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Control of Water Pollution from Urban Run-Off

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This study is one part of a major study undertaken by the Water Management Policy Group over a three year period on the "Control of Diffuse Sources of Water Pollution".

The first part of the study was undertaken during 1981 and investigated Agricultural Sources of Pollution, namely 1) water contamination by fertilizers and intensive animal breeding, and 2) the problem of pesticides and their residues.

The objective of the present study on the Control of Water Pollution from Urban Runoff is to examine the following main facets:

1) Identify the pollutants encountered, along with their sources and pathways;

2) Estimate, where possible, pollution loads, significance and potential impacts;

3) Identify possible control measures including both:

-- Preventive; through the control of product manufacture and/or land use activities;

-- Corrective; through the implementation of control features, including alternative sewerage and treatment systems.

A number of Member countries contributed by supplying information necessary for the preparation of this report. The contribution of Canada, the pilot country, is particularly appreciated. Although the majority of the data base was supplied by Canada and the United States, efforts have been made to incorporate practices that are current in other OECD Member countries. Practices required in tropical and arid regions of the world may vary from those outlined in this report. A general summary of Urban Runoff practices in a number of Member countries is included in Appendix B.

This report was reviewed by the Environment Committee in July 1985, and derestricted by the OECD Council on 25th September 1985.

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Chapter 1

INTRODUCTION

BACKGROUND

Urban drainage systems have evolved slowly over the years, dating back to Roman times, when a central gutter was provided in the street to transport all wastes. However, as cities developed, the need to remove rainfall runoff was more pronounced and in order to provide for this drainage, the Romans constructed large underground drains, discharging to the nearest watercourse (1). Such systems expanded with the growth of cities both throughout Europe and North America. These drains were usually storm drainage systems only and sanitary waste discharge was prohibited.

As cities grew in size and density, traditional sanitary disposal methods such as privies and night soil transport became inadequate and contributed to a fouled living environment. In addition, medical authorities were beginning to recognise the interrelationships between such pollution and disease epidemics. In order to remedy the problem, laws were changed first in London, in 1815, in Boston in 1833 and in Paris in 1880, to permit discharge of sanitary wastes to the storm sewers.

However, the transfer of sanitary waste build-up from streets and courtyards to receiving streams was not a satisfactory solution and the public health hazards and environmental damage associated with untreated discharge of sanitary sewage, to receiving waters was ultimately recognised toward the end of the nineteenth century. Initially, those cities situated on a receiving water with limited assimilative capacity initiated treatment practices.

URBAN RUNOFF

When precipitation, either in the form of rain or snow, falls on an urban area, some of the moisture is taken up by various forms of vegetation, some is stored temporarily in surface depressions and other retention areas for eventual evaporation back to the atmosphere and the remainder runs off from the watershed catchment.

For the purposes of this report, runoff from rainfall and snowmelt is considered to be comprised of two components:

a) The horizontal component which is discharged through the man-made and natural drainage system components, including both underground pipes and overland flow paths;

b) The vertical component which infiltrates into the soil.

Traditionally, stormwater runoff from urban areas has been considered to be relatively "clean" from a water quality standpoint, with minimal impact on receiving streams and groundwater aquifers. It is only in recent years, that a better understanding has been gained in relation to the adverse quality of urban runoff, its relationship to quantity, the associated adverse effects on the receiving waters and potential mitigative control measures.

Research undertaken in North America and Europe, particularly over the period of the past five to ten years, has demonstrated that the water quality associated with urban runoff is, in many cases, relatively poor.

Although the pollutant characteristics of urban runoff may vary widely, generally it may be stated that:

a) BOD strength is of the same order of magnitude as treated domestic sewage;

b) Concentrations of suspended solids often exceed by many times the levels found in treated sewage;

c) Bacterial parameters may exceed the levels found in treated sewage;

d) Many organic and inorganic pollutants found in industrial and municipal sewage are often found in urban runoff.

As mentioned, the characteristics of urban runoff may vary widely. So may the impact of urban runoff on the environment. The substances, their concentration, as well as the total loading over time, may have significant impact on receiving waters.

The purpose of this report is to summarise and to assess:

1) The pollutants encountered in urban runoff, including sources and pathways;

2) The magnitude of the pollutant loads discharged from urban areas along with an identification of the significance of these loads in relation to other point and non-point-pollutant sources and the potential environmental impacts;

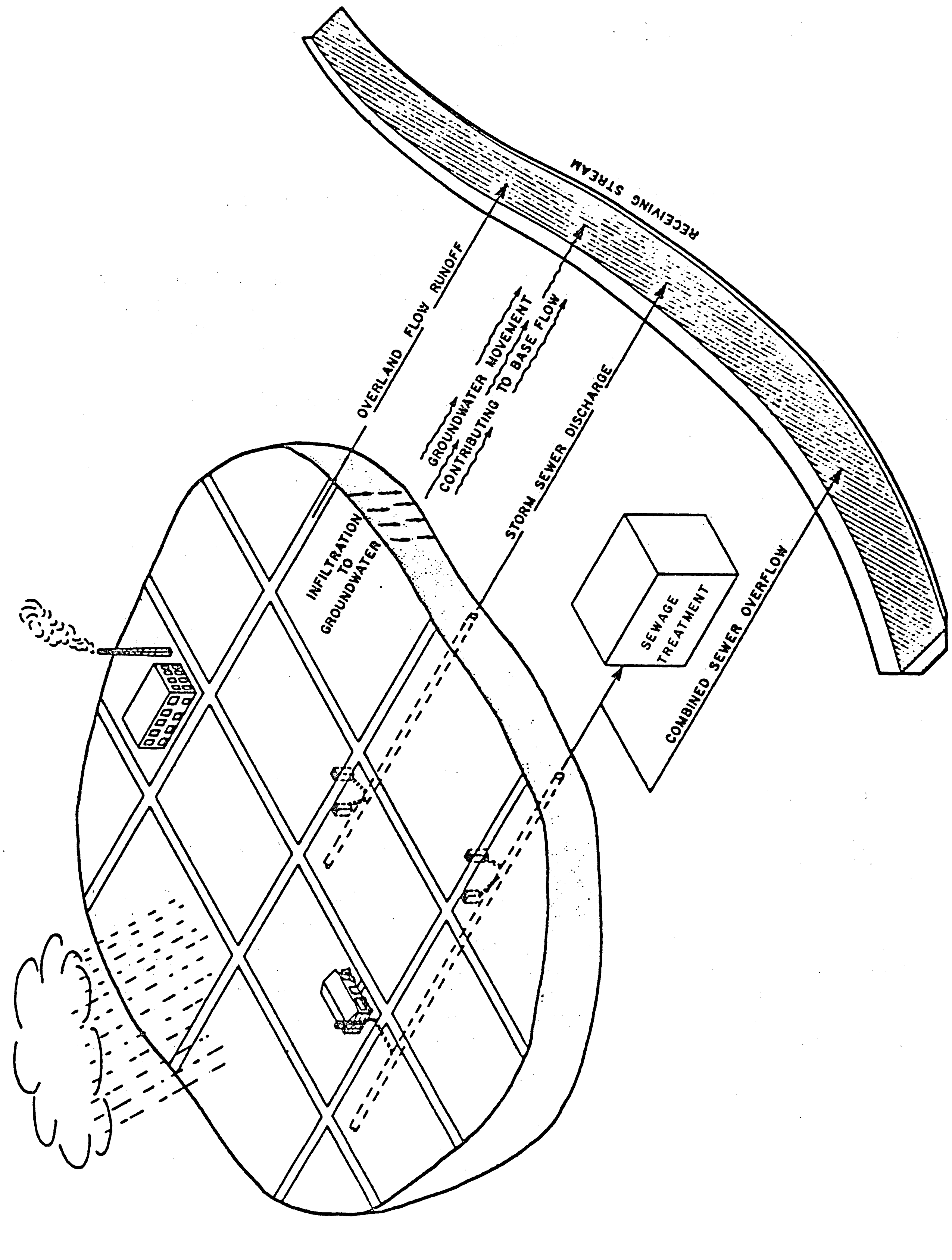
3) Identification of potential control measures, including both:

-- Preventive through the control of pollutant producing products or activities);

-- Curative (stormwater management control practices and/or treatment systems);

4) Recommended guidelines for policies and management of urban runoff and the needs for further research.

Figure No. 1



URBAN RUNOFF

Chapter 2

MECHANISMS, PATHWAYS AND SOURCES OF POLLUTANTS

CHANGES IN THE HYDROLOGICAL CYCLE DUE TO URBANISATION

The mechanisms of urban runoff affecting stormwater quality relate both to the hydrologic and to other influences of development within an urban area. Figure No. A-1 in Appendix "A" shows schematically the interrelationships between urban land-use and water quality of runoff (2).

As indicated earlier, in Chapter I, runoff for purposes of this report is considered to be comprised of both:

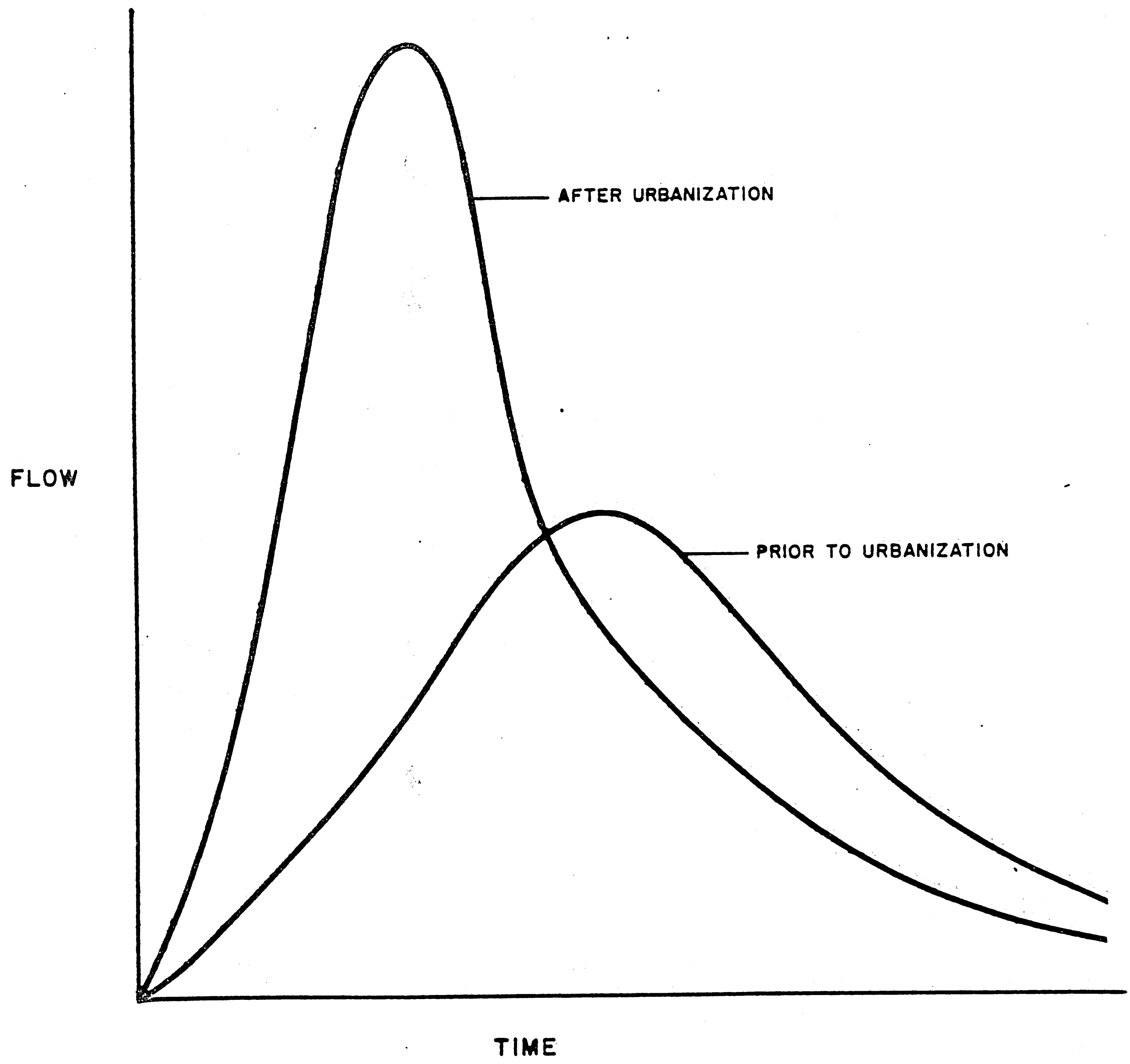
- -- A horizontal component which is discharged through the man-made and natural drainage system components; and
- -- A vertical component which infiltrates into the soil contributing to groundwater recharge.

Runoff from a watershed is affected by various factors, including:

- -- The slope of the ground surface along which the water is flowing;
- -- The relative permeability/impermeability of the soil surface;
- -- The amount of natural surface storage available to retain volumes of surface runoff.

Urban development naturally results in increased impermeable areas as a result of paved streets, building construction, etc. This larger percentage of impermeability as compared to pre-development conditions, has a dramatic effect on the mechanism of runoff, in that the large proportion of the runoff is directed horizontally, across the ground surface and infiltration is greatly reduced and, in some cases, eliminated. Overland flow velocities are increased and natural surface retention eliminated so that the rate of runoff is dramatically increased. This naturally results in increased peak flow rates of runoff and larger volumes of horizontal runoff as illustrated in Figure 2.

Figure 2



RUNOFF HYDROGRAPH COMPARISON OF
PRE VS POST URBANIZATION

Exceptions to this phenomenon are reported by the Netherlands where land slopes are extremely flat and in some instances runoff is pumped to receiving waters at controlled rates.

Urbanisation results in man-made improvements to the natural drainage system. In particular, underground pipes are constructed to transport the more frequent storm events and provide a level of convenience by minimising surface ponding and overland flow during these frequent events. This underground pipe system is generally referred to as the "minor" drainage system. Overland flow paths are changed and improved with urbanisation and include roadways and ditches, as well as major drainage channels which transport the larger, less frequent and more rare events. This overland flow system is generally referred to as the "major" drainage system.

One example which illustrates the potential changes resulting from urbanisation is shown for Ontario, Canada, schematically on Figure A-2 in Appendix "A". This diagram indicates that the horizontal component of the runoff can increase from approximately 10 per cent of precipitation in the pre-urban condition to in excess of 40 per cent after urbanisation. However, the vertical component (perculation) decreases from approximately 50 per cent of precipitation to about 30 per cent. The influences of urbanisation are well pronounced.

Urban runoff varies also, according to climatological zones and for purposes of this discussion, three basic zones are identyified:

-- Cold regions which have extensive snow cover and little, if any, runoff during the winter season;

-- Temperate zones, which are relatively consistent in terms of climate and precipitation and, as a result, are also relatively consistent relating to runoff caused from precipitation events;

-- Semi-arid regions, which provide great variability, both in terms of precipitation and runoff. The large majority of the precipitation in semi-arid regions occurs during the two equinox periods and often occurs as very large, intense storm events with associated high runoff characteristics. The remainder of the seasons can result in near drought conditions.

PATHWAYS

The pathways are those components of the system which transport not only the urban runoff, but also the pollutants associated with the urban runoff, both during the buildup stage prior to the rainfall event and also during the runoff event.

The atmosphere itself is considered as a major pathway, transporting dust and dirt accumulation to the ground surface. The transportation mechanisms are a combination of gravity fall-out from the atmosphere of the particles and, in addition, rainfall which acts as a scrubbing mechanism to the atmosphere, washing gaseous and particulate material to the ground surface.

Overland flow paths, including both natural flow paths and man-made channels, act as pathways for transport of both runoff quantity and pollutant build-up, which is washed from the land surface during rainfall events.

Pipe sewer systems, including both separate storm sewers and combined sewers, are well defined pathways for the transport of stormwater runoff and its associated pollutants. In addition to the pollutant washoff from the groundwater surface, sediment build-up, bacteriological growth and biochemical oxygen demand growth within the inactive areas of the sewer system such as catch basin sumps, depression areas of the sewers, etc. are also washed and transported within the pipe sewer systems.

Sub-surface aquifers act as flow paths for that portion of the runoff which infiltrates into the ground. The aquifers transport not only the flow but also any pollutant accumulations which are not removed in passage through the soil, such as soluble materials and liquid contaminants which travel with the runoff.

SOURCES OF POLLUTANTS

The sources of pollutants both accumulating on the ground surface and washed off an urban area in the stormwater, are contributed from a number of various sources, including:

- -- Every-day urban activities;
- -- Transportation activities;
- -- Atmospheric fallout;
- -- Corrosion;
- -- Industrial/Commercial Activities:

    Waste Landfill
    Raw Material Stock Pile
    Contaminated Land

- -- Vegetation;
- -- Soil Erosion;
- -- Construction Activities;
- -- Abrasion of Solid Surfaces.

A significant effort has been made within a number of various countries to quantify the magnitude of pollutant build-up within urban development areas (3).

Everyday Urban Activities

Everyday urban activities result in a build-up of pollutants on the ground surface, including debris from litter (items discarded by humans including paper, glass and metal objects), chemical fertilizers, organic deposition including animal faeces, etc., and many others as well. Although quantities are generally small, they can be highly visible and objectionable in a receiving stream.

According to a Californian Study (3) in urban areas, litter accumulated at the rate of approximately 1.8 kg/person/year (4 lb./person/year). Of this total, approximately 0.84 kg/person/year (1.8 lb./person/year) appears as litter between the curb lines of streets in urban areas. It was further reported that about 21 per cent of the material picked up during mechanical street sweeping was litter.

The application of chemical fertilizers, insecticides and herbicides are also important sources of chemicals in runoff. Although quantities are generally small, this material will easily wash off into receiving waters during a rainstorm event. The enrichment effect of the nutrients and the toxic effects of other various chemicals makes them important in runoff studies.

Combined sewers, which receive and transport land runoff mixed with sanitary sewage, overflow to receiving waters during rainstorm events. Such overflows can contain a multitude of pollutants from both domestic and industrial wastes.

Transportation Activities

The transportation sector may be considered an every-day urban activity but because of its influence in relationship with pollutant contribution it is categorised separately for purposes of this report. Automobile pollution, for example, includes lead and other exhaust emissions from fuel combustion, fuel and lubricant spills or leaks, and heavy metals, including iron, and chromium from corrosion, tyre and brake lining wear, etc. Airports create, in addition to exhaust emissions and fuel spills, runoff containing oxygen demanding de-icing liquids in addition to other toxic chemicals.

Work done in Washington, D.C., found that most of the street surface pollutants were traffic oriented (4) in that the pollutants, although not necessarily originating with the vehicle itself, were related to the traffic activities. Deposition rates for traffic-related contaminants from the Washington studies are summarised in Table A-1 in Appendix "A".

The effet of traffic on street pavements is one of abrasion and wear and some work done in Germany (5) has shown that at least .05 centimetres (.02 inches) of surface will be worn from a tyre lane during a summer period. This translates into approximately 0.66 kilograms/m^2 (0.13 lb/ft^2) of road per summer. Assuming four tyre lanes over a 7.5 m (24 ft) road, the wear would amount to 0.66 kg/m^2 (0.1316 lb./ft^2) of road per summer. The wear can be considerably greater if studded snow tyres are used by a large portion of the cars during the winter season.

In addition to the erosion of street pavements caused by tyre wear, additional build-up is created by anti-skid compounds and de-icing chemicals. These are very difficult, if not impossible to quantify, because of the variations in rates of applications, depending on such site specific factors as climatological region and local weather conditions. In cold regions, build-up created by anti-skid compounds and de-icing chemicals will exceed build-up from tyre wear considerably.

Atmospheric Fallout

Atmospheric fallout, in addition to the normal dust and dirt accumulation associated with urban areas, can be laden with other pollutants, including for example, sulphur dioxide and nitrous oxides from industrial stack emissions, which, when combined with precipitation, falls on the ground surface as acid rain.

The potential significance of dustfall was demonstrated in a study (6) in Cincinnati. During the study period, on an annual basis, 567 kg/ha (506 lb/acre) of dustfall were measured and 818 kg/ha (730 lb/acre) of suspended solids were measured in the storm runoff. The quantity of atmospheric fallout compared to other sources is clearly one of the significant contributors to stormwater runoff pollution. The degree of significance varies depending on local circumstances. Under Finnish conditions, for example, the following rough proportions of atmospheric load in the urban runoff water have been reported (40):

sulphate	1/2-3/4	nitrogen	1/2-2/3	vanadium	1/4-1/2
copper	1/4-1/3	organic matter (VS, TOC)	1/4-1/3	phosphorus	1/4
lead	1/5-1/4	total solids	1/5	zinc	1/10-1/5
chloride	1/20-1/5				

Corrosion

Corrosion of buildings and other facilities in an urban area results from exposure to every day atmospheric conditions, including freezing and thawing cycles, wind abrasion, rainfall and in particular, acid rain. The corroded particles accumulate on the ground surface in various forms of pollutant build-up and are eventually washed off the land with the urban runoff.

Industrial/Commercial Activities

Industrial stock piles, whether they be associated with waste products or finished products, can be a major source of pollutants in urban runoff. Waste stockpiles in particular, if not properly contained and protected, can produce contaminated runoff, both with respect to the horizontal component and also with respect to the vertical component in the form of leachate discharge to the groundwater aquifers. Both the characterisation and the quantification of such pollution sources are very site-specific but can contain many chemical toxics and heavy metal materials.

Vegetation

Waste vegetative matter from tree leaves, grass cuttings, etc., is an important source of both organic and nutrient pollutants discharged in urban stormwater. The quantity of this waste is difficult to establish and, of course, will vary significantly for different land use classifications and also for the varying densities of trees and other types of vegetation within each land use classification. Some estimates have been attempted. One example is summarised in Table A-2 in Appendix "A".

A study (41) in Halifax, Nova Scotia, estimated vegetative litter production within an urban area to be approximately 1,757 kg/ha/year.

Soil Erosion

Soil erosion is a major contributor to suspended solids in stormwater runoff and this occurs not only within new construction areas, but also within all unpaved areas of urban development.

Within new construction sites, protective vegetative cover is removed and the unprotected soil is left exposed to the atmospheric elements. In this situation, erosion can be very rapid and a very significant contributor to pollutant sediment loading. In unpaved areas of an urban development, erosion also takes place to a degree that is, of course, much less significant when protective vegetative cover is provided.

Sediment loading from erosion is very difficult to quantify because of the various physical factors which affect erosion rates. Typical erosion rates have been established (5) for natural conditions and various types of land use, including agricultural and urban development, as well as typical highway construction. An example is given in Table A-3 in Appendix "A".

Land Surface Accumulation

Accumulation of pollutants on land surfaces in an urban area, results from many factors discussed above. A number of studies have investigated the effects of land-use on the accumulation of pollutants. A summary of the results of various studies showing the dust and dirt accumulation rates for various land uses is given in Table A-4. The concentrations of pollutants found in the accumulated dust and dirt is summarised in Table A-5 in Appendix "A" for different land use characteristics.

Recent work has been undertaken in Canada (8) relating to the study of toxic substances in urban runoff. This study found that for the various land use classifications investigated, including residential, institutional and industrial, both toxic substances and heavy metals were found in urban runoff. Toxic substances investigated included PCB's, Organochlorine Pesticides, Polyaromatic Hydrocarbons, Chlorinated Benzenes and Heavy Metals. The frequency of occurrence and data relating to mean concentrations of persistent toxic concentrations studied and the frequency of occurrence of heavy metals in the collected samples was found to be high in most instances. However, the significance of this has yet to be established. The data are summarised in Tables A-6, A-7 and A-8 in Appendix "A".

MAGNITUDE AND SIGNIFICANCE OF URBAN POLLUTANT BUILD-UP AND RUNOFF

It is difficult to accurately quantify the magnitude of pollutant discharge associated with urban runoff, as there are many factors affecting this loading which depend on such things as the magnitude and density of the urban development, the nature of the development in terms of residential/industrial proportions, the type of sewer system servicing the area, climatological region, etc.

Figure A-3 in Appendix "A" is an example from an Ontario study (9) which illustrates typically the comparison of mass discharge from an urban area, comparing the dry weather flow sanitary component with the stormwater runoff component. The stormwater runoff component, varies depending on the total precipitation experienced in the particular climatological zone. In addition, stormwater runoff will vary depending on the nature and density of development within the urban area. The dry weather flow or sanitary flow component will vary almost proportionally with the population density of development within the urban area.

It is noted on examination of Figure A-3, that stormwater runoff can contribute the larger mass discharge for the less dense developments. However, as the density of an urban area increases the dry weather flow component exceeds the urban runoff volume and at the very high densities, the difference is very marked.

Concentrations of the various pollutants vary significantly throughout a storm event, being highest at the beginning of the storm and decreasing as the storm progresses and the washoff from the area takes place.

Concentrations of pollutants during the storm event are also affected by antecedent conditions, i.e. the time period from the previous storm and also management practices applied on the watershed including street sweeping, etc.

Figure A-4 in Appendix "A" is a typical comparison of concentrations and mass loadings for various pollutant discharges from an urban area over the duration of a typical storm event.

A significant amount of research has been undertaken in order to establish the range of pollutants discharged from urban areas and their significance on receiving streams in particular. The International Joint Commission established by the Governments of the United States and Canada formed a "Reference Group on Great Lakes Pollution from Land Use Activity" (PLUARG) to study the question of pollution of the Great Lakes System from land drainage. PLUARG reported in July 1978 (11); and the findings of the study were that the Great Lakes are being polluted from land drainage sources by phosphorus, sediments, some industrial organic compounds, some previously used pesticides and potentially some heavy metals. A summary of the Great Lakes Water Quality Pollutants is contained in Table A-9 in Appendix "A".

Chapter 3

THE PROBLEMS RELATING TO URBAN RUNOFF

GENERAL

The problems relating to urban runoff can be broadly classified under two categories:

-- Those problems relating to quantity of runoff;

-- Those problems relating to quality of runoff.

Although this report is meant to deal primarily with the quality considerations relating to urban runoff, it should be recognised that there is a significant interrelationship between both quantity and quality characteristics. It is therefore important to recognise some of the problems and impacts associated with quantity of runoff as well.

It is noted, for example, that high rates of urban runoff can, and often do, affect flows within the sanitary and/or combined sewer system, increasing by several times, the flows at the treatment facility. This can cause tremendous overloading of the treatment facility and also create additional treatment problems by "washout" of various biological unit processes. In addition to hydraulic overloading, a high stormwater flow component during spring runoff can lower sewage temperatures interfering with treatment unit processes and overall plant efficiencies. The result of these factors can be to increase the total loads to the receiving stream. In addition, it is possible that different pollutants can be introduced to the receiving stream from those normally encountered in urban runoff, depending on the wastewater characteristics.

QUANTITY OF RUNOFF

As discussed earlier in this report, urbanisation can have a dramatic effect on both the volume and peak rates of runoff, as a result of increased ground surface impermeability, uniform and continuous ground slopes, reduced surface depression areas for natural retention of runoff, etc.

The changes in the natural runoff phenomena caused by urbanisation of an area, therefore tend to increase the magnitude of the horizontal component of the runoff and to decrease the vertical or infiltration component to the ground water aquifers, the net result of which:

a) increases peak flows in receiving streams;

b) depletes groundwater aquifer recharge;

c) decreases base flows in receiving streams.

Increased Peak Flows

Increased rates of runoff resulting in larger peak flows, create problems, particularly in downstream channels and receiving waters. These problems relate both to higher water levels and associated flooding problems and in addition, erosion of channel banks.

Reduction of Groundwater Recharge

The increased imperviousness on urban areas reduces groundwater infiltration. A consequence of this is that groundwater recharge is reduced and in some cases groundwater aquifers become depleted.

Some of the side effects of this aquifer depletion are listed below:

-- A lowering of the groundwater table can disrupt and, in some cases, eliminate vegetation which relies on the groundwater for a source of supply;

-- A decreased recharge of groundwater in conjunction with normal levels of contamination can result in increased concentrations of contaminants within the groundwater aquifers;

-- Aquifers are used extensively in many areas for water supply sources and depletion of these aquifers naturally results in a decrease and ultimate depletion of the volume of water supply available;

-- A lowering of groundwater levels in clay soils can cause considerable shrinking; buildings constructed with foundations in such clay material will have a tendency to sink and will experience structural damage.

Decreases in Base Flows

The increased rate and volume of horizontal runoff, combined with a decrease in the vertical or infiltration component, naturally results in decreases in base flows within receiving streams. This is particularly marked in smaller watersheds, where base flows are often eliminated as a result of extensive urbanisation within the watershed.

Some of the notable adverse effects of decrease in base flows are:

-- Reduction of aquatic life;

-- Reduced potential for source of water supply for downstream users;

-- In semi-arid climatological conditions, this can contribute to creation of deserts.

QUALITY CONSIDERATIONS

The various pollutant parameters associated with urban runoff have been identified and discussed in Chapter 2. The impacts of these various pollutant parameters vary both in time and space and this is best illustrated in Figures 3 and 4 (13).

The impacts of storm runoff water quality problems can be generally classified into the following categories:

-- Public Health Protection;

-- Stream Eutrophication;

-- Aquatic Life;

-- Ecological Changes.

Public Health Protection

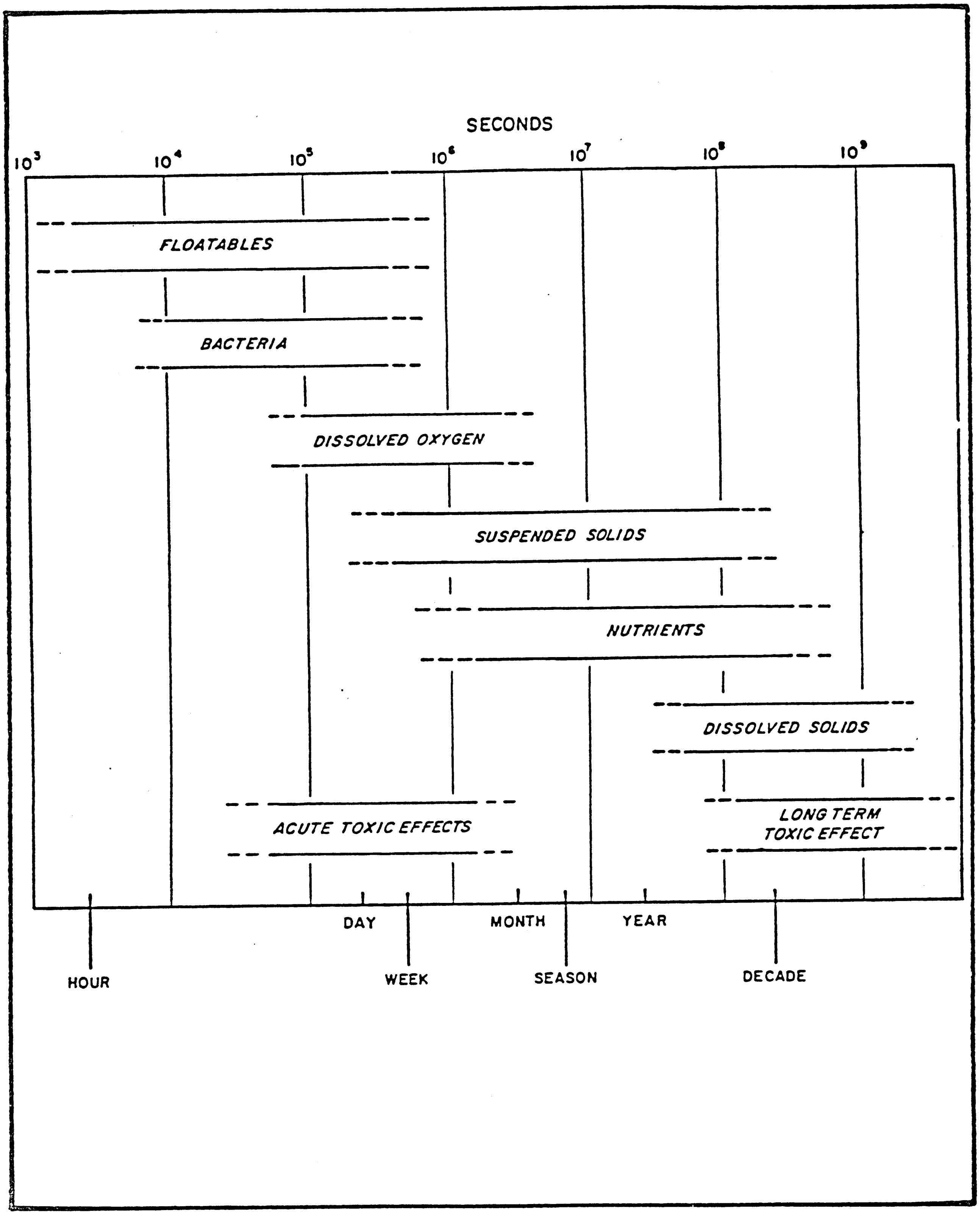
Public health is of primary concern when lakes and rivers are used for primary body contact recreational purposes such as swimming, and when surface waters and/or sub-surface aquifers are used as a source of potable water supply.

a) Recreational Considerations

The standards used to measure the safety of a water body for primary contact recreational purposes, such as swimming, in North America and most European countries usually relate to acceptable levels of total coliform, faecal coliform and faecal streptococcus. Specific criteria defining acceptable levels, however, vary significantly from country to country and even within individual countrties.

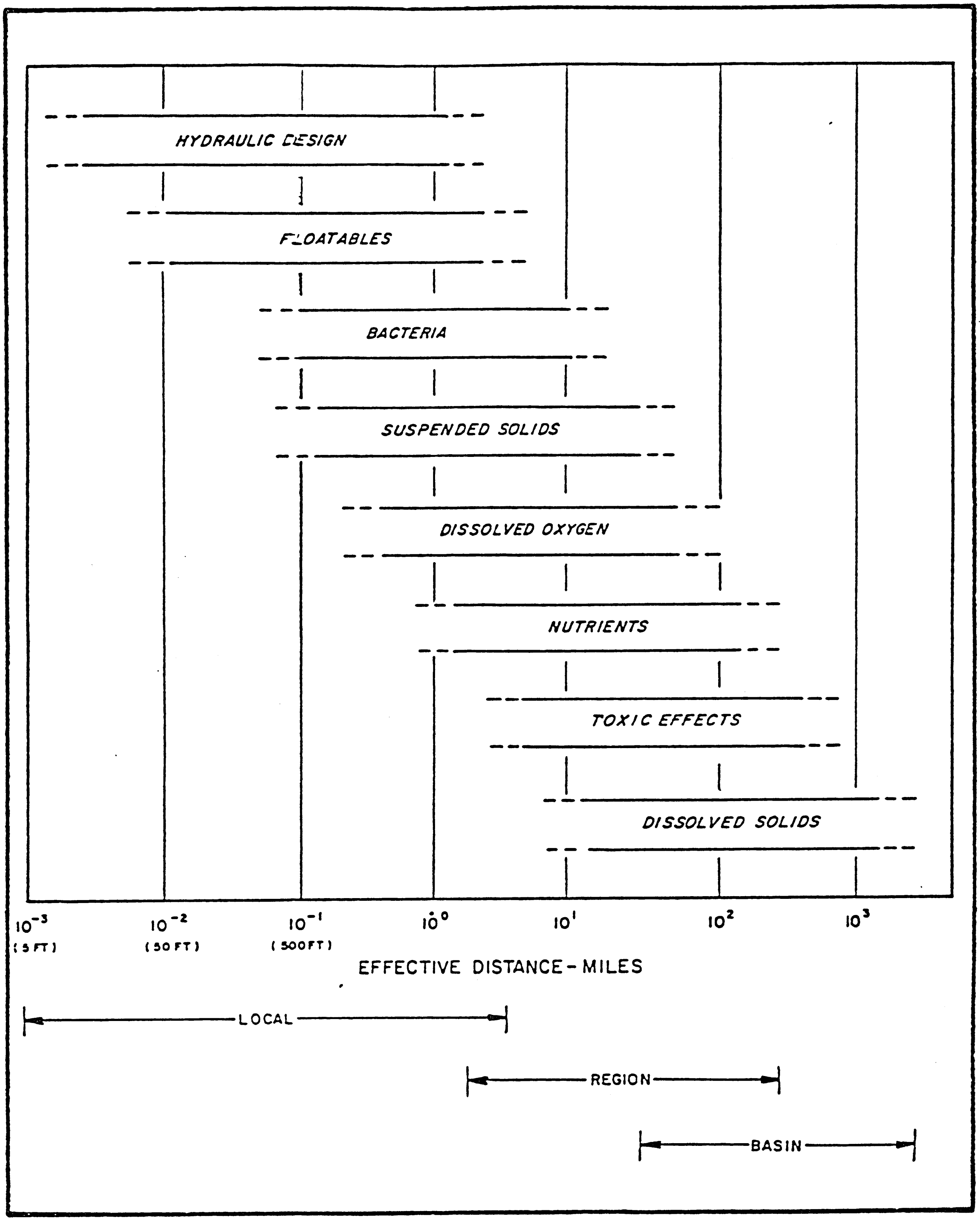
More recent studies (15) have indicated that Salmonella SP, Pseudomonas, Aeruginosa and Staph Aurens are correlated with both total and faecal coliforms for stormwater. It was also found (16) that Candida Albicans at Lake Ontario bathing beaches were correlated with faecal coliforms. These findings would indicate that there may be some positive correlation between some of the disease and infection-causing species and the coliform group.

Figure No. 3



TIME SCALES
STORM RUNOFF WATER QUALITY PROBLEMS

Figure No. 4



SPACE SCALES
STORM RUNOFF WATER QUALITY PROBLEMS

b) Potable Water Supplies

Surface waters used for potable water supply generally undergo rigorous treatment where this is found necessary. However, some pollutants, including for example various toxic materials, are not readily removed by traditional treatment procedures and these can be of particular concern, requiring sophisticated treatment technology.

Public health concerns relating to the use of surface waters for potable supply are also discussed in the following section.

Groundwater aquifers used for potable supply usually undergo minimum treatment prior to distribution, as water quality is generally good. Contamination of these aquifers by such pollutants as solvents, phenols, road salts (de-icing), pesticides, etc. are difficult and often impossible to treat and, in some cases, have required abandonment of the groundwater as a source of supply.

Stream Eutrophication

Eutrophication as referred to here, is the aging of a water body by over enrichment. This aging can be accelerated by urbanisation because more nutrients can be discharged to the receiving waters in the runoff than from pre-development conditions.

The impact of eutrophication on recreation and tourism is probably the most sensitive area for the public. It can severely alter the recreational value of many water bodies and impair related activities (swimming, fishing, etc.). As a result of the objectional aspects of the waters, such as increased turbidity, colour, odour and increased incidence of stinging insects, swimmer's itch, etc., both the social aspects and economic losses can be important and make eutrophication control necessary.

Aquatic Life

The abililty of fish and other aquatic life to survive in a water body depends to a large degree on the dissolved oxygen levels in the water. This will, of course, be affected by the Biochemical Oxygen Demand of the discharge to the receiving waters. It is, therefore, important to protect against severe oxygen sags as a result of high oxygen demand discharges and to eliminate the potential for fish kills.

Toxic materials and heavy metals can pose significant dangers for fish life and also public health hazards, when such fish are used for human consumption.

As demonstrated above, the impact of adverse stormwater quality discharge to receiving waters can have a very significant detrimental impact, not only on the environment but also on the public at large. The time and space scales for such impacts vary significantly. However, each pollutant parameter is important in its own right and deserves special attention with respect to control and mitigation.

Chapter 4

STORMWATER RUNOFF (SURFACE DRAINING) POLLUTION CONTROL MEASURES

GENERAL

Stormwater runoff pollution control measures for purposes of this discussion are classified as:

-- Preventive control measures at source;

-- Corrective control measures.

Preventive control measures are those which can be implemented in the planning and development of an urban area and in the operation and the management of the various activities within the urban area, which will eliminate the discharge of the various pollutants prior to their deposition within the drainage pathways.

Corrective control measures are those which must be implemented as either management or structural measures, to remove the pollutants from the pathways and/or the flow streams.

STORMWATER POLLUTION PREVENTIVE CONTROL MEASURES AT SOURCE

Preventive control measures are those oriented to sources and products and relate to the elimination of pollutants prior to their entering the pathways. Typical examples of preventive measures will include, for example:

1. The Use of Non-Leaded Fuels

   In North America lead was removed from gasoline as an air pollution control device. However, additional benefits are gained in terms of reduced build-up of lead on the streets and ultimately, in the urban runoff to the receiving streams.

2. Stack Emission Control

Control of emissions from stacks is one of the most significant preventive measures which can be taken to control pollutant build-up, not only within urban areas, but also undeveloped non-urban areas as well. Stack emissions have come under considerable scrutiny and public attention in recent times, relating particularly to the widespread damage being caused to fresh water lakes from acid rain.

Stacks are being constructed much taller than previously, resulting in a much wider dispersion of the effluent plume, so that although concentrations are reduced locally, mass loadings in effect remain the same and are spread out over a much wider area of influence extending, in many cases, for hundreds of miles.

In addition to gaseous emissions resulting in acid rain, particulate emissions also are of concern and contribute considerably to the atmospheric fallout. In addition to the sediment load produced, other pollutants, including heavy metals, are often associated with this particulate matter.

Control measures include, for example, wet scrubbers, electrostatic precipitators and in-stream alterations to processes to eliminate emissions at source.

3. Stock Pile Protection and Control

Many industrial processes and municipal management practices require stockpiling of various raw materials and finished products. Often such stock piles, when exposed to precipitation and weathering in general, will result in pollutant build-up and accumulation both on the ground surface for wash-off and in the form of leachate infiltration into the ground water. Protective covers can be simply clay cover material, over landfill sites, or more extensive building protection over stock piles including road salts, etc.

4. Local Legislation and Ordinances

Many municipalities have local by-laws regulating against the discharge of litter in general and in many North American cities particularly specific by-laws are being formulated to provide for control of animal faeces. Enforcement of such by-laws is difficult and requires education of and acceptance by the general public. Although difficult to measure, the benefits from such enforcement are an aesthetic improvement of the urban area and reduced pollution of urban runoff.

5. Management of Chemicals

One of the most important and frequently overlooked measures for reducing pollution in urban stormwater runoff is the reduction in indiscriminate use and disposal of toxic substances, such as fertilisers, pesticides, oils, gasolines, etc.

Spraying for weed control, fertilizing by both municipal and private agencies, and the use of pesticides, can be controlled to some degree, by increasing public awareness of potential hazards to receiving waters and public health in general. In many cases, over application is the major problem and providing instruction as to proper use and application can, to some extent, alleviate this problem.

6. Management of Roadway and Highway De-icing Practices

Effective management of de-icing practices can reduce urban pollution build-up and runoff, with respect to chlorides, sodium and suspended solids, often without substantial increase in costs and in many cases, with cost savings.

Adverse environmental effects have been reported from the use of current de-icing practices, in that increased chloride loads of up to 50 per cent are experienced during winter months. In addition, sand contributes significant portions of suspended solids and can cause maintenance problems with respect to catch basins, separate storm sewers and combined sewers.

Alternatives to current de-icing practices include:

-- Judicious application of salt and abrasives, including reduced application rates in areas where this can be justified;

-- Use of better spreading and metering equipment, with calibrated application rates;

-- Prohibit the use of chemical additives, such as ferro-cyanide, phosphate and dichromate, which can result in increased polluted snowmelt.

7. Corrosion

Corrosion of equipment, including automobiles and corrosion of structures, such as buildings, bridges, roadways, etc. result in buildup of sediment and metals, contributing to pollution of urban runoff.

Control of corrosion includes some of the previously mentioned controls such as:

-- Reduction of acid rain to reduce building corrosion;

-- Reduction or control of road salts.

CORRECTIVE CONTROL MEASURES

Corrective control measures as discussed earlier, are those techniques which are applied to the management of the drainage system, in order to remove

pollutants from the drainage pathways, either from the ground surface, from the pipe system or from the flow prior to being discharged into the receiving streams.

In reviewing the various control mechanisms, it is important to appreciate that there is a relationship between control of runoff quantity and runoff quality, which was discussed in some detail earlier in this report. If, for example, one considers storage as a control mechanism, the entire hydrograph of flow must be taken into account in the sizing of such facilities. At the same time, end-of-pipe treatment processes must consider the wide variation of flow rates to be encountered and the associated efficiencies of such rates of flow with respect to pollutant removals.

Another consideration which is important relates to the scouring or washing action of the stormwater and the variation of this mechanism with different intensities of rainfall, various types of ground surfaces and ground surface slopes.

For purposes of this discussion, corrective stormwater management control features are discussed under four separate categories, as follows:

1. Site Controls;

2. System Controls;

3. End-of-Pipe Treatment Control Measures;

4. In-river Controls.

Control strategies are strongly influenced by the type of sewer system (separate, combined or partially combined) serving an area. These services, which represent a long-term investment, are in fact the essential tools available for runoff management. Therefore it is important when planning, to consider long-term strategies and requirements and to provide maximum flexibility in terms of these requirements.

Sewer Systems and Alternative Strategies

Two basic sewer systems are normally considered in planning a drainage system. These are:

-- Separate sewers for storm drainage and sanitary waste;

-- Combined sewers to transport both storm and sanitary sewage in a common pipe.

In addition to these, some combination of systems resulting in partially combined sewers are often used. Partially combined systems may include for example:

-- Combined sewers serving one portion of an area and separate sewers serving an adjacent area;

-- Combined sewers, collecting both sanitary waste and storm drainage from building areas, and separate storm sewers to collect street drainage. This situation usually occurs to some degree when combined sewers have been separated;

-- Cross-connections from storm sewers to sanitary sewers to intercept potentially contaminated dry weather flow which can occur because of faulty or illegal connections. This technique is one approach sometimes practised in the Netherlands, for example.

Other examples of partially combined sewer systems can be demonstrated as well.

In the past, drainage systems have been designed with the primary purpose of transporting storm flows away from development to eliminate flooding. Little or no attention was given to control of pollution from diffuse sources.

In planning a drainage system for a municipality, the type of systems selected should be based, to a large extent, on a policy for pollution control adopted for an area. One of the principal considerations in such a policy must relate to the receiving water capacity both in terms of quantity and quality of discharge. In this respect, there are a number of factors or criteria to consider:

i) Loadings:

-- The pollutant loading generated from urban runoff is a function of land use and density of land use;

-- Dense developments of an industrial/commercial nature will generally produce a poor quality of runoff. The use of combined sewers to service these types of areas can be a good strategy. In this manner, runoff from many of the less severe rainstorm events will be directed to the treatment plant rather than to the receiving water;

-- The concentration of loadings varies with time throughout a runoff event. Concentrations are much higher initially and then decrease with time throughout the event. The initial high concentrations are associated with a "first flush" phenomenon when a large proportion of the debris and sediment build-up is washed from the sewer system. This is much more significant in a combined sewer system than in a storm sewer system because of the sanitary component and the larger sediment build-up in combined sewer systems between storm events;

-- The frequency of discharge to a receiving stream varies depending on the sewer system type. Combined sewers will overflow during larger events, whereas separate storm sewers will discharge during every event;

-- The receiving stream may be particularly sensitive to shock loadings. Both combined sewers and separate storm sewers can produce hydraulic shock loadings. This impact may be approximately equal for major storm events. Qualitative shock loadings are more severe from combined sewers than separate storm sewers because of the associated domestic and industrial waste component of the flow.

ii) Sewage Treatment Plant Considerations:

The type of sewer system chosen to serve a community will affect decisions which must be made relating to sewage treatment processes and capacity:

-- Combined sewer systems will naturally produce higher average flows and higher peak flows because of the stormwater component. Problems associated with this include:

-- Larger treatment capacity required for the larger flow rates;

-- Weak sewage resulting from storm flows, which can reduce treatment efficiency;

-- High peak flows which can disrupt biological processes.

-- During spring snowmelt periods in northern countries, the snowmelt component of combined sewage can lower temperatures to the point of interfering with some biological processes;

-- Benefits associated with this approach include a degree of treatment for stormwater which is directed to the plant. In a separate storm sewer system, this flow is discharged without treatment.

The selection of a sewer system strategy will naturally be strongly influenced by economic considerations. These will include capital, operation and maintenance costs of the sewer system components and the sewage treatment facilities.

The type of system selected will influence control strategies to be implemented within the system. The system chosen should, therefore, allow flexibility for adapting future changes.

Site Controls

Site controls are those control measures or stormwater management techniques which are applied in the upper reaches of the watershed catchment areas and more particularly on the individual private lots and building development, as well as street surfaces.

Specific site control measures which can be readily and realistically applied, include:

-- Storage;

-- Forced infiltration;

-- Controlled site grading;

-- Improved street sweeping.

Site Storage

It is difficult to establish an effectiveness of on-site storage in terms of removal efficiencies for the various stormwater pollutants of interest and concern. However, some of the mechanisms relating to transport and removal of the various pollutants are discussed below to give some appreciation of the relationship between site storage facilities and pollution control:

-- Detention of stormwater in a storage facility for any period of time will result in some settling and will, therefore, reduce the particulate or solids loading of the discharge. Other pollutants, for example phosphorus and metals, which may be attached to the solids matter, can also be removed to some degree. Some biological stabilization may also occur, reducing biochemical oxygen demands; in addition natural die-off of bacteria can occur.

-- Delaying runoff and extending the discharge and pollutant loading over a longer period of time enhances the ability of the receiving stream to assimilate pollutant loadings.

-- Decreased velocities of storm runoff caused by detaining peak flows, reduce scour and asociated channel erosion in downstream receiving streams.

-- Control of peak flow rates of storm water discharged to combined sewers can reduce overflows of heavily polluted combined sewage and in some instances these can be eliminated completely.

Site storage can be applied in a number of various manners to the individual developments, including for example:

a) Storage on flat rooftops of buildings;

b) Storage on impervious surfaces of parking lots;

c) Normally dry ponding areas constructed into the natural landscaping features of the development area.

a) Rooftop Storage

Rooftop storage is particularly appropriate in commercial and industrial areas, where building areas occupy a relatively large

proprotion of the development area and the building architecture of the development provides for flat rooftops.

The design of such roofs in some areas of North America provide for live loads equivalent to approximately five to ten centimeters of water. This available depth of storage represents relatively severe rainfall events.

The storage can be provided simply and economically by installing a control ring around the roof drain hopper. One such example is shown in Figure A-5 of Appendix "A".

The advantages of this approach are many and include:

1. A significant volume of storage can be provided at minimum cost;

2. The volume provided will permit settling of airborne pollutants onto the rooftop prior to discharge through the drainage system;

3. The storage allows for a reduction in peak discharge from the building with potential associated cost savings in the storm sewerage system downstream.

Disadvantages associated with such a system also are apparent and include:

1. The rooftops, although structurally capable of storing such volumes of water, do require special considerations in waterproofing techniques to maintain a waterproof building;

2. The storage is located in the watershed, such that only the direct rainfall on the rooftop can be stored and therefore, only airborne particulates can potentially be removed with this type of storage facility;

3. Because the rooftops are associated with private property, it is difficult to enforce the continued use of the rooftops for storage and prevent building owners and maintenance personnel from removing the control devices.

b) <u>Parking Lot Storage</u>

Parking lot storage is another potential area for detention of urban runoff particularly in industrial development areas which have large impervious parking lot areas associated with them. Surface retention of stormwater on impervious parking lot areas is an economical and effective method of retarding and reducing peak rates of runoff. The resulting storage on the parking lot areas will be effective in settling solids and other associated pollutants from the flow, which then may be mechanically removed from the ground surface after the storm event;

As opposed to rooftops, parking lots may be designed to store runoff from additional areas of the development, which can be readily directed to the parking lot areas;

Parking lot storage should be designed with care and in order to satisfy the overall objectives of both peak flow and quality control, some design guidelines (18) should be followed:

-- The grading of the parking lot area should be designed in order to provide relatively flat slopes, in order to minimise removal of the particulate deposition after the storm event;

-- The maximum depth of ponding should be limited to approximately thirty centimetres and this should be located in a remote part of the parking lot in order to minimise inconvenience;

-- Storage should be designed so that the duration is minimised and this can be controlled utilising a properly designed outlet control structure.

c) Dry Ponding

Normally dry ponding areas or storm water detention areas can be provided to blend into passive use areas of the development, using appropriate landscaping techniques. Surface runoff from impervious areas of the remainder of the development can be directed through proper grading practices to such a detention area, for gradual release after the storm event. This allows a settling period for removal of particulate matter and other pollutants and, in addition, dampens peak flow rates and provides for a more uniform discharge to the downstream receiving waters.

Forced Infiltration

Forced infiltration can be applied as a site control mechanism and in addition, this can be extended further downstream through the drainage system to a degree. Mechanisms for forced infiltration include for example:

-- Porous pavements;

-- Seepage pits and trenches;

-- Recharge basins

When the ground surface below pavement is permeable and storage can be provided, no runoff at all need occur from porous pavement, except in extreme storm events. Porous pavements do require some special maintenance to minimise clogging. Experimental parking lots using porous pavements have been constructed at the University of Delaware and the Woodlands in Texas. In addition, the Ministry of Transportation and Communications, Ontario, have successfully used porous pavements on a major highway, in order to aid "drying of the pavement surface during rainstorm events".

The effect on the load capacity of the road base, as well as the frost deterioration effects, have yet to be assessed.

Porous pavements will, however, increase the amount of infiltration and thus reduce the horizontal runoff from the watershed. This action will remove

a significant portion of the pollutant load normally directed to the receiving waters. The added infiltration will, however, carry some of the soluble constituents into the groundwater table, thereby increasing somewhat this component of the urban runoff loading.

Seepage trenches and recharge basins have also been applied (19) and although the primary purpose has been to minimise the effect of urbanisation on the increased horizontal component of the runoff, an added benefit of such an approach is also to provide an improved water quality of runoff.

Typical examples of seepage trenches and recharge basins are shown on Figure A-6 in Appendix A''.

Site Grading

Proper attention to site grading within new development areas can be effective in minimising overland flow velocities, thus reducing scour and peak rates of flow and at the same time, permitting more infiltration into the ground surface.

This goal is attained in a number of ways, including:

-- Minimising ground surface slopes, in order to reduce overland flow velocities and associated scour and erosion;

-- Utilisation of natural drainage features, such as drainage channels and natural swales, where this is possible.

Street Sweeping

Street sweeping is practised in most urban areas to remove accumulated dust, dirt and litter from street surfaces. It is usually undertaken for aesthetic purposes. However, street sweeping has also been shown to be an effective method of removing pollutant matters from the ground surface, prior to being washed into the receiving waters.

The effectiveness of street sweeping is a function of:

-- Frequency of cleaning;

-- Number of passes;

-- Equipment speed;

-- Pavement conditions;

-- Equipment type.

Removal rates as reported in the literature vary considerably, depending on the type and manufacture of equipment in addition to the various features described above. Removal efficiencies reported have ranged from 11 per cent to 62 per cent (3).

The relationship between the concentration of pollutants found in urban stormwater and the street sweeping frequency in one U.S. city studied, is shown in Figure A-7 in Appendix "A" (12). This Figure indicates a linear relationship between suspended solids and BOD build-up, up to a period of approximately twenty days, after which there is a tendency to stabilize. This feature, of course, will vary from one climatological region to another as antecedent rainfall conditions will also have a dramatic effect on this particular relationship. In Ontario, for example, where the frequency of rainfall during the summer period is about once in three days, such a linear relationship cannot be expected to hold.

Other studies have also shown a relationship between the number of passes of a sweeper and the removal effectiveness and this is shown on Figure A-8 in Appendix "A".

While extensive data is not available, it has generally been found that concrete pavements are somewhat cleaner than asphalt streets. Pollutant loadings for asphalt surfaces have been estimated to be 7 per cent to 20 per cent higher than for other types of pavement (20).

The type of cleaning equipment also has an effect on overall effectiveness of debris removal. Conventional sweepers are more efficient in removing the larger debris, whereas vacuum and air blast vehicles are more efficient and capable of removing the smaller fractions. Vacuum equipment, however, loses its effectiveness when pavements are wet.

Drainage System Controls

This section deals with those control mechanisms which are applied to the sewer system after the pollutants have entered the sewers and are within the sewer transport system but before reaching the point of discharge to the receiving stream.

It is clear that the control mechanisms available are somewhat limited and relate to two primary options, including:

- -- Sewer system maintenance;
- -- Storage.

Sewer System Maintenance

Both storm and combined sewers do tend to collect debris and sediment in various parts of the system, particularly under low-flow conditions. Catch basin sumps, for example, create a natural trap for sediment loads and unless these are cleaned with some regularity, they can create an environment for biological growth and result in a source for pollutant loading to the sewer system.

Similarly, combined sewers under normal dry weather flow conditions, often tend to have low velocities in the large pipes, allowing for sediment build-up, particularly in flat areas or non-uniform (sag) areas of the system. These sediments are subsequently washed out during storm event condtions and contribute significantly to "first flush" loadings to the receiving streams.

The significance of sewer system maintenance as a best management practice, is that when properly applied, extraneous solids and debris are removed in a controlled manner and thus do not accumulate as pollutant sources, to be flushed into receiving waters under storm conditions.

A regular maintenance programme should include:

-- Catchbasin maintenance;

-- Cleaning and flushing of pipes;

-- Removal of excess debris and silt from channels and ditches;

-- Control of inflow and infiltration sources.

Studies in San Francisco (1) show that on the basis of sampling from a number of catchbasins, a wide range of pollutant loadings are retained in the liquid. The data indicates that on average, the approximate BOD_5 pollutant load held in a basin computes to the equivalent waste discharge by one person in one day.

Sewer maintenance involves both routine inspection and cleaning of the system, so that any lines which are found to be plugged or restricted by build-up of solids, are properly cleaned and any repair work found necessary is undertaken.

The basic concept applied is that hydraulic, mechanical or manual equipment is pulled through the sewers so that material is removed from the system prior to being discharged to the receiving waters.

The cleaning of larger diameter sewers and interceptors involves some relatively unique problems, in that sludge accumulation can be several feet deep, requiring the need for larger, specially designed mechanical equipment.

The benefits of a properly managed sewer maintenance programme are obvious and include:

-- A reduced pollutant loading discharge to the receiving waters;

-- Increased capacity of sewers and interceptors, reducing risk of upstream flooding.

Storage

Storage incorporated into the sewer system can consist of two basic types, including:

-- In-line detention storage;

-- Off-line detention storage.

a) In-line Storage

In-line detention storage facilities are those which are constructed in series, and become an integral part of the sewer system.

Such storage areas can be in the form of storage ponds or oversized pipes ("super pipes").

Storage ponds can be either normally dry ponds or alternatively, ponds which maintain a normal water level. These can be very effectively integrated into a development in the form of artificial lakes or ponds. An example of such a system in Winnipeg, Manitoba, is illustrated on Figure A-9 in Appendix "A".

Properly designed, such systems can enhance the normal environment of the development area and experience has shown (21) that residential lands abutting the lake system have, in fact, increased property values as a result of the amenity provided.

Super pipes have also been used for in-line storage where land availability and costs do not permit for surface ponds. This approach has been applied (22) successfully by the City of Nepean, Ontario, as a water quality control facility.

Specially designed cleaning equipment is required in order to remove settled solids out from the flow after the storm events. The frequency of cleaning can only be determined after some period of operational experience and will depend on a number of things, including land use, surface maintenance procedures, etc.

b) Off-line Storage

Off-line storage is used to attenuate peak flows, reduce combined sewer overflows, capture first flush effects from combined sewer systems and provide treatment in the form of sedimentation, where possible.

Although off-line storage facilities are normally associated with combined sewer systems, such facilities have also been incorporated in separate storm sewer systems, in order to alleviate sewer surcharging and flooding conditions. An example of the implementation of off-line detention storage is illustrated schematically in Figure A-10 in Appendix "A" (23).

Off-line storage facilities, similar to in-line storage, can consist of storage ponds, either dry or wet, and/or underground reservoirs. The use of storage ponds, however, is generally limited to separate storm sewer systems and underground reservoirs are generally utilised for combined sewage overflows.

c) Storage Effectiveness

Although the majority of the storage facilities have been placed in operation to control quantity of flow and, in particular, peak discharge rates, there are a limited number of facilities which have

been constructed specifically for quality control. Studies (24) have shown that such facilities have been able to provide removal for various parameters of concern.

End-of-Pipe Treatment Facilities

End of pipe treatment controls refer to physical unit processes, to control pollution from stormwater and/or combined sewer overflows. The unit processes can include storage, physical treatment, biological treatment, land treatment and disinfection.

For purposes of this discussion, the unit processes considered include:

-- Storage;

-- Screening;

-- Swirl concentrator;

-- Dissolved air floatation;

-- High gradient magnetic separation;

-- High rate filtration;

-- Marsh treatment.

Storage

Storage can be applied as an off-line physical treatment device, to provide sedimentation treatment prior to discharge to receiving waters.

Storage located at the end-of-pipe will essentially take the same form as in-system storage, i.e.:

Normally dry and/or wet ponding facilities;

Covered or underground reservoir tanks.

End-of-pipe storage treatment facilities can and often do incorporate such features as:

-- Chemical coagulants to assist sedimentation;

-- Chemical disinfection.

An example of such a facility is the Massachusetts Charles River facility (3), which is designed to treat the one in five year storm flow of 14 150 ML/S (323 MGD).

The facilities include pre-screening, covered tanks with a total storage capacity of 4.54 ML (1.2 gal.) and chlorination facilities. The projected pollutant removal and operational performance of this facility is

summarised in Table A-10 in Appendix "A'. It is reported that overall removals on an annual basis for this facility are projected at:

BOD	60 per cent;
Suspended Solids	50 per cent;
Settleable Solids	60 per cent

Screening

Screens have been used to achieve various levels of Suspended Solids removal, either as the sole treatment process, or as a pre-treatment device to remove suspended and coarse solids, prior to additional treatment processes.

Several types of screening devices have been developed and used in stormwater treatment both in Canada and the United States.

Swirl Concentrator

Swirl and helical concentrators, although originally developed as a regulating device, achieve both quality and quantity control of storm and combined sewer discharges. The two principal types of devices include the swirl and the helical bend concentrator/regulators as described on Figure A-11 in Appendix "A" (25).

Swirl concentrators have been demonstrated for various uses, including:

Flow regulator
Degritter
Primary Separator

The swirl concentrator. as a flow regulator, allows, during dry weather conditions, sanitary dry weather flows to be diverted through a bottom orifice and discharged to the intercepting sewer. During peak storm-flow conditions, the flow to the interceptor is controlled by the bottom orifice and excess flows are discharged over the surface weir.

The swirl principal has also been applied to grit removal for pre-treatment at sewage treatment plants. In this instance, the swirl degritters are equipped with a conical shaped hopper, below the circular swirl chamber where solids accumulate prior to discharge.

The swirl primary separator was developed to remove a greater fraction of the suspended solids than the conventional swirl concentrator/regulator. The configuration of the swirl chamber developed is conical shaped, with a depth approximately equal to the tank diameter.

A number of demonstration projects, utilising swirl and helical bend concentrators have been undertaken in the United States, Canada and England.

Some data is now available relating to the efficiency of the swirl concentrator and studies in Syracuse, New York (26), have shown that mass removal of suspended solids range from 33 per cent to 55 per cent.

Dissolved Air Flotation

Dissolved air flotation has been demonstrated as an efficient treatment method to remove suspended solids and flotables, such as oil and grease found in combined sewer discharges (3).

Solids are removed from the waste stream by small bubbles of air, which are released in the reaction tank after depressurisation, and rise to the surface carrying solids. The pressurised flow carrying the dissolved air to the flotation tank is either:

a) The entire storm flow;

b) A portion of the stormwater flow;

c) Recycled dissolved air flotation effluent.

High Gradient Magnetic Separation

High gradient magnetic separators utilise the interaction of magnetic and competing forces on a mixture of magnetic and non-magnetic particles, to provide separation based on the magnetic susceptibilities of the particles.

High gradient magnetic separation has been used for a number of years in various industries, including:

Kaolin Clay Industry;

Iron Ore and Other Mineral Processes;

Purification of Chemical Refractories and Powders;

Removal of Smoke Stack Particulates;

Steel Mill Waste Water Purification.

All of the above are direct applications and do not require the addition of a seed or flocculant to be effective. The application of high gradient magnetic separation to combined sewer overflows requires a seeding of the waste stream with magnetic iron oxide and the adding of coagulants and polyelectrolites, to form a floc amenable to removal in a magnetic gradient. The flow is then passed through a matrix, where the magnetic gradient is introduced and the removal occurs.

Backwash facilities are provided to flush accumulated floc and particles from the matrix, when the magnetic gradient is reduced to zero.

Removal efficiencies on a pilot bench-scale study undertaken in Boston (27) indicated that removal efficiencies were better than sedimentation because the magnetic forces on the fine particles are many times greater than normal gravitational forces. The Boston study indicated that removals in the order of 90 per cent and higher for suspended solids, BOD and coliform were possible.

High Rate Filtratin

A high-rate filtration demonstration treatment system was evaluated (28) for the removal of suspended solids, phosphorus and nitrogen, utilising in-line alum addition, coagulation, polymer addition, flocculation and filtration.

Suspended solids and phosphorus are removed by alum addition, coagulation and high-rate filtration and the ammonia nitrogen is removed by an exchange/adsorption process.

Comparison of Treatment Efficiencies

Pollutant removal has been evaluated in the U.S. for the various physical treatment processes (3) and this is summarised in Table A-11 in Appendix "A" (3).

It is noted that there is a wide variation in removal efficiencies for the various treatment processes. Treatment efficiencies for suspended solids removal for example, range from a low of 5 per cent for static screening to a high of 98 per cent for high gradient magnetic separation. Similarly, BOD removal efficiencies vary from a low of 0 for static screens, to a high of 98 per cent again for high gradient magnetic separation. Phosphorus removal, where reported, generally ranges in the order of 10 per cent to 50 per cent for the various processes examined.

In River Controls

(River Purification Lakes)

In the United Kingdom, severe river pollution caused by the urban runoff from Birmingham and district (the second largest city in the Unitd Kingdom) is being alleviated by the use of a system of river purification lakes. A detailed research programme (39) showed that the bulk of the polluting suspended matter carried by the River Tame, which drains the Birmingham conurbation, during the "first flush" period of a storm could be settled out in a primary lake from which the deposited sludge could be removed by suction dredger. Passage of the settled river water through a further series of lakes was shown to improve the river water quality to an acceptable level.

The primary purification lake on the River Tame was commissioned in 1980 and the scheme will be completed by causing the settled river water to pass through a further five lakes during which natural purification processes will greatly improve over water quality. The primary lake alone has already improved the average suspended solids concentration of the river by 43 per cent and the BOD by 29 per cent, with much greater percentage purification ocurring during periods of urban run-off. Fish life is now returning to the River Tame after more than a century of gross pollution during which the river has been practically lifeless.

The river purification lake system improves river water quality under both polluting urban run-off conditions and under normal flow conditions when the retention time in the system is proportionately greater.

Chapter 5

STRATEGIES FOR RUNOFF MANAGEMENT AND CONTROL

OBJECTIVES OF RUNOFF MANAGEMENT AND CONTROL

The primary objective in the development of urban drainage systems has traditionally been to provide a convenience drainage system and to prevent flooding. It is now recognised that stormwater runoff from an urban area is contaminated by many pollutants including sediment, nutrients, bacteria, metals and other toxic materials. These pollutants have a potentially adverse effect on receiving water bodies. In light of this, it is important that urban drainage policy deals with two primary objectives:

-- Quantity control;

-- Quality control.

There are some social factors associated with an urban drainage policy which includes pollution control as a primary objective. These factors are mostly beneficial and include for example:

-- Improved quality of the environment;

-- Improved water quality for: potable consumption
aquatic life
eutrophication control;

-- Improved recreation amenities.

However, some social opposition can be expected from:

-- The private sector relating to implementation of source controls;

-- Additional costs for abatement measures reflected in additional energy consumption and increased costs of goods and services.

Flexibility in the range of available options for design varies depending on the age of the development area. Old cities with well-established drainage systems allow a limited flexibility and control options are often limited. Controls such as improved street sweeping practices, and end of pipe treatment devices can be considered.

In new development areas, the range of options is almost unlimited, particularly when drainage planning is undertaken in conjunction with area planning.

A true economic evaluation comparing costs and benefits of stormwater management controls is a difficult assignment because of the problems associated with establishing monetary value to many of the derived benefits.

A better approach is to establish objectives for water quality and then assess alternative control methods in terms of a "least cost" or "cost effectiveness" evaluation.

Policy for urban drainage should relate to an overall pollution control strategy and include both quality and quantity objective.

A comprehensive policy should include the following criteria:

1) Municipalities should develop master drainage plans for all watersheds within their boundaries. The purpose of this policy is to foster master drainage planning in developing municipalities. In this way stormwater drainage systems can be developed so that existing problems are identified and future problems avoided;

2) Municipalities with sewage collection and treatment systems should formulate a pollution control strategy that considers both wet and dry weather pollution sources;

3) Pollution control from urban drainage is a long-term commitment. Operation and maintenance of control structures and treatment facilities are part of this commitment.

CONCLUSIONS/RECOMMENDATIONS CONCERNING GENERAL GUIDELINES AND SPECIFIC ACTIONS

Some general conclusions have been made relating to quality of urban runoff:

i) Land use, soil type and density and local precipitation all affect the quality of runoff water. Considerable variability may be expected both at the local level and on a regional basis.

ii) Historically, municipal sewage and industrial wastewaters have been the more significant point sources of water pollution. With improved abatement measures in these areas, the impact of urban runoff may be more significant and require some control.

iii) Control of sources is made difficult by their dispersed nature. This can have both economic and social implicatins.

iv) Combined sewer overflows may introduce a wide variety of pollutants because of the use of such sewers to convey industrial and commercial wastewater.

General and specific recommendations relating to urban runoff control policies are:

i) Every municipality should formulate an urban drainage policy based on an overall pollution control strategy.

ii) The choice of an urban drainage system depends on local circumstances. Important factors influencing the choice will include environmental quality objectives, economic and legal requirements and the nature of the existing system.

iii) Pollution control should begin at source at both the local and the regional level.

Control measures may include:

-- Atmospheric fallout controls;

-- Prudent use and storage of de-icing material in the transportation sector;

-- Corrosion control of all exposed surfaces;

-- Erosion controls from construction activities;

-- Improved wear resistance to road surfaces;

-- Lead controls in fuels.

iv) Management controls should be implemented to control surface runoff quality prior to entry into the sewer system:

-- Frequent street sweeping;

-- Sound management of snow dumps;

-- Legislation for control of animal excrement in urban areas.

v) Drainage systems should be designed so that the natural water budget conditions are disturbed to the smallest possible extent. This will require infiltration and percolation where possible. It is important that such practices do not transport pollution to important groundwater aquifers.

vi) All possible means should be utilised (both natural and structural) to slow runoff and reduce runoff to pre-development flow rates. Examples of such methods are illustrated in Figure 1.

vii) Control devices should be considered both within the drainage system and at the end of the pipe to provide hydraulic and quality control.

viii) Mathematical simulation of drainage systems can help in the evaluation of alternatives and the associated economics. Their use should be encouraged.

ix) Sewer use controls are required to prevent illegal connection of storm and sanitary or combined sewers. These controls must also limit the type and amount of substances discharged to each of them.

x) National networks for urban meteorological observations should be established where these do not exist.

xi) Research should be continued and expanded in the area of urban hydrology both on a local and a national level. Information is necessary relating to:

-- Rainfall-runoff characteristics;

-- Pollution aspects of urban runoff, particularly relating to heavy metals and micro-pollutants;

-- Establishment of links between pollution and sources.

Appendix A

FIGURES AND TABLES

Figure A-1

FLOW CHART OF CONNECTIONS BETWEEN URBAN LAND USE TYPES AND WATER QUALITY

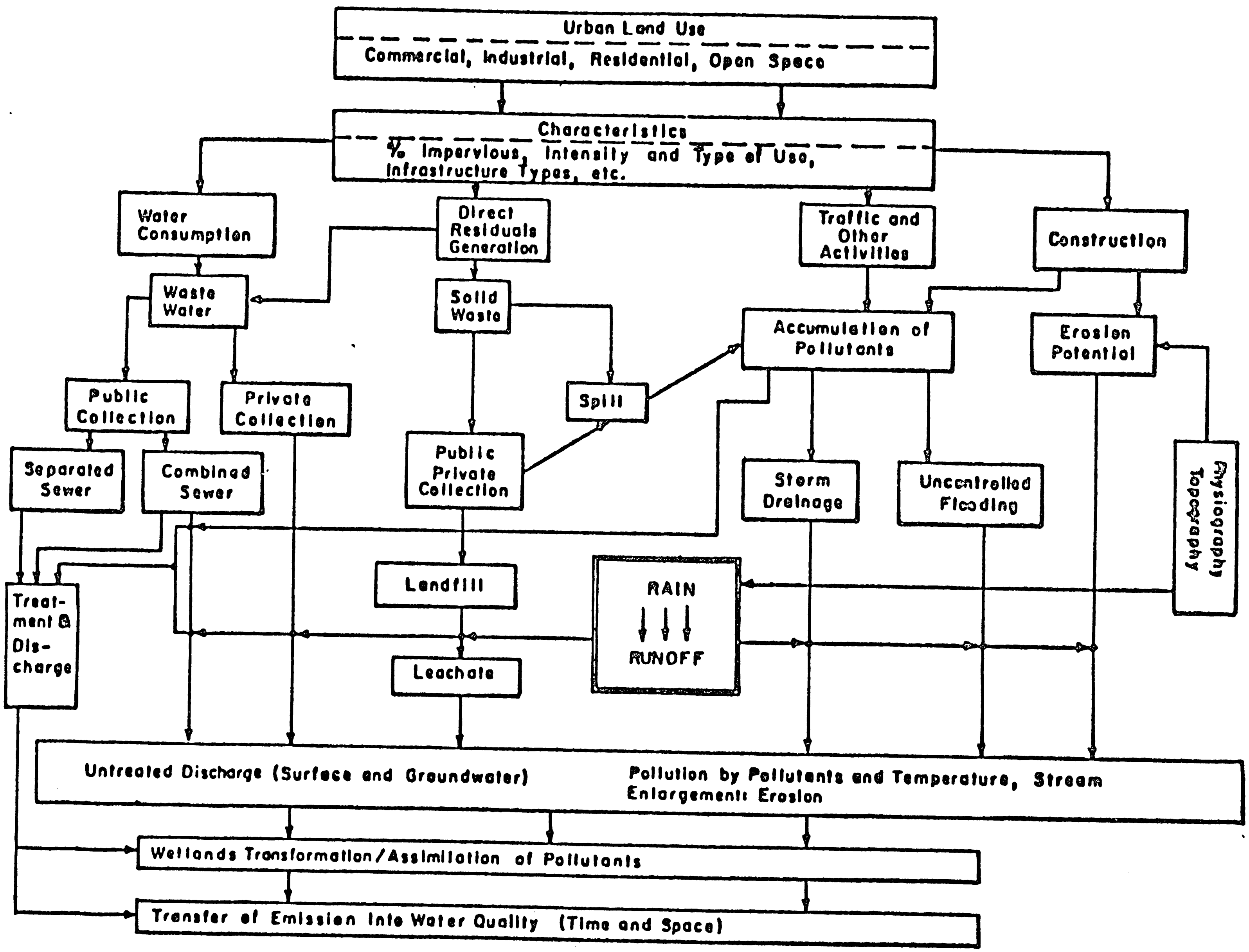


Figure A-2

HYDROLOGIC CHANGES RESULTING FROM URBANISATION

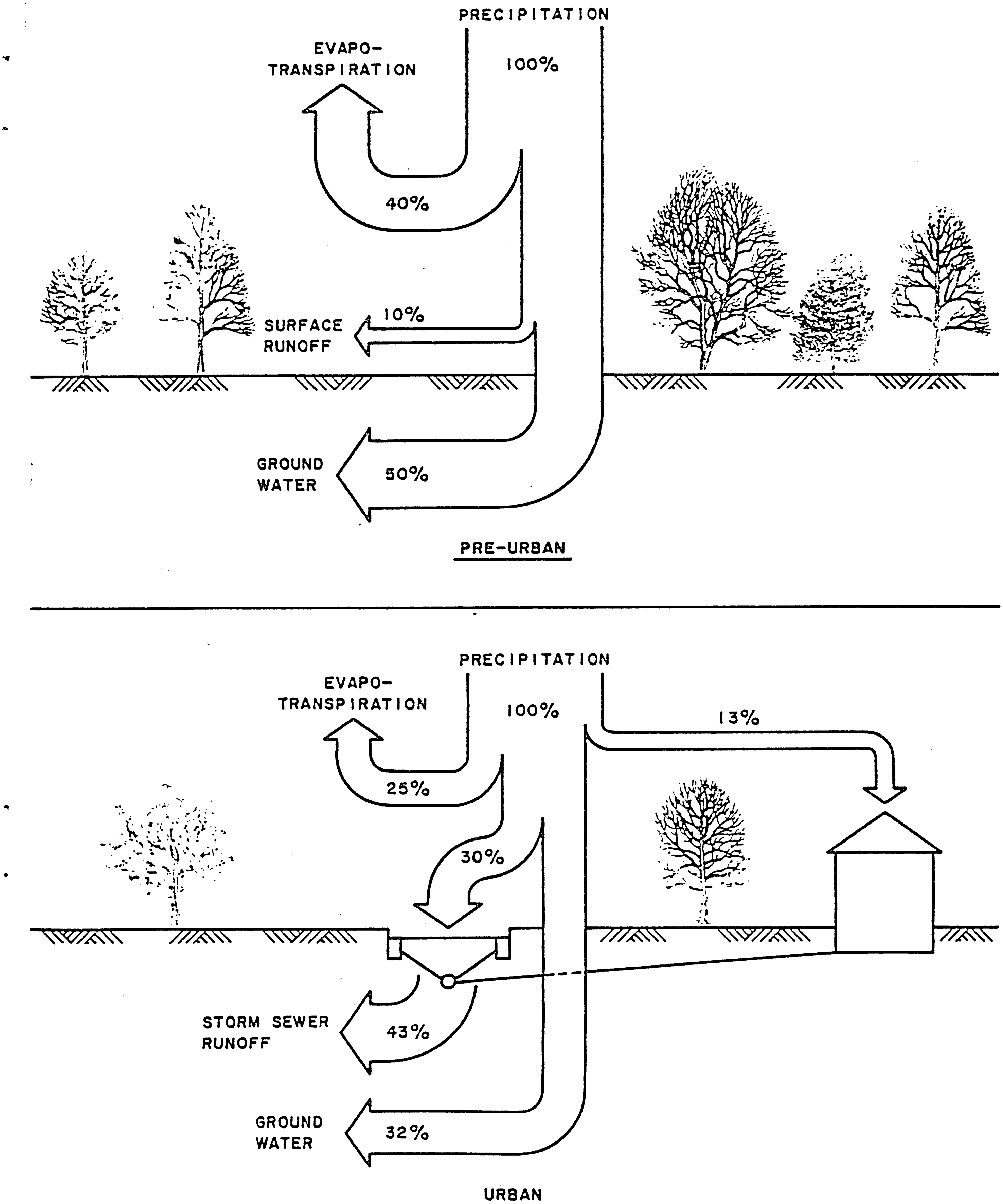
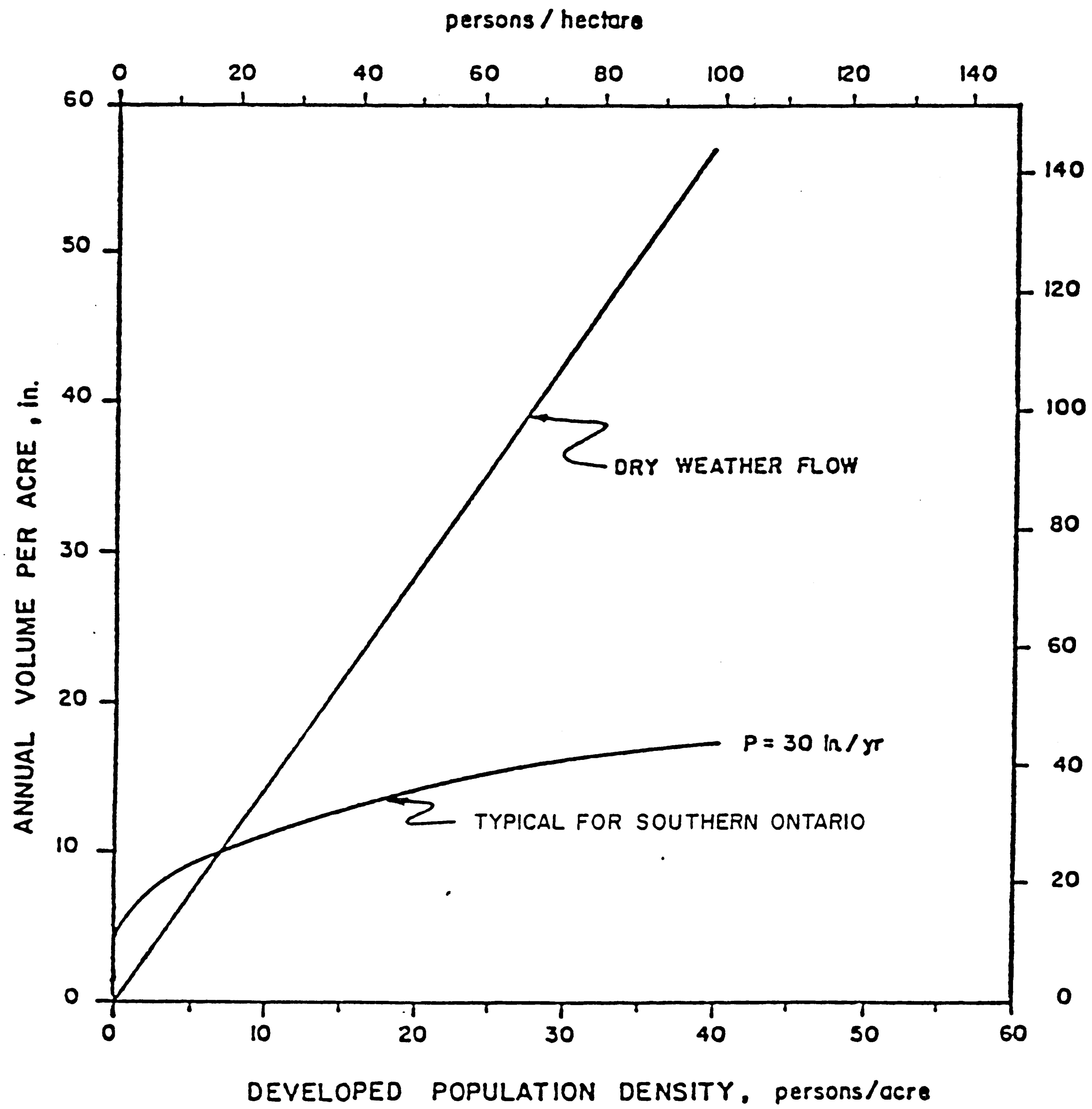
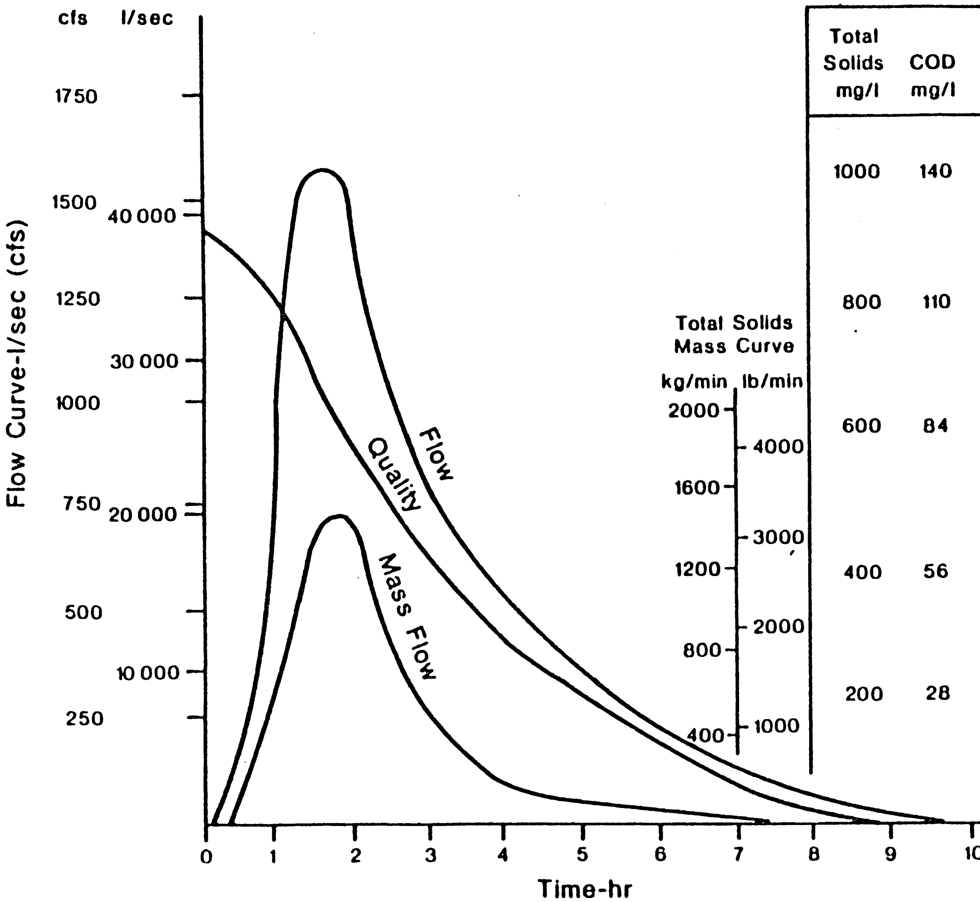


Figure A-3

COMPARATIVE MAGNITUDE OF ANNUAL WET- AND DRY-WEATHER FLOWS





Quantity Curve
Concentration per Five Days of Accumulation

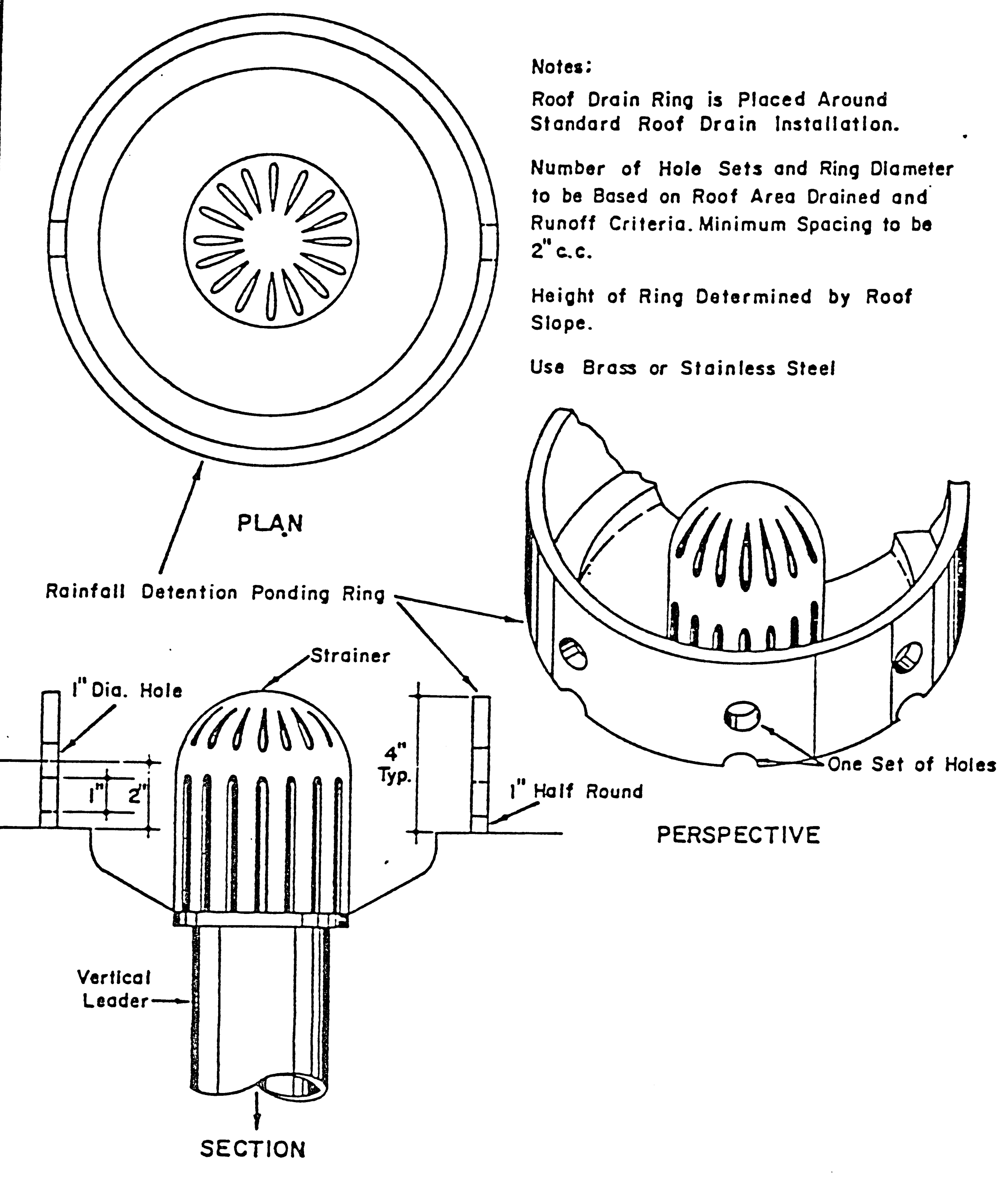
Total Solids mg/l	COD mg/l	BOD_L mg/l	Total Phosphates mg/l	Kjeldahl Nitrogen mg/l	Lead mg/l	Zinc mg/l	Total Coliforms *	Fecal Coliforms
1000	140	70	3.0	3.0	1.8	0.40	250 000	17 000
800	110	56	2.4	2.4	1.4	0.32	200 000	14 000
600	84	42	1.8	1.8	1.1	0.24	150 000	10 000
400	56	28	1.2	1.2	0.72	0.16	100 000	6800
200	28	14	0.6	0.6	0.36	0.08	50 000	3400

* Approximate Number of Organisms per 100 ml

QUALITY-QUANTITY HYDROGRAPH FOR CASE STUDY

Figure A-5

RAINFALL DETENTION PONDING RING FOR FLAT ROOFS

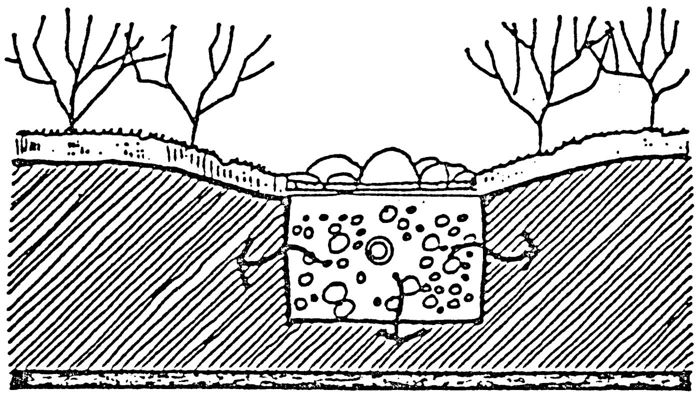


a. rooftop detention devices

Source: Wright-McLaughlin Engineers. Denver, Colorado

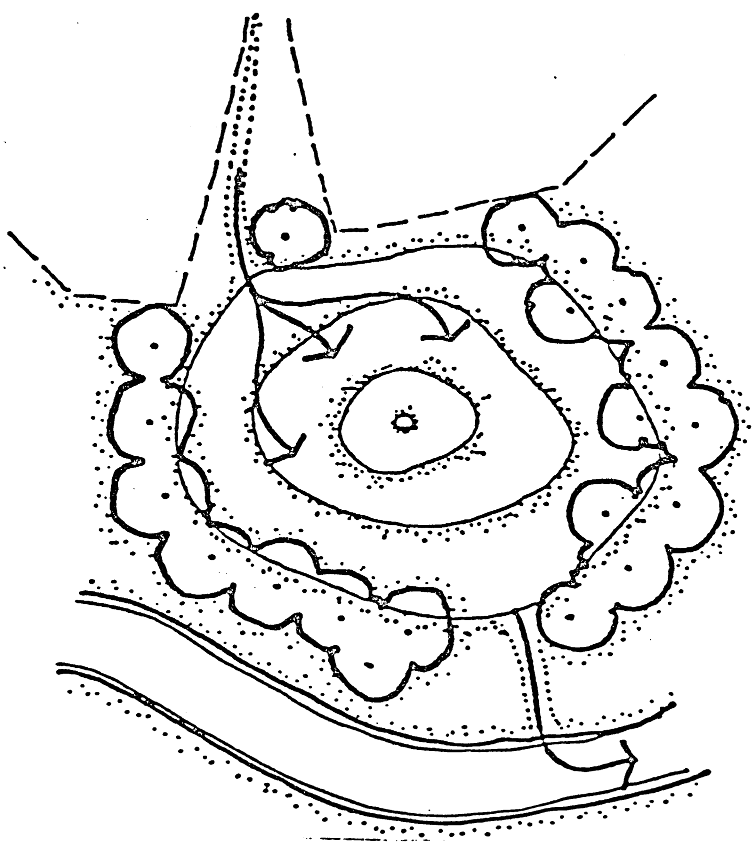
Figure A-6

STONE AND SAND TOPPED SEEPAGE TRENCH



Can be used in park setting and landscaped to simulate intermittant stream bed providing visual interest as well as infiltration. The use of a filter fabric liner is optional.

RECHARGE BASIN TYPICAL PLAN



Shallow side slopes maximise distribution of runoff for more rapid infiltration

Figure A-7

EFFECT OF STREET SWEEPING FREQUENCY ON MEAN BOD CONCENTRATION IN URBAN STORMWATER RUNOFF, Des Moines, Iowa.

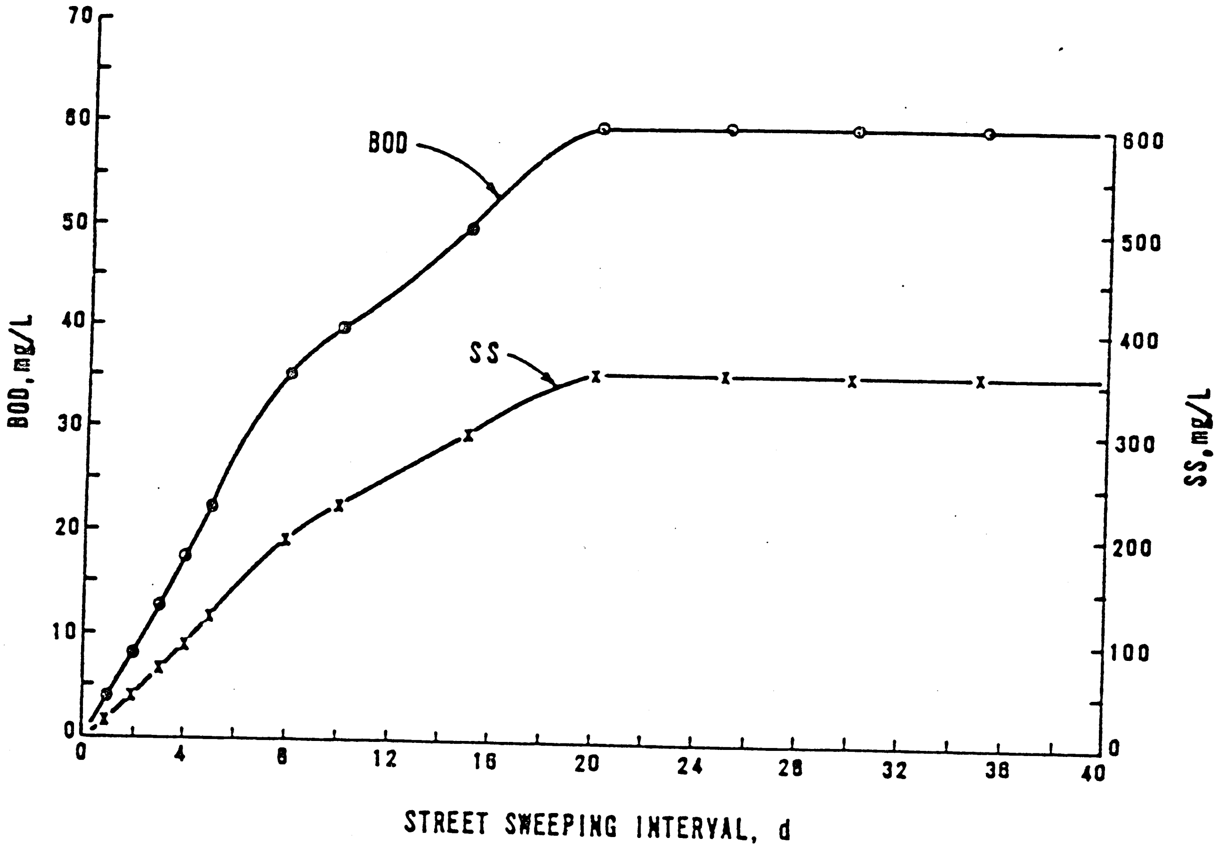


Figure A-8

STREET SWEEPING REMOVAL EFFECTIVENESS WITH NUMBER OF PASSES

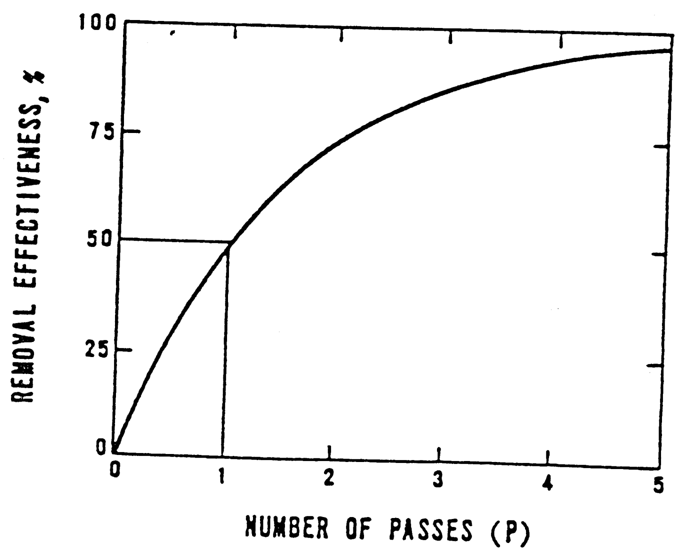


Figure A-9

STORAGE PONDS -- WINNIPEAG, MANITOBA

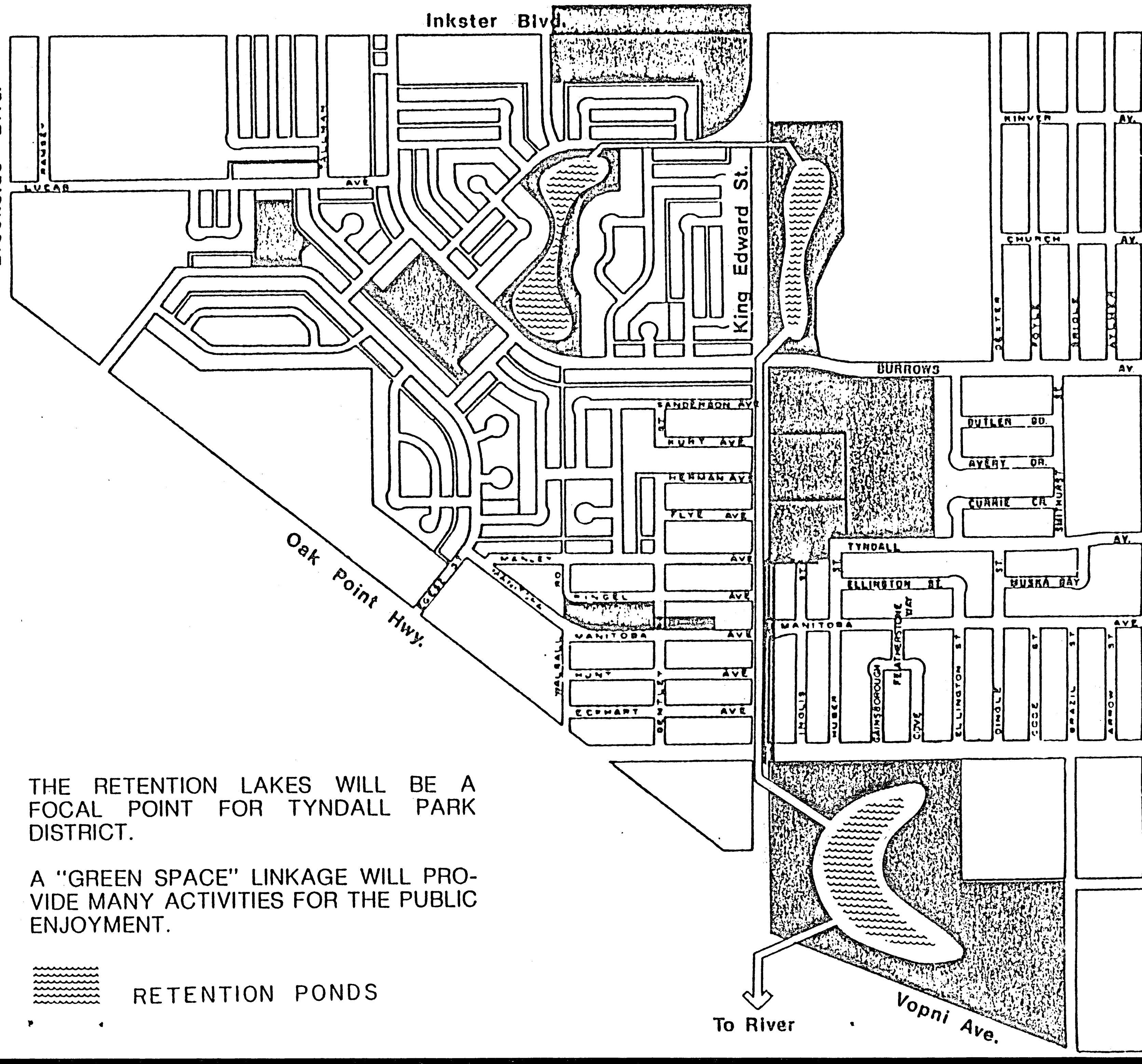
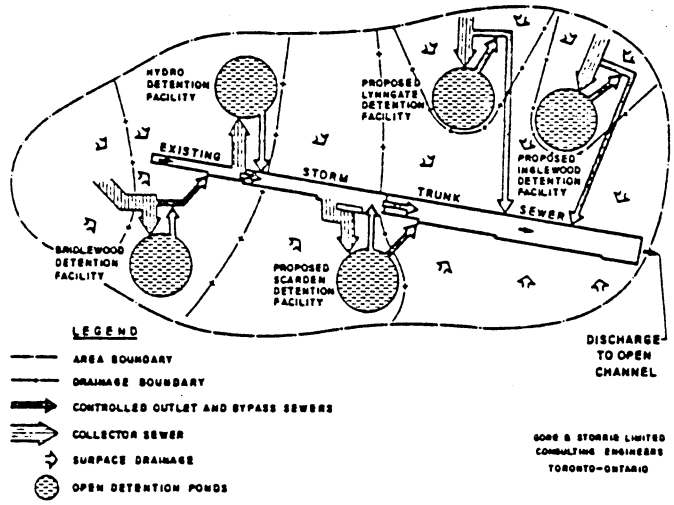
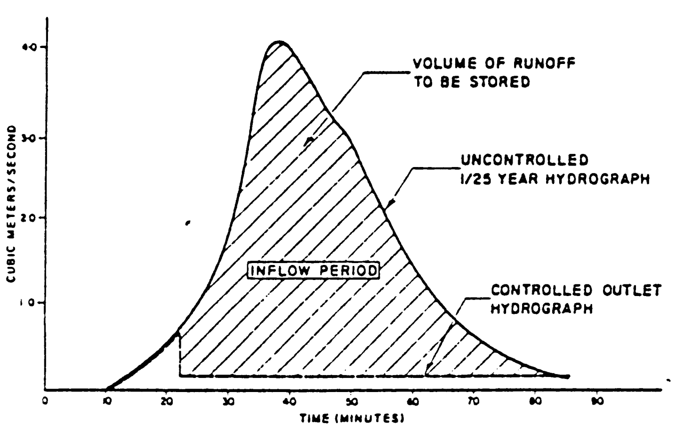


Figure A-10

OFF-LINE DETENTION STORAGE



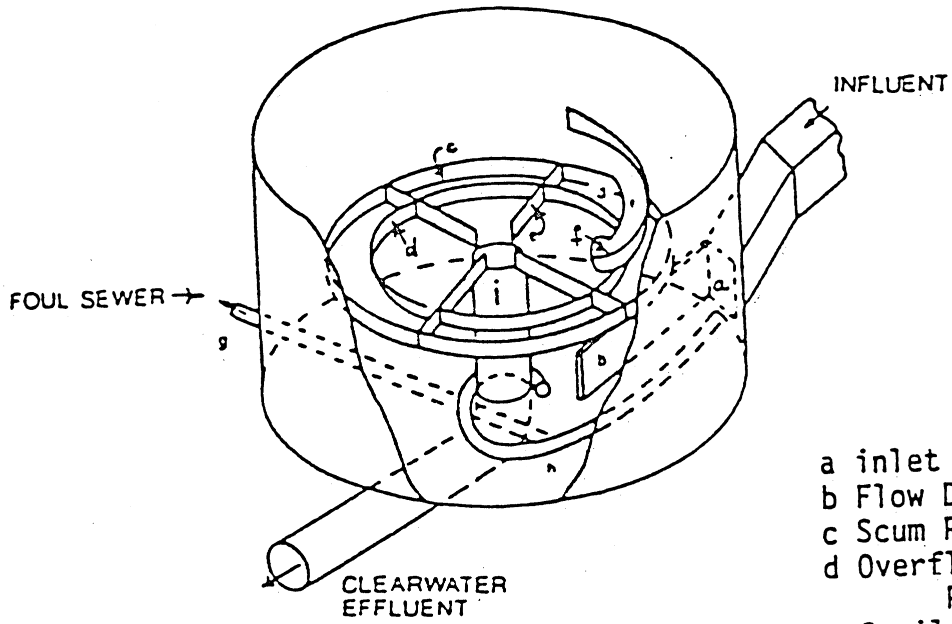
FLOW SCHEMATIC FOR SUB-TRUNK 'D'



INFLOW HYDROGRAPH TO BRIDLEWOOD PARK DETENTION FACILITY

Figure A-11

SWIRL/HELICAL BEND/SOLIDS SEPARATORS



a inlet Ramp
b Flow Deflector
c Scum Ring
d Overflow Weir & Weir Plate
e Spoilers
f Floatables Trap
g Foul Sewer Outlet
h Floor Gutters
i Downshaft
j Floatables Deflector

A. SWIRL

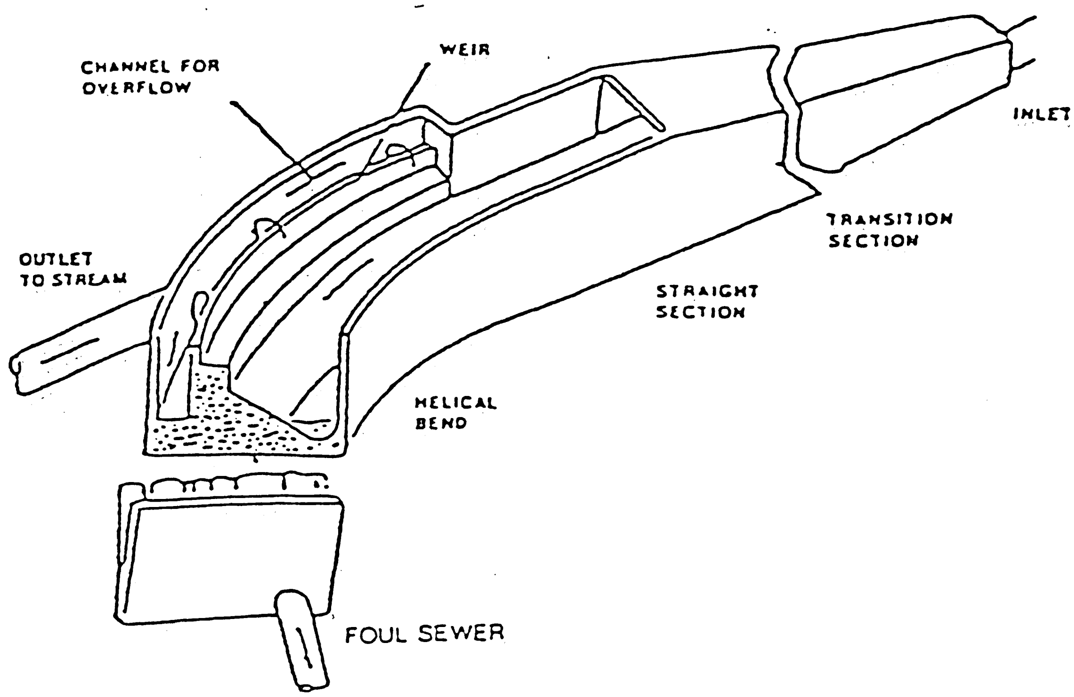


Table A-1 (4)

DEPOSITION RATES OF TRAFFIC-RELATED ROADWAY MATERIAL

Parameter	Units	Deposition Rate
Dry weight	lb/1 000 axle-mi	2.38
Volume	qt/1 000 axle-mi	0.63
Volatile solids	lb/1 000 axle-mi	0.12
BOD		5.43×10^{-3}
COD		0.13
Grease		1.52×10^{-2}
Total phosphate - P		1.44×10^{-3}
Nitrate - N		1.89×10^{-4}
Nitrate - N		2.26×10^{-5}
Kjeldahl - N		3.72×10^{-4}
Chloride		2.20×10^{-3}
Petroleum		8.52×10^{-3}
n-paraffins	lb/1 000 axle-mi	5.99×10^{-3}
Asbestos	fibres/axle-mi	$3.86 \times 10^{+5}$
Rubber	lb/1 000 axle-mi	1.24×10^{-2}
Lead		2.79×10^{-2}
Chromium		1.85×10^{-4}
Copper		2.84×10^{-4}
Nickel		4.40×10^{-4}
Zinc		3.50×10^{-3}
Magnetic fraction	lb/1 000 axle-mi	0.13

lb/1 000 axle-mi x 0.28 = kg/1 000 axle-km
qt/1 000 axle-mi x 0.59 = L/1 000 axle-km

Table A-2 (7)

VEGETATIVE LITTER PRODUCTION

Source	Yield of Waste Matter lb/acre yr.
Evergreens (a)	3 300
Deciduous trees (a)	2 854
Rye grass (b)	3 675-5 612

a. Full canopy

b. Florida

lb/acre yr. x 1.121 = kg/ha yr.

Table A-3 (5)

EROSION RATES

Sediment Source	Erosion rate, $tons/mi^2.yr$	Geographic Location	Comment
Natural	15-320		
Agricultural	200-70 000		
Urban	50 000	Kensington, Md	Extensive construction
	1 000-100 000		Small urban construction area
	1 000	Washington DC	750 mi^2 average
	500	Philadelphia Pa	
	146-2 300	Washington DC watersheds	As urbanisation increase
Highway	36 000	Fairfax Co. Va	Construction on 179 acres
construction	50 000-150 000	Georgia	Cut slopes

$tons/mi^2$ yr. x 3.5 = kg/ha yr.
mi^2 x 2.590 = km^2

Table A-4 (3)

DUST AND DIRT ACCUMULATION RATES

	Single Family	Multi-Family	Commercial	Industrial
APWA at Chicago				
Mean, lb/curb-mi-d	37	121	174	284
Median, lb/curb-mi-d	18	90	143	111
Number of samples	60	93	126	46
Adjusted URS data at several cities				
Mean, lb/curb-mi-d	155	107	46	292
Mean, without extreme, lb/curb-mi-d	71	56	20	138
Median, lb/curb-mi-d	69	32	20	74
Number of samples	21	14	17	20
Biospherics at Washington DC, (shopping centre only)				
Mean, lb/curb-mi-d	-	-	62	-
Median, lb/curb-mi-d	-	-	67	-
Number of samples	-	-	8	-
Overall mean, lb/curb-mi-d	45	110	150	240

lb/curb-mi-d x 0.28 = kg/curb km-d

Table A-5 (3)

CONCENTRATIONS OF POLLUTANTS BY LAND USE CHARACTERISTICS -- PPM OF DRY SOLIDS

	Land Use			
Pollutant	Single Family residential	Multi-Family residential	Commercial	Industrial
BOD	5 260	3 370	7 190	2 920
COD	39 300	42 000	61 700	25 100
Total nitrogen	460	550	420	430
Soluble PO_4-P	16	19	20	8
Cadmium	3.3	2.7	2.9	3.6
Chromium	200	180	140	240
Copper	91	73	95	87
Iron	21 300	18 500	21 600	22 500
Manganese	450	340	380	430
Nickel	38	18	94	44
Lead	1 570	1 980	2 330	1 590
Strontium	32	19	17	13
Zinc	310	280	690	280
Fecal coliforms, No./g	82 500	388 100	36 900	30 700
Total coliforms, No./g	891 000	1 900 000	1 000 000	419 000

Table A-6 (8)

FREQUENCY OF OCCURRENCE OF PERSISTENT TOXIC SUBSTANCES

Substance	Type of Sample	Frequency % Land Use: Residential C_r	B_r	H_r	Institutional C_{inst}	Industrial C_{ind}	H_{ind}	S_{ind}
PCBs	Water	75	54	80	80	83	100	100
Organochlorine Pesticides	Water	100	100	100	100	100	100	100
Polyaromatic Hydrocarbons	Water	ND*	-	-	ND	ND	ND	ND
Chlorinated Benzenes	Water	ND	-	-	ND	ND	ND	ND
Heavy Metals	Water	100	100	100	100	100	100	100
PCBs	Sediment	100	63	60	100	100	100	100
Organochlorine Pesticides	Sediment	100	100	100	100	100	100	100
Polyaromatic Hydrocarbons	Sediment	25	-	-	ND	25	60	100
Chlorinated Benzenes	Sediment	50	-	-	50	57	83	100
Heavy Metals	Sediment	100	-	-	100	100	100	100

* = Not Detected.

Legend C = Cornwall; B = Burlington; H = Hamilton; S = Sarnia.

Table A-7 (8)

MEAN CONCENTRATIONS OF PERSISTENT TOXIC SUBSTANCES

Substance	Type of Sample	Mean Concentrations (Water Samples in PPB, Sediment Samples in PPM) — Land Use: Residential			Institutional	Industrial		
		C_r	B_r	H_r	C_{inst}	C_{ind}	H_{ind}	S_{ind}
PCBs	Water	.064	.040	.034	.005	.004	.079	.028
Organochlorine Pesticides	Water	.036	.050	.034	.031	.027	.076	.065
Polyaromatic Hydrocarbons	Water	ND*	-	-	ND	ND	ND	ND
Chlorinated Benzenes	Water	ND	-	-	ND	ND	ND	ND
Heavy Metals	Water	554	593	700	90	2 309	1 767	416
PCBs	Sediment	.220	.105	.132	1.29	2.61	5.58	2.00
Organochlorine Pesticides	Sediment	.117	.105	.132	.160	.151	.687	1.30
Polyaromatic Hydrocarbons	Sediment	1.90	-	-	ND	92.9	13.5	9.30
Chlorinated Benzenes	Sediment	.067	-	-	.011	.047	.173	1.18
Heavy Metals	Sediment	61.8	-	-	-	1 315	142	184

Table A-8 (8)

FREQUENCY OF OCCURRENCE OF HEAVY METALS IN COLLECTED SAMPLES

Metal	Water mg/l	Sediment mg/kg
Arsenic	.0001	.05
Cadmium	.001	.10
Chromium	.001	.50
Cobalt	.001	.10
Copper	.001	.10
Lead	.001	.50
Mercury	.0005	.01
Nickel	.001	.10
Selenium	.0001	.05
Zinc	.001	.10

The limits of detection for the combined water and sediment will be the same as for the sediment

Table A-9 (11)

GREAT LAKES WATER QUALITY POLLUTANTS
Parameters for which a Great Lakes water quality problem has been identified

POLLUTANT	PROBLEM		SOURCES				REMARKS
			DIFFUSE				
	Lakewide	Nearshore or Localised	Land Runoff	Atmosphere	In-Lake Sediments	POINT	
Phosphorus (1)	Yes	Yes	Yes	Yes	Yes (a)	Yes	a) Percentage unknown; not considered significant over annual cycle
Sediment (b)(1)	No	Yes	Yes (c)	Negligible	Under some conditions	Neglible	b) May contribute to problems other than water quality (e.g. harbour dredging) c) including streambank erosion
Bacteria of Public Health Concern	No	Yes	Minor (d)	No	No	Yes	d) land runoff is a potential, but minor source: combined sewer overflows generally more significant
PCBs (1)	Yes	Yes	Yes	Yes	Yes	Yes	
Pesticides (1) (Past)	Yes (e)	Yes	Yes	Yes	Yes	No	e) Some residual problems exist from past practices
Industrial Organics (1)	Yes	Yes	Yes	Yes	Yes	Yes	
Mercury (1)	Yes	Yes	Minor	Yes	Yes	Yes	
Lead (1)	Potential (1)	Potential (1)	Yes	Yes	Yes	Yes	f) Possible methylation to toxic form
Parameters for which no Great Lakes water quality problem has been identified, but which may be a problem in inland surface waters or groundwaters							
Nitrogen	No	No (g)	Yes	Yes	Minor	Yes	g) Some inland groundwater problems
Chloride	No	No (h)	Yes	Neglible	No	Yes	h) Some local problems exist in nearsnore areas due to point sources
Pesticides (1) (Present)	No	No	Yes	No	No	Yes	1) New pesticides have been found in tne environment; continued monitoring is required
Other Heavy Metals	Potential (1)	Potential (1)	Yes	Yes	Yes	Yes	
Asbestos (1)	No	Yes	No	?	Yes	Yes	1) See Upper Lakes Reference Group Report (37)
Viruses (k)			NO DATA AVAILABLE				
Acid Precipitation	No	No (m)	No	Yes	No	No	m) A potential problem for smaller, soft water, inland lakes

1) Sediment per se causes local problems, phosphorus and other sediment-associated contaminants have lakewide dispersion

Table A.10

PROJECTED PERFORMANCE OF CHARLES RIVER POLLUTION CONTROL FACILITY

Flows to Station			Detention	Reduction %		
Mgal/d	h/yr	Mgal/yr	time, min	BOD	Suspended Solids	Settleable Solids
1.0	5 260	223	....	100	100	100
2.0	2 450	206	....	100	100	100
3.0	550	69	....	100	100	100
4.0	100	17	....	100	100	100
5.0	50	11	342.6	88	98	99
15.4	160	103	111.2	40	56	83
17.5	20	15	97.8	40	56	83
25.5	35	37	67.1	28	34	57
37.5	35	55	45.7	24	29	45
50.5	20	42	33.9	20	24	35
65.5	15	41	26.1	17	19	28
81.0	10	34	21.1	15	17	24
98.0	5	34	10.4	10	11	14
131	15	83	13.1	12	15	16
164	5	34	10.4	10	11	14
198	3	25	8.6	8	9	12
230	7	68	7.4	6	7	10
263	3	33	6.5	5	6	8
298	2	25	5.7	3	5	6
323	3	41	5.3	2	4	5
323	12	...	.....	...	...	...
Total	8 760	1 183				

Table A.11

COMPARISON OF TYPICAL PHYSICAL TREATMENT REMOVAL EFFICIENCIES FOR SELECTED POLLUTANT PARAMETERS

Physical unit process	Percent reduction					
	Suspended solids	BOD_5	COD	Settleable solids	Total phorphorus	Total Kjeldahl nitrogen
Sedimentation						
-- Without chemicals	20-60	30	34	30-90	20	33
-- Chemically assisted	68	68	45	.....	..	..
Swirl concentrator/ flow regulator	40-60	25-60	..	50-90	..	..
Screening						
-- Microscreens	50-95	10-50	35	.....	20	30
-- Drum screen	30-55	10-40	25	60	10	17
-- Rotary screens	20-35	1-30	15	70-95	12	10
-- Disc strainers	10-45	5-20	15	.....		..
.. -- Static screens	5-25	0.20	13	10-60	10	8
Dissolved air floatation (a)	45-85	30-80	55	93(b)	55	35
High rate filtration (c)	50-80	20-55	40	55-95	50	21
High gradient magnetic separation (d)	92-98	90-98	75	99	..	..

a) Process efficiencies include both prescreening and dissolved air floatation with chemical addition.

b) From pilot plant analysis.

c) Includes chemical addition.

d) From bench scale and small scale pilot operation, 1 to 4 L/min (0.26 to 1.06 gal/min).

Appendix B

MEMBER COUNTRY SUBMISSIONS

SITUATION IN BELGIUM

Drainage Network

With a few exceptions, Belgian towns have combined sewerage networks.

Only the new town of Louvain-la-Neuve has a separate network.

The towns along the Belgian coast were originally equipped with separate networks, but parasite branches have become so numerous that the entire network can be considered a combined unit.

However, some new residential areas in large cities and the new industrial zones sometimes have separate networks.

In some built-up areas, small tunnelled water ways are used as sewers; this presents serious wastewater dilution problems; separation is a prerequisite to any treatment.

Collector

The problems vary depending on the regions of the country -- northern Belgium is rather flat, whereas the south is moderately hilly; this calls for different approaches in finding solutions to technical problems.

The same goes for pluviometry.

In Flanders, 50 per cent of the collectors (lines connecting the sewer networks with the purification plant) are storage collectors, generally calculated to receive five to ten times the dry weather flow and to allow a maximum of ten discharges per year (Ir. KUIPERS method).

In the Walloon part of Belgium, large collector networks extend over several sub-basins where there is variation in the intensity of rainfall and its distribution in time.

They also act as a buffer; however, their capacity in this role has never really been assessed.

Purification Plant (42)

Existing purification plants are large enough to treat 2.5 times the dry flow. Sometimes they are equipped with storm basins.

In small and medium-sized urban centres (5 000 to 50 000 people), the storm basins are able to receive a volume equivalent to the amount of water needed for the sewers and collectors to drain themselves, and this volume is inversely related to the velocity of dry weather flow.

Studies done on Urban Pollution Runoff

1. Charleroi

Measurements taken during storms showed COD levels of 470 mg/l, BOD_5 of 100 mg/l and Suspended Solids of 700 mg/l. This water can, however, be easily treated since, after settling (settling time was half an hour), chemical oxygen demand was 70 mg/l, biological oxygen demand was 30 mg/l and Suspended Solids were 60 mg/l.

Rare extremes have been noted, for example:

COD of 10.264 mg/l
BOD_5 of 1.570 mg/l
SS of 2.720 mg/l

This study showed the advantage of collecting rain water in holding tanks (which would serve as primary settling tanks) before purification and discharging only rain water from the end of a storm, which is much less polluted, directly into waterways.

For thirty minutes, a flow thirty times the dry weather flow would have to be stored. It has been estimated that by using this method, 90 per cent of the pollution load could be removed. Similar results would be obtained by using the results of the STUTTGART-BUSNAU study.

Remark: These storage tanks should have a by-pass so that less polluted water does not dilute the first flow of pollution.

2. Brussels (43)

High concentrations of pollution were also noted in the first rain water. Measurements have shown that four times more pollution can be discharged into water ways than is collected. It has been estimated that 100 tonnes of sediment per day accumulate in the network during dry weather (50 per cent of the total load).

In general, it appears from measurements that pollution during rainy weather is much greater than pollution during dry weather (expressed in COD or SS), and the following recommendations can be made:

1) Reduce the volume of rain water by:

a) Decreasing impermeable surfaces;

b) Decreasing slopes of runoff surfaces that are too steep;

c) Decreasing exposure of bare ground on work sites.

2) Use temporary storage: it should be noted that in Belgium, the streets are generally cleaned mechanically (with brushes) instead of being washed.

In some Belgian towns there is an additional problem; the sewer networks are lower than the receiving water ways (sinking due to mining) and sewage is pumped along with runoff into receiving water ways in order to avoid flooding. The networks for collecting sewage and rain water, and channelling small streams are generally interconnected and all the water is pumped out. The different types of water must first be separated before the water can be treated.

SITUATION IN CANADA

Background

The population of Canada, as tabulated in the 1981 national census, is slightly in excess of 24 million. Approximately 75 per cent of these people are located in urban areas which are serviced by more than 61 000 km of sanitary sewers (72 per cent separate, 28 per cent combined or partly combined). Statistics are not maintained on storm sewer systems in Canada's urban communities; suffice to say that each community provides for storm water drainage through a variety of surface and subsurface systems.

Drainage systems in Canada are normally installed as separated sanitary and storm water collectors. Combined sewer systems, which exist principally in many of the older sections of established communities, are gradually being replaced or modified to control combined sewer overflow discharges. Management and control of stormwater is practised in many jurisdictions to meet water quality objectives, in receiving bodies of water to control instances of hydraulic overloadings on the receivers and for economic reasons. This latter factor is quite relevant in areas where the topography is flat and/or where development is taking place at a distance from a receiving water body. Conduit sizing and routing presents a major cost difficulty in these situations and retention or detention devices are often used as a means of reducing capital expenditures.

Throughout Canada, municipalities have adopted controls to limit the amount and type of discharge directed to both storm and sanitary sewers. The planning and controls which are used in relation to sewer servicing are implemented at the local level, usually in concert with general directives and provincial authorities. Urban drainage planning and servicing is also done at the local level with guidance from provincial agencies.

Magnitude and Significance of Urban Runoff

In Canada in the late 1960s and early 1970s it was recognised that water quality objectives in bodies of surface water could not always be met through the implementation of municipal and industrial point source controls. The impact of urban runoff through combined sewer overflows and storm sewer discharges was often recognised as a significant factor, as illustrated in the following tables: Table 1 shows the concentrations of selected pollutants found in stormwater and combined sewer overflows; Table 2 compares annual loadings anticipated from a Canadian community with separate sewers and

secondary treatment (with phosphorus removal) or sanitary wastes; Table 3 compares annual unit area runoff loadings for various urban land uses. To put this information into perspective, a study on the Grand River Basin in Ontario (in which 3 per cent of the land area is urbanised) showed that urban runoff accounted for 6.3 per cent of the suspended sediment load, 4 per cent of the total phosphorus load, 1.9 per cent of the total nitrogen load and 41.9 per cent of the lead load at the mouth of the river.

Table 1

RANGE OF POLLUTANT CONCENTATIONS IN STORMWATER AND COMBINED SEWER OVERFLOWS (1)

	Concentration (mg/litre)						
Source	BOD	COD	SS	Pb	N-Kjel.	NO_2+NO_3	P-Tot.
Stormwater	1-630	5-1 090	2-4 122	0.02-1.8	0.2-20	0.2-9.6	.04-11.0
Combined sewer overflows	4-1 730	25-2 000	6-7 700	0.01-4.8	1.8-26	0.1-2.8	.2 -218.0

Table 2

COMPARISON OF ANNUAL LOADINGS IN STORMWATER AND SECONDARY WASTE TREATMENT PLANT EFFLUENT

		Annual Loadings (kg/ha)			
Population Density (per/ha)	Source	BOD	SS	N	P
60	Stormwater	34	392	9	1.6
	Secondary effluent	164	246	39	27
150	Stormwater	90	560	11	3.4
	Secondary effluent	410	615	87	68

Table 3

SUMMARY OF RANGES OF UNIT AREA LOADS OF SELECTED MATERIALS BY LAND USE FROM PILOT WATERSHED STUDIES (2)

	Annual Unit Area Loads (kg/ha/yr)							
Land Uses	Suspended Solids	Total Phosphorus	Filtered Reactive Phosphorus	Total Nitrogen	Lead	Copper	Zinc	Chloride
URBAN:								
General Urban	210-1 750	0.3-2.1	0.05-0.3	6.21-10	0.14-0.5	0.05-0.13	0.3-0.6	130-380
Residential	620-2 300	0.4-1.3	0.2	5-7.3	0.06	0.03	0.02	1 050
Commercial	50-830	0.1-0.9	0.02-0.08	1.9-11	0.17-1.10	0.07-0.13	0.25-0.43	10-150
Industrial	400-1 700	0.9-4.1	0.3	1.9-14	2.2-7.0	0.29-1.3	3.5-12.0	-
Developing Urban	27 500	23	0.1	63.0	-	-	-	75-160

Other quantity related aspects of urban storm water management in Canada which are considered significant issues include the degree and severity of basement flooding, particularly in combined sewer areas, and the erosion and flooding of receiving channels in downstream areas. As mentioned earlier the expansion of urban areas in directions more remote from readily available receivers contributed significantly to the cost considerations of runoff conduits and routing.

Policy Directions

With an increased awareness of the quantitative and qualitative aspects of urban runoff and the need to accomodate a more comprehensive and longer term approach to servicing and pollution control, the following approach is encouraged in most Canadian jurisdictions.

First, local authorities are encouraged to develop master drainage plans for all watersheds within their boundaries. The purpose of this is to ensure that stormwater drainage systems are developed in a manner compatible with watershed needs, to identify existing water quality and flooding problems and to avoid future problems.

Second, local authorities with responsibility for sewage collection and treatment are urged to formulate and implement a comprehensive pollution control strategy which includes consideration of both wet and dry weather pollution sources. In this way it is felt that the consideration of receiving water objectives and the cost and effectiveness of wet weather versus dry weather controls will lead to a more cost effective investment in pollution control.

Third, it is recommended that local authorities adopt a major/minor approach to servicing. That is an approach which recognises the dual role of the drainage system to provide for convenience during minor (high frequency) runoff events and to minimise property damage and protect life during major (rare) runoff events. In this way expenditures for sewer construction are expected to be reduced since the minor system is designed in a manner that avoids excessive costs associated with overly conservative design techniques and rare design storms. The major system is designed to provide protection against damage from storms which exceed the capacity of the minor system.

Finally, erosion and sediment control programmes are recommended in the planning and construction stages of development with suitable maintenance programmes as follow-up.

Technology and Research Needs

As urban drainage management has shifted from basic research and the development of analytical tools (models), more interest has been devoted to technologies suitable for the control of drainage quantity and quality. The majority of controls utilised to date usually address peak runoff alteration and flood reduction. Examples are inlet controls and surface and subsurface storage facilities (online and offline). The most cost effective means of improving the quality of runoff has often been found to be improved street

sweeping. The quantitative improvements of storage are also utilised frequently for qualitative control. Both screening systems and swirl or helical concentrators are used for quality control of runoff. Few chemical or mechanical systems are utilised in Canada. Stormwater management models are used extensively in Canada for both quantitative and qualitative purposes in many of the design and assessment areas.

A number of problems associated with urban drainage design require further research. These include design storm definition and use, characterisation and modelling of runoff quality, modelling of major storms, impacts of urban drainage and the economics of urban drainage design.

SITUATION IN FINLAND

State of the Art/Background

The annual precipitation in Finland is 500-750 mm. Of this 30-50 per cent comes as snow. The maximum daily rainfall is of the order of 40-60 mm.

The population density in Finland is 15.6 persons/km^2. In 1980, the number of people served by municipal sewage works was 3 293 000 (69 per cent of population) (44). The total amounts of waste water was 1 422 000 m^3/day. In all, waste waters of 3 113 000 inhabitants were purified at 552 municipal treatment plants. Two thirds of the plants were simultaneous-precipitation plants. The total average treatment efficiency of the sewage works was 77 per cent for organic matter (BOD_7) and 80 per cent for phosphorus. (BOD_7 and P are the central parameters encountered.)

During the 1960s and 1970s, the separate system has been nearly without exception the sewer system adopted in the new Finnish urban developments. In 1980, the length of separate storm sewers totalled approximately 15 per cent of the length of all sewers (22 000 km) in the Finnish municipalities. The proportion of sanitary sewers was 65 per cent, and that of combined sewers 20 per cent. There is no accurate nation-wide estimate for the drainage area supplied with combined sewers or for the amount of overflows. The existing combined systems are situated in the downtown areas of some major cities. In recent years a lot of emphasis has been placed to reduce the amount of overflows where they have caused pollution problems. No treatment for runoff water is required in the separate sewer systems.

Knowledge on the Magnitude and Significance of Urban Pollutant Build-up and Runoff

Beyond the overflows from the combined sewer systems, there is no indication of a water pollution problem caused by runoff water alone. Yet, runoff and leakage water inflows have been proved to reduce purification efficiency in the sewage works where the proportion of combined sewers is significant (45).

A recent nation-wide study has collected data on the quantity and quality of urban surface runoff water at seven experimental test catchments during a three-year period (40, 46-49). Special attention was focused towards the impact of the atmospheric pollution (particle deposition) on runoff water.

The average quality of the surface runoff water at the test sites varied as follows (40, 46-49):

Parameter	Unit	Average content in	
		Storm water	Melting water
SS	mm/1	89 - 280	50 - 750
BOD_7	mg/1 O_2	9 - 28	10 - 43
tot P	mg/1 P	0.25 - 0.52	0.22 - 1.1
tot N	mg/1 N	1.1 - 2.2	1.9 - 5.5
lead	mg/1 Pb	0.092 - 0.43	0.046 - 0.65
zinc	mg/1 Zn	0.14 - 0.50	9.20* - 0.37*
copper	mg/1 Cu	0.013 - 0.19	0.028*- 0.31*
cadmium**	mg/1 Cd	0.001 - 0.004	0.001 - 0.003

* Observations only from two catchments
** Concentrations generally at the detection limit of analysis (< 0.001 mg/1 Cd).

On the basis of gathered data, the following estimates have been derived for the annual washout of pollutants with the surface runoff water in a separate sewer system (40, 49).

Parameter	Unit	Washout
SS	$t/km^2/a$	10 - 100
BOD_7	$t/km^2/a$ O_2	1.0 - 10
tot P	$t/km^2/a$ P^2	0.020 - 0.20
tot N	$t/km^2/a$ N	0.20 - 1.0
lead	$t/km^2/a$ Pb	0.010 - 0.15
zinc	$t/km^2/a$ Zn	0.020 - 0.15
copper	$t/km^2/a$ Cu	0.0030 - 0.050
cadmium**	$t/km^2/a$ Cd	0.00010- 0.00050

** See remark above

A theoretical calculation with the data gathered yielded a conclusion that the untreated surface runoff water contributes the following proportion of the total recipient load of a separate sewer system, in which waste water is purified by a biological-chemical process (40).

SS	50-75	per cent
BOD_7	10-20	per cent
tot P	5-10	per cent
tot N	< 5	per cent
lead	> 90	per cent

The atmospheric particle deposition was found to contribute a substantial basic pollutant load to the urban surface runoff water. A rough proportion of the atmospheric load is estimated to be the following (considering loads to and from the runoff generating surfaces, which yields a definite lower limit for the aerial contribution) (40, 49):

SO_4	1/2	- 3/4
tot N	1/2	- 2/3
V	1/4	- 1/2
VS, TOC, Cu	1/4	- 1/3
tot P	1/4	
Pb	1/5	- 1/4
TS	1/5	
Zn	1/10	- 1/5
Cl	1/20	- 1/5

Pollution Control Measures Taken

Concerning the preventative measures at source, part of the roof waters have been traditionally infiltrated in single-family residential areas. Forced infiltration is at an experimental stage, being part of a research on more economic municipal engineering solutions (50).

The corrective measures in the drainage systems are mostly limited to sewer system maintenance. The major cities have studied possibilities for storage control in their downtown problem areas.

Socio-Economics and Policy Considerations for Control Measures

In the permit terms concerning discharge of effluents from the municipal sewage treatment plants, limits are given to the BOD_7 value and phosphorus content of effluent, and in most cases also to the percentage treatment efficiency. Limit values of 20 or 25 mg/l O_2 and 0.5-1.0 mg/l P, and 85 or 90 per cent reduction, are common to a relatively efficient treatment today. In order to eliminate disturbances to the treatment process, caused by leakage and drainage water inflows of the sewer networks, a requirement is included in the permit terms to minimise the amount of these inflows. The community is often obliged to prepare a renovation plan for its sewer network.

In practice, the present permit terms imply an abandonment of combined sewer systems, possibly excluding limited downtown areas of the major cities. For the present, treatment of runoff water in the separate sewer systems has not been required.

The recent research work verifies that the basic policy adopted, concerning the choice of the type of sewer system, is correct. Policy consideration is still needed to decide whether a separation of sewers in the old downtown areas is preferable. Similarly, in the future, a policy has to be established concerning the infiltration of surface runoff water, and the significance of the micropollutants contained in runoff water.

Research Activities and Needs

The following major research projects have been completed:

-- Survey and evaluation of the performance of municipal wastewater treatment plants (45);

-- Survey and evaluation of the quantity, quality and airborne pollution of urban surface runoff waters (40, 46-49);

-- Survey and evaluation of the combined sewer systems (51);

-- Flow forecasting in the general planning of municipal sewage works (52).

The major projects going on are as follows:

-- Experiments on the infiltration of surface runoff water (50);

-- Investigation for the improvement of combined sewer systems;

-- Survey and evaluation of the leakage inflows to sewer networks;

-- Forecasting of the performance of municipal wastewater treatment plants.

The most urgent future research need is considered as for the following items:

-- Methods for the renovation of existing sewer networks;

-- Significance of the micropollutants in urban runoff water (and waste water).

SITUATION IN FRANCE

Historical Background: Institutions

The development of public drainage networks began in France towards the middle of the last century. At that time, concern to dispose both of sanitary waste and rainfall runoff as far away and as quickly as possible led to the installation of the combined system still operating nowadays in older city centres.

The separate system appeared between the two World Wars for reasons associated with the functioning of biological treatment stations. In practice it was made compulsory in 1949 when the official Technical Instruction on draining for conurbations was issued, which recommended it as part of reconstruction.

Throughout that period, the emphasis in the discharge of drainage water mainly concerned the possibility of waste water treatment. The sanitation and public health standpoint predominated, since runoff waters were not thought to be polluted.

The new Technical Instruction of 1977 was no real innovation. Although safeguarding the quality of the natural environment had been an important topic for ten years, no technological progress has been described for limiting pollution loads discharged directly by public drainage networks.

In that period too much priority was still being attached to sanitary waste water, and the number of treatment stations constructed per year peaked at that time.

However, the new Technical Instruction was mainly concerned to recognise existing knowledge in its own field, leaving open the possibility of further technological advances. This policy, together with the creation in the same year of a central service responsible for urban investment projects within the Ministry of Urban Development and Housing, made it possible to undertake general studies of urban hydrology and more particularly, of control of pollution due to urban runoffs.

Two main approaches were decided on by the "Division des Equipements/Urbains" in association with the specialists concerned. One was to investigate the characteristics of pollution loads from storm runoffs, the other was to apply technologies for controlling pollutant discharges from sanitary drainage. The outcome of the work undertaken proved of interest,

especially by showing the direct discharges of public drainage into the natural environment. However the findings, which ought to facilitate the installation of specific facilities, are hard to disseminate, partly because of institutional context.

It is the local authorities who, either directly or through joint boards, commission public drainage networks. However the latter are heavily subsidized, either by the Ministry of the Interior or by the Ministry of Agriculture. The urban devolution policy which the government has been implementing for two years will mean that more funds will go to local authorities. Moreover, there are still some ten or so ministries with powers in regard to water.

In fact two ministerial departments are mainly concerned by pollution from urban runoffs: the Ministry of Town Planning and Housing already mentioned, and the Secretariat of State for the Environment through the "Agences Financière de Bassin", tripartite bodies (industry, water users and elected representatives) one of whose main functions is the equalisation within each hydrographic basin of the costs of controlling water pollution. Starting from an overall policy of protecting the natural environment through building treatment stations, they have naturally been drawn to concern themselves with how the waste water networks are operating, and then with the functioning of drainage systems generally. This has been reflected by the attempts under way to extend the powers of the "Services d'Assistance Technique à l'Exploitation des Stations d'Epuration" (SATESE) to cover the satisfactory operation of drainage systems.

State of Knowledge

1. Characteristics of run-off pollution

As well as embarking on research into the characteristics of runoff water pollution, considerable attention has been devoted to the problems of measuring it. Research began into the reliability and representativeness of automatic samplers. Mathematical simulation was used to devise an optimum sampling method, in accordance with assumptions about the pollution trend, the flow and site constraints. This is now being widely extended to cover the whole chain of measurements required, rainfall, flow rates, samplers etc. Special research has been undertaken into the sampling of suspended solids.

A national research programme into the pollution characteristics of runoff water was begun in 1978 and will be completed in 1983. For two years, pollution was measured for four basins with a strict separative system (BOD_5, COD, SS, heavy metals, nitrogen, phosphorus, etc.). Over three hundred events were sampled according to a carefully prepared experimental plan. The complete set of data is planned for the end of 1983. It is hoped to have answers to such questions as whether there are general relationships between annual pollution loads and land-use patterns, and what are the pluviometric characteristics of the most polluting event.

Other studies of pollution characteristics have been carried out at the same time. A presentation of what were regarded as the most reliable findings was given to a congress on "Drainage Tomorrow" organised by the Société Hydrotechnique de France, in September 1982 and showed that the order of magnitude of the largest pollution loads in one year is of some kilogrammes per waterproofed hectare for COD and some hundreds of kilogrammes per waterproofed hectare for suspended solids. On the basis of these data and various other assumptions, pollution discharged into the natural environment in France over one year by runoff waters can be estimated as follows:

-- Organic Substances: 200 10^3 tonnes, SS 280 10^3 tonnes;

These figures can be compared with the following estimates for pollution discharged by local communities and industries connected, after treatment:

-- Organic Substances: 980 10^3 tonnes, SS: 1 210 10^3 tonnes

Not much progress has yet been made in the modelling of runoff quality. The general view is that statistically and conceptually reliable models will not be available for a long time. However a number of approches to the modelling of runoff water quality have been tried out for the movement of solids within the networks.

2. Techniques for the control of network discharge pollution

These techniques can be classified into one of two groups, according to whether or not they apply to the drainage network itself. Among those which do not, some processes are for reducing peak flows, which has the effect of reducing the pollution load and eliminating the shock effect characteristic of runoff water pollution.

Porous road surfaces have been tested to find out more about how reliable they are, in terms both of traffic support and of hydrological efficiency.

A report on all the available technologies for reducing peak flows has been published.

Research has been undertaken into the biological and ecological aspects of retention basins, clarifying their role in reducing runoff water pollution.

A study has been put in hand to collect data with which to assess the efficiency of street cleansing in reducing the runoff load.

Of the techniques applicable to the drainage network, the main interest is in decantation. On the one hand, studies have been undertaken of sand chamber efficiency and theoretical research has been begun into the problems of macro-turbulence during outflow. This is being pursued by studying the behaviour of particles in a physical model, leading to the development of a mathematical model. The point has now been reached at which prototypes of devices to improve the performance of conventional decanters are being studied.

3. Prospects

The research prospects in urban runoff pollution must be seen against a background with both positive and negative aspects. Among the latter there is the economic crisis, which, by imposing priorities, is liable to postpone, at least for a while, all but the most pressing environmental concerns. This means that work on runoff water pollution characteristics will certainly be abandoned. Conversely, insofar as they are aimed at flood control and reducing investment in the building of public drainage systems, peak-shaving techniques will probably continue to be developed.

Similarly, since standards for concentrations of micro pollutants in surface water used to produce drinking waters have become stricter, there seems to be a need to continue with work on potential sources of such micro pollutants and in particular, heavy metals. The latter seems mostly to come from runoff waters, strongly associated with suspended solids. Consequently, research and experiments into decantation will continue to have priority.

Among the positive aspects is the introduction of an urban plan which, as part of a "programme mobilisateur" for research into housing and the human environment, is intended to prompt and co-ordinate a range of town planning actions. Initial discussions have shown the great potential interest of water problems within the city and the urban water cycle has been chosen as a priority topic.

SITUATION IN THE FEDERAL REPUBLIC OF GERMANY

The systematic development of urban waste water systems started at the beginning of the 19th century. Although the first systems only collected domestic waste water, they were soon expanded to collect rainwater from the streets. Already at that time, two different waste water systems developed in the territory now known as the Federal Republic of Germany.

1. Collection of domestic waste water and rainwater from streets, yards and roofs in one mains systems -- combined system;

2. Collection of domestic waste water in one mains system and collection of rainwater from streets, yards and roofs in a second mains systems -- separate system.

Although the combined system was installed in most towns in the beginning, the further development of these towns and mains systems led not only to technical and financial problems but also to difficulties with regard to water pollution.

The level of the overflows which had been installed was usually too low and the corresponding pipes were badly positioned. This, coupled with insufficient maintenance of the ducts, often led to varying degrees of water pollution.

To overcome this, towns situated in lowlands with low-fall waste water systems and/or near water suitable for development, tried to reduce the construction costs of large combined waste water plants and purification plants by collecting the rainwater separately and channelling it as directly as possible.

a) Separate system --.channelling of rainwater:

-- Directly into receptor water;

-- Directly into an infiltration basin;

-- Into a rainwater retention basin with further dosed discharge into receptor water.

b) Combined system -- channelling of rainwater together with waste water into a waste water treatment plant with rainwater overflow leading directly into receptor water.

Scrutiny of the paths trodden by the Federal Republic of Germany reveals the following developments.

About 85 per cent of the 62 million inhabitants of the Federal Republic of Germany are connected to a waste water system. The ratio of separate systems to combined systems is 30 : 70. In this connection, it should, however, be mentioned that this ratio is increasingly changing in favour of the separate system.

Consideration of the distribution of separate and combined systems throughout the Federal Republic of Germany reveals a difference between north and south.

Percentage of separate systems in each Federal Land (1975):

Schleswig-Holstein	76 per cent
Hamburg	52 per cent
Lower Saxony	80 per cent
North Rhine-Westphalia	25 per cent
Hessen	15 per cent
Rhineland-Palatinate	8 per cent
Baden-Württemberg	8.5 per cent
Bavaria	15 per cent
Saarland	8.7 per cent
Berlin West	65 per cent

North Germany draws mostly on separate systems and south Germany almost exclusively on combined systems.

Each of these systems has its weaknesses. Malfunctioning in the separate system leads to increased pollution of the receptor water.

As far as the drainage in the combined system is concerned, a heavy rainfall leads to the discharge of waste water into the receptor water if the rain overflow level is exceeded. Low falls and large pipe diameters in the combined system also constitute a problem during periods of drought. The drainage pipes of federal highways and motorways often usually end in receptor water or in an infiltration basin. However, if these roads pass through protected water collection grounds, the rainwater is channelled out of the protected area.

The municipalities are responsible for all waste water systems in public areas (the control of the federal highways and motorways comes under the purview of the road construction offices of the respective Federal Land). The responsibility for private areas lies with private landowners.

Since the Waste Water Charges Act came into force, the municipalities have had to pay a waste water fee for the discharge of rainwater. This fee must, however, be used for water protection purposes.

SITUATION IN THE NETHERLANDS

State of the Art/Background

a) General features of urban runoff management in the Netherlands:

- -- In the past the quantitative aspects have had the highest attention;
- -- In recent years more attention has been payed to qualitative aspects, because:
  - -- The number and capacity of treatment plants increases steadily; as a consequence pollution caused by sewer overflow becomes more important;
  - -- The pollutants in urban runoff become more interesting.
- -- The control of the effects of runoff is mainly based on:
  - -- A good design of the drainage infrastructure;
  - -- Emission control at the sources;
- -- Take specific measures as: road sweeping, placing emission reducing devices etc.
- -- Municipalities are primary responsible for the wastewater streams and the sewer systems in their urban area.

b) Sewer systems:

- -- The specific Dutch conditions cause some limitations. The specific conditions are: high population density, many urban areas, flat country, many stagnant surface waters, high groundwater tables, many flat polders, groundwater as a source of drinking-water, a rainfall of ± 759 mm year.
- -- Until 1950 mainly combined sewer systems.
- -- After 1950 separate and improved separate systems as well.

-- The choice of the system is based on subjective critria as:

-- Local and/or historical situations;

-- Spatial, technical and financial limitations;

-- The rain water quality and storm water quality attract the attention, as well as the discharge into the surface water;

-- The increasing concern about soil and groundwater quality may influence the choice of the sewer system.

Knowledge of the Magnitude and Significance of Urban Pollutant Build-up and Runoff

a) Magnitude of runoff problems:

-- Mainly local problems (mostly odour troubles and hygienic aspects). The overflows take place on town canals and ponds.

-- The present design overflow frequency is about five to ten times a year, the design storage capacity in the sewer systems is mostly 7-9 mm. Rainfall is about 750 mm per year and the occurrence of a shower of rain of more than 10 mm is ten times a year on the average.

-- Many older systems have higher overflow frequencies and less storage capacity. Overflows still often take place at unsuitable locations. That is why many adaptations are necessary.

-- A reduction of the overflow frequency requires mostly expensive technical measures. Because of a lack of knowledge the optimal spending of financial means is a problem.

b) Quality parameters for runoff:

-- The quality of the receiving surface water is assessed on the basis of:

-- The oxygen consumption of the water and of the sludge;
-- The bacterial quality: E-coli as indicator mechanism of faecal contamination;

-- Aesthetic aspects: floating materials, suspended solids, transparency, algae, etc.;

-- Eutrophic conditions; N and P levels (especially in stagnant waters);

-- Micropollutants (for instance heavy metals and the like) get more and more attention.

Pollution Control Measures taken and Planned

a) Preventive measures:

-- A careful use of substances such as weed-killers, fertilizers, salt for roads etc.;

-- The stimulation of alternative collection systems for medicaments, used oil, used chemicals in laboratories etc.;

-- A reduction of discharges by the encouragement of re-use (e.g. regeneration of materials), treatment of industrial waste water;

-- Regulations by municipalities.

b) Corrective measures:

-- To improve sewer systems by:

-- Better design;
-- Replacement of old sewers (if possible in combination with town renovation);

-- Attention to wrong connections in separate systems;

-- Sewering of car parks and factory sites with discharge to treatment plants.

-- Reducing stormwater discharges by:

-- Increasing the storage capacity;

-- The construction of swirl overflows, retention/sedimentation basins etc.;

-- Sweeping roads and other paved surfaces.

Socio-Economics and Policy Considerations for Control Measures

a) Compare different control measures in this respect:

-- Preventive measures are stimulated by public information and legislation. The awakening of the interest in the quality of the environment is stimulated.

-- Corrctive measures can be compelled by discharge permit. The system of levies and a restricted number of possibilities for subsidising very expensive projects have a stimulating effect.

b) Considerations and guidelines for present and future policies:

-- The technical knowledge based on research has to become wider and deeper because:

-- More justified technical choices can be made.

-- The environmental effects of solutions can be estimated at their true value.

-- A long-term planning of the municipal sewer works is needed to optimise maintenance, management, inspection, control, data storage etc. to achieve a maximum efficiency against acceptable costs.

-- Norms and standards directed towards design, construction and management of sewer systems must be developed to lay the foundation of the municipal sewer works. Smaller municipalities can take advantage of this because they cannot accomplish these affaires on their own. Meanwhile norms and standards directed towards surface water quality and ground water protection will make higher demands on discharges.

-- Guarantees for public health and ecosysystems, especially concerning water supply and recreation, will have to be provided.

Research

a) Activities:

-- To get insight in the discharge of storm water and the effects of those discharges on surface water, as well as the influences of swirl concentrations, retention/sedimentation basins etc. and clean-up programmes, a wide research programme started in 1979. The data collection will be continued until 1985. The number of measuring apparatus that is or will be installed is:

-- Water quality measurements	6x
-- Storm water measurements	6x
-- Swirl concentrators, retention/sedimentation basins	5x
-- Cleaning activities	2x

Attention will be payed to the emission aspects as well as to the surface water in which the discharges take place:

-- Parallel with the above mentioned programme another small research project is planned. The purpose is to get insight in the appearance of organic micropollutants (and possibly of heavy metals) in storm water. If desirable research on sources and pathways can follow.

-- An examination has been made of the dispersion and washing away of road salt and heavy metals on a state road.

-- As an aid during interpretation and evaluation of results, the results of routine measuring programmes for surface water, groundwater networks and rain water in Holland are used.

b) Needs:

- -- To draw parallels with similar (expensive and time consuming) research programmes in other countries. For this purpose it must be possible to exchange results;
- -- A further development and design of norms and standards to improve the organisational and control structures;
- -- To get acquainted with the presence of materials and the transport of these materials over paved surfaces and open soils into sewers, ground and surface water.
- -- To get acquainted with the use and quantity of heavy metals in daily life; Cu tap water, zinc and gutters etc.

SITUATION IN NORWAY

Background

Norway has a population of 4 million persons. Of these, approximately 25 per cent discharge their sewage directly to the ocean with adequate assimilative capacity. Approximately 20 per cent is discharged to individual private systems (low population density areas).

The remaining population is served by approximately 25 000 km of municipal sewer lines directed to treatment plants. (Private sewers not included). Approximately 60 per cent of the municipal sewers are combined sewer systems and the rest separate sewer systems. During recent years approximately 1 000 km of municipal sewer lines were constructed per year. The combined sewer network is believed to have approximately 1 300 storm overflows.

The receiving waters in Norway are relatively clean. The North sea is a recipient for many communes; however some fjords are narrow and may require some treatment. The main problem for the inland water resources is eutrophication. This is mainly due to excessive phosphorus discharge from communes.

Norway has a Ministry for environmental problems. Under this Ministry is established a State Pollution Control Authority (SFT). This Authority handles national guidelines for all types of pollution, including communal sewage and storm runoff, and issues licences for industrial discharges.

The responsibility to issue licences for communal sewage is delegated to the County Authorities.

The legislation concerning pollution has recently been revised and gives the Authorities the necessary tools to handle most pollution.

Decisions made by the counties or SFT can be appealed to the Ministry of Environment.

The status of the sewerage system is roughly as follows:

-- Treatment plants representing roughly 40 per cent of the treatment capacity are performing such that they do not fill the requirements of the Authorities' licences.

-- It is common that only 60-70 per cent of the sewage entering the sewer system reaches the sewage treatment plants. (This is mainly believed to be caused by the fact that the storm drainage pipe is situated under the sanitary pipe in the trenches).

-- It is common that the sewage water composition reaching the sewage treatment plant contains approximately 50 per cent infiltration water. During rain periods this amount increases considerably.

In the period after World War II, it was common practice to construct combined sewer systems. In the last decades the Authority made it compulsory to build separate sewer lines. This was due to the belief that it would cause less flooding damage in cellars, cause less problems for the treatment plants and reduce pollution to the environment.

A relatively comprehensive research programme on sanitary engineering (including urban hydrology) was launched in 1971. This programme has led to a better understanding and more competent engineering.

Philosophy

In Norway, the treatment processes chosen could mainly be said to be phosphorus removal for the inland water resources, and the Oslo fjord and mechanical treatment for ocean discharges where no specific problems exist.

The Authorities have now given guidelines for the choice of sewer systems. These guidelines permit building of new combined sewers in urbanised areas where this type of sewer system is preferred. However, local analysis is recommended for each catchment and municipality.

Pollution from storm runoff has so far not been given priority with respect to concrete measures.

Nevertheless Norway is aware of the high content of heavy metals and organic micro-pollutants in storm runoff from urban areas. This problem will be given more attention in the future.

Storm runoff from separate drainage pipes is normally not handled by the pollution licensing authorities. This attitude is changing, especially for cases where urban runoff (for instance from roads) drains into surface draining water supplies.

The storm runoff can create major problems due to large peak flow rates and volumes in a short time. This is one of the reasons for implementing a policy for local handling of storm water. This implies for instance infiltration into areas where this could be done safely, use of natural water courses and detention of runoff to minimise the rate of discharge downstream.

Other special measures which are encouraged are:

-- Renewal of older sewer lines which are found to have leakages;

-- Installation of swirl concentrates at storm overflows and on the influent to the treatment plants. (This will reduce the problems of hydraulic overloading and remove solids from the discharge).

-- Use of efficient tools like mathematical models when this is suitable.

-- Establishment of an urban hydrology measurement programme. This includes rain intensity data and runoff characteristics.

The Norwegian Hydrology Coordinating Committee (NHK) are trying to start a five-year research programme on urban hydrology (1983-1987) at a cost of approximately KrN 2 million per year. The main problems to be addressed in this research is:

-- Rain intensity and runoff characteristics;

-- Pollution in storm runoff (mainly heavy metals and micro-pollutants);

-- Snowmelt intensities;

-- Control measures.

SITUATION IN THE UNITED KINGDOM

State of the Art/Background. General Features of Urban Runoff Management in England and Wales. Sewer Systems and Problems Encountered therein

The water industry was established as a co-ordinated structure in 1973 with the designation of ten regional water authorities (RWA). These bodies are responsible for managing the whole of the water cycle within statutorily designated hydrological boundaries. Urban runoff is managed on an agency basis by local authorities who undertake the maintenance of the fabric of sewerage systems at the request of the RWAs. Financial and policy decision are the responsibility of the RWAs who are financed by charging for the supply of water and the treatment of waste water. Water quality is managed directly by the RWAs pollution control officers who investigate problems and advise on remedies.

It is estimated that there are 220 000 km of sewers in England and Wales and that 96 per cent of households are connected to the public sewerage system (54). Householders are usually responsible for house drains or private sewers from the house up to the point of connection with the public sewer, usually in the road. Otherwise, the drainage systems are the responsibility of the public authorities..

Arrangements for the receipt and discharge of surface waters vary from district to district. In old towns and in areas of suitable ground conditions runoff from roofs and yards may well be discharged to soakaways while runoff from roads may be discharged to local ponds and watercourses or intercepted by foul sewers. In modern towns and in new developments, separation of surface waters from domestic and industrial waste waters (foul sewage) is undertaken by providing separate and distinct drainage systems. These discharge directly to local water courses often via a system of water meadows designed to store water temporarily following very heavy rainfall. "Dirty" areas such as private garage blocks and industrial yards may be connected to the foul sewers.

A comprehensive survey of the distribution of combined and separate drainage system does not appear to have been carried out. A sample survey conducted amongst two hundred and twenty six local authorities in 1963 revealed that entirely separate systems were in a minority of 8 per cent, although partially-separate systems comprised the majority at 41 per cent. Entirely combined systems accounted for 29 per cent and the remaining 22 per cent comprised mixtures of the systems (55).

Neither separate nor combined systems have been found to be entirely satisfactory for pollution control purposes. The discharge from separate systems is locally polluting particularly after long dry spells during which water stored in roadside catchpits deteriorates in quality and presents a significant polluting load upon displacement by incoming runoff. This pollution tends to manifest itself as a contamination of stream sediments and biota by heavy metals rather than destruction of biota by deoxygenation as might be caused by the discharge of dilute sewage from combined sewers. Separate systems also increase the risk of polluting local watercourses by deliberate and accidental spillage of pollutants although this risk is also present below combined sewer overflows. Combined systems theoretically permit the treatment of contaminated surface waters in admixture with sewage. In practice the pipework is unlikely to have sufficient capacity to convey the water resulting from all foreseeable rainfall events and to prevent flooding with sewage. In sensitive areas storm overflows are necessary.

If these operate prematurely as a result of the increase in the dry weather flow caused by urban expansion since the system was installed then frequent pollution of watercourses may occur. This problem is mostly encountered in the old industrial connurbations of the West Midlands, South Yorkshire and South Lancashire and is a significant contributor to the pollution of those 9 per cent of the total length of rivers in England and Wales placed in the polluted categories of class III (7.5 per cent (and class IV (1.5 per cent) of the National Water Council's river classification scheme (53).

Knowledge of the Magnitude and Significance of Urban Pollutant Build-up and Runoff. Magnitude of Runoff Problems. Quality Characteristics

The average residual rainfall in England and Wales is 460 mm which gives rise to an average water flux of 182.8 million m^3/d. If it is assumed that 5 per cent of the total area of England and Wales of about 15 million ha is covered by impervious surfaces then about 9.5 million m^3/d is generated as urban runoff. This may be compared with a total sewage effluent flow of about 12 million m^3/d and indicates that under conditions of uniform precipitation combined drainage systems with a capacity of about 2 times dry weather flow would suffice to convey all storm water to treatment. In practice of course spatial and rapid temporal variation in precipitation rates requires pipe sizes to be capable of passing peak discharges of many multiples of dry weather flow.

Rates of aerial deposition and yields of pollutants from urban catchments in Europe have been summarised (56). For example, these data indicate mean yields of 487, 59 and 0.83 kg of SS, BOD and Pb per impervious ha per year in Europe and the United Kingdom. For a net rainfall of 460 mm, these mass flows would produce annual flow-weighted mean concentrations of 106, 12.8 and 0.18 mg/l respectively. In comparison with sewage effluent only the contribution of Pb would appear to be significant since the suspended solids are likely to be of a largely mineral nature and to possess relatively low respiratory demands. Storm sewage is significantly more polluting having an average composition of 484 and 75 mg/l SS and BOD respectively.

Most UK studies on pollution by stormwater have been concerned with providing comparisons with the quality of sewage and sewage effluents in terms of the sanitary characteristics BOD_5, SS and NH_3-N. Because of the widespread use of rivers for the conveyance of treated but not disinfected

sewage effluent, storm runoff is not regarded as a significant source of bacteria in inland areas. The presence of bacteria from combined sewer overflows may however be of significance in coastal regions where rivers and streams enter the sea in the vicinity of bathing beaches and discharges of storm water may be made directly onto beaches. Because of the presence of nutrients derived from sewage effluent and agricultural runoff, many lowland English rivers are inherently eutrophic and urban surface runoff is hence not regarded as a major additional source of these nutrients.

It is clear from the literature that the set of water quality determinants most frequently encountered comprises SS, Cl, BOD_5, COD, NH_3, NO_3, P, Pb, Zn and Cu. Consistent determinations of these in samples of storm sewage urban runoff precipitation and receiving streams would seem to afford most of the information necessary for managing stormwater quality.

Pollution Control Measures

On combined drainage systems, treatment works are designed to afford full treatment to flows up to 3 x DWF and to afford sedimentation to flows in excess of these. Where discharges of storm sewage from foul sewers impose unacceptable burdens on the receiving stream, remedial measures favour the provision of "first flush" capture tanks with subsequent return of the sewage of treatment. In the case of urban stormwater discharges by separate systems, settlement in artificial impoundments has been found to be a very effective means of treatment. At least two new towns (Milton Keynes and Stevenage) make use of urban runoff water to provide recreational lakes. In the case of Stevenage the lake supports a first-class cyprinid fishery.

In large connurbations, where remedial work to the sewerage system is impractical on the large-scale and where where frequent pollution occurs as a result of premature discharges of storm sewage, the Severn Trent Water Authority provides whole river treatment in detention lakes. These lakes afford settlement to all but the very exceptional flood flows. Experimental work has been reported (39) and has led to the installation of a scheme of the R. Tame below Birmingham with impressive improvements to river water quality downstream.

Socio-Economics and Policy Considerations for Control Measures

The separation of surface runoff from sewage results in a lower and more predictable flow to treatment and allows the provision of a smaller diameter pipe for the conveyance of sewage. The advantages are thus a closer control on the sewage treatment process with gains in efficiency and manpower productivity and the avoidance of septic conditions in sewers with an increased life for fabric of the sewer. Segregation also avoids spillages of dilute sewage to watercourses and this helps to preserve the visual amenity of river banks by avoiding the stranding of unsightly sewage-derived solids.

While the surface waters are not free from pollutants they are nevertheless less polluting than dilute sewage and are likely to be better aerated with the consequence that damage to biota is localised. On the other hand, volumes of surface water are likely to exceed those of dilute sewage

spilled from a combined system and are likely to be more frequently discharged. As a result work may be necessary to modify and enlarge drainage channels in and below urban areas to avoid flooding. Other disadvantages of separation are the additional costs of installing dual sewers and the increased risks of pollution of local waters by illegal or accidental spillages of pollutants. The risk of negating the benefits of separation by inadvertently cross connecting the two systems is frequently cited as a disavantage. This may have been overemphasised since it should be possible to construct the dual system in incompatible parts and to institute a rigorous system of inspection before covering up any new drainage work.

It is clear that the balance between advantages and disadvantages is likely to be delicately poised and the decision to adopt either system can only be made after a thorough examination of all local factors. An essential part of this examination is a comparison of the costs involved and a judgement as to which system is likely to give better value for money in protecting the environment. Post-war experience in the new towns would tend to favour the installation of separate systems in the creation of new urban areas. Large-scale urban renewal schemes might also afford an opportunity for re-drainage by separate systems. It would however be impractical and hence probably uneconomic to embark on a programme of separation in the majority of existing heavily trafficked industrial and commercial centres unless a very gradual approach were adopted on an opportunistic basis. A fuller description of the advantages and disadvantages of both systems is contained in the report of the Working Party on Storm Sewage (Scotland) (57).

The analysis of existing urban drainage systems and the design of cost-effective new systems has been helped by the development of the Wallingford Procedure (58). The procedure comprises a set of computer programmes which can be used to simulate the performance of existing systems under conditions of surcharge or enables cost comparisons between alternative design solutions. These new analytical methods, together with the development of instrumentation to measure the actual performance of drainage systems, are proving to be valuable tools in the investigation of urban drainage problems.

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