100% positive)	6
	Deer mice feces (64% positive)	6
	Meadow mice feces (80% positive)	6
Edwardsiella tarda	Gull feces (0.4% positive)	2
Klebsiella pneumoniae	Human feces (30 to 40% positive)	14
Vibrio cholerae	Construction sites (regular contributor)	4
Shigella dysenteriae	Construction sites (regular contributor)	4
Staphylococci	Bath and laundry waters	18
	Texas stream sediments (20 to 240/gram)	4
	Texas soils (160 to 1,000/gram)	4
	Texas lake sediments (15 to 2,600/gram)	4
Pseudomonas aeruginosa	Human feces (ubiquitous)	18
	Sewage	8
	Rideau River (fairly common)	7
	Deer feces	6
	Song Sparrow feces	6
	Textile mill (non-fecal) effluent	3
	Texas stream sediments (<20 to 20/gram)	4
	Texas soils (<20 to 1,000/gram)	4
	Texas lake sediments (15 to 2,600/gram)	4
Salmonella	Household and kennel dog feces (15 to 20%)	16
	Agricultural animal feces (frequent)	12
	Sheep feces (from contaminated feed) (3 to 15%)	20
	Wild bird (grackles, cowbirds, starlings and gulls) feces	21

Table B-4 (cont.). Test Samples Where Specific Bacteria Types Were Found

Bacteria types	Samples	Reference
S. typhimurium	Domestic pets and wild animal (raccoon, skunk, and muskrat) feces	19
	Rideau River water	7
	Gull feces (5 to 8%)	2,10
	Grackles (birds) feces (2%)	21
	Cowbird feces (4%)	21
	Starling feces (5%)	21
S. thompson	Domestic pets and wild animal (raccoon, skunk, and muskrat) feces	19
	Gull feces (13%)	10
S. typhi	Construction sites (regular contributor)	4
S. paratyphi	Construction sites (regular contributor)	4
S. blockley	Herring gull feces (2%)	21
	Starling feces (5%)	21
S. saint paul	Starling feces (9%)	21
S. braenderup	Herring gull feces (2%)	21
S. munchen	Herring gull feces (2%)	21
S. derby	Herring gull feces (2%)	21
S. enteritidas	Herring gull feces (2%)	2,21
S. heidelberg	Herring gull feces (2%)	21
S. infantis	Herring gull feces (2%)	21
S. montevideo	Herring gull feces (2%)	21
S. panama	Herring gull feces (2%)	21
S. reading	Gull feces (10%)	2
Fecal Streptococci	Stormwater (greater abundance than fecal coliforms)	13
	Farm animals, dogs, cats and various wild animal feces (greater abundance than fecal coliforms)	13
	Dog feces (great variety of fecal strep. types)	1
	Canadian geese and whistling swan feces (more fecal coliform)	15
	Vegetation (due to insects)	5

Table B-4 (cont.). Test Samples Where Specific Bacteria Types Were Found

Bacteria type	Sample	Reference
Streptococcus faecalis	Human feces (may be predominant type)	1,11,20
	Mammal feces (11%)	1,17,20
	Dog feces (may be predominant type)	11
	Cat feces (may be predominant type)	11
	Hog feces	1
	Chicken feces	1
	Rodent feces (may be predominant type)	11
	Reptile feces (20%)	17
	Bird feces (9%)	17
	Insect feces	1
	Vegetation (due to insects?)	20
	Soil	20
S. faecalis var. *liquifaciens*	Present in most samples tested (ubiquitous)	1,13
	Human feces (26%)	1,13
	Mammal feces (22%)	17
	Dog feces (10%)	1
	Cat feces (6%)	1
	Cow feces (4%)	1
	Sheep feces (19%)	1
	Pig feces (2%)	1
	Bird feces (14%)	17
	Chicken feces (22%)	1,13
	Turkey feces (22%)	1
	Reptile feces (61%)	17
	Rodent feces (35%)	1
	Insects (48%)	1
	Freshwater fish (17%)	1
	Vegetation (13%)	1
	Agricultural soils (35%)	1
Atypical *S. faecalis*	Human feces	17,20
	Mammal feces (36%)	17
	Dog feces (14%)	13
	Cat feces (2%)	13
	Pig feces	1
S. facium	Bird feces (9%)	17
	Fowl feces	20
	Chicken feces	1
	Reptile feces (13%)	17
	Rodent feces (0.4%)	13
	Insects	1
	Freshwater fish (3%)	13
	Vegetation (35%)	13
	Soil	20

Table B-4 (cont.). Test Samples Where Specific Bacteria Types Were Found

Bacteria type	Sample	Reference
S. facium var. caselliflauus	Fowl feces	20
	Vegetation (significant)	20
	Soil	20
S. bovis and S. equinus	Dog feces (32% significant amount)	11,13
	Cat feces (2%)	11,13,20
	Livestock (predominant fecal strep.)	11
	Cow feces (66% significant amounts)	13
	Sheep feces (42% significant amounts)	13
	Pig feces (19% significant amounts)	13
	Duck feces (49% significant amounts)	13
	Chicken feces (1% trace amounts)	13,20
	Turkey feces (2% trace amounts)	13,20
	Rodent feces (17% significant amounts)	11,13
	Freshwater fish (7%)	13
	Vegetation (9%)	13
	Agricultural soils (2%)	13
S. bovis	Most non-human mammal feces	20
	Cow feces	1,20
	Sheep feces	20
	Deer feces	20
S. equinus	Horse feces (predominant)	1,20
	Pig feces	1
S. mitus and S. salivarius	Human feces (can be predominant fecal strep.)	20
	Suburban runoff (septic tank failures)	20
	Stream sediments (septic tank failures in area)	20
S. durans	Human feces	20
	Mammal feces	20
	Vegetation	20
	Soil	20
S. zymogenes	Mammal feces	17
	Bird feces	1
S. inulinaceus	Human feces (great abundance in fresh samples)	1
	Chicken feces (great abundance in fresh samples)	1
Enterococci	Ubiquitous (survive better than fecal coliforms)	9,20
	Human feces (74% predominant)	13
	Large animals with varied diet (common)	17

Table B-4 (cont.). Test Samples Where Specific Bacteria Types Were Found

Bacteria type	Sample	Reference
	Dog feces (44%)	13
	Cat feces (90% predominant)	13
	Cow feces (30%)	13
	Sheep feces (39%)	13
	Pig feces (79% predominant)	13
	Fowl feces (predominant)	20
	Duck feces (51%)	13
	Chicken feces (77% predominant)	13
	Turkey feces (77% predominant)	13
	Rodent feces (47%)	13
	Insects (52%)	13
	Freshwater fish (74%)	13
	Vegetation (43%)	13
	Agricultural soils (63%)	13
Raffinose fermenters	Cow feces	1
	Chicken feces	1

* Table B-4 references:

1. Bartley and Slanetz, 1960
2. Berg and Anderson, 1972
3. Cabelli, Kennedy, and Levin, 1976
4. Davis, 1979
5. Van Donsel, Geldreich, and Clarke, 1967
6. Drake, Woods, and Hammerstrom, 1961
7. Environment Canada, 1978
8. Environment Canada, 1980
9. Feachem, 1975
10. Fennell, James, and Morris, 1974
11. Geldreich, 1965
12. Geldreich, et al, 1968
13. Geldreich and Kenner, 1969
14. Geldreich, 1976
15. Geldreich, 1980
16. Marron and Senn, 1974
17. Mundt, 1963
18. Olivieri, Kruse, and Kawata, 1977b
19. Qureshi and Dutka, 1979
20. Seidler, 1979
21. Snoeyenbos, Morin, and Wetherbee, 1967

recent livestock pollution (Feacham, 1975; Geldreich, 1976; Bartley and Slanetz, 1960; Geldreich and Kenner, 1969).

Table B-5 summarizes the bacteria concentrations observed in feces samples from different mammals and birds. Drake, Woods, and Hammerstrom (1961) found a wide variation in the coliform content of some wild and domestic animal feces. Coliform bacteria were present in small numbers or were absent for some feces, such as from rabbits, shrews, deer, elk, some squirrels, and many birds. Mouse, chipmunk, and other squirrel feces samples have coliform bacteria concentrations ranging from absent to very large numbers. They also stated that coliform bacteria were not found in some carnivores (shrews) but were present in large numbers in other carnivores (coyotes and bears). They also found no significant differences in the fecal coliform content of different animals of the same species that were collected in different areas. However, feces from different species of animals collected in the same area could have large differences in their fecal coliform concentrations. They also noted that some mammals (coyote, bear, some gophers, and some squirrels) had coliform concentrations in their feces that were similar to human coliform concentrations. Animals with soft or moist feces (man and many domestic animals such as cows, dogs, and pigs) had very high numbers of coliform bacteria (many thousands to millions of coliform bacteria per gram). The feces of other animals, especially those with hard or dry feces, may contain few or no coliform bacteria.

Geldreich (1976) summarized a study that showed the variations in fecal strep. bacteria concentrations in human feces from different locations. Feces collected from humans living in Cincinnati had concentrations more than five times greater than samples collected from healthy people in Nagpur, India (13 million and 2 million fecal strep. organisms per gram, respectively). He also reported that fecal strep. densities in farm animal, cat, dog, mice, and chipmunk feces samples were in the order of millions of organisms per gram. Rabbit feces fecal strep. concentrations, however, may be several orders of magnitude lower than those found in other animals. It is interesting to note that the Ottawa waterbird feces samples were reported to have the largest total coliform, fecal coliform, and fecal strep. concentrations when compared to all other samples reported (except for the fecal strep. dog feces concentrations). Gull feces generally have the highest fecal coliform concentrations in their feces, followed by Ottawa pigeons, ducks, dogs, sheep, and humans. Other urban bird feces (pigeons, sparrows, robins, starlings, and blackbirds) were all reported to have much lower fecal coliform concentrations, except for some Ottawa pigeon feces fecal coliform concentrations that were unusually high.

B.9 FECES DISCHARGES FROM WILDLIFE

Table B-6 summarizes reported discharges of feces from different mammals and birds. These discharges are expressed in grams per animal per day and vary quite widely, depending on the study. Animals can deposit substantial quantities of feces in an urban area, depending upon the animal's population. Geldreich (1976) stated that major contributions of bacteria in urban communities are from fecal discharges from cats, dogs, and rodents. These feces are deposited on soil, asphalt, and cement. He stated that the one-half million dogs in New York City deposit about 150,000 pounds of feces on the streets, sidewalks, and park areas per day. Significant populations of rodents may also contribute large amounts of

Table B-5. Bacteria Concentrations in Feces Samples (MPN of organisms/gram feces) (reference)

Organism	Total Coliforms	Fecal Coliforms	Fecal Strep.
Mammals			
Humans	86,000 to 230,000,000 (1)	13,000,000 (med) (5)	1,900,000 (med) (5)
Farm animals			
pig		3,300,000 (med) (5)	84,000,000 (med) (5)
sheep		16,000,000 (med) (5)	38,000,000 (med) (5)
cow		230,000 (med) (5)	1,300,000 (med) (5)
horse		13,000 (med) (5)	6,300,000 (med) (5)
Rural wildlife			
coyote	1,200,000 (1)		
bear	200,000 (1)		
mule deer	2 to 27; 11 (med) (1)		
elk	4 to 10,000; 4 (med) (1)	5,100 (med) (5)	760,000 (med) (5)
Domestic pets			
cat	7,900,000 (med) (3)	7,900,000 (med) (3)	27,000,000 (med) (3)
dog	23,000,000 (med) (3)	23,000,000 (med) (5)	980,000,000 (med) (3)
Possible urban wildlife			
cottontail rabbit	1400 to 2200; 1800 (med) (1)		
white-tailed rabbit	132 (1)		
black-tailed jackrabbit	92 to 10,000; 920 (med) (1)		
rabbit	90 (med) (3)	20 (med) (3)	47,000 (med) (3)
rodents		160,000 (med) (4)	4,600,000 (med) (4)
rats	330,000 (med) (3)	180,000 (med) (4)	79,000,000 (med) (5)
		330,000 (med) (3)	7,700,000 (med) (3)
shrews	none (1)		
deer mice	4600 to 330,000; >250,000 (med) (1)		
meadow mice	180,000 to 290,000; 220,000 (med) (1)		
field mice		330,000 (med) (5)	7,700,000 (med) (5)
pocket gopher	2,000,000 (1)		
chipmunks	7000 to 4,600,000; 30,000 (med) (1) 150,000 (med) (3)	150,000 (med) (3)	6,000,000 (med) (3)
golden-mantled ground squirrel	19,800 (1)		
columbian ground squirrel	100,000 to >16,000,000; 8,000,000 (med) (1)		
pine squirrel	27 (1)		
Birds			
Farm birds			
chicken		1,300,000 (med) (5)	3,400,000 (med) (5)
turkey		290,000 (med) (5)	2,800,000 (med) (5)
Rural birds			
quail	2 to 349; 7 (med) (1)		
pheasant	19 to 23,000; 1800 (med) (1)		

Table B-5 (cont.). Bacteria Concentrations in Feces Samples

Organism	Total Coliforms	Fecal Coliforms	Fecal Strep.
Possible urban land-birds			
robin	221 (1)	25,000 (med) (5)	12,000,000 (med) (5)
song sparrow	2 to 349; 6 (med) (1)		
english sparrow		25,000 (med) (5)	1,000,000 (med) (5)
oregon junco			
starling		10,000 (med) (5)	12,000,000 (med) (5)
red-winged blackbird		9000 (med) (5)	11,000,000 (med) (5)
pigeon		10,000 (med) (5) to 100,000,000 (2)	12,000,000 (med) (5)
Possible urban waterbirds			
Lake Merritt waterbirds (composite)	200,000 (7)	200,000 (7)	920,000 (7)
Ottawa (fresh samples) waterbirds (composite)	91,000,000 to 4,400,000; 130,000,000 (med) (2)	78,000,000 to 2,900,000,000; 120,000,000 (med) (2)	470,000 to 280,000,000; 180,000,000 (med) (2)
Ottawa (aged samples) waterbirds (composite)	600,000,000 to 5,500,000,000; 3,100,000,000 (med) (2)	550,000,000 to 4,500,000,000; 2,500,000,000 (med) (2)	51,000,000 to 1,300,000,000; 650,000,000 (med) (2)
swan	480,000 (2)	320,000 (2)	45,000 (2)
herring gull		71,000,000 (6)	810,000 (6)
lesser black-backed gull		370,000,000 (2)	1,100,000 (2)
common gull		53,000,000 (2)	90,000 (2)
black-headed gull		27,000,000 (2)	200,000 (2)
duck		33,000,000 (med) (5)	54,000,000 (med) (5)
goose			840,000 (med) (5)

References:
(1) Drake, Woods, and Hammerstorm, 1961
(2) Environment Canada, 1980
(3) Geldreich, et al, 1968
(4) Geldreich and Kenner, 1969
(5) Geldreich, 1976
(6) Gore and Storrie/Proctor and Redfern, 1981a
(7) Pitt and Bozeman, 1979

Table B-6. Feces Discharges

Animal	Discharge* (grams/animal/day)	reference
Mammals		
Humans	150	1
Farm animals		
pig	680	4
sheep	1,100	4
cow	7,000	4
horse	7,000	4
Domestic pets		
cat	70	4
dog	140	4
	23 to 100	5
Possible urban wildlife		
rabbit	550	4
rat	35	4
mouse	10	4
Birds		
Farm birds		
chicken	55	4
	180	1
turkey	160	4
	450	1
Possible urban birds		
pigeon	25 to 50	2
gulls	10 to 25	3
duck	70	4
	340	1
goose	160	4

* estimated application factors: 0.01 for land animals and 0.5 for waterfowl

References:
1. Geldreich, 1976
2. Gore & Storrie/Proctor & Redfern, 1981a
3. Gould and Fletcher, 1978
4. Howe, 1969
5. Marron and Senn, 1974

fecal material in urban areas. Fortunately, very little of this fecal bacteria enters receiving waters. Faust (1976), in an agricultural watershed in the Rhode River near Chesapeake Bay, found that only about one percent of the fecal coliform bacteria deposited by cattle in the watershed was washed into the receiving waters. Sometimes the yields (application rates) were higher, with high values around 5 percent and on one occasion reaching 25 percent. They concluded that fecal coliform discharges can be substantial from a watershed that has the equivalent of about one-half cow per hectare. Evans and Owens (1973), from a study in Scotland, stated that most of the bacteria in the runoff water came from the soil. They found that the soil bacteria washoff yield was only about one-tenth of one percent of the estimated total soil bacteria population. They felt that the maximum annual discharge of bacteria from the contaminated soil would only be about 0.15 percent of the total soil bacteria population.

B.10 MAMMAL AND BIRD POPULATIONS AND BACTERIA DISCHARGES IN URBAN AREAS

Table B-7 summarizes the expected populations of mammals and birds in the lower Rideau River watershed. There are other domestic and wild animals in this watershed (such as other birds and rodents) but their population estimates are not available. It is estimated that about 16,000 dogs and the same number of cats live in this watershed, corresponding to approximately one dog or cat for every other house. The waterbird estimates are based upon actual population counts made along the river.

Table B-8 is an estimate of the total annual bacteria discharges from these mammals and birds based upon these population estimates, the fecal discharges, the application factors, and the bacteria concentrations in the feces. The total estimated discharges are two to three orders of magnitude greater than what is expected in the annual urban runoff bacteria yield. This large difference may be associated with bacteria die-off or by laboratory analysis procedures. If the urban runoff samples were not completely mixed before analysis, each reported organism could actually be associated with many organisms from a clump of feces.

As a rough estimate, the values in Table B-8 may all be considered to be affected by the same die-off rates and analytical measurement methods. The percentage contributions associated with each animal may, therefore, be reasonably valid. The major source of fecal coliforms in the Rideau River is expected to be pigeons (when using the high Ottawa pigeon fecal coliform values), followed by dogs and ducks. The other sources shown would all contribute less than a total of five percent. Dogs are expected to contribute almost half of the river total coliform organisms, while pigeons on the bridges and ducks on the river make up most of the remainder. Dogs are expected to contribute almost all of the river fecal strep. bacteria, with ducks on the river contributing less than five percent. Pitt and Bozeman (1979) found that lake birds can contribute a significant amount of fecal strep. bacteria to a lake refuge in the middle of an urban area. However, urban runoff components contribute much more bacteria during wet weather conditions.

It is interesting to compare these calculated estimates of fecal coliform contributions with those reported elsewhere. Faust and Goff (1977) reported 10^9 to 10^{10} fecal coliforms discharged per hectare per year in the Chesapeake Bay area from cultivated lands, forests, and pastures. These values are about ten to 100 times the estimated urban area yields for the lower Rideau River watershed (see Section 8).

Table B-7. Estimated Bird and Pet Populations for Lower Rideau River Watershed (below Hogs Back)

Animal	Population Density (animals/ha)	Total estimated in Lower Rideau River Watershed (4000 ha)
Dogs(1)	4	16,000
Cats(1)	4	16,000
Robins(2)	7	28,000
Pigeons (land)(1)	1	4,000
Pigeons (on bridges)(3)	---	600
Ducks (on river)(3)	---	100
Gulls (on river)(3)	---	150
Swans (on river)(3)	---	15
Other birds on river(3) (sparrows and blackbirds)	---	10

(1) estimated from Colt, Tanj, and Tchobanoglous, 1977

(2) estimated from Howard, 1974

(3) Regional Municipality of Ottawa-Carleton, 1980

Table B-8. Annual Bacteria Yield Estimates from Different Sources

Animal	Animal Pop. in Lower Rideau R. Watershed	Feces Discharge (grams/ animal-day)	Annual Feces Discharge (grams/ year)	Application Factor (fraction to river)	Equivalent Feces Discharge to River (grams/ year)	Total Coliforms MPN/gram	Total Coliforms MPN/yr	Total Coliforms % of total	Fecal Coliforms MPN/gram	Fecal Coliforms MPN/yr	Fecal Coliforms % of total	Fecal Strep. MPN/gram	Fecal Strep. MPN/yr	Fecal Strep. % of total
Discharge to Land:														
Dog	16,000	100	$6x10^8$	0.01	$6x10^6$	$2.3x10^7$	$1.4x10^{14}$	54	$2.3x10^7$	$1.4x10^{14}$	19	$9.8x10^8$	$.5.9x10^{15}$	95
Cat	16,000	70	$4x10^8$	0.001	$4x10^5$	$7.9x10^6$	$3.2x10^{12}$	1	$7.9x10^6$	$3.2x10^{12}$	<1	$2.7x10^7$	$1.1x10^{13}$	<1
Robins	28,000	10	$1x10^8$	0.01	$1x10^6$	$2.2x10^2$	$2.2x10^8$	<1	$2.5x10^4$	$2.5x10^{10}$	<1	$1.2x10^7$	$1.2x10^{13}$	<1
Pigeons (land)	4,000	35	$5x10^7$	0.01	$5x10^5$	$1.3x10^7$	$6.5x10^{12}$	3	$1.0x10^8$	$5.0x10^{13}$	7	$1.2x10^7$	$6.0x10^{12}$	<1
Direct Discharge to River:														
Pigeons (on bridge)	600	35	$8x10^6$	0.5	$4x10^6$	$1.3x10^7$	$5.2x10^{13}$	20	$1.0x10^8$	$4.0x10^{14}$	54	$1.2x10^7$	$4.8x10^{13}$	1
Ducks (on river)	100	200	$2x10^7$	0.5	$3x10^6$	$1.3x10^7$	$4.8x10^{13}$	18	$3.3x10^7$	$1.2x10^{14}$	16	$5.4x10^7$	$2.0x10^{14}$	3
Gulls (on river)	150	20	$1x10^6$	0.5	$5x10^5$	$1.3x10^7$	$6.5x10^{12}$	3	$5.3x10^7$	$2.7x10^{13}$	4	$9.0x10^4$	$4.5x10^{10}$	<1
Swans (on river)	15	200	$1x10^6$	0.5	$5x10^5$	$4.8x10^5$	$2.4x10^{11}$	<1	$3.2x10^5$	$1.6x10^{11}$	<1	$4.5x10^4$	$2.3x10^{10}$	<1
Other birds (on river)	10	10	$4x10^4$	0.5	$2x10^4$	$1.3x10^7$	$2.6x10^{11}$	<1	$2.5x10^4$	$5.0x10^8$	<1	$5.0x10^6$	$1.0x10^{11}$	<1
Total from urban runoff							$1.5x10^{14}$	58		$1.9x10^{14}$	26		$5.9x10^{15}$	96
Total direct discharge to river							$1.1x10^{14}$	42		$5.5x10^{14}$	74		$2.5x10^{14}$	4
Grand Total							$2.6x10^{14}$			$7.4x10^{14}$			$6.2x10^{15}$	

APPENDIX C
URBAN RUNOFF BACTERIA TYPES AND THEIR SANITARY SIGNIFICANCE

It is important to understand the meanings of the different coliform indicator tests. The fecal coliform test is not specific for any one coliform type, or groups of types, but instead has an excellent positive correlation for coliform bacteria derived from the intestinal tract of warm blooded animals (Geldreich, et al, 1968). The fecal coliform test measures Escherichia coli as well as all other coliforms that can ferment lactose at 44.5°C and are found in warm blooded fecal discharges. Geldreich (1976) found that the fecal coliform test represents over 96 percent of the coliforms derived from human feces and from 93 to 98 percent of those discharged in feces from other warm blooded animals, including livestock, poultry, cats, dogs, and rodents. The variations in the specific fecal coliform bacteria biotypes are related to both fecal moisture content and diet, as shown in Appendix B. Moisture and diet may also affect the variety of bacteria biotypes found in the fecal coliform populations from different animal groups. In many urban runoff studies, all of the fecal coliforms were E. coli (Quresh and Dutka, 1979). Fecal strep. bacteria are all of the intestinal Streptococci bacteria from warm blooded animal feces (Geldreich and Kenner, 1969). The types and concentrations of different bacteria biotypes varies for different animal sources. Qureshi and Dutka (1979) found that pathogenic bacteria biotypes are present in southern Ontario urban runoff and are probably from several different sources.

C.1 EFFECTS OF PATHOGENS IN URBAN STORMWATER

Van Donzel, Geldreich, and Clarke (1967) reviewed water-borne disease outbreak information for 1946 to 1960. Almost 26,000 cases were listed for almost 230 known outbreaks in the United States and Puerto Rico. At least 29 of these outbreaks, involving more than 9,000 cases, were associated with stormwater runoff caused by either runoff washing human and animal feces or sewage into wells, springs, streams, reservoirs, and open water mains, or by widespread flooding of individual and public water systems. Qureshi and Dutka (1979) have mentioned the potential health hazards of stormwater discharges throughout rain events in southern Ontario.

Several authors, however, did not think that urban runoff may present a significant health problem. Olivieri, Kruse, and Kawata (1977a) did not believe that urban runoff constitutes a major health problem because of the large numbers of viable bacteria cells that must be consumed to establish an infection. For urban runoff, it may be impossible to consume enough bacteria cells to establish the infective dose. The importance of urban runoff in disease transmission in the Ottawa area was also questioned by Gore and Storrie/Proctor and Redfern (1981b). They stated that little or no correlations were found between indicator and pathogenic bacteria in the stormwater runoff and receiving waters. They further stated that the currently applied objectives in Ottawa for fecal coliforms for body contact recreation are neither universal nor absolute standards relating to disease or infection. They concluded that these numeric objectives should be reviewed for their applicability to the Rideau River beaches.

C.2 HEALTH EFFECTS ASSOCIATED WITH SALMONELLA IN URBAN RUNOFF

Salmonella has been reported in some but not all urban stormwaters. Qureshi and Dutka (1979) frequently detected Salmonella in southern Ontario stormwaters. They did not find any predictable patterns of Salmonella isolations as they were found throughout the various sampling periods. Olivieri, Kruse, and Kawata (1977a) found Salmonella frequently in Baltimore runoff, but at relatively low concentrations and required sample concentration. Typical concentrations were from five to 300 Salmonella organisms/ten liters. The concentrations of Salmonella were about ten times higher in the stormwater samples than in the urban stream receiving the runoff. They also did not find any marked seasonal variations in Salmonella concentrations. Field, et al (1976) also stated that Salmonella were frequently found in most Baltimore urban runoff samples. Almost all of the stormwater samples that had fecal coliform concentrations greater that 2000 organisms/100 mL had detectable Salmonella concentrations. About 27 percent of the samples having fecal coliform concentrations less than 200 organisms/100 mL had detectable Salmonella.

However, quite a few urban runoff studies did not detect Salmonella. Schillinger and Stuart (1978) found that Salmonella isolations were not common in a Montana subdivision study and that the isolations did not correlate well with fecal coliform concentrations. Environment Canada (1980) stated that Salmonella were virtually absent from Ottawa storm drainage samples in 1979. They concluded that Salmonella are seldom present in significant numbers in Ottawa urban runoff. The types of Salmonella found in southern Ontario were <u>S. thompson</u> and <u>S. typhimurium</u> var. <u>copenhagen</u> (Qureshi and Dutka, 1979).

Olivieri, Kruse, and Kawata (1977b) stated that the primary human enteric disease producing Salmonella biotypes associated with the ingestion of water include <u>S. typhi</u> (typhoid fever), <u>S. paratyphi</u> (paratyphoid fever), and Salmonella species (salmonellosis). These biotypes are all rare except for Salmonella. The dose of Salmonella required to produce an infection is quite large (approximately 10^5 organisms). The salmonellosis health hazard associated with water contact in urban streams is believed to be small because of this relatively large infective dose. If two liters of stormwater having typical Salmonella concentrations (ten Salmonella organisms per/ten liters) is ingested, less than 0.001 of the required infective dose would be ingested. If a worse case Salmonella stormwater concentration of 10,000 organisms/ten liters occurred, the ingestion of 20 liters of stormwater would be necessary for an infective dose. They stated that the low concentrations of Salmonella, coupled with the unlikely event of consuming enough stormwater, make the Salmonella health hazard associated with urban runoff small.

Geldreich (1965) recommended a fecal coliform standard of 200 organisms/100 mL because the frequency of Salmonella detection increased sharply at fecal coliform concentrations greater than this value. Setmire and Bradford (1980) stated that the National Academy of Sciences recommends a fecal coliform standard of 70/100 mL in waters with shellfish harvesting to restrict Salmonella concentrations in edible tissues. Field, et al (1976) concluded that the use of indicator bacteria to protect Salmonella ingestion is less meaningful in stormwater runoff than in other waters.

Marron and Senn (1974) pointed out the possibility of dogs transmitting salmonellosis. They did not feel that this constitutes a serious public health threat but people should be aware of the possibility of infection and direct contact with dog feces should be minimized.

C.3 HEALTH EFFECTS ASSOCIATED WITH STAPHYLOCOCCI IN URBAN RUNOFF

Staphylococcus aureus is an important human pathogen as it can cause boils, carbuncles, abscesses, and impetigo on skin on contact. Olivieri, Kruse, and Kawata (1977b) stated that the typical concentrations of Staphylococci are not very high in urban streams. They also stated that there was little information available relating the degree of risk of staph. infections with water concentrations. They concluded that Staph. aureus appears to be the most potentially hazardous pathogen associated with urban runoff, but there is no evidence available that skin, eye, or ear infections can be caused by the presence of this organism in recreational waters. They concluded that there is little reason for extensive public health concern over recreational waters receiving urban storm runoff containing staph. organisms. Urban storm runoff and its receiving waters are typically aesthetically unattractive because of litter and high suspended solids concentrations during and immediately following storm events. Body contact recreation during these times when the pathogenic microorganism concentrations may be high is therefore limited.

C.4 HEALTH EFFECTS ASSOCIATED WITH SHIGELLA ORGANISMS IN URBAN RUNOFF

Olivieri, Kruse, and Kawata (1977b) stated that there is circumstantial evidence that Shigella is present in urban runoff and receiving waters and could present a significant health hazard. There are current problems in isolating and quantifying Shigella bacteria. Shigella species causing bacillary dysentery are one of the primary human enteric disease producing bacteria agents present in water. The infective dose of Shigella necessary to cause dysentery is quite low (ten to 100 organisms). Because of this low required infective dose and the assumed presence of Shigella in urban waters, it may be a significant health hazard associated with urban runoff.

C.5 HEALTH EFFECTS ASSOCIATED WITH STREPTOCOCCUS IN URBAN RUNOFF

Streptococcus faecalis and atypical S. faecalis are of limited sanitary significance (Geldreich, 1976). Streptococcus determinations on urban runoff are most useful for identifying the presence of S. bovis and S. equinus that are specific indicators of non-human, warm blooded animal pollution. However, it is difficult to interpret fecal strep. data when their concentrations are lower than 100 organisms/100 mL because of the ubiquitous occurrence of S. faecalis var. liquifaciens. This biotype is generally the predominant strep. biotype occurring at low fecal strep. concentrations.

C.6 HEALTH EFFECTS ASSOCIATED WITH PSEUDOMONAS AERUGINOSA IN URBAN RUNOFF

Pseudomonas is reported to be the most abundant pathogenic bacteria organism in urban runoff and streams (Olivieri, Kruse, and Kawata (1977b). This pathogen is associated with eye and ear infections and is resistant to antibiotics. They also stated that past studies have failed to show any relationships between *P. aeruginosa* concentrations in bathing waters and ear infections. However, Pseudomonas concentrations in urban runoff are at significantly greater concentrations (about 100 times) than the values associated with past bathing beach studies. Cabelli, Kennedy, and Levin (1976) stated that *Pseudomonas aeruginosa* is indigenous in about 15 percent of the human population. Swimmer's ear or other Pseudomonas infections may, therefore, be caused by trauma to the ear canals associated with swimming and diving, and not exposure to Pseudomonas in the bathing water.

Environment Canada (1980) stated that there is preliminary evidence of the direct relationship between very low levels of *Pseudomonas aeruginosa* and an increase in incidents of ear infections in swimmers. They stated that a control level for this Pseudomonas biotype of between 23 and 30 organisms/100 mL is being considered. Cabelli, Kennedy, and Levine (1976) stated that *P. aeruginosa* densities greater than ten organisms/100 mL were frequently associated with fecal coliform levels considerably less than 200 organisms/100 mL. *P. aeruginosa* densities were sometimes very low when the fecal coliform levels were greater than 200 organisms/100 mL. An average estimated *P. aeruginosa* density associated with a fecal coliform concentration of 200 organisms/100 mL is about 12/100 mL. They further stated that *P. aeruginosa* by itself cannot be used as a basis for water standards for the prevention of enteric diseases during recreational uses of surface waters. The determinations of this biotype should be used in conjunction with fecal coliform or other indicator organism concentrations for a specific location. They recommended that bathing beaches that are subject to urban runoff pollution be temporarily closed until the *P. aeruginosa* concentrations return to a baseline concentration.

C.7 HEALTH EFFECTS OF OTHER PATHOGENS IN URBAN RUNOFF

Candida albicans is a yeast found in Ottawa area urban runoff and receiving waters (Environment Canada, 1980). This yeast can cause oral, cutaneous, and vaginal mycosis. Other potential health problems associated with urban runoff might be from histoplasmosis and cryptococcosis that are associated with accumulations of guano at various bird roosts in or near areas of human habitation (Locke, 1974).

E. coli and *Vibrio cholerae* are disease producing pathogens associated with the ingestion of water. The cholera pathogen is quite rare, but *E. coli* is more common in urban runoff. The required infective dose of both of these pathogens is about 10^8 organisms (Olivieri, Kruse, and Kawata, 1977b).

Dog feces are capable of transmitting many diseases, including leptospirosis, brucellosis, toxoplasmosis, tuberculosis and other diseases. However, these problems are quite rare and do not indicate a serious public health threat. Visceral larval migrans (VLM) is the most serious disease associated with dog feces. This mostly affects children under four years of age who ingest the bacteria through ingestion of feces or contaminated soil. Symptoms include blindness.

Viruses may also be important pathogens in urban runoff. Very small amounts of a virus are capable of producing infections or disease, especially when compared to the large numbers of bacteria organisms required for infection (Berg, 1965). The quantity of enteroviruses which must be ingested to produce infections is usually not known (Olivieri, Kruse, and Kawata, 1977b). Viruses are usually detected at low levels in urban receiving waters and storm runoff. They stated that even though the minimum infective doses may be small, the information available indicates that stormwater virus threats to human health is small. Because of the low levels of virus necessary for infection, dilution of viruses does not significantly reduce their hazard.

C.8 PATHOGENS OBSERVED IN URBAN RUNOFF

Table C-1 summarizes the pathogenic bacteria biotypes that have been observed in the Rideau River. The occurrence of Salmonella biotypes is low and their reported density is less than one organism/100 mL. Pseudomonas aeruginosa are frequently encountered at densities greater than ten organisms/100 mL, but only after rains. As a comparison, Tables C-2 and C-3 show typical pathogenic bacteria biotype concentrations found in raw sanitary wastewaters. The occurrence of these bacteria biotypes is much greater in sanitary wastewaters than in urban runoff. Table C-4 summarizes the occurrence of various pathogenic bacteria types found in urban stormwaters at various sites. The observed ranges of concentrations and percent isolations of these biotypes vary significantly from site to site and at the same location for different times. However, it is seen that many of the potentially pathogenic bacteria biotypes can be present in urban stormwater runoff. Table C-5 lists the pathogenic bacteria biotypes that affect mammals and birds and that can be transmitted by contaminated water. Many of these biotypes, of course, are rare but this table does demonstrate the wide range of possible diseases that can be transmitted by polluted waters, including urban runoff.

C.9 SUMMARY

Many potentially pathogenic bacteria biotypes may be present in urban runoff. Because of the low probability of ingestion of urban runoff, many of the potential human diseases associated with these biotypes are not likely to occur. The pathogenic organisms of most concern in urban runoff are usually associated with skin infections and body contact. The most important biotype causing skin infections would be Pseudomonas aeruginosa. This biotype has been detected frequently in most urban runoff studies in concentrations that may cause potential infections. However, there is little information associating the cause and effect of increased Pseudomonas concentrations with increased infections. Shigella may be present in urban runoff and receiving waters. This pathogen, when ingested in low numbers, can cause dysentery.

Table C-1. Pathogenic Organism Densities Observed in the Rideau River

Organism	Occurrence	Density
Salmonella biotypes *S. typhimurium* *S. infantis* *S. agona* *S. haardt* *S. saint paul* *S. nienstedten*	low(1)	<0.2-0.8/100mL
Pseudomonas aeruginosa	frequent	>10/100mL only after rains
Edwardsiella tarda	rare	---
Candida albicans (a yeast)	1 to 7% positive	1-2 cfu/100mL

(1) very seldom found in Ottawa urban runoff

Source: Environment Canada, 1980

Table C-2. Pathogenic Bacteria Types Found in Raw Sanitary Wastewater in Baltimore, MD

Staphylococcus aureus:	42-4,600/100mL, mean of 820/100mL
Pseudomonas aeruginosa:	average of 220,000/100mL

Source: Olivieri, Kruse, and Kawata, 1977b

Table C-3. Bacteria Biotypes Found in Sanitary Wastewater

	Fecal Streptococci Occurrence(%)			
City	Entero-cocci	*S. bovis* *S. equinus*	Atypical *S. faecalis*	*S. faecalis liquifaciens*
Preston, ID	80	0	0	21
Fargo, ND	100	0	0	0
Moorehead, MN	90	10	0	0
Cinncinnati, OH	72	3	2	24
Lawrence, MA	84	4	0	12
Monroe, MI	79	1	4	16
Denver, CO	86	11	3	0

Source: Geldreich and Kenner, 1969

Table C-4. Pathogenic Bacteria Types Found in Urban Stormwater (organisms/100mL)

City, Province/ State	catchment/ land-use	Staphylococcus aureus	Pseudomonas aeruginosa	Salmonella	Streptococci	Enterovirus	others	reference
Burlington, Ontario	Aldershot Plaza		14-3,000	S. senftenberg & S. newport isolated			total fungi: $2x10^4-2x10^6$	Qureshi & Dutka, 1979
	Malvern Road		<1-740	100% negative			total fungi: 9-400 Heterotroph count: $4x10^5-2x10^7$	"
Milwaukee, WI	highway runoff	all <1,000	all <1,000	45% positive				Gupta, et al, 1981
Baltimore, MD	Stoney Run	<3-80	200-240,000	0.03->13				Field, et al, 1976
	Glen Ave.	<3-150	130-260,000	0.02->110				"
	Howard Park	6-920	790-54,000	0.04->13				"
	Jones Falls	4-11	940-1,600,000	0.17-3				"
	Bush Street	<3-4,600	110-75,000	<0.02-27				"
	Northwood stormwater	<3-460	17-9,200	<0.02-0.43 94% positive				"
	stormwater	38	1,100	0.13	50,000	0.3 PFU		Lager, et al, 1977
Cinncinnati, OH	business district				79% positive(1)			Geldreich & Kenner, 1969
	residential area				80% positive(2)			"
	rural area				87% positive(3)			"
overall:		<3-4,600	<1-1,600,000	<1-110 (mostly positive)	>80% positive			

(1) Strep. bacteria types found: S. bovis/S. equinus (2%)
Atypical S. faecalis (1%)
S. faecalis liquifaciens (19%)
S. thompson: 4,500/100ml

(2) Strep. bacteria types found: S. bovis/S. equinus (0.5%)
Atypical S. faecalis (1%)
S. faecalis liquifaciens (18%)

(3) Strep. bacteria types found: S. bovis/S. equinus (0.5%)
Atypical S. faecalis (0.2%)
S. faecalis liquifaciens (12%)

Table C-5. Bacterial Parasites Affecting Mammals and Birds that can be Transmitted by Contaminated Water

Species (Synonym)	Host[(1)]	Disease and Clinical Manifestation
**Actinobacillus mallei*	Horse	Glanders (farcy)
	Man	Glanders
Bacillus anthracis	Cattle, sheep, horse	Anthrax--acute septicemia
Bordatella bronchiseptica	Swine	Anthrax--acute pharyngitis
Brucella abortus	Cattle	Brucellosis, contagious abortion (undulant fever, Bang's disease)
*B. melitensis	Goat, sheep, man	Brucellosis (undulant fever)
B. suis	Swine	Brucellosis (undulant fever), abortion
Clostridium perfringens	Sheep	Enterotoxemia, lamb dysentery
Corynebacterium pseudotuberculosis	Cattle, swine	Hemorrhagic enteritis
	Sheep	Caseous lymphadenitis
Erysipelothrix insidiosa (E. rhusiopathiae)	Swine, turkey	Erysipelas
*Francisella tularensis	Lagomorphs, rodents, man	Tularemia
Haemophilus gallinarum	Chicken	Infectious coryza
*Leptospira canicola	Dog, man	Leptospirosis
*L. icterohemorrhagiae	Rat, man, dog	Leptospirosis
*L. pomona	Cattle, swine, man	Leptospirosis
Mycobacterium avium	Turkey, chicken	Tuberculosis of intestine, spleen, and liver
M. bovis	Cattle	Tuberculosis
M. paratuberculosis	Cattle, sheep, goat	Johne's disease
Pasteurella haemolytica	Sheep	Septicemia in lambs; mastitis
	Cattle	Pneumonia, hemorrhagic septicemia
*Pseudomonas aeruginosa	Dog	Otitis externa, dermatitis
	Man	Otitis, wound infections (burns), urinary tract infections, sinusitis, meningitis
	Cattle	Mastitis
	Horse	Abortion
	Swine	Necrotic enteritis
*Salmonella choleraesuis	Man	Septicemia, abscesses, gastroenteritis
	Cattle	Gastroenteritis in calves
*S. enteritidis	Man	Gastroenteritis
S. gallinarum	Fowl	Fowl typhoid
*S. paratyphi	Man	Paratyphoid fever
S. pullorum	Chicken	Bacillary white diarrhea
*S. typhimurium	Domestic animals, man	Gastroenteritis
*S. typhi (S. typhosa)	Man	Typhoid fever
*Shigella dysenteriae	Man	Shigellosis, bacillary dysentery
*S. flexneri	Man	Shigellosis, bacillary dysentery
*S. sonnei	Man	Shigellosis, bacillary dysentery
*Vibrio cholerae	Man	Cholera
V. jejuni	Cattle	Dysentery
*Yersinia enterocolitica	Man	Pseudotuberculosis, colitis
	Rodents	Pseudotuberculosis
*Y. pseudotuberculosis	Rodents, turkey, swine, man	Pseudotuberculosis

* affect humans
(1) animals are listed in order of decreasing susceptibility
Source: Altman and Dittmer, 1973

APPENDIX D
EFFECTS OF STREET CLEANING ON OTTAWA URBAN RUNOFF DISCHARGES

Figure D-1. The effects of cleaning frequency and parking controls on street loadings for smooth/moderate textured Ottawa streets having medium parking densities.

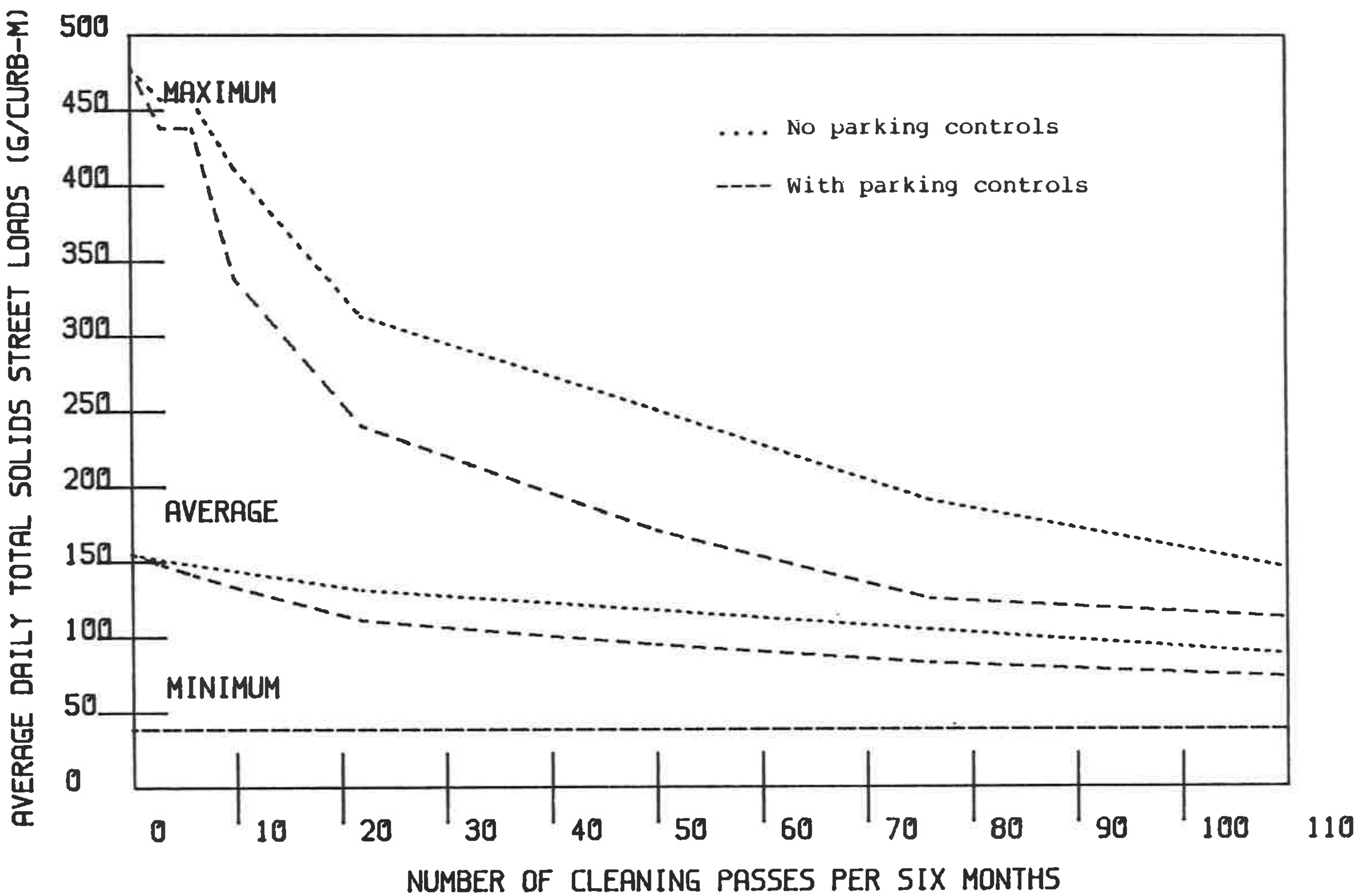


Figure D-2. The effects of cleaning frequency and parking controls on street loadings for smooth/moderate textured Ottawa streets having extensive parking densities.

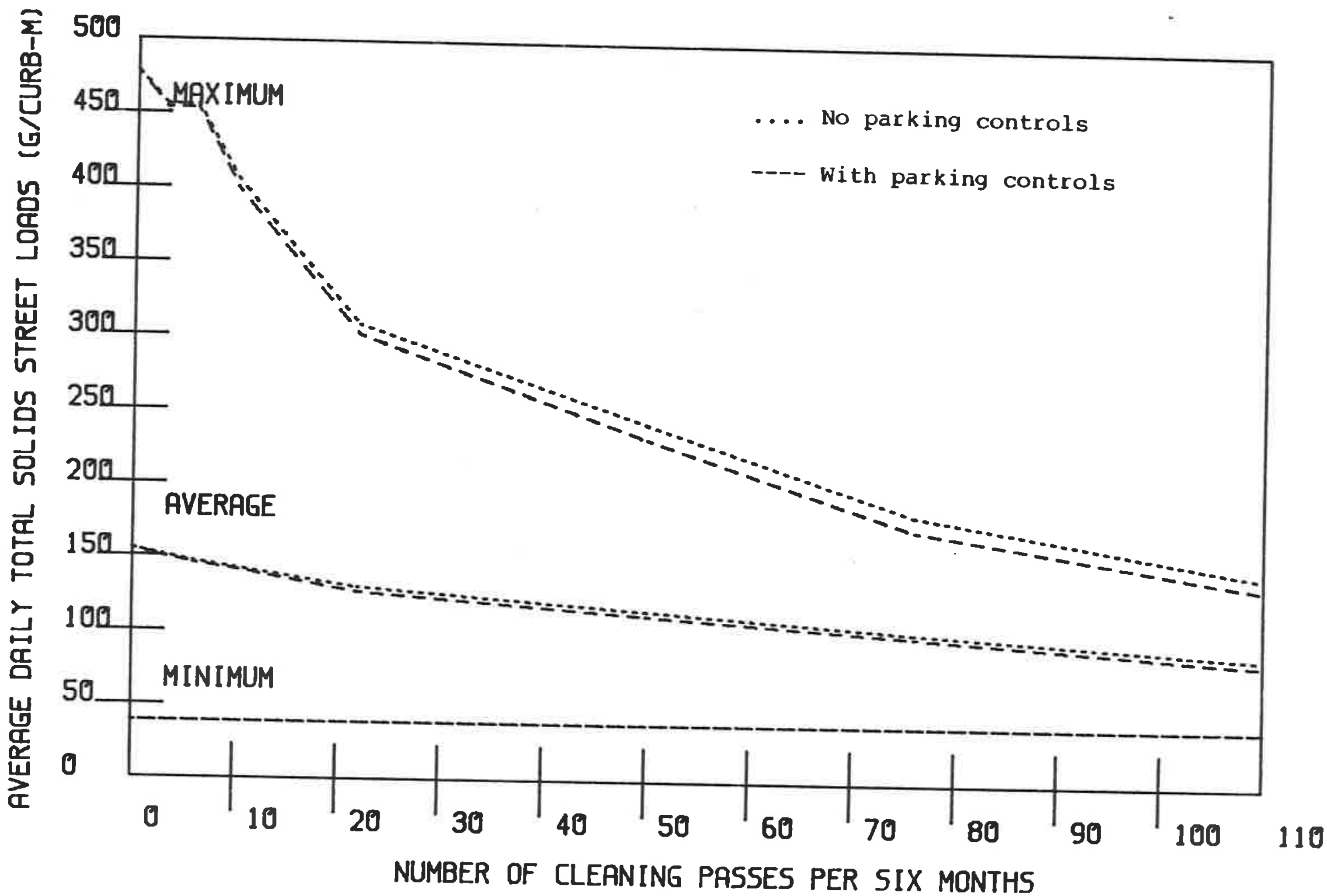


Figure D-3. The effects of cleaning frequency and parking controls on street loadings for rough textured Ottawa streets having light parking densities.

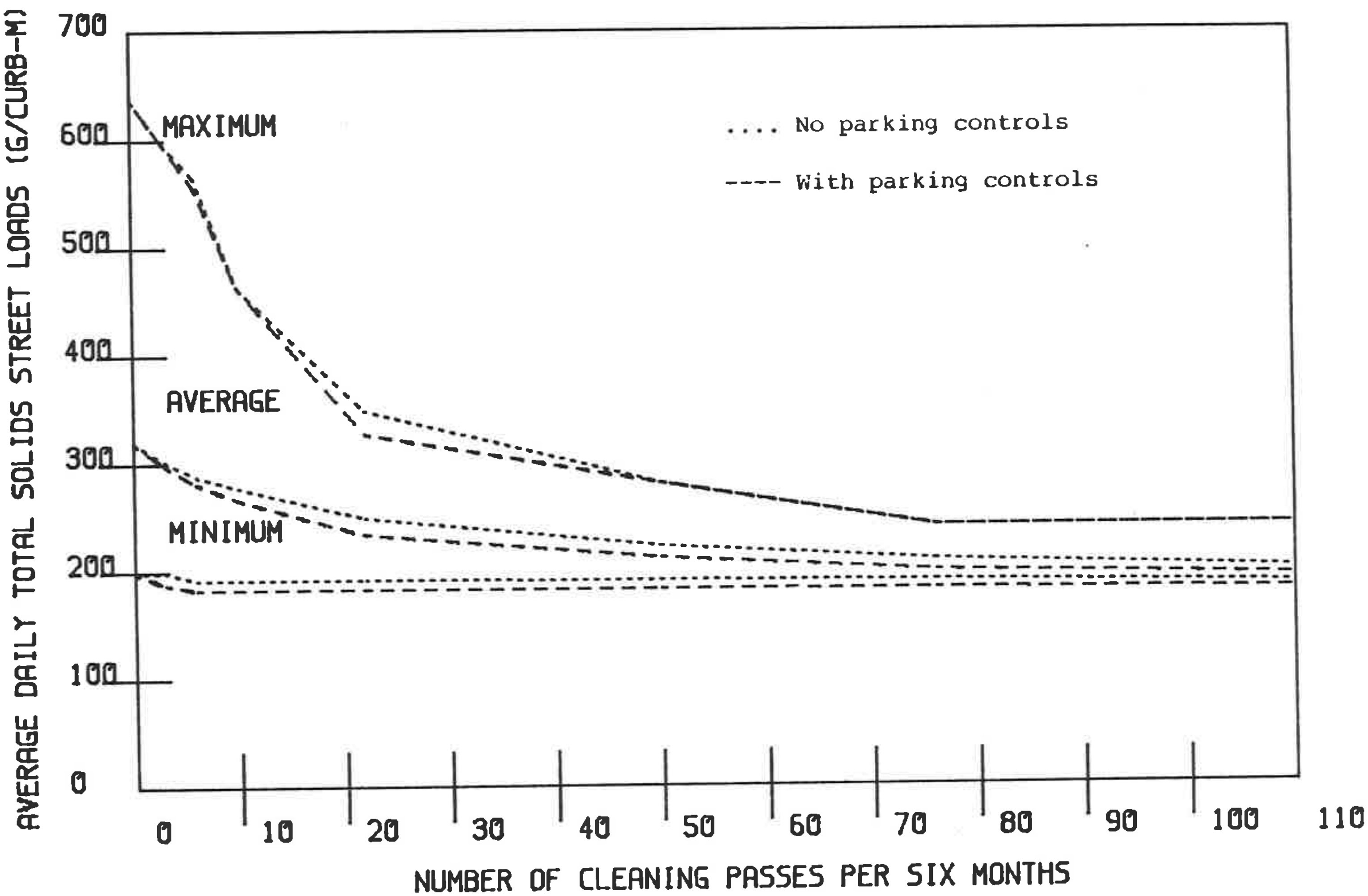


Figure D-4. The effects of cleaning frequency and parking controls on street loadings for rough textured Ottawa streets having medium parking densities.

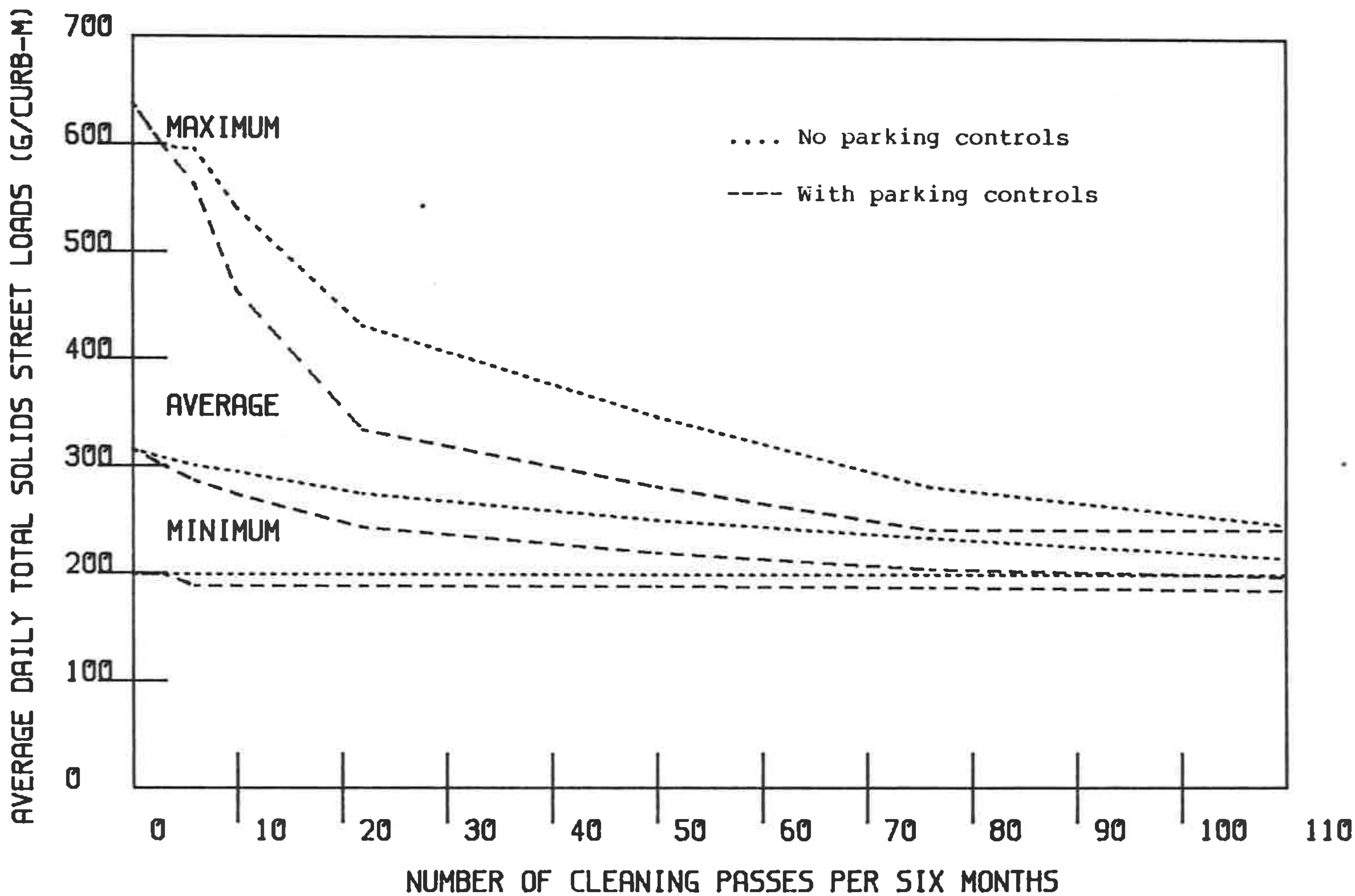


Figure D-5. The effects of cleaning frequency and parking controls on street loadings for very rough textured Ottawa streets having light parking densities.

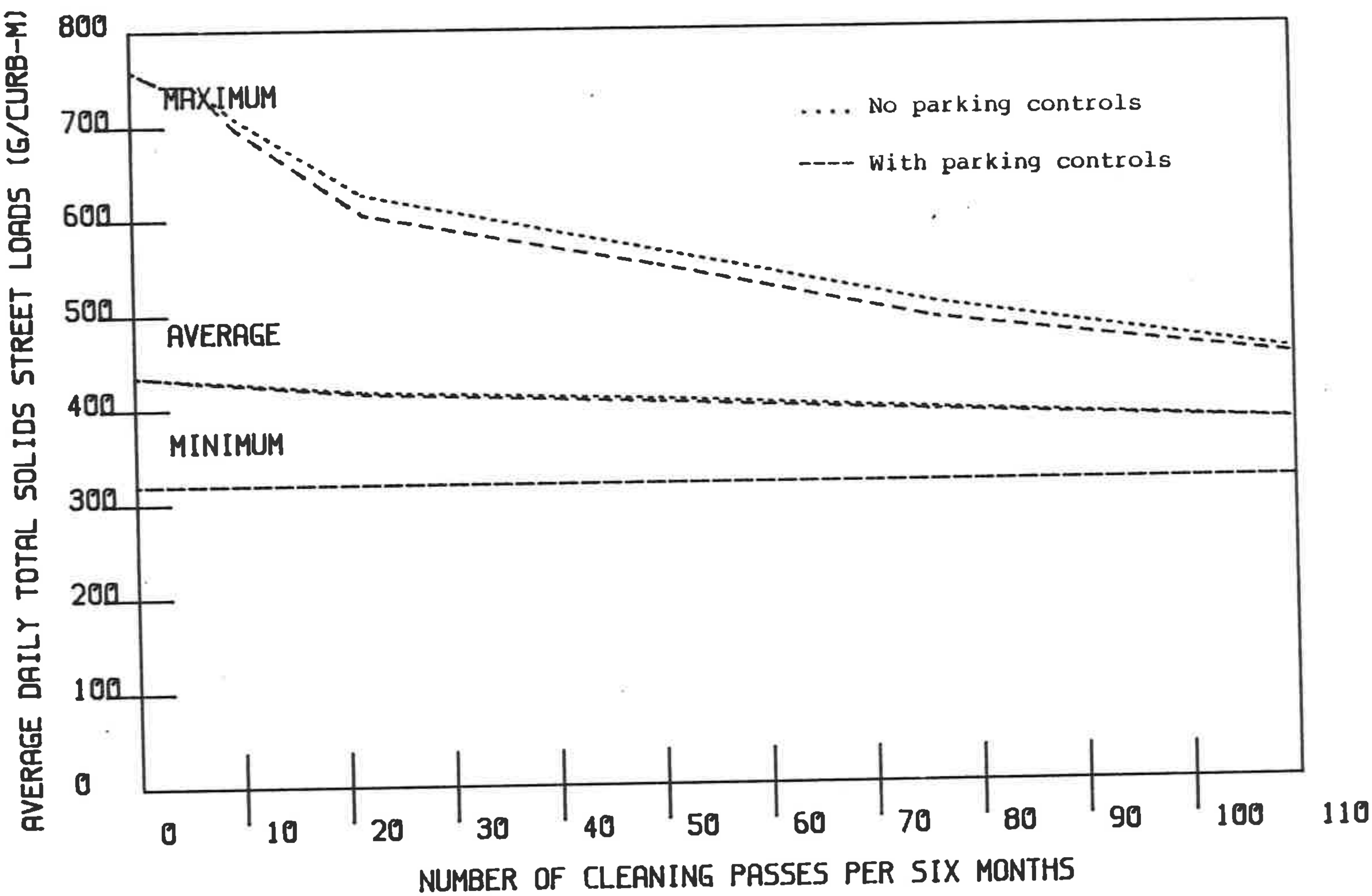


Figure D-6. Total street dirt removal for smooth/moderate textured Ottawa streets having medium parking densities.

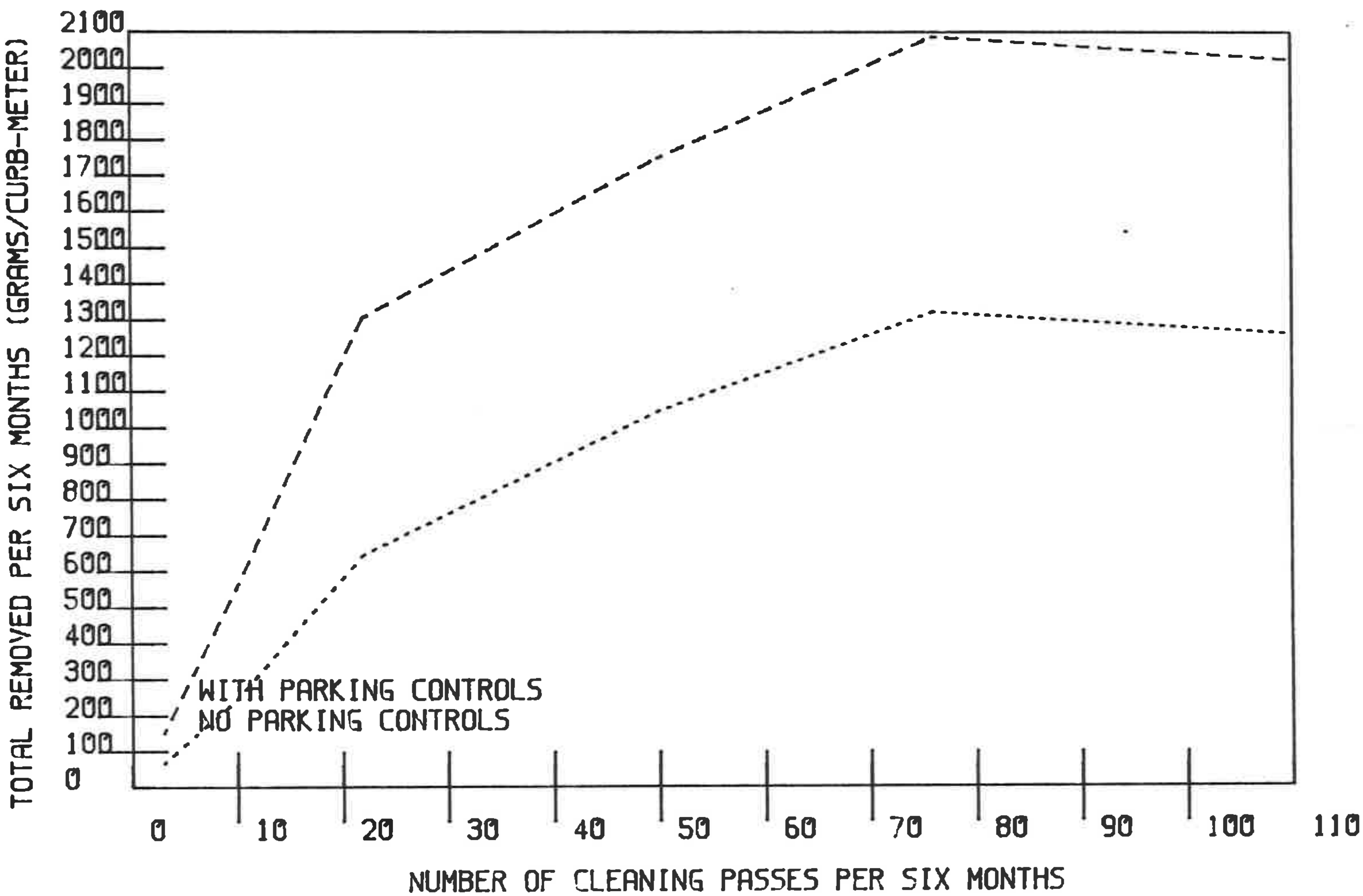


Figure D-7. Average street dirt removal per pass for smooth/moderate textured Ottawa streets having medium parking densities.

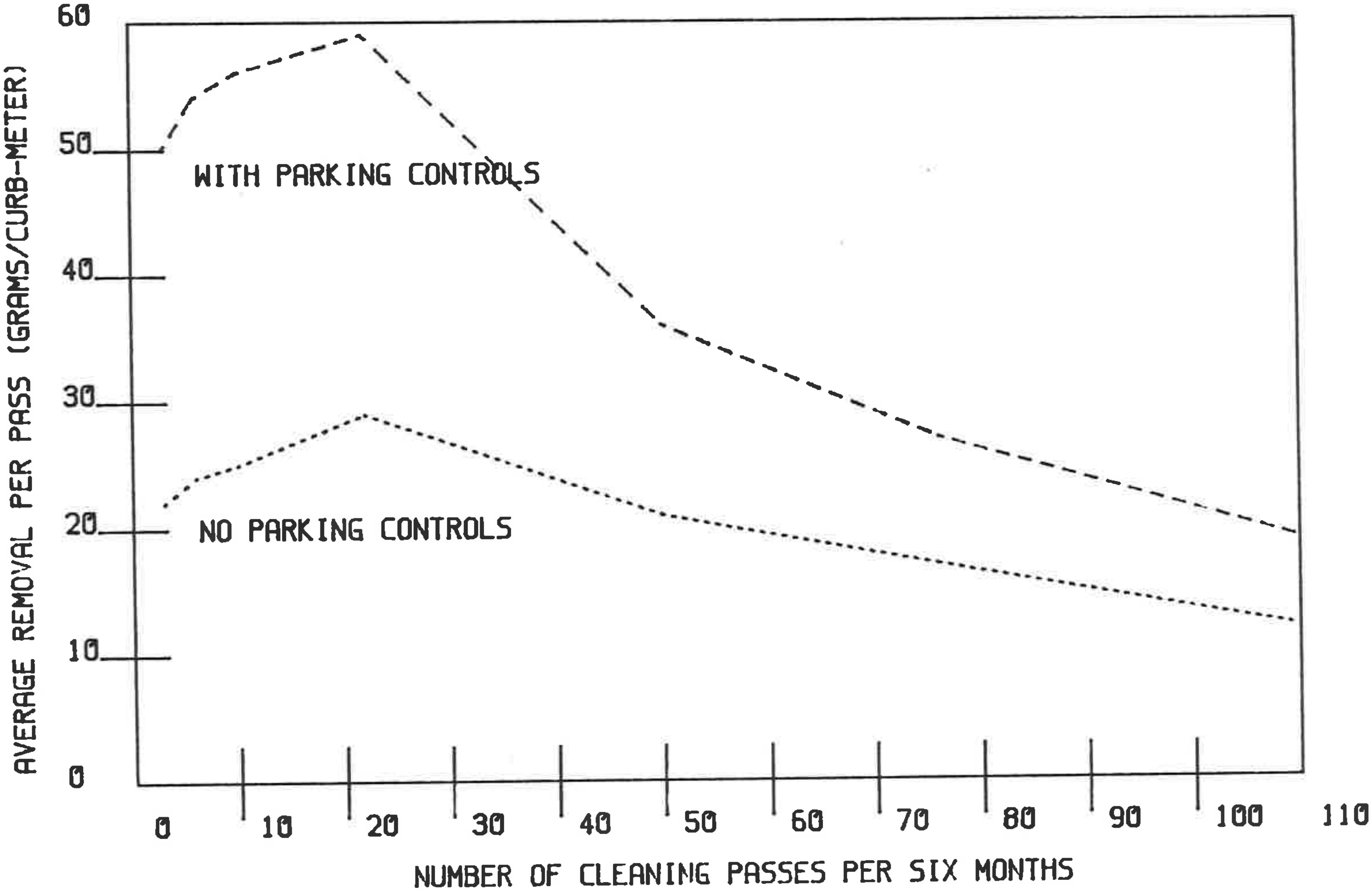


Figure D-8. Unit removal costs for smooth/moderate textured Ottawa streets having medium parking densities.

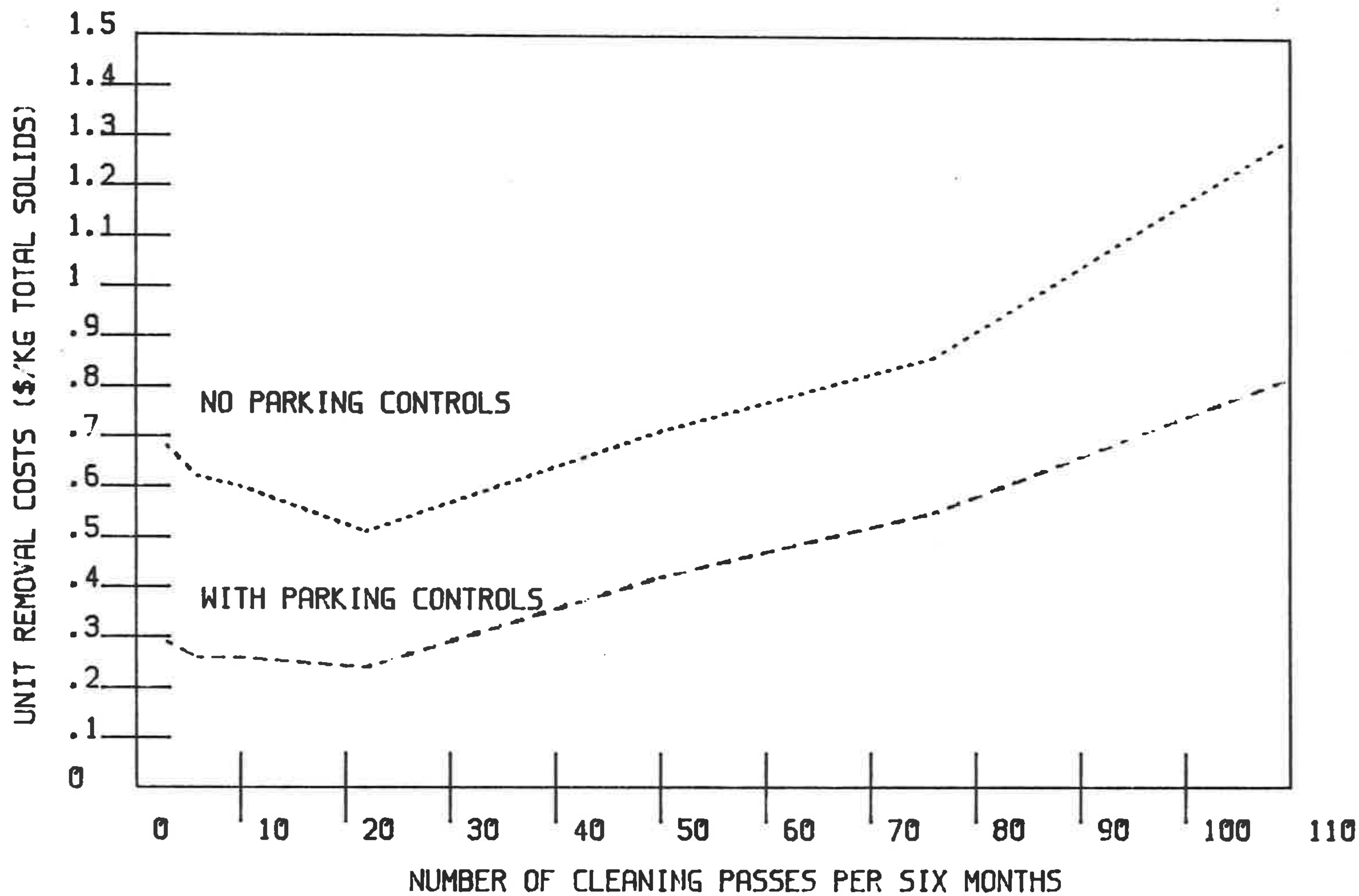


Figure D-9. Total street dirt removal for smooth/moderate textured Ottawa streets having extensive parking densities.

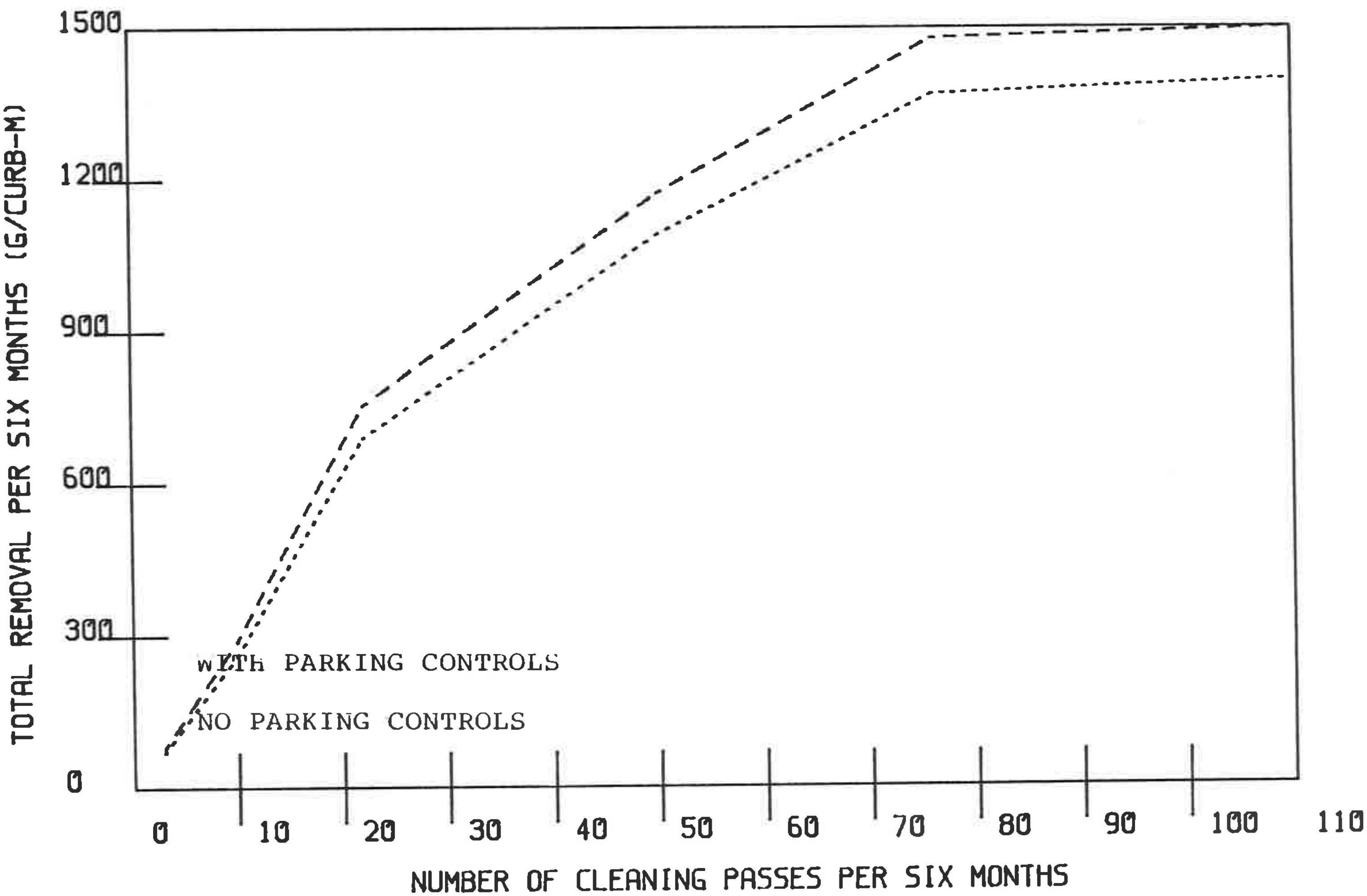


Figure D-10. Average street dirt removal per pass for smooth/moderate textured Ottawa streets having extensive parking densities.

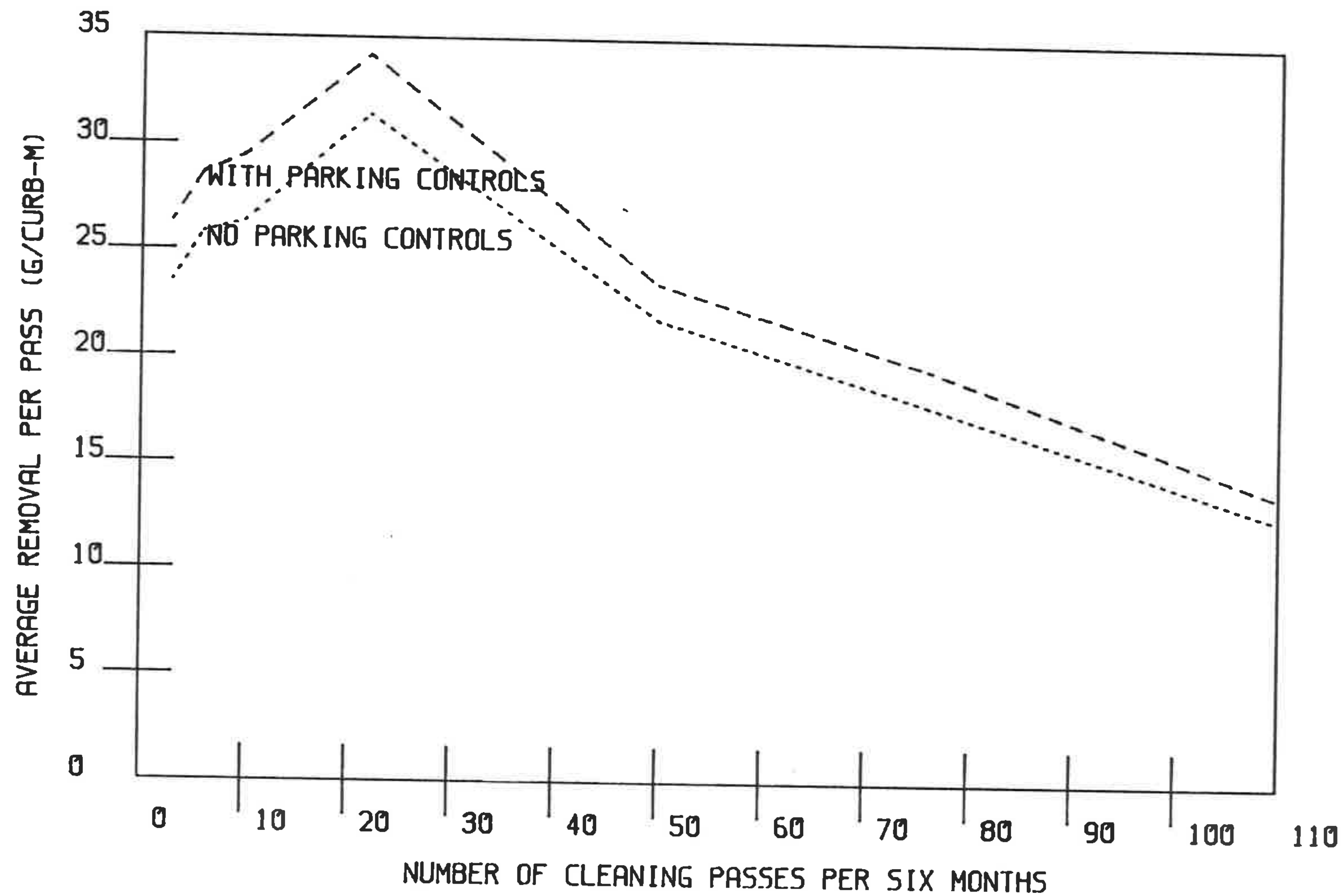


Figure D-11. Unit removal costs for smooth/moderate textured Ottawa streets having extensive parking densities.

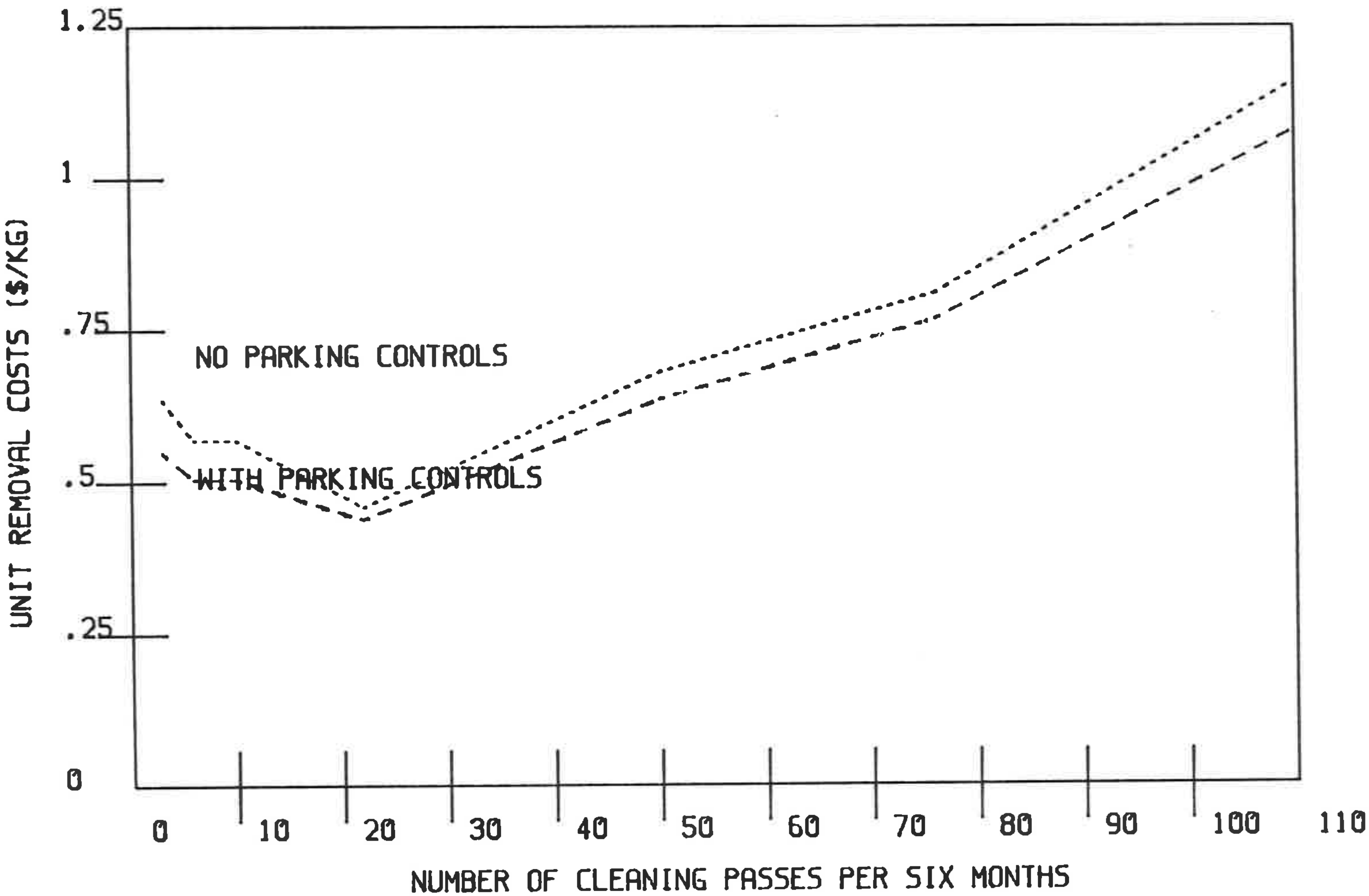


Figure D-12. Total street dirt removal for rough textured Ottawa streets having light parking densities.

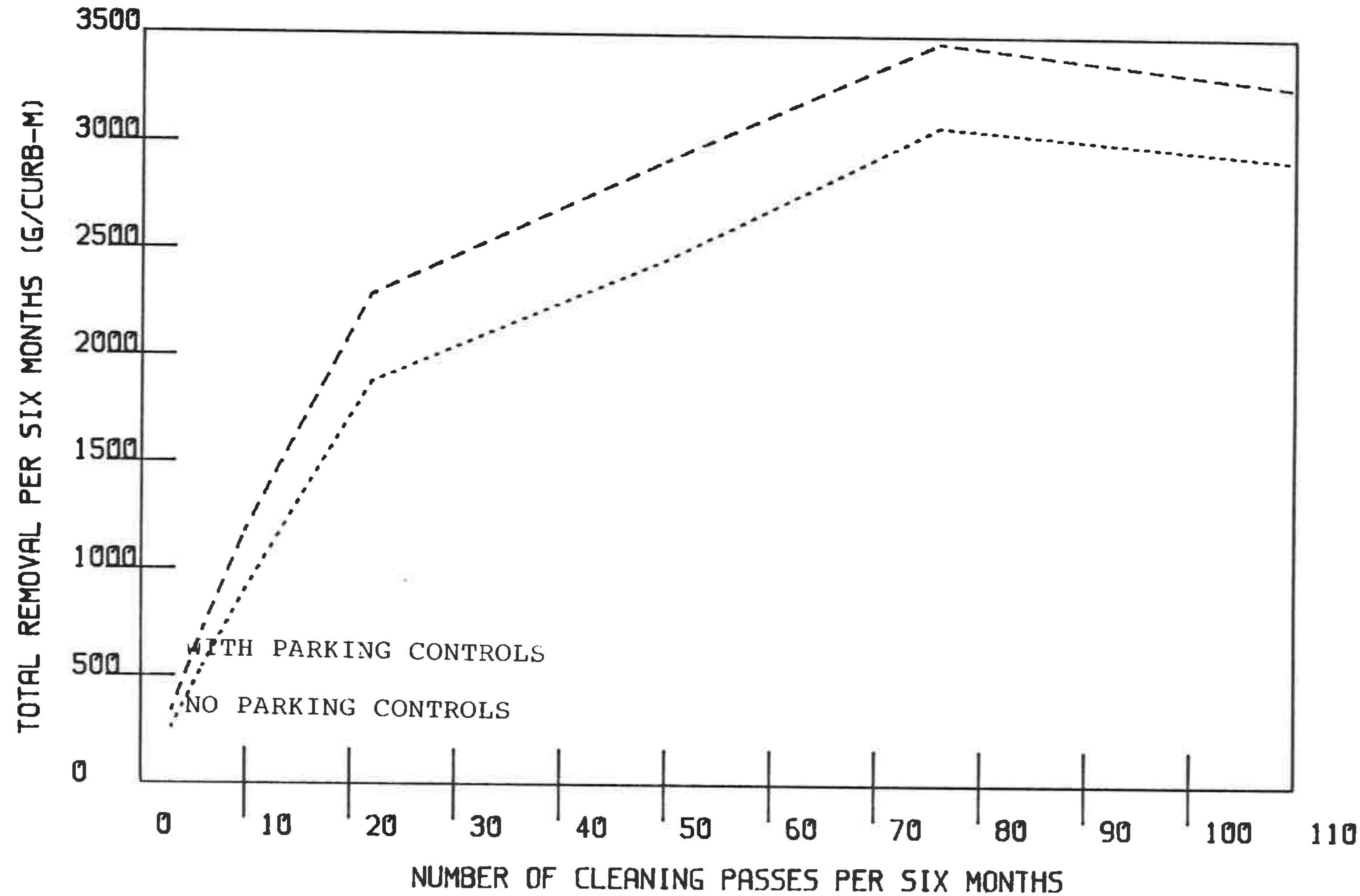


Figure D-13. Average street dirt removal per pass for rough textured Ottawa streets having light parking densities.

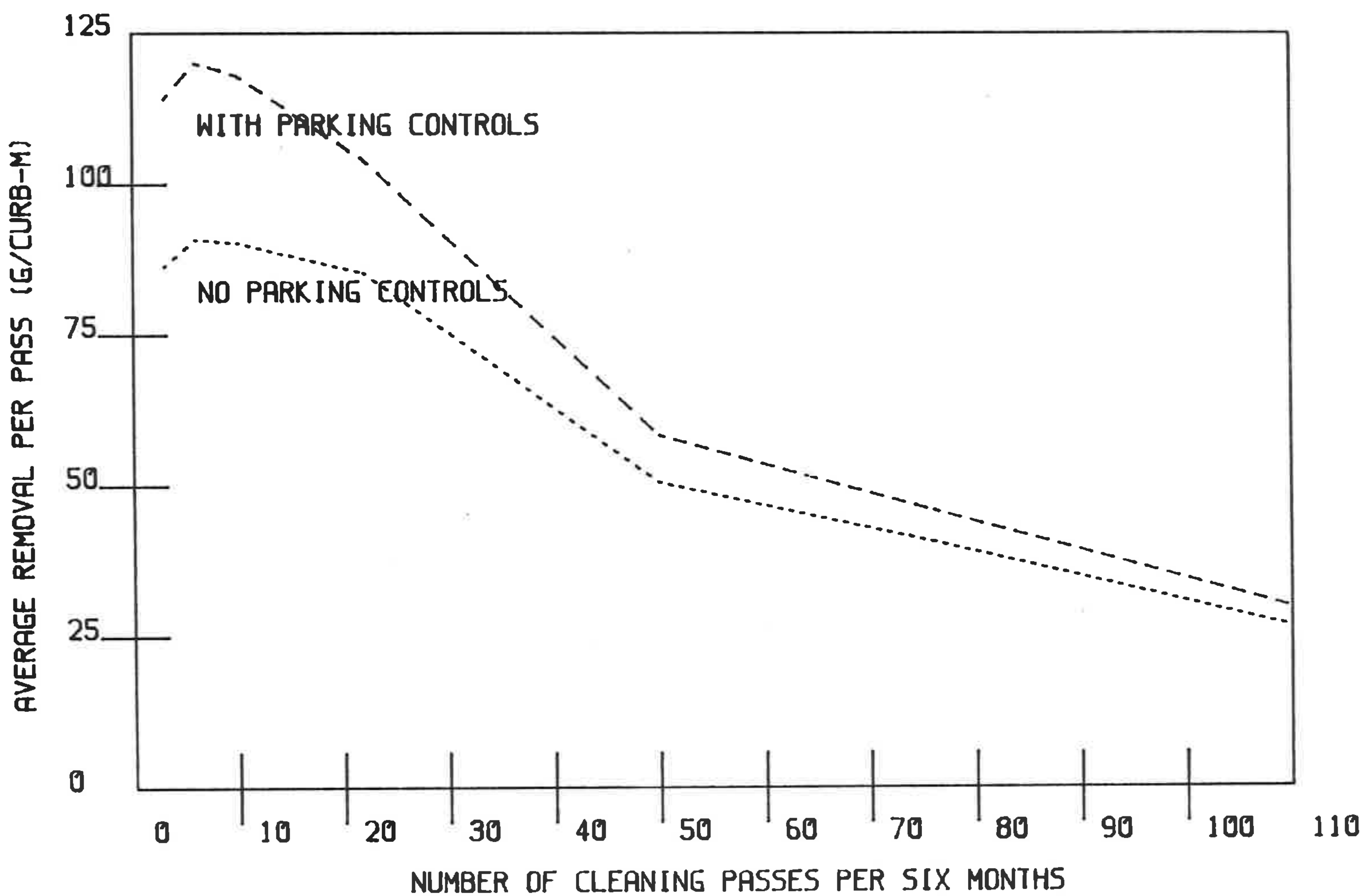


Figure D-14. Unit removal costs for rough textured Ottawa streets having light parking densities.

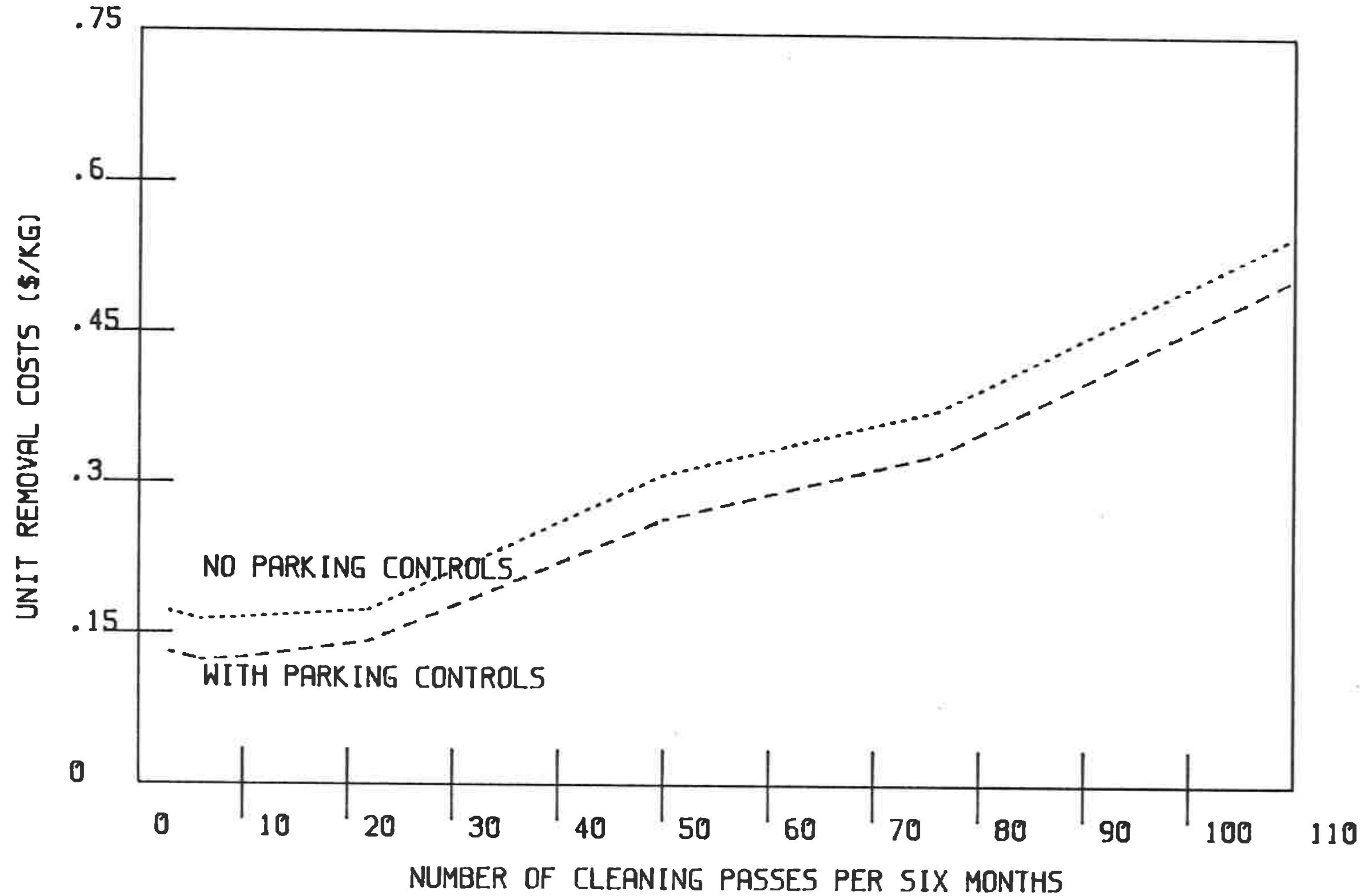


Figure D-15. Total street dirt removal for rough textured Ottawa streets having medium parking densities.

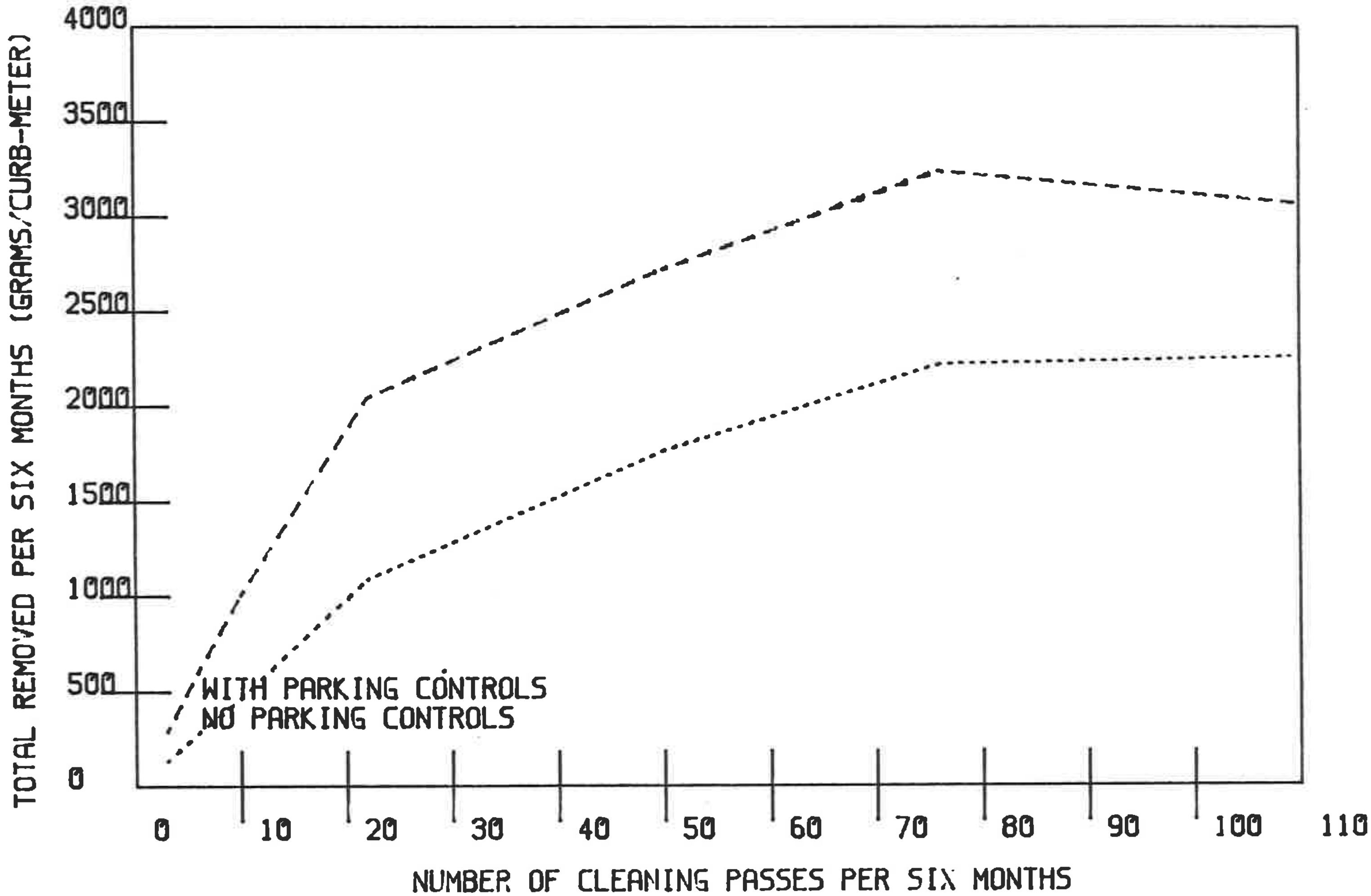


Figure D-16. Average street dirt removal per pass for rough textured Ottawa streets having medium parking densities.

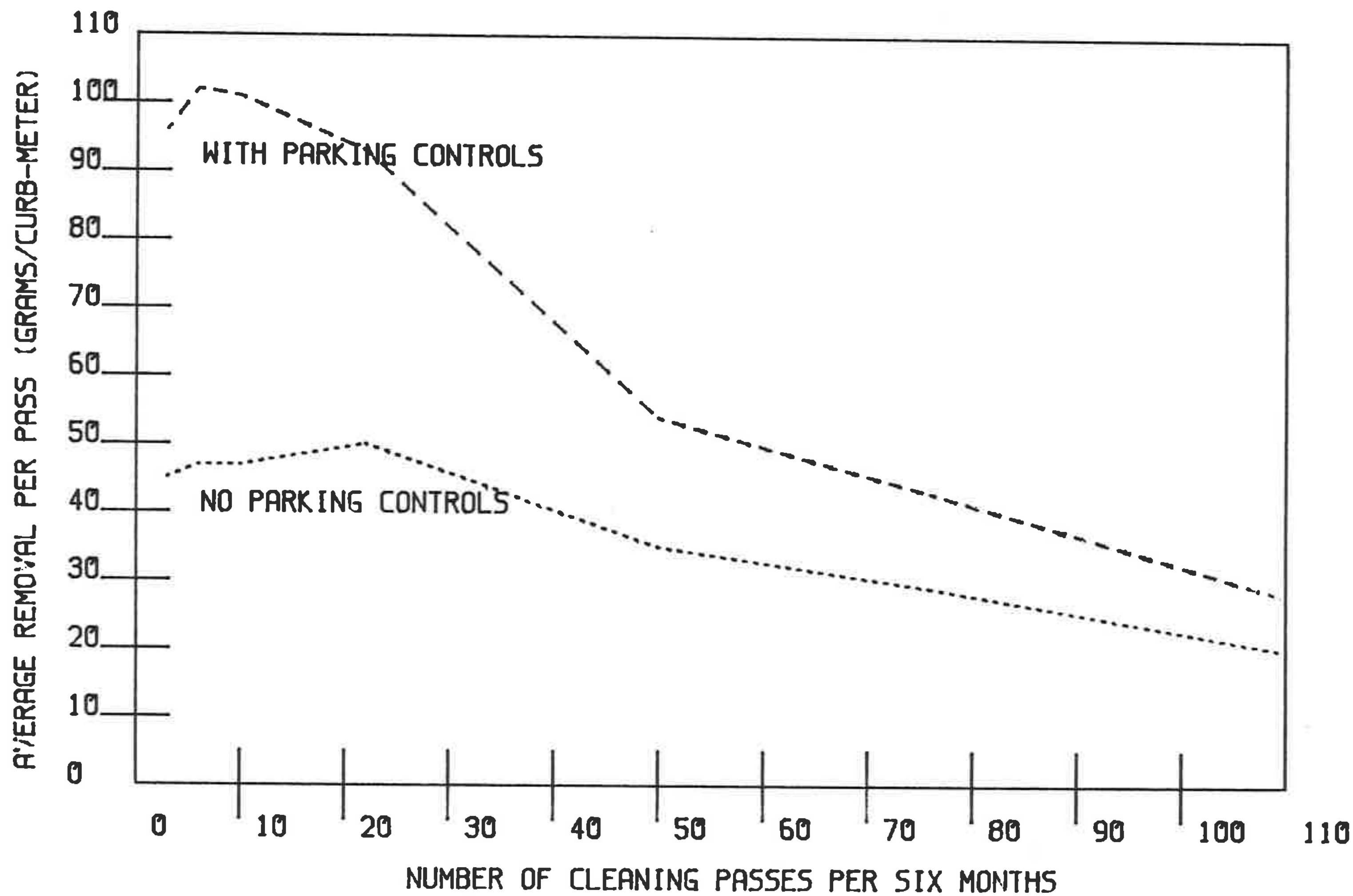


Figure D-17. Unit removal costs for rough textured Ottawa streets having medium parking densities.

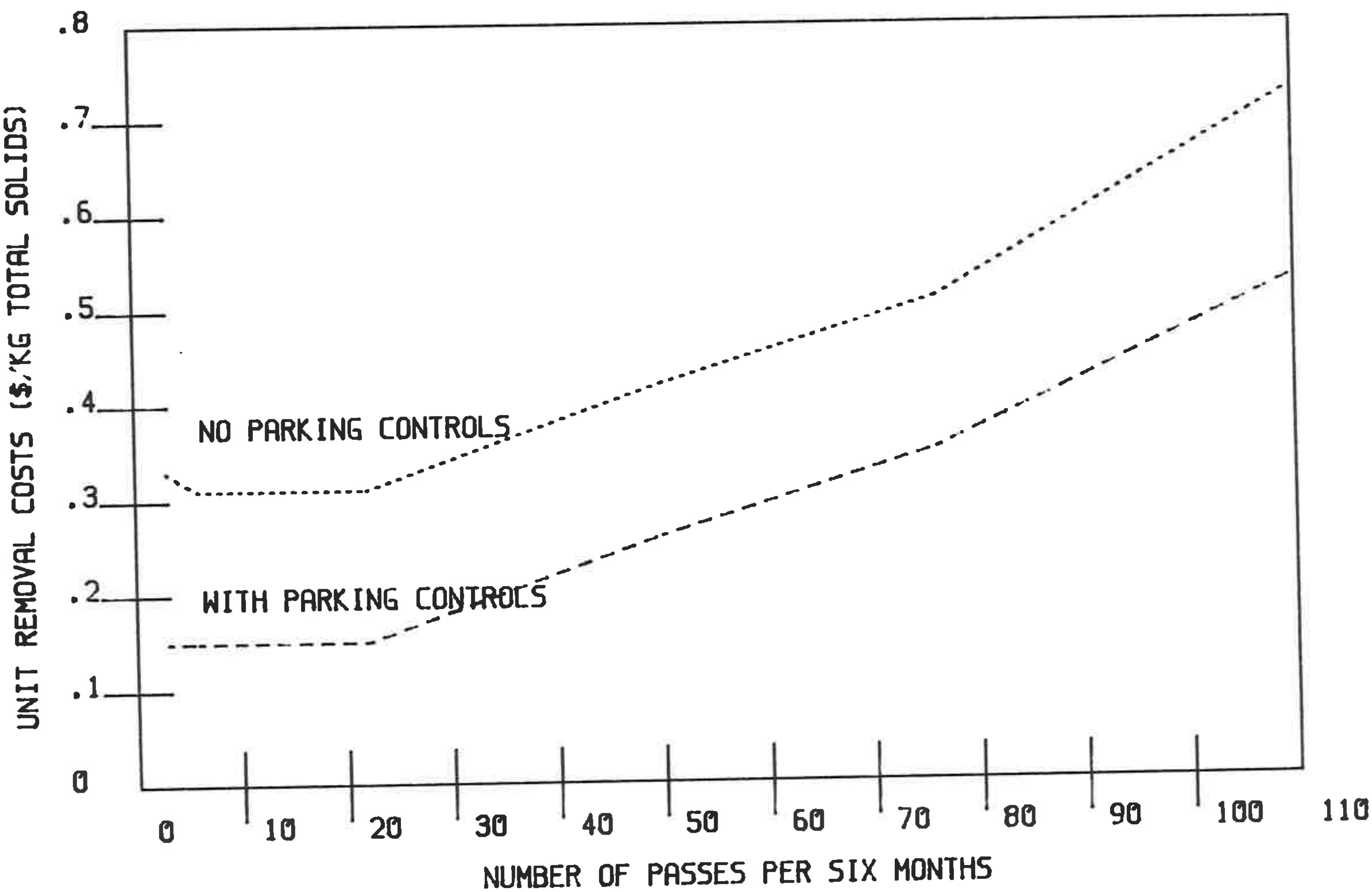


Figure D-18. Total street dirt removal for very rough textured Ottawa streets having light parking densities.

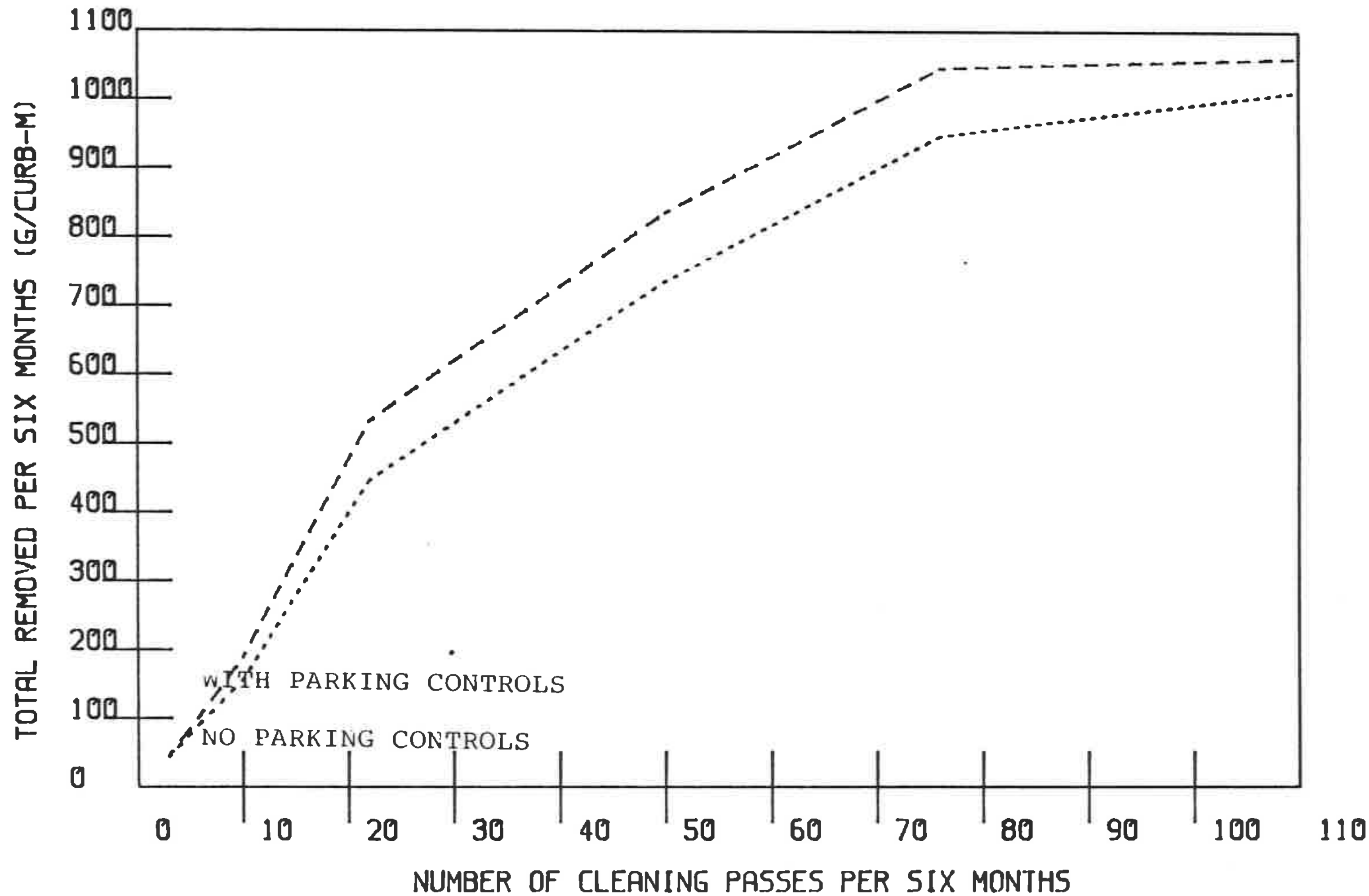


Figure D-19. Average street dirt removal per pass for very rough textured Ottawa streets having light parking densities.

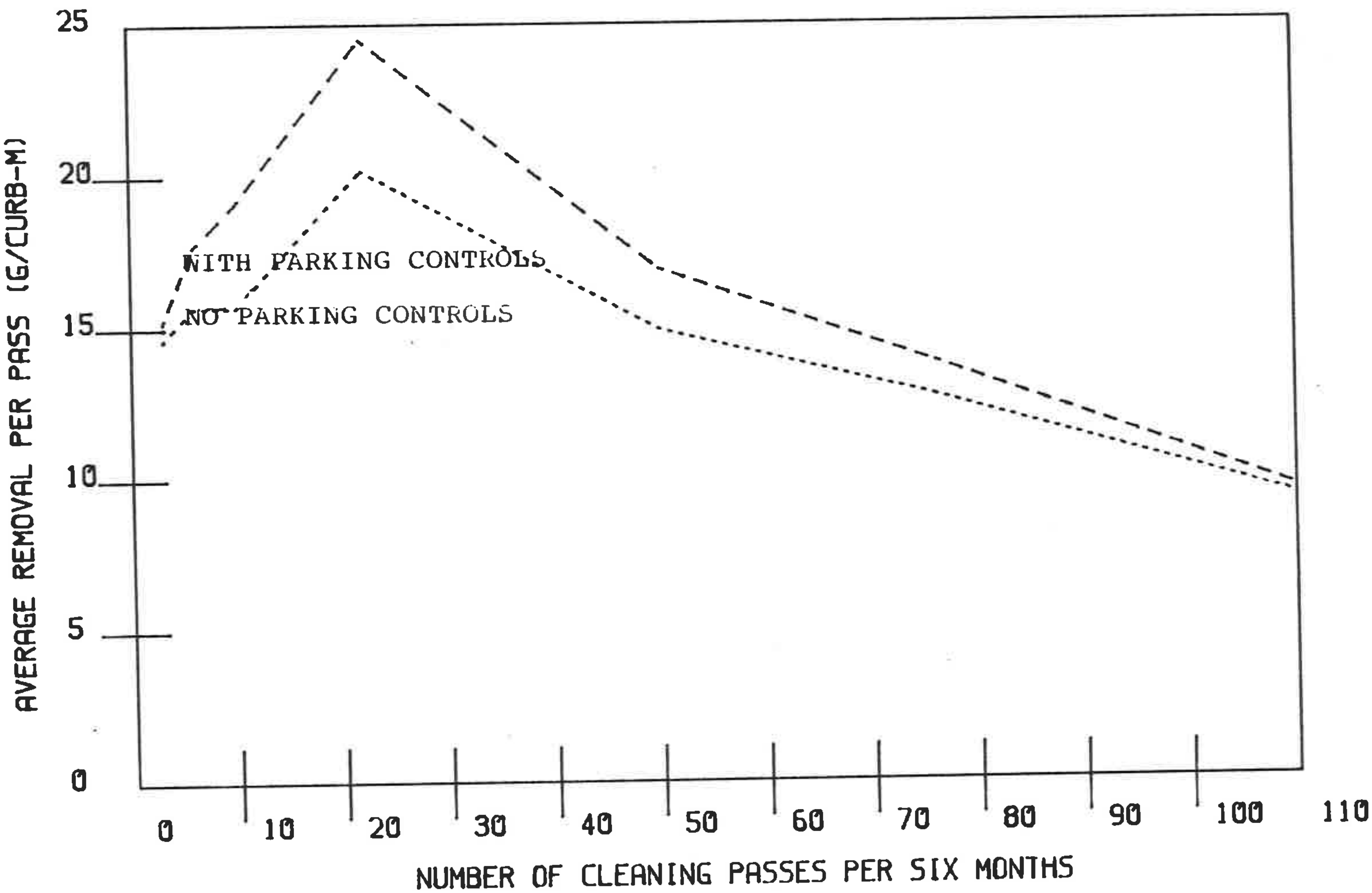


Figure D-20. Unit removal costs for very rough textured Ottawa streets having light parking densities.

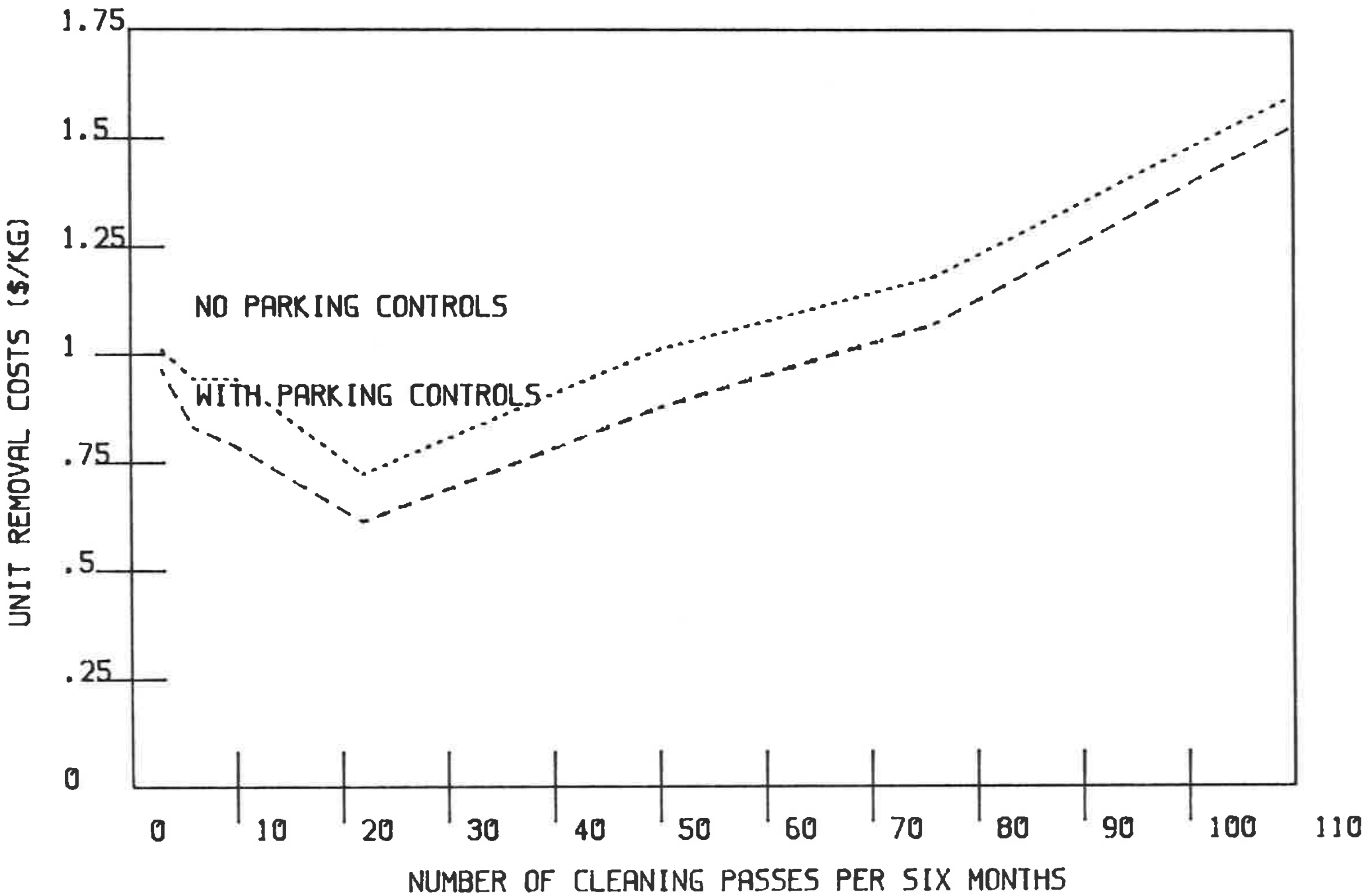
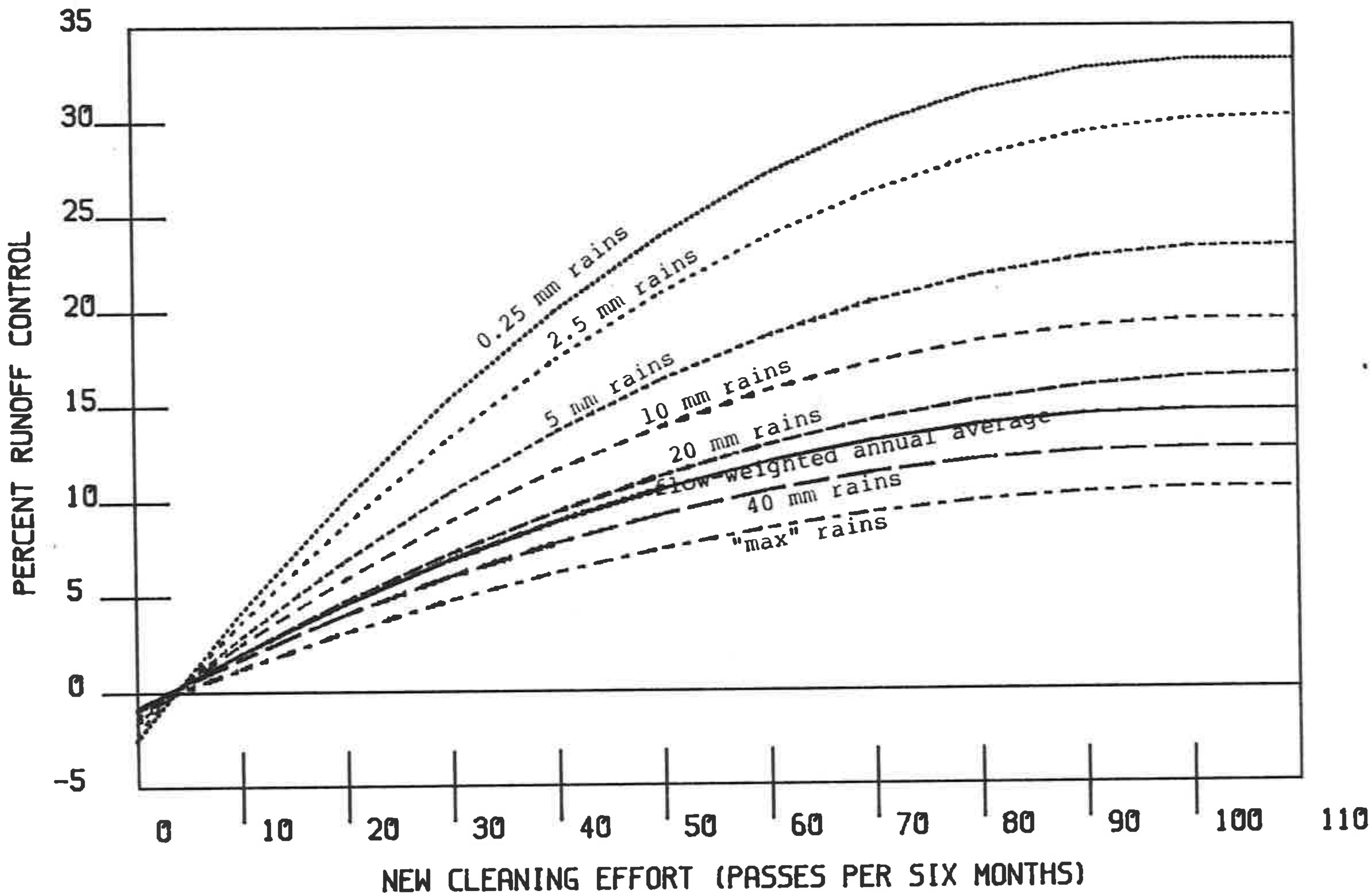
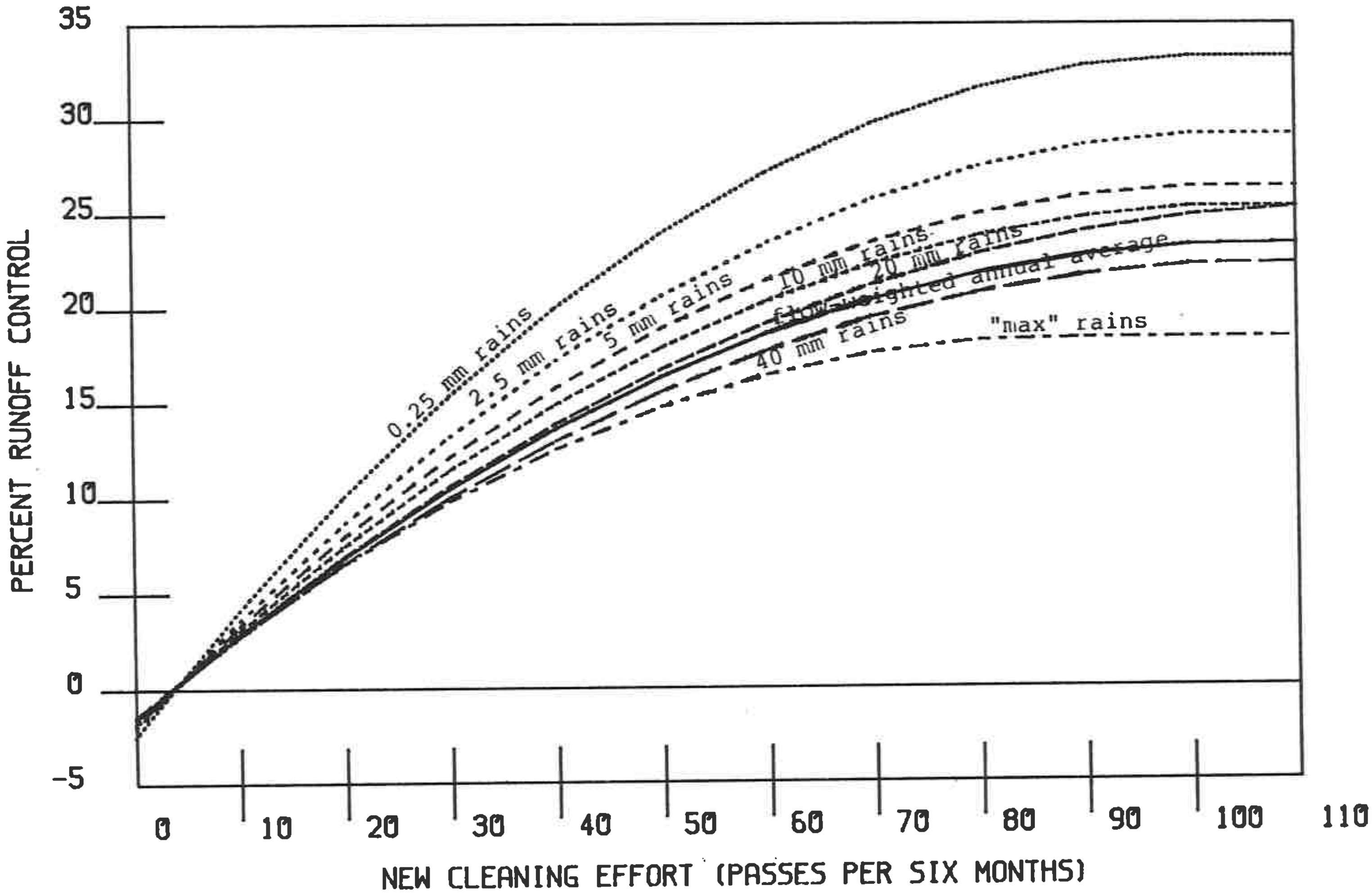


Figure D-21. Fecal Strep. bacteria runoff control by street cleaning.*



* This example is for the Alta Vista test catchment, which has smooth/moderate textured streets and light parking. The base cleaning effort is three passes per six months with no parking controls. The new program also does not have parking controls.

Figure D-22. Lead runoff control by street cleaning.*



* This example is for the Alta Vista test catchment, which has smooth/moderate textured streets and light parking. The base cleaning effort is three passes per six months with no parking controls. The new program also does not have parking controls.

Table D-1. Changes in Average Daily Street Loadings Due to Changes in Cleaning Frequency in Ottawa (new load/old load ratio)

frequency	same freq. but change from no parking controls to parking controls	if base is 2/month with no controls changing to other freq.: with no controls	if base is 2/month with no controls changing to other freq.: with controls	if base is 1 per 2 months with no controls changing to other freq.: with no controls	if base is 1 per 2 months with no controls changing to other freq.: with controls	if base is no cleaning, changing to other freq.: with no controls	if base is no cleaning, changing to other freq.: with controls
smooth and moderate texture streets with light parking							
5/week	0.95	0.56	0.53	0.52	0.50	0.49	0.46
3/week	0.93	0.64	0.59	0.59	0.55	0.56	0.52
2/week	0.92	0.73	0.68	0.68	0.63	0.64	0.59
1/week	0.93	0.85	0.79	0.79	0.74	0.75	0.69
2/month	0.96	1.00	0.96	0.93	0.89	0.87	0.84
1/month	0.98	1.05	1.03	0.98	0.96	0.92	0.90
1 per 2 months	1.00	1.08	1.09	1.00	1.01	0.94	0.95
1 per 3 months	1.00	1.09	1.09	1.01	1.01	0.95	0.95
none	1.00	1.15	1.15	1.07	1.07	1.00	1.00
smooth and moderate texture streets with medium parking							
5/week	0.83	0.62	0.51	0.59	0.49	0.57	0.48
3/week	0.79	0.73	0.58	0.69	0.55	0.68	0.54
2/week	0.81	0.82	0.66	0.78	0.63	0.76	0.61
1/week	0.85	0.91	0.77	0.87	0.74	0.84	0.72
2/month	0.92	1.00	0.92	0.95	0.88	0.93	0.86
1/month	0.95	1.03	0.98	0.98	0.93	0.95	0.91
1 per 2 months	0.98	1.05	1.03	1.00	0.98	0.97	0.95
1 per 3 months	0.98	1.05	1.03	1.00	0.98	0.97	0.95
none	1.00	1.08	1.08	1.03	1.03	1.00	1.00
smooth and moderate texture streets with extensive (short-term) parking							
5/week	0.96	0.62	0.59	0.58	0.56	0.57	0.54
3/week	0.97	0.72	0.70	0.68	0.66	0.66	0.64
2/week	0.97	0.81	0.79	0.77	0.75	0.75	0.73
1/week	0.98	0.91	0.89	0.86	0.84	0.84	0.82
2/month	0.99	1.00	0.99	0.95	0.94	0.92	0.91
1/month	0.99	1.03	1.02	0.97	0.97	0.95	0.94
1 per 2 months	1.00	1.06	1.05	1.00	1.00	0.97	0.97
1 per 3 months	1.00	1.06	1.05	1.00	1.00	0.97	0.97
none	1.00	1.09	1.09	1.03	1.03	1.00	1.00
rough texture streets with light parking							
5/week	0.97	0.72	0.70	0.67	0.65	0.63	0.61
3/week	0.95	0.75	0.72	0.70	0.66	0.66	0.63
2/week	0.95	0.81	0.76	0.75	0.71	0.71	0.67
1/week	0.94	0.90	0.85	0.83	0.78	0.79	0.74
2/month	0.96	1.00	0.96	0.93	0.89	0.88	0.85
1/month	0.97	1.04	1.01	0.96	0.94	0.92	0.89
1 per 2 months	0.99	1.08	1.06	1.00	0.99	0.95	0.94
1 per 3 months	0.99	1.09	1.08	1.01	1.00	0.96	0.95
none	1.00	1.14	1.14	1.05	1.05	1.00	1.00
rough texture streets with medium parking							
5/week	0.92	0.73	0.67	0.70	0.65	0.68	0.63
3/week	0.88	0.79	0.70	0.76	0.67	0.74	0.65
2/week	0.87	0.85	0.74	0.82	0.72	0.80	0.69
1/week	0.89	0.93	0.83	0.92	0.80	0.87	0.77
2/month	0.93	1.00	0.93	0.96	0.89	0.93	0.87
1/month	0.95	1.02	0.97	0.98	0.93	0.95	0.91
1 per 2 months	0.97	1.04	1.01	1.00	0.97	0.97	0.95
1 per 3 months	0.98	1.05	1.02	1.01	0.98	0.98	0.95
none	1.00	1.07	1.07	1.03	1.03	1.00	1.00
very rough texture streets with light parking							
5/week	1.00	0.89	0.89	0.88	0.88	0.87	0.87
3/week	0.99	0.93	0.92	0.92	0.91	0.91	0.91
2/week	0.99	0.96	0.95	0.94	0.94	0.94	0.93
1/week	0.99	0.98	0.97	0.97	0.96	0.96	0.95
2/month	1.00	1.00	1.00	0.99	0.99	0.98	0.98
1/month	1.00	1.01	1.01	0.99	0.99	0.99	0.99
1 per 2 months	1.00	1.01	1.01	1.00	1.00	0.99	0.99
1 per 3 months	1.00	1.01	1.01	1.00	1.00	0.99	0.99
none	1.00	1.02	1.02	1.01	1.01	1.00	1.00

Table D-2. Effects of Street Cleaning on Fecal Strep. Annual Discharges (percent removal)*

Study Areas	Street Texture	Parking Conditions	New Cleaning Effort (# passes per 6 months) 110	76	50	22	10	6	3	0
Alta Vista	smooth and mod.	light	15	13	10	7	2	1	0	-2
	smooth and mod.	medium	13	10	7	4	2	1	0	-1
	smooth and mod.	extensive	13	10	7	4	2	1	0	-1
	rough	light	10	9	8	5	2	1	0	-2
	rough	medium	9	8	6	3	1	1	0	-1
	very rough	light	4	3	2	1	0	0	0	0
Clegg and Leonard	smooth and mod.	light	20	17	13	9	3	1	0	-3
	smooth and mod.	medium	17	13	9	5	2	1	0	-1
	smooth and mod.	extensive	17	13	9	6	2	1	0	-1
	rough	light	14	12	10	7	3	2	0	-2
	rough	medium	12	10	7	3	2	1	0	-1
	very rough	light	5	3	2	1	0	0	0	0
Merivale	smooth and mod.	light	7	6	5	3	1	0	0	-1
	smooth and mod.	medium	6	5	3	2	1	0	0	0
	smooth and mod.	extensive	6	5	3	2	1	0	0	0
	rough	light	5	5	4	3	1	1	0	-1
	rough	medium	5	4	3	1	1	0	0	0
	very rough	light	2	1	1	0	0	0	0	0
Billings Bridge and St. Laurent	smooth and mod.	light	14	12	10	6	2	1	0	-2
	smooth and mod.	medium	12	9	7	4	2	1	0	-1
	smooth and mod.	extensive	13	10	7	4	2	1	0	-1
	rough	light	10	9	8	5	2	1	0	-2
	rough	medium	9	7	5	2	1	1	0	-1
	very rough	light	4	2	2	1	0	0	0	0

* The base program is 3 passes/6 months with no parking controls. The new program also does not have parking controls.