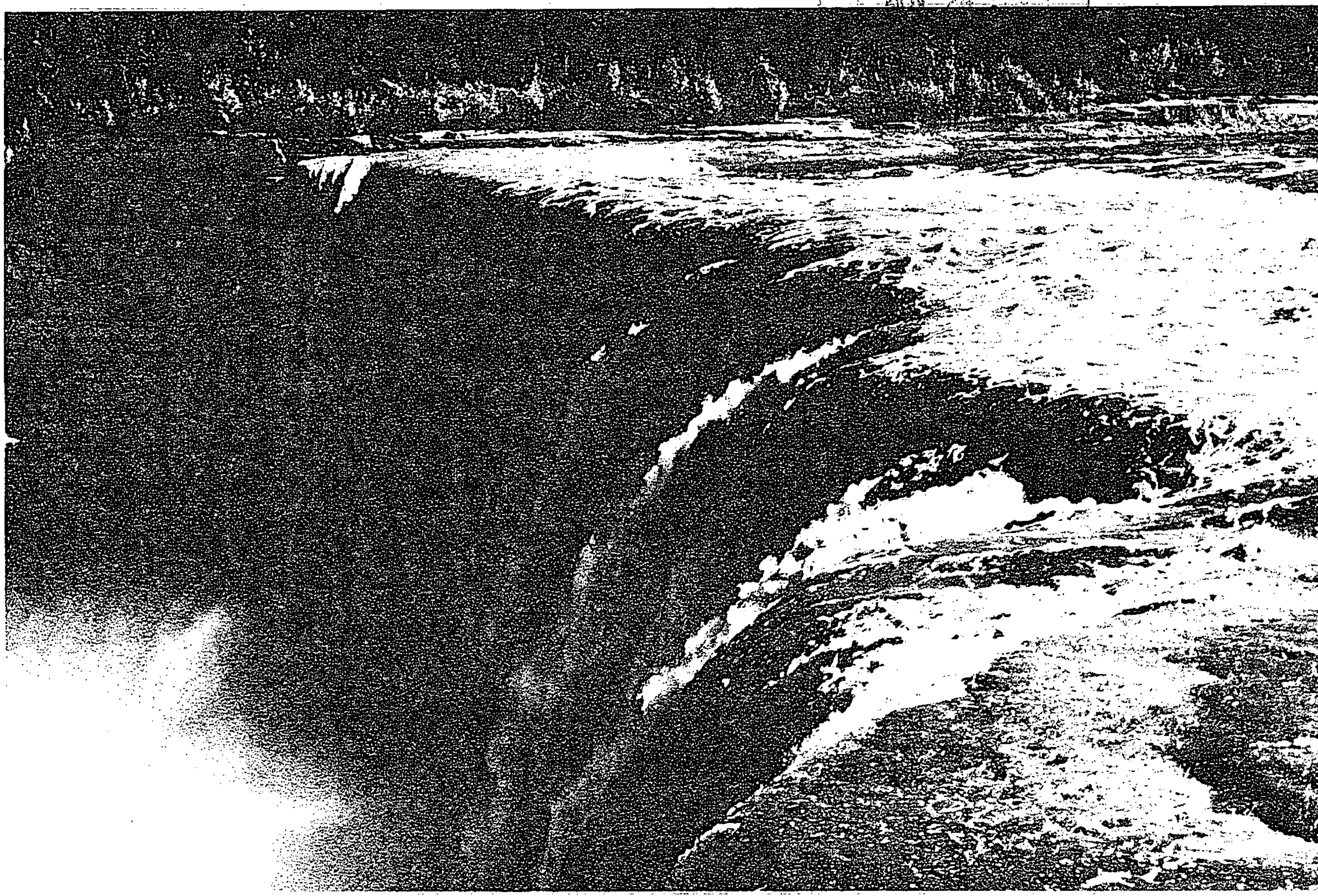
Environment Canada   Environnement Canada

Urban Hydrological Modeling and Catchment Research in Canada

J. Marsalek



TECHNICAL BULLETIN NO. 98

Reprint of Technical Memorandum No. IHP-3
ASCE Urban Water Resources Research Program
American Society of Civil Engineers
New York, N.Y., June 1976

(Résumé en français)

INLAND WATERS DIRECTORATE,
CANADA CENTRE FOR INLAND WATERS,
BURLINGTON, ONTARIO, 1976

Environment Canada / Environnement Canada

Urban Hydrological Modeling and Catchment Research in Canada

J. Marsalek

TECHNICAL BULLETIN NO. 98
Reprint of Technical Memorandum No. IHP-3,
ASCE Urban Water Resources Research Program,
American Society of Civil Engineers,
New York, N.Y., June 1976
(Résumé en français)

INLAND WATERS DIRECTORATE,
CANADA CENTRE FOR INLAND WATERS,
BURLINGTON, ONTARIO, 1976.

Cat. no: En36-503/98

ISBN 0-662-00315-2

CONTRACT NO. 07KX.KL210-6-4526

THORN PRESS LIMITED

FOREWORD

The American Society of Civil Engineers' Urban Water Resources Research Program was initiated and developed by the ASCE Urban Water Resources Research Council (formerly the Urban Hydrology Research Council). The basic purpose of the Program is to help establish coordinated long-range research in urban water resources on a national scale.

Phase I of the Program, 1967-1969, was sponsored by the Office of Water Resources Research (OWRR) and the U.S. Geological Survey. The theme of Phase I was research needs assessment. Phase II, 1969-1971, was sponsored exclusively by OWRR. The theme of Phase II was urban water management. Phase III, 1971-1974, sponsored by OWRR, emphasized translation of research into practice, facilitation of urban runoff research, and collaboration and participation in research of municipalities and other organizations. The twenty-eight reports and technical memoranda resulting from the above activities are cited, with brief abstracts, in a recent paper.(1) Concluded since was a project supported under a contract with the San Francisco Bay Region Study, USGS,(2) and four Technical Memoranda in the regular series.(3-6)

Currently, the Program is engaged in two projects: "A Mechanism for the Transfer of Urban Water Research Results and Technology," supported by OWRT; and "International Urban Hydrology Research Capabilities," supported by NSF. The report herein is one of a special series of IHP Technical Memoranda distributed under the NSF grant.

A Steering Committee designated by the ASCE Council gives general direction to the Program: S. W. Jens (Chairman); W. C. Ackermann; J. C. Geyer; C. F. Izzard; D. E. Jones, Jr., and L. S. Tucker. M. B. McPherson is Program Director (23 Watson Street, Marblehead, Mass. 01945). Administration support is provided by ASCE Headquarters in New York City.

---

1. McPherson, M. B., and G. F. Mangan, Jr., "ASCE Urban Water Resources Research Program," J.Hyd.Div., ASCE Proc., Vol. 101, No. HY7, pp. 847-855, July, 1975.

2. McPherson, M. B., Regional Earth Science Information in Local Water Management, ASCE, New York, N.Y., 155 pp., July, 1975.

3. Shubinski, R. P., and S. N. Nelson, "Effects of Urbanization on Water Quality," ASCE UWRR Program Technical Memorandum No. 26, ASCE, New York, N.Y., 34 pp., March, 1975. (Available from NTIS as PB 242 297).

4. Wolff, J. B., F. P. Linaweaver, Jr., and J. C. Geyer, "Commercial Water Use," ASCE UWRR Program Technical Memorandum No. 27, ASCE, New York, N.Y., 67 pp., December, 1975. (Available from NTIS as PB 250 998).

5. McPherson, M. B., "Household Water Use," ASCE UWRR Program Technical Memorandum No. 28, ASCE, New York, N.Y., 109 pp., January, 1976. (Available from NTIS as PB 250 879).

6. Grigg, N. S., J. W. Labadie, G. R. Trimble and D. A. Wismer, "Computerized City-Wide Control of Urban Stormwater," ASCE UWRR Program Technical Memorandum No. 29, ASCE, New York, N.Y., 81 pp., February, 1976.

PREFACE

by M. B. McPherson

Special IHP Series of Technical Memoranda

The report which follows is the third in a special series of ASCE Program Technical Memoranda for the International Hydrological Programme. The prototype report was for the USA.(1) A number of contributed national reports, of which the Canadian report herein is the second to be received, will be issued subsequently through 1976. The first contributed national report was from Australia.(2) ASCE is being supported for the collection and distribution of these state-of-the-art reports on urban hydrology by a U.S. National Science Foundation research grant on "International Urban Hydrology Research Capabilities".

Background

This endeavor originated from activities and aspirations of the Unesco Subgroup on the Hydrological Effects of Urbanization of the International Hydrological Decade which concluded in 1974. Members of the Subgroup represented the Federal Republic of Germany, France, Japan, Netherlands, Sweden, U.K., U.S.S.R. and U.S.A. The writer served as U.S. representative and chairman of the Subgroup. The Subgroup final report(3) is divided as follows: Part I, "International Summary"; Part II, "Case Studies of Hydrological Effects of Urbanization in Selected Countries"; and Part III, "Illustrative Special Topic Studies". The final draft of Part I was resolved by representatives of over thirty nations who participated in an International Workshop at Warsaw, Poland, November, 1973.(4) A very important output from the workshop was the identification of ten crucial international research projects proposed for inclusion in the Unesco component of the International Hydrological Programme which commenced in 1975 as the successor to the IHD.

Because of pessimism over the prospects of Unesco being able to support all of the proposed research, ASCE took early supportive action by applying for an NSF grant to assist in two of the ten recommended projects:

R1. Catchment Studies Report. Prepare a "state-of-the-art" report on research executed in urban catchment areas, which would include instrumentation, data acquired, analysis performed and applications.

R3. Mathematical Models Report. Prepare a "state-of-the-art" report on mathematical models applied to urban catchment areas and dealing with, for instance, rainfall-runoff relationships and water balances, both with respect to water quantity and quality.

Additional reasons for ASCE assisting in the preparation of these two reports under NSF support were that these activities would reflect U.S. concern on urban matters, that they would probably serve as a stimulus for greater recognition of the vital importance of urbanization aspects in the IHP, and that they would likely provoke analogous support on related projects by other nations.

At its first session in April, 1975, the International Council for the IHP adopted "IHP Project 7, Effects of Urbanization on the Hydrological Regime and on Quality of Water," which includes the two subjects in question. This action makes possible close coordination and cooperation with Unesco by the ASCE Program on the state-of-the-art reports.

Of particular significance was the very strong emphasis of the Warsaw Workshop and the Subgroup on the urgency of addressing all such reports to users of research findings. That is, an accentuation of user participation and user orientation of IHP urban products clearly indicated that facilitation of the translation of research findings into implementation practice should be a central goal.

In most countries, economic growth, population growth, non-agricultural water use and pollution are intertwined. Water in its many manifestations plays a vital role in the extremely complex processes of urbanization, and thus affects a nation's health and growth. The most significant conclusion reached by the IHD/Unesco Subgroup is that most urban hydrological problems and effects are similar in technologically and economically advanced countries. Further, many problems confronting the developing nations have at one time or another already been encountered by many developed nations. This strongly suggests that great benefits would result from exchanging of information and increased international cooperation in research and development.

About the Contributed Report for Canada

Mr. Marsalek clearly indicates the substantial progress that has been made in urban hydrology research in Canada, mostly over the past few years. Also, his excellent report on "Instrumentation for Field Studies of Urban Runoff" (his Reference No. 34) contains many practical guidelines for field data acquisition, some of which are included herein as Appendix II.

On behalf of the ASCE Urban Water Resources Research Council, the writer wishes to take this opportunity to thank Mr. Marsalek for assembling an excellent report which should facilitate international communication on the state-of-the-art in urban hydrology.

Acknowledgment

Processing, duplication and distribution of this Technical Memorandum was supported entirely by U.S. National Science Foundation research grant Number ENG74-20326, from the Division of Engineering, Civil and Environmental Technology Program, to the American Society of Civil Engineers, for 1975 and 1976. Technical liaison representative for the U.S. NSF is Dr. Arthur A. Ezra.

References

1. McPherson, M. B., "Urban Mathematical Modeling and Catchment Research in the U.S.A.," ASCE UWRR Program Technical Memorandum No. IHP-1, ASCE, New York, N.Y., 49 pp., November, 1975.

2. Aitken, A. P., "Urban Hydrological Modeling and Catchment Research in Australia," ASCE UWRR Program Technical Memorandum No. IHP-2, ASCE, New York, N.Y., 21 pp., May, 1976.

3. Unesco, Hydrological Effects of Urbanization, Studies and Reports in Hydrology 18, The Unesco Press, Paris, 280 pp., 1974.

4. ASCE, "Report, International Workshop on the Hydrological Effects of Urbanization, Warsaw, 1973," to the U.S. NSF, New York, N.Y., 61 pp., January, 1974.

TABLE OF CONTENTS

ABSTRACT

Results of a critical survey of urban test catchment research and urban hydrological modeling in Canada are presented. A catalogue of selected urban test catchments and related research projects was prepared. Information on catchment characteristics, instrumentation, data acquired, analysis performed and data applications was included in the catalogue. The Section on Urban Hydrological Modeling includes descriptions of newly developed models, modifications and refinements of some existing models and selected Canadian engineering applications of urban runoff models.

RÉSUMÉ

Le présent rapport traite des résultats obtenus à la suite d'une importante étude touchant non seulement les travaux de recherche effectués dans certains bassins versants qu'on a soumis aux essais, mais aussi les modèles d'hydrologie urbaine au Canada. On a dressé un inventaire préliminaire de certains bassins versants urbains expérimentaux et de projets de recherche analogues. L'inventaire comprenait notamment des renseignements relatifs aux caractéristiques principales du bassin versant, aux appareils utilisés, aux données recueillies, aux analyses effectuées et aux utilisations variées des données. La section portant sur les modèles d'hydrologie urbaine décrit les nouveaux modèles conçus, les modifications et les perfectionnements apportés à quelques modèles courants ainsi qu'un certain nombre d'utilisations des modèles d'écoulement urbain auxquels les ingénieurs canadiens font appel.

SECTION 1

INTRODUCTION

Terms of Reference

The UNESCO Intergovernmental Council for the International Hydrological Programme (IHP) adopted, as part of its activities, IHP Project 7: Effects of Urbanization on the Hydrological Regime and on Quality of Water. Included in Project 7 are two sub-projects: 7.1, Urban Catchment Research; and 7.2, Urban Hydrological Modeling. The Intergovernmental Council for the IHP requested from the participating countries state-of-the-art reports on both sub-projects. The first such contribution[31] was distributed and endorsed as a basis for the development of similar reports from other countries.

The report which follows is a Canadian contribution to IHP Project 7. The terms of reference for both sub-projects have been adopted from the U.S. contribution and can be summarized as follows:

1. Urban Catchment Research — prepare a "state-of-the-art" report on research executed in urban catchment areas. The report should deal with instrumentation, data acquired, analysis performed and applications.

2. Urban Mathematical Modeling — prepare a "state-of-the-art" report on mathematical models applied to urban catchment areas and dealing with, for instance, rainfall-runoff relationships and water balances, both with respect to water quantity and quality.

Methodology

Information presented in this report has been collected and assessed by the author, who accepts the responsibility for any misinterpretation of the basic data supplied by the co-operators listed below. More than 300 information sources were examined by means of a literature survey, a questionnaire and follow-up interviews.

Acknowledgment

The co-operation of numerous persons who have responded to the project questionnaire is gratefully acknowledged. Special thanks are due to the individuals, listed alphabetically by surname below, who have provided information included in the report:

B. J. Adams, University of Toronto, Toronto, Ontario
K. E. Armstrong, Alberta Environment, Edmonton, Alberta
J. C. Anderson, Gore & Storrie Limited, Ottawa, Ontario
N. Benneworth, Canadian British Consultants Ltd., Halifax, Nova Scotia
K. T. Brodersen, Environmental Protection Service, Ottawa, Ontario
R. S. Cebryk, City of Edmonton, Edmonton, Alberta
J. Dartois, Université du Québec, Québec City, Québec
H. Demard, Université du Québec, Québec City, Québec
P. A. Ehler, Town of Midland, Midland, Ontario
C. Eicher, Gore & Storrie Limited, Toronto, Ontario
J. Ganczarczyk, University of Toronto, Toronto, Ontario
W. F. Geiger, Dorsch Consult Limited, Toronto, Ontario
M. Gibbons, Stanley Associates Engineering Ltd., Edmonton, Alberta
J. F. Hartt, University of Windsor, Windsor, Ontario

J. G. Henry, University of Toronto, Toronto, Ontario
W. L. Keay, Regional Municipality of Ottawa-Carleton, Ottawa, Ontario
C. S. Kitchen, City of Toronto, Toronto, Ontario
F. I. Lorant, M. M. Dillon Limited, Toronto, Ontario
B. H. Luckman, University of Western Ontario, London, Ontario
J. E. MacKenzie, City of Ottawa, Ottawa, Ontario
C. MacRae, University of Western Ontario, London, Ontario
H. Mar, City of St. Catharines, St. Catharines, Ontario
W. A. Mechler, Greater Vancouver Sewerage and Drainage District, Vancouver, British Columbia
B. Molke, Canadian-British Engineering Consultants (1971) Limited, Don Mills, Ontario
Z. Novak, Ministry of the Environment, Toronto, Ontario
A. R. Perks, Proctor & Redfern Limited, Toronto, Ontario
B. Ruddy, Borough of North York, Willowdale, Ontario
S. I. Solomon, Shully I. Solomon Limited, Toronto, Ontario
F. A. Tonelli, Ministry of the Environment, Rexdale, Ontario
G. L. Trider, Environmental Protection Service, Halifax, Nova Scotia
D. H. Waller, Nova Scotia Technical College, Halifax, Nova Scotia
W. E. Watt, Queen's University, Kingston, Ontario
J. Whiting, Saskatchewan Research Council, Saskatoon, Saskatchewan
P. E. Wisner, James F. MacLaren Limited, Willowdale, Ontario

SECTION 2

URBAN CATCHMENT RESEARCH IN CANADA

Introduction

An urgent need for urban water resources data, and particularly for urban runoff data, has been identified under the research programme of the Urban Drainage Subcommittee (UDS) for the Canada-Ontario Agreement on Great Lakes Water Quality. Such data would serve for the assessment of pollution caused by urban runoff and combined sewer overflows, for the planning, design and operation of drainage systems; and also for the development, verification and calibration of urban stormwater management models. It was realized at the same time that the lack of urban water resources data would likely inhibit achievement of advances in the management of urban water resources.

A survey of urban catchment research carried out in 1973[24] indicated that there were only a few instrumented urban catchments in Canada, of which only two had produced data suitable for urban runoff modeling. The UDS reacted to this situation by establishing several new urban test catchments in the Province of Ontario. A similar action has been taken recently by the Province of Quebec. On a nationwide basis, however, urban catchment research still has not reached a level consistent with the large expenditures in urban drainage facilities. Urban catchment research in Canada seems to be plagued by a number of problems, some of which are briefly discussed below:

a) Lack of co-ordination. There is no national network of urban test catchments and no nationwide co-ordination of catchment research. As a result, the current network of test catchments does not extend to all climatic regions, and the type of information and data formats vary from case to case, thus inhibiting comparative studies on various catchments.

b) Lack of suitable instruments. Several studies of instrumentation for catchment research have been carried out recently.[24,26,34] All of these indicate a lack of reliable instruments for the measurement and sampling of sewer flows. Even well-designed instrumentation systems may require up to six months for the elimination of malfunctions before they become fully operational.

c) High costs. Urban runoff data collection projects are rather costly and their success is not guaranteed.

As an illustration of the cost and success question, an experience with a typical runoff data collection project conducted by a private company (specializing in environmental studies) for the Urban Drainage Subcommittee is summarized below:

Activities		Number of Events Monitored		Costs
		Precipitation & Runoff Quantity	Precipitation & Runoff Quantity & Quality	
1st Year	Establishment and Instrumentation of the Catchment	-	-	$10,000
2nd Year	Data Collection & reporting	6 (>0.30")	2	$10,000
3rd Year	Data Collection, computer simulation with an existing model, reporting	2 (>0.30")	5	$22,000
	Totals	8	7	$42,000

The above costs do not include the cost of chemical and microbiological analyses of stormwater samples. These analyses were performed by a government laboratory and their commercial value is estimated at $20,000. Thus the total project cost would be about $62,000.

At the present time, the data collection programs appear to be too expensive for all but the largest municipalities. The government funding of these projects also lacks continuity.

In spite of the aforementioned difficulties, the urban catchment research has progressed significantly, especially during the last three years, and this progress is documented in this report.

The reported research studies on urban catchments may be divided into the following three categories: studies of the effects of urbanization on hydrology of undeveloped watersheds; studies of the effects of runoff from urban areas on receiving waters; and studies of the characterization of flows in sewer networks.

Studies of the Effects of Urbanization on Hydrology of Undeveloped Watersheds

Studies of the Kanata[22] and North Pickering[43] basins dealt with the effects of rapidly progressing urbanization on the hydrology and water quality of runoff from undeveloped watersheds. In both cases, runoff quantity and quality were monitored.

Kanata, one of three satellite communities that will house the expanding population of the Ottawa area, is being developed by a single developer. Some runoff control measures were implemented in the development. Houses were built in a park-like setting with limitations on the extent of impervious areas. The roof leaders are not connected to sewers. A progress report[22] summarized preliminary results obtained in 1972 and 1973. Unfortunately, the study was discontinued in 1973.

The North Pickering study[43] is still active. The effects of urbanization on the hydrology of the area undergoing development were simulated with a Distributed Hydrologic Model. The results of these simulations will be compared with runoff data being collected.[44]

Studies of the Effects of Runoff from Urban Areas on Receiving Waters

Two studies of this nature are presently in progress, the Pollution from Land Use Activities Reference Group (PLUARG) study[40] and the Whitemud Creek study.[4] Both studies are essentially upstream/downstream studies which will indicate the water quality effects caused by urban land use under various conditions including rainfall. In the PLUARG study, several urban areas in the Grand River and Saugeen River basins (Ontario) are to be investigated. The Whitemud Creek study (Edmonton, Alberta) is still in the planning stage.

Evidently, only a few field studies of the effects of urbanization on the hydrology of developing watersheds and on receiving waters have been conducted in Canada. Such studies require large resources, and typically, are carried out over extended time periods.

Studies of the Characterization of Flows in Sewer Systems

In these studies, time varying quantity and quality of sewer flows are studied within the sewer networks. The first studies of this nature were limited to field observations of precipitation/runoff phenomena, very rarely considering both runoff quantity and quality. Recent studies consider both of these aspects of urban runoff, and frequently the runoff data collection is pursued in support of computer modeling of sewer systems. Such a procedure enhances the meaning and interpretation of the data collected and makes the simulation of sewer system behaviour more reliable.

Attempts have been made to characterize sanitary flows (dry and wet weather), combined sewer flows (wet weather), storm sewer flows, foundation drain flows, road sewer flows, roof runoff, and winter urban runoff (including snowmelt).

Projects discussed here are divided into two categories: comprehensive data collection projects, typically dealing with precipitation, runoff quantity and quality; and projects of a limited scope, typically designed to produce calibration data or first estimates of runoff quantities and pollutional loads. Only projects in the first category will be discussed in detail.

Selected Sewer System Comprehensive Data Collection Projects

Fifteen data collection projects have been selected for inclusion in this category. In all these cases, the projects represent well-documented efforts providing data which either have been used for hydrological modeling and research, or have a potential for such a use. The basic characteristics of the test catchments are listed in Table 1 and the location of these catchments is shown in Figure 1. Detailed descriptions of test catchments and the evaluation and use of data collected therefrom are presented in Appendix I.

Suitability of the collected data for detailed hydrological modeling was evaluated on the basis of two criteria: the test catchment and its physical and operational characteristics are well defined and documented; and short interval (say 1 to 5 minutes) precipitation data and continuous runoff measurements are available. The accuracy and synchronization of both data records are important. If water quality simulation is included, a third criterion also applies: water quality data collected at short intervals (5 to 15 minutes) are available. These data have to be synchronized with the precipitation and runoff data and also have to cover the initial phase of runoff.

In many of the early studies, modeling of urban runoff was not among the study objectives. It is therefore little surprising that the data from some

TABLE 1. SELECTED CANADIAN URBAN TEST CATCHMENTS

CATCHMENT	LOCATION	SEWER SYSTEM (C = combined and S = separate)	SIZE (hectares)	IMPERVIOUSNESS, PER CENT	PHENOMENA MONITORED: RAINFALL	PHENOMENA MONITORED: RUNOFF FLOW	PHENOMENA MONITORED: RUNOFF QUALITY	STATUS: ACTIVE	STATUS: COMPLETED	DATA AVAILABILITY: AVAILABLE	DATA AVAILABILITY: PUBLISHED	DATA AVAILABILITY: NOT YET AVAILABLE	RUNOFF MODELING	REFERENCE (Section 5)
Bannatyne	Winnipeg, Man.	C	220	36	X	X	X		X	X			Yes	42
Barrington	East York, Ont.	S	17.4	37	X	X	X		?	X	X*		No	39
Brucewood	North York, Ont.	S	19.4	48	X	X	X		X	X	X*		Yes	28
Calvin Park	Kingston, Ont.	S	36	27	X	X		X		X			Yes	53
Carling	London, Ont.	S	32.4	75	X	X	X	X				X	-	27
Fairfield	Halifax, N.S.	C	68	34	X	X	X	X		X	X*		Yes	51
Hamilton	Hamilton, Ont.	C	71.3	45	X	X	X	X				X	Yes	14
Idylwyld	Saskatoon, Sask.	S	6.9	55	X	X		X		X			Planned	19
Les Saules	Quebec, Que.	S	25	40	X	San. Flow	San. Flow	X				X	?	8
Malvern	Burlington, Ont.	S	23.5	34	X	X	X	X		X	X		Yes	35
Rigaud	St. Foy, Que.	C	39	44	X	X	X	X				X	?	8
St. Pascal	St. Pascal, Que.	S	200	13	X	X San. Flow	X San. Flow	X				X	?	8
Toronto-East	Toronto, Ont.	C	137	49	X	X	X	X				X	Yes	9
Toronto-West	Toronto, Ont.	C	944	54	X	X		X		X			Yes	42
Windsor	Windsor, Ont.	S	12.1	38	X	X	X		X	X	X		No	10

*In press (May, 1976).

Figure 1. SELECTED CANADIAN URBAN TEST CATCHMENTS – LOCATION MAP

of these studies do not meet the above modeling criteria, but this circumstance does not diminish the success of those studies.

Thirteen of the fifteen catchment studies identified in Table 1 were fully or partially sponsored by the federal and provincial governments. The remaining two studies were fully sponsored by municipalities. The actual field data collection was done in seven cases by universities, in three cases by private companies, in three cases by municipalities, and in two cases by the federal and provincial governments.

Four of the catchment research projects have been discontinued, namely the Bannatyne, Barrington, Brucewood and Windsor projects. The remaining eleven projects are active, but for only five of these has some field data been made available so far.

Geographical distribution

Most of the urban research catchments were established in the two most populous provinces, Ontario and Quebec (9 and 3 respectively in Figure 1). The remaining three catchments are in Manitoba, Nova Scotia and Saskatchewan. It would appear desirable to establish additional research catchments, particularly in the Pacific Region, Prairies and Atlantic Region.

Size of the catchments

Size varies from about 7-hectares (Idylwyld) to 944-hectares (Toronto-West). Four-fifths of the catchments discussed are of small size, less than 80-hectares. Smaller catchments are easier and less expensive to instrument and document. For study of runoff routing, however, larger catchments are preferable.

Sewer systems

Six catchments are served by combined sewers and nine by separate storm sewers. In the latter case, storm sewers only are monitored in seven cases, sanitary sewers only are monitored in one case and both sanitary and storm sewers are monitored in one case.

Land use

Low density residential areas with some commercial and institutional land use are most typical. Five of the catchments, namely Brucewood, Calvin Park, Les Saules, Malvern, and Rigaud, are modern suburban developments. The remaining catchments are older residential areas (30 to 70 years old) except for the Idylwyld catchment which represents a freeway drainage area.

Effects of other than low density residential land use on runoff quantity and quality were investigated on a very limited basis. Some information on airport runoff,(55) commercial plaza runoff,(33) and oil refinery runoff(55) was collected, mostly in connection with engineering projects.

Additional studies of the effects of land use on the surface accumulation of pollutants and quality of runoff water seem to be justified.

Sewer System Data Acquisition Devices

The principal components of data acquisition systems are precipitation gauges, flowmeters, wastewater samplers and recorders. Many such instruments were examined in a recent report on instrumentation for field studies of urban runoff.[34] An expanded summary of that report[34] is included herein as Appendix II.

Tipping-bucket raingauges were used in most projects. These gauges are preferable in urban runoff studies mainly because of their superior mechanism for actuating circuits and good accuracy of measuring rainfall of medium intensities. The number of raingauges per catchment varies from 1 to 8. The latter number refers to the Idylwyld catchment. Note that two gauges are recommended even for the smallest catchments,[26] and the largest test catchment discussed, the West-Toronto Study Area, should be monitored with at least three raingauges.

Sewer flows are typically measured by means of constriction flow meters. Among these, weirs are much more common than Venturi flumes. Standard rectangular weirs are used at drainage outlets. Inside sewers, vertical slot or partial trapezoidal weirs are used because they allow passage of solids through the installation. Weir installations should be calibrated because the rating curves of weirs installed in pipes, or at the pipe end, depart significantly from those obtained for rectangular laboratory flumes.[34] Weir head is most frequently measured by floats or air bubblers.

Various types of flow measuring weirs were used in nine of the studies listed in Table 1. Venturi flumes were used in several cases. Among these, Palmer-Bowlus and Parshall flumes are common. In studies for West-Toronto and Windsor, flow rates were estimated from the measured depth of flow and Manning's equation. Such a procedure is very popular in engineering studies because of its low cost, but it is not acceptable in research studies because of large uncertainties in the measured flow. In all the reported studies, the sewer flows were measured at a single point.

The above-described flow measuring techniques become inoperational for pressure flow conditions. In sewers subject to frequent surcharge, the use of dual free/pressure flowmeters is recommended. None of these instruments has been installed in Canada so far, but a laboratory study of the U.S. Geological Survey dual measuring flume was carried out recently.[58] Determination of calibration curves for two flume sizes and flume ventilation requirements were included in the study.

Sewer flow quality is monitored by collecting and analyzing samples. Typically, sequential grab samples are collected either at regular time intervals or after a constant volume of flow has passed through the installation. In the latter case, a flowmeter and a flow integrator are used to activate an automatic sampler.

Sequential grab sampling makes it possible to determine the variation of constituent concentration with time and also the total constituent emission during a runoff event. In most cases, samples are collected by automatic samplers activated either by a raingauge or by a rise in the sewer water level. Well-known commercial samplers are used, among these ISCO, Manning, North Hants, Sigmamotor and Sirco. In one case, a little-known French sampler SEIN* was used. A principal advantage of this sampler is that up to 24 sequential 2-litre samples can be collected, and 2-litre samples would be adequate in most studies. Depending on the number of analyses to be performed, a sample size of 1-litre appears to be the minimum.

---

*Manufactured by Sein-Ecologie, 171 rue Veron, Alfortville, France.

Automatic samplers are the least reliable instruments among those discussed here. Where space permits, it is advisable to install and operate two samplers independently to increase the probability of successful data collection.(35)

Water quality and microbiological parameters investigated in the reported studies varied from case to case. A list of parameters studied is given in Table 2. Depending on the type and number of analyses performed, analytical costs may represent a major component of the urban runoff study costs. Frequently, the costs of analyses are more than 100 dollars per sample. Consequently, a careful consideration of the number of samples to be analyzed is warranted. Application of experimental design has been proposed(34) for selection of the number of samples required to describe adequately variations in runoff quality. Experimental design, which requires assumption of a simple empirical model for runoff quality, has not been tested so far.

With regard to data recording, ideally a central magnetic or punched tape recorder is used to produce computer-compatible and well-synchronized records of precipitation, flow rate and sample collection. Such systems were used in the Idylwyld catchment study and in the studies carried out by the INRS Institute of the University of Quebec.

Two examples of the data acquisition systems are presented schematically in Figures 2 and 3. The first one (Figure 2) is the Idylwyld system, a fully automated system controlled by a minicomputer. Precipitation and runoff flow rates are monitored. The second example, Figure 3, refers to the system designed by the INRS and installed on the Les Saules and Rigaud catchments. Precipitation and runoff quantity and quality are monitored.

Sewer System Data Evaluation and Use

Canadian urban runoff data of good quality are rather scarce at present. Six out of the fifteen selected comprehensive studies are still in the initial stage and have not yet produced any significant results.

Good precipitation and runoff quantity data suitable for hydrological modeling are available for the Calvin Park and Idylwyld catchments. West-Toronto data, which consist of precipitation and combined sewer overflow rates, appear to contain significant uncertainties in the measured precipitation and flows and this somewhat limits the use of these data.

Precipitation and runoff quantity and quality data are presently available for six catchments: Bannatyne, Barrington, Brucewood, Fairfield, Malvern and Windsor. The Bannatyne and Fairfield catchments are served by combined sewers and the other four catchments are served by separate storm sewers. Bannatyne, Barrington and Windsor data appear to have some limitations. For the Bannatyne catchment, no precipitation data measured on the catchment are available. The events observed on the Barrington catchment are of a minor character. In the Windsor study, precipitation was not measured on the catchment and the runoff flow rates were measured rather inaccurately. The remaining catchment studies, Brucewood, Fairfield and Malvern, have produced fairly good data on runoff quantity and quality for a number of storm events.

With regard to data use, the earlier studies, such as for the Bannatyne, Fairfield and Windsor catchments, were instrumental in establishing the pollutional character of combined sewage and stormwater, but particularly for the Fairfield combined sewer catchment.

TABLE 2. WATER QUALITY AND MICROBIOLOGICAL PARAMETERS INVESTIGATED IN URBAN RUNOFF STUDIES

PARAMETER	FREQUENCY OF USE	
	COMMON	LESS COMMON
Biochemical Oxygen Demand	X	
Chemical Oxygen Demand	X	
Total Organic Carbon		X
Total Solids	X	
Suspended Solids	X	
Dissolved Solids	X	
Volatile Suspended Solids	X	
Volatile Dissolved Solids		X
Total Organic Kjeldahl Nitrogen	X	
Nitrogen - Ammonia		X
Nitrate and Nitrite	X	
Phosphorus - Total P	X	
Orthophosphate Hydrolyzable	X	
Orthophosphate Soluble	X	
Oil and Grease		X
Phenols		X
Chloride	X	
Organic Chlorine		X
Cadmium		X
Chromium		X
Copper		X
Lead	X	
Mercury		X
Nickel		X
Zinc		X
Total Coliform	X	
Fecal Coliform	X	
Fecal Streptococcus		X
Fecal Sterol		X
Pseudomonas Aeruginosa		X
Salmonella		X

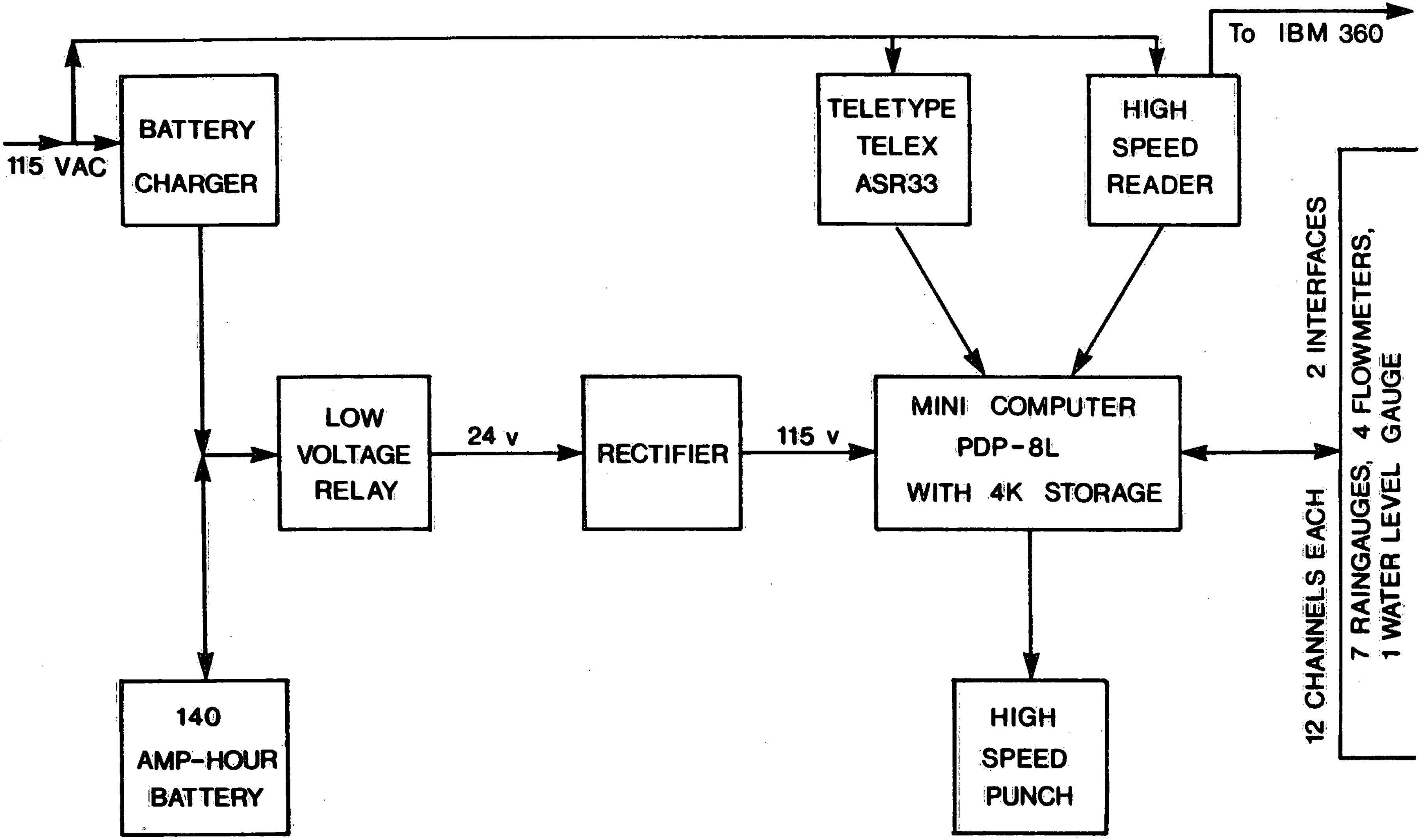


Figure 2. IDYLWYLD DATA ACQUISITION SYSTEM (After Ref.19)

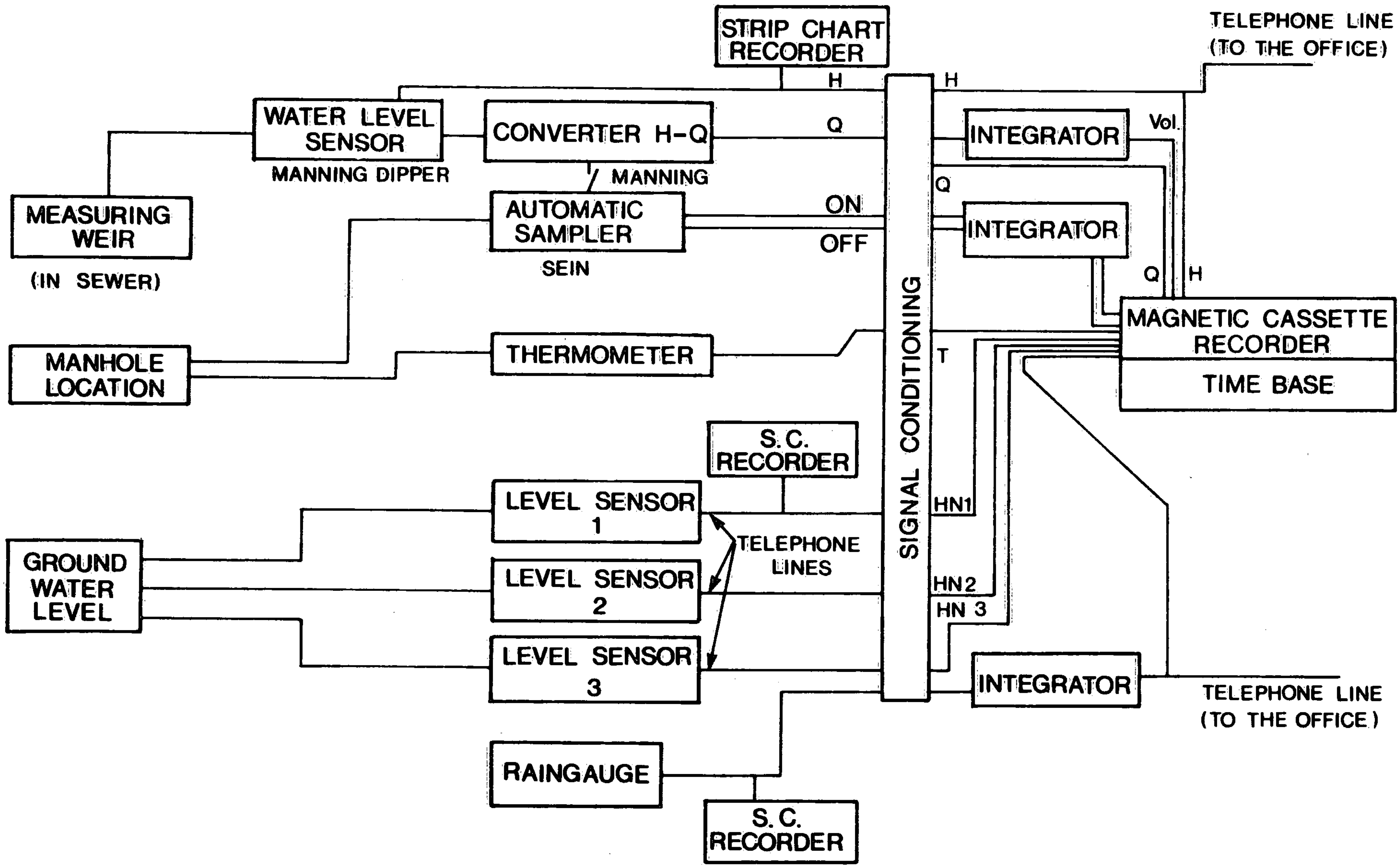


Figure 3. LES SAULES DATA ACQUISITION SYSTEM (Sketched after ref. 8, all instruments and links are included)

Runoff and combined sewer overflow quality data reported for various test catchments are summarized in Table 3.

More recent studies attempted to determine the relationships between precipitation and runoff quantity and quality. Urban runoff models are frequently used in these studies to assist in the analysis and interpretation of the collected data. Such an approach was taken, for example, in the Brucewood, Calvin Park and Malvern studies, and is planned for several others. Data from well-instrumented and documented catchments, such as Brucewood, Calvin Park, Fairfield and Malvern, were used for the development, verification and testing of urban runoff models.

Sewer System Urban Runoff Field Studies of Limited Scope

Urban runoff studies designed to provide limited data for planning and engineering studies fall into this category. In some cases, these studies were in the planning or early stages and it was difficult to judge their scope and extent. It is conceivable that some of these studies could develop in the future into comprehensive studies providing data for urban hydrological research. Brief descriptions of about twenty studies belonging to this category are presented in Appendix I herein.

TABLE 3. RANGE OF CONCENTRATIONS IN OBSERVED COMPOSITION OF COMBINED SEWAGE AND STORMWATER FOR SELECTED CANADIAN URBAN TEST CATCHMENTS

CONSTITUENT	URBAN TEST CATCHMENTS						
	COMBINED SEWAGE		STORMWATER				
	BANNATYNE	FAIRFIELD	BARRINGTON	BRUCEWOOD	FAIRFIELD	MALVERN	WINDSOR
(mg/litre)							
BOD	32-1730	90*	11-320**	0.6-110	45*	1-131	0-78
COD			40-880**	20-920		7-840	
Chloride			5-255**	2-3240			4-1585
Lead			0.5-1.8**	0.2-1.8		0.5-0.9	
Nitrates			0.2-1.9**	0.2-4.0		0.01-11.0[a]	0-4.7
Nitrites			0.02-0.9**	0.02-0.26			0.001-0.57
Ammonia			0.1-5.2**	0.1-3.3		0.005-2.3	0-0.71
Total phosphorus			0.32-11.0**	0.1-1.6		0.01-5.4	
Suspended solids	430-7700	90-1885**	60-630**	15-770	36-680**	1-1080	23-1230
(MPN/100 ml) Total coliform		5.5×10^{7}*	1.0×10^{4} to 2.0×10^{8}**	1.0×10^{2} to 8.2×10^{4}	4.9×10^{6}*	1.4×10^{3} to 5.6×10^{6}	2.0×10^{2} to 1.2×10^{6}
(MPN/100 ml) Fecal coliform		1.7×10^{6}*	1.0×10^{3} to 2.4×10^{6}**	1.0×10^{1} to 7.3×10^{3}	1.0×10^{4}*	1.0×10^{2} to 3.3×10^{5}	1.0×10^{1} to 2.0×10^{5}
Reference (Section 5)	42	49	39	28	49	36	10

*Arithmetic mean value
**Range of event maximum values

[a]Nitrates plus Nitrites

SECTION 3

URBAN HYDROLOGICAL MODELING

National Surveys

In 1973, the Department of Environment commissioned a survey of Canadian urban drainage practice. The survey(29) indicated that practically all urban drainage design was based on the Rational Method. The Rational Method was used even in cases which would be beyond the accepted limits of the scope of application of the method, e.g., for the design of stormwater storage. The only municipality using a runoff hydrograph model was the City of Toronto.

A 1976 survey reported here indicated that good progress has been made in the field of urban hydrological modeling. A number of modeling research projects have been executed or started, and runoff models have been used in many engineering and planning studies. Although a trend towards using hydrological models for drainage design has been established, most of the design work is still being done with conventional, approximate methods. Three types of urban hydrological modeling were reported: urban runoff; sanitary flows; and combined sewage flows.

In this section are discussed the development of new models, modification and interfacing of existing models, comparative studies and testing of models, and engineering applications.

Development of New Urban Hydrological Models

Five new urban hydrological models are reported here. A brief description of these models follows.

Queen's University Urban Runoff Model (QUURM)

The QUURM(53,54) is a precipitation-runoff model developed for urban catchments. At the present time it is a research-oriented model undergoing further development and refinement. The model is non-proprietary, but a complete model documentation (user's manual) has not yet been published. The model deals with runoff quantity only.

The QUURM model consists of two parts, the generation of inlet hydrographs and their routing through a sewer network. A single linear reservoir approach is used to generate inlet hydrographs from rainfall excess for each sub-catchment consisting of various area types. Runoff hydrographs from various subareas form the inlet hydrographs and these are routed through the sewer network using a modified time-offset method. The time offset is calculated for an effective Manning n and a representative velocity corresponding to the average discharge is calculated for the central half of the inlet hydrograph.

The QUURM was tested on data from the Calvin Park (Kingston) and Oakdale (Chicago) catchments with very good results.(29) The main QUURM assets are its simplicity and low computer requirements.

Subdivision Hydrograph Model (SHM)

The SHM has been developed by the Department of Civil Engineering, University of Toronto, for a particular project.(18) It is a hybrid model incorporating some features of the Storm Water Management Model (SWMM) of the U.S. Environmental Protection Agency, The Chicago Hydrograph Method, and also some new features such as runoff routing through various types of storage.

Rainfall excess in the SHM is calculated by subtracting the infiltration (Horton's Formula) and surface depression capacity from the actual rainfall. Overland flow and gutter flow are calculated by a stepwise procedure using the Manning equation for uniform flow. For a selected time step, the runoff flow is approximated by a successive quasi-steady state calculation in each interval. Catchbasin outflow hydrograph and storage outflow hydrographs are combined to form lateral sewer flow hydrographs, which are then routed through the sewer network using a time-offset method. Flow routing through a holding reservoir is optional. The model has built-in routing functions for various storage alternatives, among which are roof storage and parking lot storage.

The SHM was tested on one catchment for four storms and fairly good results were obtained. The model listing has been published but no other documentation has been published so far. The SHM seems to be particularly useful for analysis of on-site runoff storage in small urban subdivisions.

Distributed Hydrologic Model (DHM)

The DHM was developed by Shully Solomon and Associates Limited for environmental impact assessment for the North Pickering Project.(43) It is a distributed, continuous simulation model requiring calibration.

Rainfall excess in the DHM is routed over the watershed, considering various land use and soil characteristics. Numerical solutions are based on a finite differences method. The model structure was recently expanded for runoff quality and snowmelt. The final report is due in 1976.

An earlier version of the DHM was applied in the environmental assessment of a new urban development at North Pickering, Ontario. No comments on the DHM documentation or applicability can be made at this time.

Theory of Overflows from Storage and Treatment Plant Systems

This theory was developed by Unies Limited, under sponsorship of the Urban Drainage Subcommittee.(21) Starting with the probabilistic aspects of the climate, the statistics of untreated runoff discharge is developed using mathematically derived probability functions. In the first step, a rainfall excess volume is calculated by subtracting losses from the actual rainfall volume. The excess volume then enters a storage device. The filling state of storage is described by a probabilistic function. Between storm events, the volume stored is depleted by diverting a constant flow to the treatment plant. The probability of storage overflow is calculated as well as the volume of these overflows. After introducing cost functions for storage and treatment, an optimum combination of storage and treatment capacities can be studied.

This theoretical model was proposed for a preliminary analysis of discharges and overflows from urban drainage networks incorporating storage and treatment facilities. Note that by introducing a storage device, the runoff calculation may be simplified and limited to the hydrograph volumes only, as opposed to the traditional analysis considering entire runoff hydrographs. The documentation of this procedure is limited.

Simulation of Sanitary Flows

The Department of Civil Engineering, University of Toronto, has developed a parametric time-series model for sanitary flows.[1] The model serves for planning and design of the deployment configuration of sanitary sewer networks.

Modification and Interfacing of Existing Urban Hydrological Models

Numerous urban hydrological models have been introduced during the last ten years. Only limited attempts have been made to review and test existing urban runoff models in order to assist potential model users.[17,20,29,37,51]

The development of new urban runoff models is costly, and in some cases these new models do not have any clear advantages over the existing ones, and therefore do not advance the state of the art of modeling. Consequently, some researchers prefer to concentrate their efforts on modification and interfacing of the existing, verified runoff models. Such an approach was adopted, for instance, by the Urban Drainage Subcommittee, which sponsored and directed a study[42] primarily dealing with the modification of the Storm Water Management Model (SWMM) of the U.S. EPA. The selection of this model was based on the results of a previous study dealing with several urban runoff models.[29]

The need to modify the SWMM for Canadian conditions was created by several factors, namely, the Canadian climate, environmental concerns, engineering practices and costs. Some of the principal parts of the study dealing with the modification of the SWMM are described below. An interfacing of urban hydrological models, as proposed in the study, is shown in Figure 4.

Data Analysis Model (DAM)

Applications of urban runoff models require large volumes of input data, the preparation of which amounts to a significant portion of the total project cost. It is therefore desirable to simplify and computerize this part of the runoff modeling to the maximum possible extent.

The DAM[42] treats only climatological data and serves as an interface between existing data banks and both planning and design runoff models. The flow chart of the DAM is shown in Figure 5.

The DAM was devised to provide input data for the STORM model of the U.S. Army Corps of Engineers. For this planning-level, a continuous simulation model using hourly precipitation and temperature data is required. Such data are readily available for a large number of locations from the Data Banks of the Canadian Atmospheric Service in a digital form on a magnetic tape.

Detailed runoff simulation typically requires short-interval precipitation data (5-15 min.) which are also available from the above source, but not in a digital form. Before using the DAM, the user would have to digitize precipitation data in arbitrary time intervals. Once this has been done, the data processing is the same as in the former case.

Precipitation and temperature data are read from the tape and pre-processed by stripping and interpreting overpunches, building and sorting precipitation and temperature files from raw data, and punching the data on computer cards. Precipitation records of up to 6 gauges are read, combined into a single record defined as a weighted average of all the gauges, and the data quality is checked by plotting single and double mass curves for individual gauges. A similar procedure is followed for the temperature data.

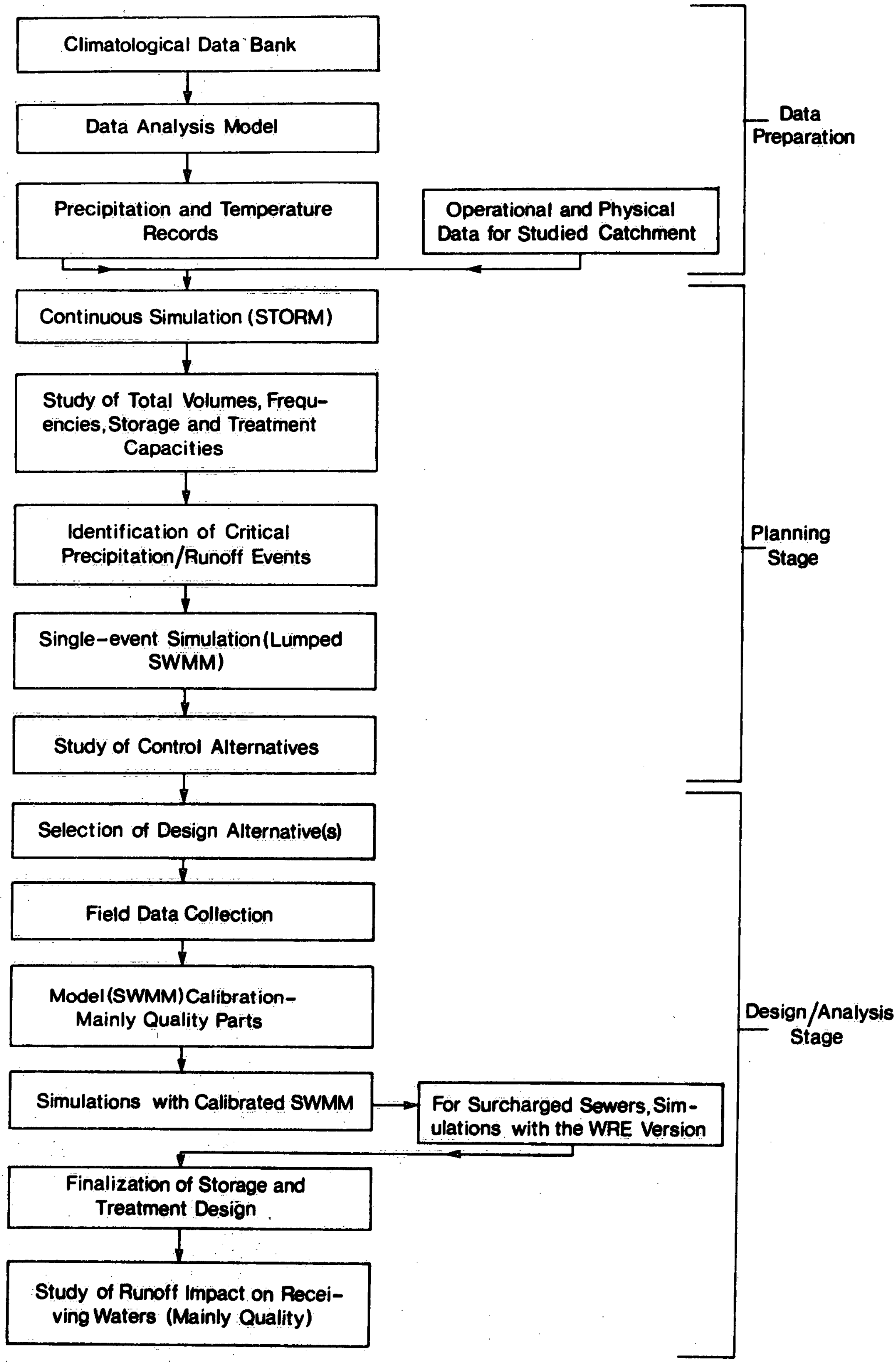


Figure 4. INTERFACE OF COMPUTER MODELS IN URBAN RUNOFF STUDIES (After Ref. 57)

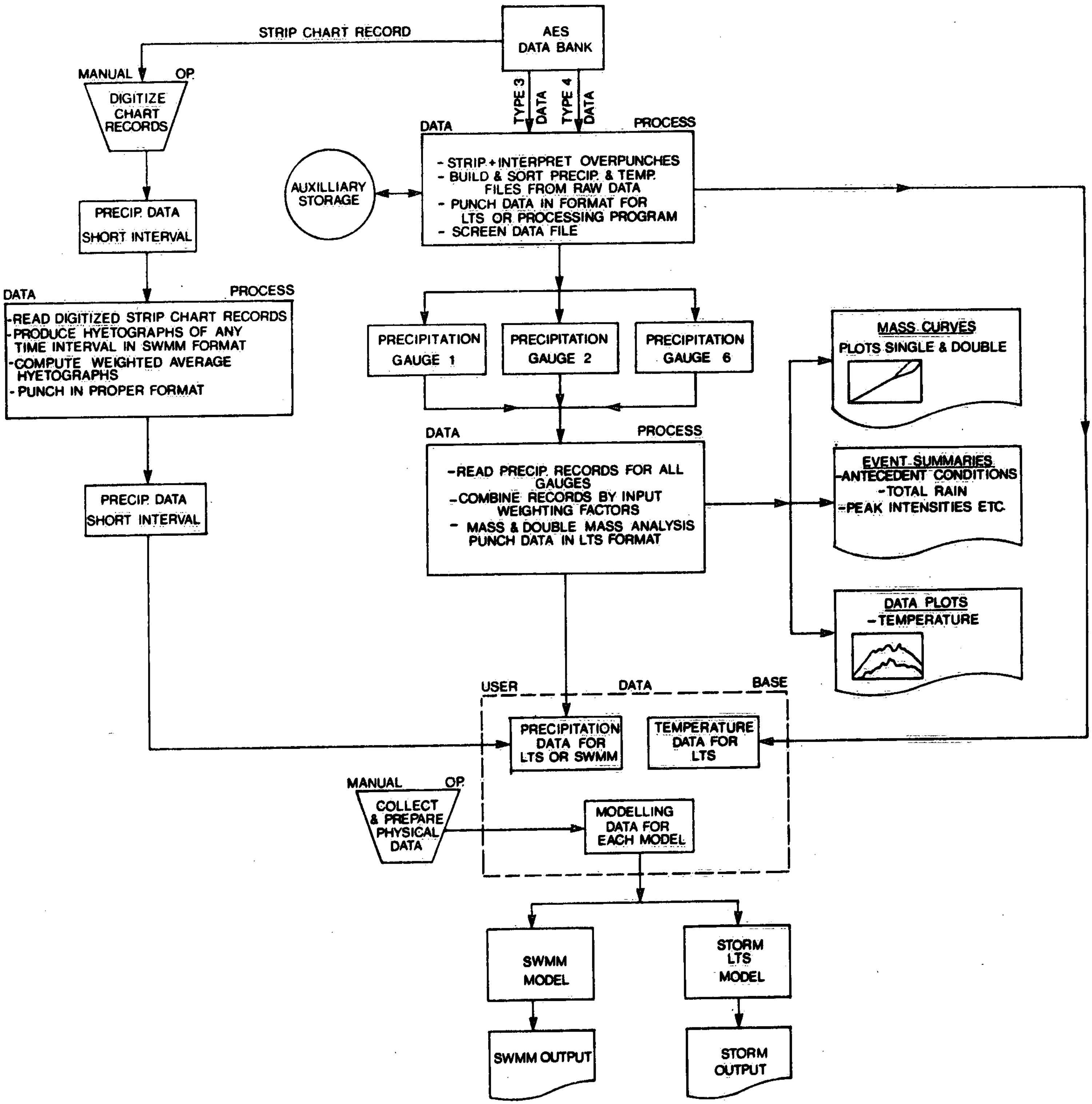


Figure 5. FLOWCHART FOR DATA ANALYSIS MODEL (After Ref. 42)

The output of the DAM consists of the punched data cards for STORM or SWMM and of event summaries. These summaries list the times of start and end of each storm event, event duration, the total depth of rainfall, the peak intensity and the antecedent dry weather period. The event summaries are useful for a rapid review of precipitation data and, eventually, for the identification of critical rainfall/runoff events. An example of the DAM output is shown in Table 4.

Operation of the SWMM as a Planning Model

The feasibility was investigated of using the SWMM, in a multi-event simulation mode, as a planning tool.(42) The SWMM was not, however, modified to operate in the continuous simulation mode, because this would require the addition of a water balance accounting.

For planning purposes, the SWMM simulations could be made less expensive by reducing the number of subcatchment and transport network elements to a minimum and increasing the time step. Following the methodology developed at MIT,(7) even large catchments could be represented in the planning stage by a single overland flow element. Depending on the circumstances, few or no transport elements are used.

Parameters of the lumped overland flow element were defined as spatial averages. The element width, directly related to the length of overland flow, was defined as twice the total length of all main drainage pipes and gutters serving the area. For runoff transport, the volume of pipes in the simplified system should be approximately equal to the volume of the real system.

The simulations made with the lumped SWMM closely approximated those made with the discretized model. No changes were made in the Storage/Treatment Block of the SWMM, since this block has low computer-time requirements. Simulation time steps were sometimes extended to 60 minutes with good results.

Generalized SWMM Runoff Quality Model

In an attempt to combine the best features of the SWMM and STORM quality subroutines, a new quality subroutine was developed.(42) Important features of this model are summarized below.

The model calculates runoff quality on the basis of catchment characteristics and runoff hydrographs which have to be supplied by the user. Runoff quality calculation may be based either on the entire runoff from the catchment or on the runoff from impervious areas only. A single catchment can feature up to five different land uses. The accumulation of pollutants on the catchment surface is accounted for by specifying loading rates for each land use and by specifying composition of "dust and dirt". Such information is provided by the user. Catchbasin contribution to the total pollutional load is considered in the model. Finally, the runoff quality is calculated using the SWMM algorithm. Up to ten constituents can be simulated, namely BOD, COD, Suspended Solids, Settleable Solids, Coliforms, N, PO_4, Cl, Pb, and Oil and Grease.

Pollutographs, mass curves and surface load statistics for each pollutant are produced by the model. Some verification of the model was attempted, but appears to be inconclusive.(42) The generalized quality model can be easily calibrated, which constitutes its main advantage. It may be used in conjunction with any method for the calculation of runoff quantity.

TABLE 4. DATA ANALYSIS MODEL (DAM) OUTPUT SAMPLE (After Ref. 42)

STORM EVENT SUMMARY FOR 1973,
SWMM — WEST-TORONTO STUDY AREA

(A storm has been defined as having a total rainfall greater than 0.03-in. (0.76-mm) and having less than 3 consecutive dry hours).

Storm Number 1

Started on the 4th month, 2nd day, 2nd hour
Antecedent dry days unknown
Ended on the 4th month, 3rd day, 10th hour
Total duration in hours = 33
Total rainfall in hundredths of inches = 29 (7.3-mm)
Maximum intensity in hundredths of inches per hour = 2 (0.5-mm/hr.)

Storm Number 2

Started on the 4th month, 4th day, 16th hour
Antecedent dry days = 1,208
Ended on the 4th month, 4th day, 24th hour
Total duration in hours = 9
Total rainfall in hundredths of inches = 14 (3.5-mm)
Maximum intensity in hundredths of inches per hour = 3 (0.8-mm/hr.)

Storm Number 3

Started on the 4th month, 27th day, 10th hour
Antecedent dry days = 22.375
Ended on the 4th month, 28th day, 4th hour
Total duration in hours = 19
Total rainfall in hundredths of inches = 48 (12-mm)
Maximum intensity in hundredths of inches per hour = 8 (2.0-mm/hr.)

Storm Number 4

Started on the 5th month, 1st day, 9th hour
Antecedent dry days = 3.167
Ended on the 5th month, 1st day, 13th hour
Total duration in hours = 5
Total rainfall in hundredths of inches = 16 (4.1-mm)
Maximum intensity in hundredths of inches per hour = 7 (1.8-mm/hr.)

Storm Number 5

Started on the 5th month, 2nd day, 21st hour
Antecedent dry days = 1.292
Ended on the 5th month, 2nd day, 21st hour
Total duration in hours = 1
Total rainfall in hundredths of inches = 6 (1.5-mm)
Maximum intensity in hundredths of inches per hour = 6 (1.5-mm/hr.)

Snowmelt Quantity and Quality

Snowmelt can be accompanied by intense rainstorms in the spring season or occasionally in late fall, thus contributing to large runoff. At the same time, the snowmelt water appears to be heavily polluted and this creates environmental concerns about the impact of snowmelt runoff on receiving waters. It was therefore decided to study the simulation of snowmelt quantity and quality.[42]

Following a literature survey, Anderson's snowmelt model[2] was selected to be built into the SWMM as a user option. This was one of the first attempts to simulate snowmelt in the urban environment and, mostly because of a lack of field data, numerous approximations had to be made.

The snowpack distribution and physical parameters were assumed to be known prior to the storm. The problem is then reduced to that of describing the physical changes in the snow cover during the snowmelt and/or rainfall periods and the resulting effects on the runoff. The model requires hourly air temperature and wind speed data as climatological input data. The basic calculation is made in hourly intervals. If required by the runoff calculation, the computed hourly volumes are linearly interpolated for other time intervals.

Since hardly any field data were available to formulate a conceptual model of the quality of snowmelt water, the same approach as in the SWMM quality model was used. Pollutant accumulation on and washoff from the catchment surface was considered. The list of SWMM water quality constituents was expanded for chlorides and lead. The input of chlorides onto the catchment surface was derived from typical application rates of de-icing salts.

Limited attempts have been made to verify the snowmelt quantity and quality model on the Brucewood catchment for three events.[28] Though the model results indicated trends similar to those observed, more extensive testing will be required to reach conclusive results.

Modification of the Storage Block

The costs of runoff control measures in the SWMM reflect U.S. economic conditions. It was necessary to substitute the Canadian costs into the model.[42] These costs had to be estimated only, because very few runoff control facilities have been built in Canada. As more experiences with building these facilities become available, these costs will be reviewed and updated.

Behaviour of a Storm Water Retention Pond

In this study,[12] carried out by the Department of Civil Engineering, University of Toronto, the regime of a storm water retention pond was simulated. The precipitation-runoff phenomena were simulated by the STORM, which produced simulated inflow into the siltation basin-reservoir system studied. A new subroutine, interfaced with STORM, was written to simulate the effects of such a system on water quality. The subroutine calculates the frequency of solids removal efficiency of the siltation basin, monthly frequency analysis of the water quality in the reservoir, inflow-outflow hydrographs, and pollutographs for six constituents (BOD, DO, N, PO_4, Suspended Solids, and Settleable Solids). The model has been applied to a storm water pond in Mississauga, Ontario, and verification of the model is planned using the same facility.

Testing of Urban Runoff Models and Comparative Model Studies

Testing and comparative model studies are of utmost importance to model users who are attempting to select a "right" model for their application. In testing studies, the ability of a model to reproduce various runoff events observed on test catchments is evaluated. From a scientific point of view, neglecting the uncertainties in the input/output data and the extent of calibration bias in such an approach is not fully satisfactory and may not fully indicate the biased or incomplete structure of the model. This simplified testing, however, yields a good indication of model performance and reliability, particularly if only well-verified precipitation-runoff data are used. It has been noted(36) that none of the existing test catchments in Canada allows a fully rigorous testing of urban runoff models.

Note also that in the above procedure the overall model performance is evaluated rather than the performance of individual model components, such as overland flow generation, routing, etc.

The following urban runoff models have been tested to various extents in several Canadian studies: Dorsch HVM, Queen's University QUURM, British RRL, STORM, SWMM, University of Cincinnati UCUR, and Water Resources Engineers version of SWMM (WRE-SWMM).

The first study(29) dealt with the HVM, QUURM, RRL, SWMM, and UCUR models. These models were applied on several test catchments and the simulated hydrographs were compared to the observed ones. The goodness of fit was evaluated in two ways. Firstly, the runoff volumes, peak flows and times to peak were considered. Secondly, the entire hydrographs were considered.

All the models performed fairly well. When comparing only the volumes, peaks and times to peak, there was no statistically significant difference in the performance of various models on most catchments. On average, about 70% of the simulated runoff volumes and peak flows, and 85% of the times to peak, were within ±20% of the observed values. It should be stressed that only runoff generation on small catchments (less than 37-hectares) and simple flow routing were tested. Special features of some of the above models, such as a dynamic-wave flow routing in the HVM model, were not fully utilized or tested.

From a user point of view, the SWMM of the U.S. EPA was rated best. It is by far the best documented non-proprietary model which is continuously updated and refined.

In a recent contract study(42) sponsored and directed by the Urban Drainage Subcommittee, the HVM, STORM, SWMM, and WRE-SWMM models were tested. Most attention was paid to the SWMM, on which a sensitivity analysis was carried out.

Sensitivity Analysis of the SWMM Runoff and Transport Blocks

An appreciation of the sensitivity of a runoff model to variation in the input data is important for the preparation of input data for a detailed simulation. The sensitivity analysis indicates what detail and accuracy of input parameters is required. For some parameters, rough estimates may be acceptable without decreasing appreciably the accuracy of simulations. In this study,(42) several additional parameters were considered in comparison to the SWMM sensitivity analysis that had been reported previously.(15)

Repeated simulations were made for a selected storm on a 4.5-hectare catchment. The parameters affecting the SWMM runoff quantity (Runoff Block) can be listed in order of decreasing importance as follows: imperviousness; catchment width; infiltration capacity; surface depression; gutter and catchment surface roughness; and ground slope.

In the Transport Block, the conduit length, number of conduits and conduit roughness were tested. The effect of the conduit length was rather minor for pipes shorter than 4000-feet (1220-m). For a 10,000-ft. (3,050-m) pipe, an attenuation of the order of 40% was obtained.

When a hydrograph was routed through a single element of a length L, a lesser attenuation was obtained than by routing the hydrograph through several pipes of a total cumulative length L.

Increasing roughness attenuated proportionately the peak flow.

In a similar manner, the sensitivity of the runoff quality subroutine was studied considering the following parameters: the washoff equation exponent b; options for the calculation of Suspended Solids (SS); number of dry days, street cleaning, catchbasin load; pipe slopes (Transport Block); and the specific gravity of solids (Transport Block).

The washoff exponent b affects directly the rate of the pollutant removal, particularly in the initial period of runoff. Neither of the two options for the calculation of SS proved to be applicable over a wide range of antecedent conditions. The number of dry days is a very important parameter because it affects nearly linearly the total runoff pollution load. The effect of street cleaning is very pronounced for high cleaning efficiencies. Catchbasin loads contribute very little to the total pollution load.

The slope of combined sewers and the specific gravity of solids affect significantly the sediment deposition-scouring process, and consequently the quality simulations.

<u>Testing of the HVM, SWMM, STORM, and WRE-SWMM Models</u>

Three Canadian test catchments were used in these tests,[42] namely Bannatyne, Brucewood, and Toronto-West. Only the SWMM was applied on all the three catchments. An acceptable agreement between the SWMM simulated and observed runoff quantity was found. For stormwater and combined sewage quality, the agreement between the SWMM simulations and observations was less satisfactory and it was evaluated as an order-of-magnitude agreement.

The STORM was applied on the Bannatyne and Toronto-West catchments. Runoff volumes and frequency of overflows (Toronto-West) were reproduced by STORM quite well.

The HVM and WRE-SWMM models were applied on the Bannatyne catchment for two events. In one of these, the sewer system was surcharged. Both models performed quite well under such conditions and produced more realistic hydrographs than the SWMM, which produced a truncated hydrograph.

<u>Other Studies</u>

The SWMM and RRL models were tested and compared on the Fairfield catchment.[51] The results obtained with both models appear to be, with the exception of the calibrated runoff volumes, worse than those obtained for other catchments. This may have been caused by uncertainties in the input data and the minor character of many test events used in this study.

The SWMM was also tested on the Malvern catchment.(35) The calibrated SWMM was used to reproduce 25 precipitation-runoff events. A very good fit between simulated and observed values was obtained: 90% of the SWMM-simulated runoff volumes, 80% of the simulated peak flows, and 100% of the simulated times to peak were within ±20% of the observed values.

The runoff quality simulations were less satisfactory with only an order-of-magnitude agreement between the simulated and observed values.

Results of testing the SWMM on 8 urban catchments were summarized in a recent paper.(36) The paper concluded that while the SWMM quantity simulations were fully satisfactory for free flow in sewers, the quality simulations were in general much less satisfactory, and additional testing and/or refinement of the quality subroutine is required.

Engineering Applications of Urban Runoff Models

Engineering applications of urban runoff models reported in the survey conducted for this report are briefly described below. Inevitably, the list of applications is incomplete. The purpose of this description is only to indicate the progress made in Canadian drainage design during the last three years and to demonstrate the potential of urban runoff models. The projects are listed alphabetically, according to their location.

Edmonton (Alberta)

The City of Edmonton has engaged James F. MacLaren Limited to carry out a master drainage study of a 4500-hectare area served by combined sewers. Two subareas are to be studied in detail. The WRE-SWMM will be applied.(55)

Halifax (Nova Scotia)

The City of Halifax engaged Canadian-British Consultants Limited, to study the feasibility of storm water retention in the Kearney Lake Road area.(5) The Illinois Urban Drainage Area Simulator (ILLUDAS) was used in this study.

Hamilton (Ontario)

The Hamilton-Wentworth Regional Government engaged Proctor & Redfern Limited to study combined sewer overflows and urban runoff on two study areas.(41) The STORM, SWMM, and WRE-SWMM were applied in this study.

Humber River Mouth Study (Toronto, Ontario)

The Metro Toronto Region Conservation Authority engaged James F. MacLaren Limited to study combined sewer overflows, their control, and their effects on the Humber River.(55) SWMM was applied in this study.

Merivale Industrial Park Study (Merivale, Ontario)

The Region of Ottawa-Carleton, the Central Mortgage and Housing Corporation and the Urban Drainage Subcommittee have engaged Gore & Storrie Limited to study the changes in runoff and its pollutional loads resulting from the development of a new industrial park and to investigate runoff control alternatives.(3) STORM and SWMM are being used in this study.

Midland (Ontario)

The Town of Midland engaged Canadian-British Consultants Limited to model urban runoff and its effects on an urban lake. The STORM is being applied in this study.

Mississauga (Ontario)

The City of Mississauga engaged James F. MacLaren Limited to analyze the existing storm sewer system in the Port Credit area and to develop relief sewer alternatives.[55] The WRE-SWMM was applied in this study.

Oil Terminals Study (London and Toronto, Ontario)

The Petroleum Association for Conservation of Canadian Environment engaged James F. MacLaren Limited to study pollutional loads in surface runoff from oil terminal sites.[55] The modeling work was done with the SWMM and was supported by some field measurements.

The Province of Ontario

The Urban Drainage Subcommittee engaged the American Public Works Association to evaluate the magnitude and significance of pollution loading from urban stormwater runoff in Ontario.[40] As a part of this study, runoff simulations on four urban areas were performed with the STORM to estimate pollution loadings and to evaluate various storage/treatment alternatives. Technologically efficient combinations of storage and treatment were identified and priced. The results were presented in a normalized form and can be used by engineers and planners to derive preliminary estimates of costs of runoff pollution control.

North Pickering (Ontario)

The Ministry of Housing engaged Shully Solomon & Associates Limited to carry out an environmental assessment of the impact of urbanization on several watersheds in the North Pickering area.[43] A Distributed Hydrologic Model developed by the consultant was used.

St. Catharines (Ontario)

The City of St. Catharines engaged Proctor & Redfern Limited to study wet-weather flows in two sanitary sewerage areas.[32] A proprietary model SWAN was used in this analysis.

Toronto (Ontario)

The City of Toronto was the first Canadian municipality using extensively urban runoff hydrograph models. The City has engaged Dorsch Consult Limited to carry out the design/analysis of a number of drainage districts.[25] The proprietary Dorsch HVM model has been used exclusively in these studies. The Dorsch HVM pressurized flow routing capability was the main reason for selecting this model.

Toronto Airport Study (Ontario)

A study of environmental problems at the Toronto International Airport was commissioned by the Department of Environment to James F. MacLaren Limited.[55] The study included some limited monitoring of runoff quantity and quality, and runoff modeling with the STORM and SWMM.

Vancouver (British Columbia)

The City of Vancouver and the Greater Vancouver Sewerage and Drainage District carried out a demonstration study with the Dorsch HVM model on a 333-hectare area. Later, the results obtained with the HVM on one of the sub-catchments (38-hectares, 78% impervious) were compared with those produced by the SWMM and ILLUDAS.[20]

Vaughan (Ontario)

The Town of Vaughan engaged James F. MacLaren Limited to develop a master drainage concept for a proposed residential development of 1820-hectares in the area of Thornhill-Vaughan.[55] The SWMM was applied in this study.

Winnipeg (Manitoba)

The City of Winnipeg engaged James F. MacLaren Limited to analyze the combined sewer system in three sewerage districts and to develop relief sewer alternatives.[30] The WRE-SWMM is being used.

The frequencies of use of various urban runoff models in the above reported engineering applications are shown in Figure 6.

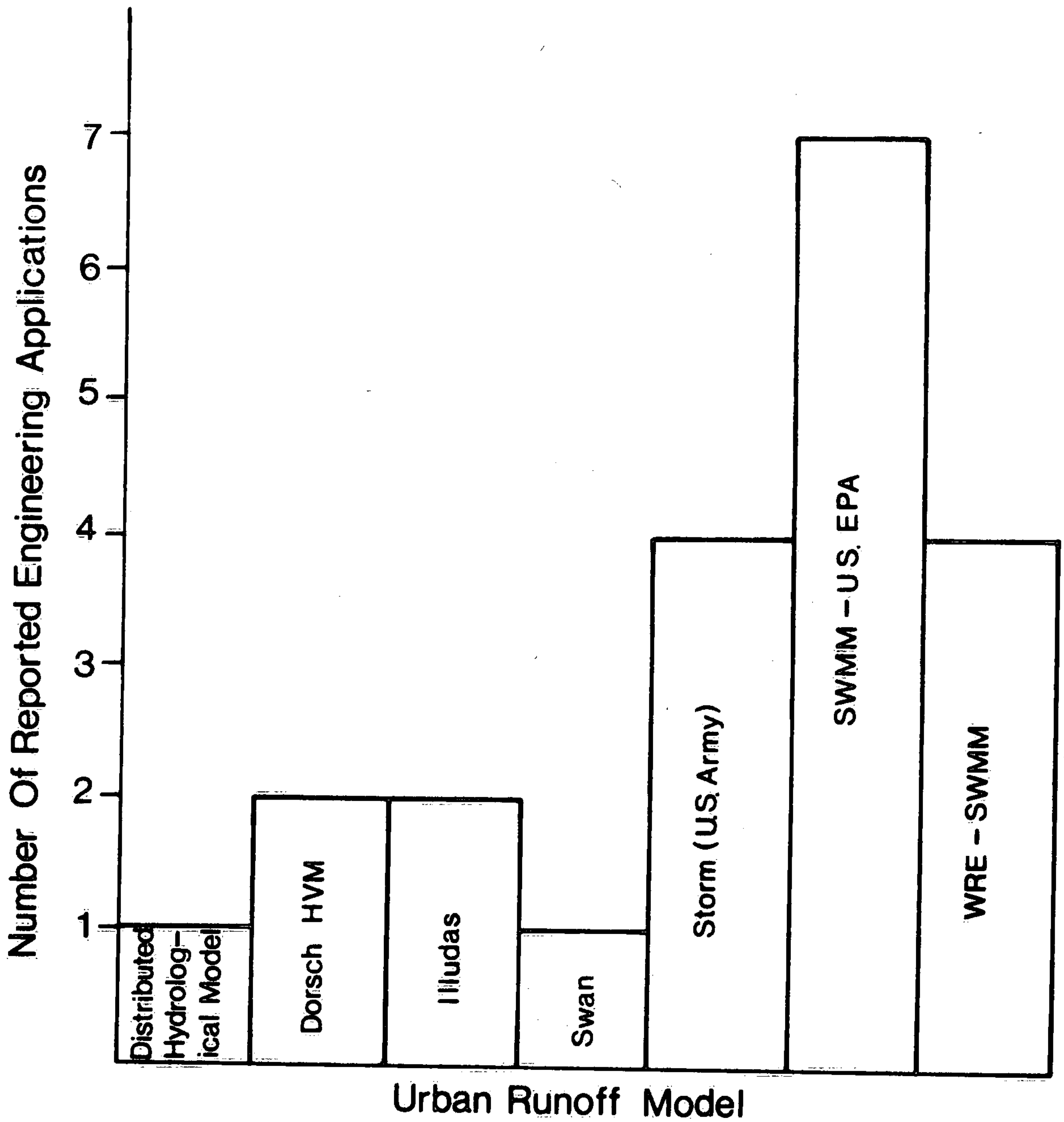


Figure 6. NUMBER OF REPORTED ENGINEERING APPLICATIONS OF VARIOUS URBAN RUNOFF MODELS

SECTION 4

SUMMARY AND CONCLUSIONS

The state of the art in urban hydrological modeling seems to surpass the available calibration/verification data base. The ultimate goal of the creation of a good urban water resources data base remains, therefore, worthwhile and necessary. A critical survey of the Canadian urban test catchments revealed that only five catchments have produced field data suitable, to various extents, for the development and verification of urban runoff quantity models. These five areas are Brucewood, Calvin Park, Fairfield, Idylwyld, and Malvern.

For runoff quality, only Brucewood, Malvern, and possibly Fairfield, have produced field data approaching the desired standard.

Five newly established catchments hold promise for production of good urban runoff quantity and quality data.

A variety of data acquisition systems are used in runoff studies. Precipitation is measured commonly by means of tipping-bucket raingauges. The number of gauges per catchment is rather limited, which may be caused by the lack of suitable gauge sites. Sewer flows are typically measured by weirs, less frequently by Venturi flumes. Water quality is monitored by collecting sequential grab samples and analyzing them for a number of constituents. The most frequently studied constituents are the biochemical oxygen demand (BOD), the chemical oxygen demand (COD), chlorides, lead, and various forms of nitrogen, phosphorus and solids. Among microbiological parameters, total coliform and fecal coliform densities are frequently studied.

Samples are typically collected by means of automatic samplers which remain the least reliable component of the data acquisition systems. The recording of all the information by a single recorder helps to maintain a good synchronization of records. Ideally, magnetic or punched tape recorders producing computer-compatible records are used.

Urban runoff data collected on the Canadian catchments have been used to characterize the quality and quantity of stormwater and of combined sewage overflows, to develop new urban runoff models, and to verify and modify some of the existing runoff models.

Most of the data collection projects do not include measurements other than for the drainage outfall. The impact of urban effluents on receiving waters is rarely studied in the field. Some studies of this nature, however, were started recently.

The lack of urban runoff data seems to impair progress in the development, testing, verification and calibration of runoff models. Tendencies to substitute noncalibrated model results for actual field data, without any verification attempts, are showing up in engineering studies. Such a trend is undesirable and detrimental.

Several aspects of urban hydrological modeling are being developed in Canada. Most of the interest is centered around the modeling of urban runoff, its conveyance and control by storage and treatment, and the impact of runoff on receiving waters. Both storm water and combined sewage are considered in this context.

Though some new urban runoff models have been developed in Canada, the major efforts seem to be directed towards the testing and modification of existing runoff models. Two U.S. models, the STORM and SWMM, have received particularly wide attention, and the latter model was modified, to some extent, to reflect Canadian conditions. It is fully recognized, however, that there is a need for an entire hierarchy of urban runoff models. Various applications require different models having certain features and belonging to various levels in the model hierarchy.

Although most engineering drainage design is still based on old, approximate methods, the urban runoff models have emerged in Canadian drainage practice as an important alternative during the last three years. The number of engineering applications based on urban runoff models is increasing and this trend is well documented by the examples cited in this report. The models not only contributed to a more rational design but, in many instances, led to significant savings in drainage costs.

SECTION 5

REFERENCES

1. Adams, B. J., and Panagiotakopoulos, D., "Network Approach to Optimal Wastewater Treatment System Design," Publication 75-13, Department of Civil Engineering, University of Toronto, Toronto, Ontario, 34 pp., December, 1975.

2. Anderson, E. A., "National Weather Service River Forecast System — Snow Accumulation and Ablation Model," National Oceanic and Atmospheric Administration, NOAA Technical Memorandum NWS HYDRO-17, Silver Springs, Maryland, 217 pp., November, 1973.

3. Anderson, J. C. (Gore & Storrie Limited, 135 York Street, Ottawa, Ontario), Personal Communication, 1976.

4. Armstrong, K. E. (Alberta Environment, 10040 - 104 Street, Edmonton, Alberta), Personal Communication, 1976.

5. Benneworth, N. (Canadian-British Consultants Limited, P.O. Box 1269N, Halifax, Nova Scotia), Personal Communication, 1976.

6. Brandstetter, A., "Evaluation of (25) Mathematical Models for the Simulation of Time - Varying Runoff and Water Quality in Storm and Combined Sewerage Systems," presented at the EPA Conference on Environmental Modeling and Simulation, Cincinnati, Ohio, April 20-22, 1976 (in press).

7. Bras, R. L., and Perkins, F. E., "Effects of Urbanization on Catchment Response," Journal of the Hydraulics Division, ASCE Proc., Vol. 101, No. HY3, pp. 451-466, March, 1975.

8. Couillard, D., Dartois, J., Demard, H., Mascolo, D., and Potvin, L., "Réseaux de collecte des eaux usées. Tome 3: Caractéristiques des bassins Les Saules, Sainte Foy et Saint-Pascal," Research on Wastewater Collection. Vol. 3: Characteristics of Les Saules, Sainte Foy and Saint Pascal Basins (in French). INRS - Eau Scientific Report No. 61, Quebec, Quebec, 145 pp., December, 1975.

9. M. M. Dillon Limited, "Storm Water Management Model Verification Study," Report to the Urban Drainage Subcommittee, Toronto, Ontario, 50 pp., March, 1976.

10. Droste, R. L., and Hartt, J. P., "Quality and Variation of Pollutant Loads in Urban Stormwater Runoff," Canadian Journal of Civil Engineering, Vol. 2, No. 4, pp. 418-429, 1975.

11. Ehler, P. A. (Town of Midland, Midland, Ontario), Personal Communication, 1976.

12. Ganczarczyk, J., "Behaviour of a Stormwater Retention Pond (A Tentative Title)," Report to the Urban Drainage Subcommittee, Department of Civil Engineering, University of Toronto, Toronto, Ontario, 1976.

13. Gibbons, M. (Stanley Associates Engineering Limited, 11748 Kingsway Avenue, Edmonton, Alberta), Personal Communication, 1976.

14. Gore & Storrie Limited, "EPA Storm Water Management Model Verification on Hamilton Study Area," An Interim Report to Urban Drainage Subcommittee, Toronto, Ontario, 46 pp., March, 1975.

15. Graham, P. H., Costello, L. S., and Mallon, H. J., "Estimation of Imperviousness and Specific Curb Length for Forecasting Stormwater Quality and Quantity," Journal Water Pollution Control Federation, Vol. 46, No. 4, pp. 717-725, April, 1974.

16. Hartt, J. P., "A Study of Pollution Loadings from Urban Runoff," Proceedings of the Canadian Symposium on Water Pollution Research, Vol. 8, pp. 16-25, University of Waterloo, February, 1973.

17. Heeps, D. P., and Mein, R. G., "An Independent Evaluation of Three Urban Stormwater Models," Report No. 4/1973, Civil Engineering Research Reports, Monash University, Victoria, Australia, 92 pp., 1973.

18. Henry, J. G., and Ahern, P. A., "The Effect of Storage on Storm and Combined Sewers," Report to the Urban Drainage Subcommittee, Department of Civil Engineering, University of Toronto, Toronto, Ontario, 86 pp., October, 1974.

19. Hesterman, L. C., "Urban Drainage Basin Study, Idylwyld Drive Freeway Underpass," Report E 74-9, Saskatchewan Research Council, Saskatoon, Saskatchewan, 45 pp., July, 1974.

20. Hodgson, J., "A Comparison of Three Runoff Simulation Models," Greater Vancouver Sewerage and Drainage District, Vancouver, B.C., 25 pp., February, 1975.

21. Howard, C. D. D., "Theory of Overflows from Storage, Treatment Plant Systems," Report to the Urban Drainage Subcommittee, Unies Limited, Winnipeg, Manitoba, 25 pp., 1974.

22. Jolly, J. P., "Kanata Hydrologic Research Basin," Progress Report, Department of Civil Engineering, University of Ottawa, Ottawa, Ontario, 38 pp., August, 1973.

23. Killoran, L. B., DeBellefeuille, M., and Tennant, A. D., "Surveillance of Storm Drainage and Effluent Discharge from Federal Properties to the Rideau River, National Capital Area," Report EPS-5-OR-75-1, Environmental Protection Service, Ottawa, Ontario, 62 pp., June, 1975.

24. Kirkpatrick, G. A., "A Review of Flow Measuring Devices," pp. 191-198, Urban Runoff, Quantity and Quality, ASCE, New York, N.Y., 1975.

25. Kitchen, C. S. (City of Toronto, Department of Public Works, Toronto, Ontario), Personal Communication, 1976.

26. Linsley, R. K., "A Manual on Collection of Hydrologic Data for Urban Drainage Design," Hydrocomp Incorporated, Palo Alto, California, 1973.

27. Luckman, B. H., and MacRae, C. (University of Western Ontario, Department of Geography, London, Ontario), Personal Communication, 1976.

28. James F. MacLaren Limited, "Brucewood Monitoring Programme, Vols. I-III," Draft reports submitted to Hydraulics Research Division, Canada Centre for Inland Waters, Burlington, Ontario, 1976.

29. James F. MacLaren Limited, "Review of Canadian Design Practice and Comparison of Urban Runoff Models," Research Report No. 26, Canada-Ontario Agreement Research Program, 212 pp., October, 1975.

30. James F. MacLaren Limited, "Drainage Criteria Manual for The City of Winnipeg," (Draft) Report to the City of Winnipeg, November, 1974.

31. McPherson, M. B., "Urban Mathematical Modeling and Catchment Research in the USA," ASCE Urban Water Resources Research Program Technical Memorandum No. IHP-1, ASCE, New York, N.Y., 49 pp., November, 1975.

32. Mar, H. (City of St. Catharines, City Hall, St. Catharines, Ontario), Personal Communication, 1976.

33. Marsalek, J., "Aldershot Test Catchment," Unpublished Report, Hydraulics Research Division, Canada Centre for Inland Waters, Burlington, Ontario, 22 pp., 1976.

34. Marsalek, J., "Instrumentation for Field Studies of Urban Runoff," Research Report No. 42, Hydraulics Research Division, Canada Centre for Inland Waters, Burlington, Ontario, 82 pp., 1976.

35. Marsalek, J., "Malvern Urban Test Catchment — Progress Report No. 1," Hydraulics Research Division, Canada Centre for Inland Waters, Burlington, Ontario, 54 pp., June, 1976.

36. Marsalek, J., "Testing of the Storm Water Management Model of U.S. EPA," presented at the EPA Conference on Environmental Modeling and Simulation, Cincinnati, Ohio, April 20-22, 1976 (in press).

37. Marsalek, J., Dick, T. M., Wisner, P. E., and Clarke, W. G., "Comparative Evaluation of Three Urban Runoff Models," Water Resources Bulletin, Vol. 11, No. 2, pp. 306-328, April, 1975.

38. Mechler, W. A. (Greater Vancouver Sewerage and Drainage District, 2294 West 10th Avenue, Vancouver, B.C.), Personal Communication, 1976.

39. Mills, W. G., "Water Quality of Urban Stormwater Runoff," M.Eng. Thesis (draft), University of Toronto, Toronto, Ontario, January, 1976.

40. Novak, Z. (Ministry of the Environment, 135 St. Clair Avenue West, Toronto, Ontario), Personal Communication, 1976.

41. Perks, A. R. (Proctor & Redfern Limited, 75 Eglinton East, Toronto, Ontario), Personal Communication, 1976.

42. Proctor & Redfern Limited, and James F. MacLaren Limited, "Storm Water Management Model Study," A draft report submitted to Urban Drainage Subcommittee, Toronto, Ontario, January, 1976.

43. Solomon, S. I., "A Hydrologic Model for Environmental Assessment of the Rouge, Little Rouge, Petticoat and Duffins Watersheds," Report to Ministry of Housing, Shully I. Solomon Limited, Toronto, Ontario, 1975.

44. Solomon, S. I. (Shully I. Solomon Limited, 50 Prince Arthur, Toronto, Ontario), Personal Communication, 1976.

45. Tonelli, F. A. (Ministry of the Environment, Resources Road and 401, Rexdale, Ontario), Personal Communication, 1976.

46. Trider, G. L. (Environmental Protection Service, Halifax, Nova Scotia), Personal Communication, 1976.

47. Waller, D. H., "Factors That Influence Variations in the Composition of Urban Surface Runoff," Proceedings of the 7th Canadian Symposium on Water Pollution Research, pp. 84-95, Hamilton, Ontario, 1972.

48. Waller, D. H. (Department of Civil Engineering, Nova Scotia Technical College, Halifax, Nova Scotia), Personal Communication, 1976.

49. Waller, D. H., "Pollution Attributable to Surface Runoff and Overflows from Combined Sewerage Systems," Final Report to Central Mortgage and Housing Corporation, Ottawa, Ontario, 168 pp., April, 1971.

50. Waller, D. H., and Coulter, W. A., "Winter Runoff from an Urban Catchment," Report to Urban Drainage Subcommittee, Toronto, Ontario, 1974.

51. Waller, D. H., Coulter, W. A., Carson, W. M., and Bishop, D. G., "A Comparative Evaluation of Two Urban Runoff Models," Report to Urban Drainage Subcommittee, Toronto, Ontario, 40 pp., April, 1974.

52. Warnock, R. G., "A Study of Pollutional Loadings from Urban Storm Runoff," Proceedings of the Sixth Canadian Symposium on Water Pollution Research, Toronto, Ontario, 1971.

53. Watt, W. E., "QUURM — Queen's University Urban Runoff Model," Preprints of the Second Canadian Hydrotechnical Conference, May 14-16, 1976, Burlington, Ontario, 1975.

54. Watt, W. E., and Kidd, C. H. R., "QUURM — A Realistic Urban Runoff Model," Journal of Hydrology, Vol. 27, pp. 225-235, 1975.

55. Wisner, P. E. (James F. MacLaren Limited, 435 McNicoll, Willowdale, Ontario), Personal Communication.

56. Wisner, P. E., Jalal, K. F., Roake, A. F., and Torrens, L., "Application of STORM and SWMM for Assessment of Urban Development Alternatives in Canada," presented at the EPA Conference on Environmental Modeling and Simulation, Cincinnati, Ohio, April 20-22, 1976 (in press).

57. Wisner, P. E., Marsalek, J., Perks, A. R., and Belore, H. S., "Interfacing Urban Runoff Models," A paper presented at the ASCE Specialty Conference on Environmental Engineering Research, Development and Design, July 20-23, 1975, Gainesville, Florida, 1975.

58. Zukovs, G., "An Investigation of a Sewer Flowmeter Suitable for Open Channel and Pressure Flow Measurement," B.A. Sc. Thesis, Department of Chemical Engineering and Applied Chemistry, University of Toronto, Toronto, Ontario, 1976.

APPENDIX I

SELECTED CANADIAN URBAN TEST CATCHMENTS

AND SUMMARY OF

URBAN RUNOFF FIELD STUDIES OF LIMITED SCOPE

1. Bannatyne Catchment (Winnipeg, Manitoba)

In the overall assessment, the Bannatyne data are not considered suitable for urban hydrological research, with the precipitation data being a major weakness. However, the data were found suitable for a demonstration of an urban runoff model.[42]

The Bannatyne catchment[42] was monitored by City of Winnipeg personnel during the summers of 1969, 1970 and 1971. The project objective was to characterize the quantity and quality of wet-weather flows in a combined sewer. The catchment is a well-defined drainage district of 220-hectares and is served by combined sewers. Residential, commercial and industrial land uses are represented in the catchment. The total catchment imperviousness is 36%.

Originally, several recording raingauges were located within the catchment, but records from these gauges were lost. Precipitation data are available for three gauges located 3 to 6 kilometres from the catchment. Runoff flows were measured by means of a rectangular weir and continuous stage recording. Up to 12 sequential grab samples were manually collected at 10-minute intervals during periods of high flows. For long duration storms, the data do not span the entire runoff event. The samples were analyzed for two parameters.

Some of the collected data have been used in a recent study[42] to demonstrate the application of the Storm Water Management Model (SWMM) developed for the U.S. Environmental Protection Agency (EPA). In total, 24 data sets for 1971 were examined for this purpose. A reasonable agreement between the three raingauges was found only for six storms of low to medium intensity (8 to 20-mm/hr). For these events, weighted-average hyetographs were derived and used for the demonstration of the SWMM. In this demonstration, the observed runoff quantities were simulated with fair agreement, and for the quality aspects the simulations reproduced the observations within an order of magnitude. The quality data cover only some of the periods of runoff. High pollutant concentrations were observed, which may be attributed to the sediment deposition and scouring in low-gradiant sewer pipes.

2. Barrington Catchment (East York, Ontario)

In an overall evaluation, the Barrington data represents a good source of storm water quality data for very minor events. Any modeling efforts would have to be limited to these conditions.

The Barrington catchment[39] was established and monitored by the Borough of East York, with some assistance from the Urban Drainage Subcommittee. The project objective was to characterize the quantity and quality of storm water and, in a later stage, to study the efficiency of various alternatives for runoff quality control. The project has been active for two years (1974, 1975) and a further continuation is under consideration.

The Barrington catchment is an older (50 years) residential area, in which the sewers were separated in the 1960's. The roof drains are connected to the former combined sewers. Only 17.4-hectares out of the total area of 22.7-hectares contribute runoff to the modified storm sewer system.

Precipitation was measured by a single tipping-bucket raingauge located within the catchment. Runoff flows were measured by means of a calibrated vertical slot weir and continuous stage recording was accomplished by means of a Wesmar ultrasonic sensor. Stormwater samples were collected at 5 to 15 minute intervals and analyzed for up to 20 parameters. Some grab samples were collected manually and others were collected by means of a Sigmamotor automatic sampler. Separate recorders were used for precipitation, runoff flow and quality data.

A large number of events have been partially monitored. The number of fully monitored events, for which complete precipitation, runoff flow and quality data are available, is rather limited (about 10). Nearly all these events are rather minor, with peak flows of about 0.056-m^3/s (2-cfs). No checking of the data has been reported.[39] The synchronization of various records may be adversely affected by the use of separate recorders.

The quality data indicate fairly high concentrations of pollutants in storm water. This could possibly be attributed to the minor character of events observed and to the absence of roof runoff. During minor events, only small runoff volumes are available to wash off surface contaminants and to dilute the contents of catchbasins. That is, the Barrington storm sewers carry mostly the highly polluted runoff from the streets without any dilution by the less polluted runoff from roofs.

3. Brucewood Catchment (North York, Ontario)

The Brucewood data appear to be suitable for detailed hydrological modeling. The scope of the data, however, is somewhat limited.

The Brucewood study[28] was sponsored by the Urban Drainage Subcommittee and carried out by J. F. MacLaren Limited. The study had several objectives: firstly, to collect urban runoff data (1974-75); secondly, to monitor snowmelt on the catchment (1975); and thirdly, to simulate the observed events with a modified SWMM. The project has been completed.

The Brucewood catchment is a 19.44-hectare modern residential development served by separate storm sewers. The catchment total imperviousness is 48%. Land use is characterized by single-family detached and semi-detached residences built in the late 1960's. The catchment is well defined and documented.

Precipitation was measured by a single raingauge (a tipping bucket) located just outside of the catchment. Runoff flows were measured by means of a rectangular weir located at the drainage outfall. The weir head was measured with a Manning Dipper-Transmitter. Both precipitation and weir head data were transmitted over leased telephone lines and remotely recorded. Runoff quality samples were collected manually as well as automatically (by a Sirco sampler). The sampling interval varied from 5 to 15 minutes. The samples were analyzed for about 15 parameters. Some additional quality data were obtained, namely samples of catchbasin contents, street dust and dirt, and sewer base-flow.

During the snowmelt period, the above instrumentation system was only slightly modified. Temperature and wind data were obtained from a nearby meteorological station. The snow-covered area was determined from airphotos. Samples of snowmelt water and snow-slush were collected and analyzed.

The Brucewood instrumentation system was fairly good, but plagued by frequent malfunctions and breakdowns. About twenty well-documented storm events have been monitored. For half of these, precipitation (>5-mm) and runoff hydrographs are available. For the other half, runoff pollutographs are also available. Typically, these latter events are of a minor character.

Three snowmelt events have been recorded on the catchment and have been well documented. These data have been used for the verification of a snowmelt model.[42]

The Brucewood data were used for the verification of the SWMM.[28,42] For runoff quantities, fair agreement between the observations and simulations was obtained. The observed pollutographs were reproduced by the SWMM only with "an order of magnitude" agreement.

4. Calvin Park Catchment (Kingston, Ontario)

The Calvin Park Data are well suited for detailed runoff modeling. The Calvin Park catchment[53] has been monitored by the Department of Civil Engineering of Queen's University. The project has been partially sponsored by the National Research Council. The project objective is to collect urban precipitation-runoff data and to develop a computer model to simulate these phenomena. Runoff quality has not been studied. Data collection started in 1973 and the project is still active.

The Calvin Park catchment is a 36.45-hectare modern suburban development characterized by a low total imperviousness of 27%. The land use can be classified as follows: low density residential, 70%; medium-to-high density residential, 15%; and institutional, 15%. The catchment is well defined and documented. Roof leaders are not connected to the storm sewers serving the area.

Precipitation is monitored by two raingauges located within the catchment boundaries. The output of one of these gauges (a tipping bucket) is recorded by a Stevens Type A Water Level Recorder, which also serves to record the stage upstream of a calibrated vertical-slot weir. This results in a good synchronization of the precipitation and runoff data.

Ten runoff events were monitored on the catchment during the period from 1973 to 1974. All these events are well documented and verified.[29,53] The results of more recent measurements have not been yet reported. The Calvin Park data have been used for the development of the Queen's University Urban Runoff Model[53] and for a comparative study of several urban runoff models.[29]

5. Carling Street Catchment (London, Ontario)

This is a new project[27] jointly sponsored by the University of Western Ontario and the (Ontario) Ministry of the Environment. The data will be collected by the Department of Geography, University of Western Ontario. The main project objective is to characterize precipitation, runoff flows and their quality on a highly impervious urban catchment.

The catchment area is 32.40-hectares and the total imperviousness is 75%. The catchment is served by separate storm sewers. A variety of land uses are represented in the catchment: residential, commercial, industrial and institutional.

One tipping-bucket and six standard raingauges were installed within the catchment area. Runoff flows are monitored by means of a weir and recorded by a Stevens (Type F) Water Level Recorder. Manual as well as automatic sequential grab sampling is used. In the latter case, a North Hants sampler is used to collect samples at 15-minute intervals. The samples are analyzed for 15 parameters.

No data are available as yet. The project holds promise to yield good quality data on urban runoff.

6. East York Catchment (East York, Ontario)

The Urban Drainage Subcommittee retained M. M. Dillon Limited to establish, instrument and monitor an urban test catchment in East York. The objectives of this project[9] are to collect urban runoff quantity and quality data on a catchment served by combined sewers, and to use this data for the verification of the SWMM. The project started in 1974 and is expected to continue until 1977.

The East York catchment is an older area of 155-hectares served by combined sewers. The land use distribution is as follows: low density residential, 88%; high density residential, 1%; institutional, 6%; commercial, 1%; and parks and open space, 4%. The catchment total imperviousness is 49%.

Precipitation, dry and wet weather flows in a combined sewer, composition of combined sewage and air temperature are monitored. A single tipping-bucket raingauge is used with a recorder printing the data and time, to the nearest minute, for every 0.01-inch (0.25-mm) of precipitation. A calibrated vertical slot weir is used to measure the flows. The weir head is measured by an air bubbler and recorded, together with the air temperature, by a Bristol Dynamaster strip-chart recorder. The sampler activation is also recorded on the same chart.

A Sirco automatic sampler (1000-ml) is used to collect sequential grab samples of combined sewage at regular time-intervals of 7-minutes. The samples will be analyzed for about 10 parameters. Because the project started only recently, no data are available as yet. It is expected that the project will produce good quality data suitable for hydrological modeling.

7. Fairfield Catchment (Halifax, Nova Scotia)

The Fairfield catchment was one of the first urban test catchments established in Canada. The Fairfield data have been found suitable for urban runoff modeling.[51]

The Department of Civil Engineering, Nova Scotia Technical College, carried out a number of research projects related to the Fairfield catchment. The objectives of these projects can be summarized as follows: characterization of quality of surface runoff and combined sewage (1969-1970);[49] characterization of winter runoff (quantity and quality);[50] testing of urban runoff models;[51] deposition and scour of solids in sewer pipes (a new project starting in 1976);[48] and collection of precipitation-runoff data. Some of these studies have been co-sponsored by the Central Mortgage and Housing Corporation and by the Urban Drainage Subcommittee.

The Fairfield catchment is an older area of 67.7-hectares served by combined sewers. The land use is residential (92%) and commercial (8%). The imperviousness of the catchment was difficult to determine, since some roof leaders are connected to the combined sewer whereas others are not. A linear regression of the observed rainfall and runoff volumes indicated an imperviousness of 34%.

As many as three tipping-bucket raingauges were used in various projects to monitor precipitation on the catchment. A critical depth meter was used to measure combined sewage flows and the surface runoff was measured by weirs located at the street inlets. Separate recorders were used for precipitation and flow measurement. A large variety of water quality data have been collected, including information on the quality of urban surface runoff, combined sewage, roof runoff and the contents of catchbasins. Additional observations of dustfall, dirt accumulation, and sediment accumulation in sewers were also made. Water samples were collected automatically as well as manually. In the former case, a custom-built sampler was used.(49) Most of the samples were analyzed for three parameters. Bacteriological counts were also performed.

A large volume of data characterizing the quality of surface runoff and combined sewage was collected and well documented.(49) However, complete records of precipitation, flow quantity, and flow quality are available only for a limited number of events. These data were published mostly as graphs, which makes it tedious to use them for modeling. Additional urban runoff data may become available through the current data collection program. Winter runoff data (snowmelt) were collected successfully for only two events.(50)

The data collected in 1969-1970 were used to characterize the composition of combined sewage, surface runoff and effluent from a retention tank. Effects of dry period length, season, land use, sediment deposition, dustfall, and city works practice, were investigated.(49)

Fifteen of the observed precipitation-runoff events were used in comparative studies involving two urban runoff quantity models.(51) It appears that some of the quality data could be also used for modeling of urban runoff quality. Other studies are presently underway.(48)

8. Hamilton Catchment (Hamilton, Ontario)

The Hamilton test catchment was established and instrumented by Gore & Storrie Limited in late 1975. This study(14) is sponsored by the Urban Drainage Subcommittee. The study objectives are to collect urban precipitation-runoff data and to verify the SWMM. It is expected that the study will continue in 1976 and possibly in 1977.

The Hamilton catchment is a 71.3-hectare development served by combined sewers. The land uses represented on the catchment are single family residential (75%), commercial and institutional (5%), and open space (20%). There are 3,050 persons living within the catchment boundaries.

Two tipping bucket raingauges are located within the catchment area. Flow rates are measured by means of a calibrated, modified V-notch weir and a Bristol air-bubbler. The measured weir heads are converted into flow rates. Combined sewage samples are collected automatically by a Sirco automatic sampler. The samples are collected sequentially at 5 to 10-minute intervals. Precipitation, precipitation intensity, flow rate, sampler operation and temperature are recorded by a Bristol multichannel recorder. No significant data are available as yet.

9. Idylwyld Catchment (Saskatoon, Saskatchewan)

The Idylwyld data represent a good source of data for detailed runoff modeling.(19) The catchment has been established, instrumented and monitored by the Engineering Division of the Saskatchewan Research Council (Saskatoon). In the early stages of the project, some financial support was received from the Saskatchewan Department of Highways. The project objectives(19) are to collect short interval rainfall data, including their variance over a small watershed, and the resulting runoff. Such information will be used to evaluate the present drainage design method.

The Idylwyld test catchment is a unique, well defined catchment representing a section of a vehicular freeway and the adjacent land. The catchment area is 6.9-hectares having a total imperviousness of 55%. A unique feature of the catchment is that 77% of the pervious area has a slope steeper than 0.10.

Surface runoff is conveyed by storm sewers to a stormwater lift station which also receives some groundwater flow.

The collection of precipitation-runoff data is fully automated and controlled by a PDP-8L minicomputer. The minicomputer is interfaced with eight tipping-bucket raingauges located on the catchment, three 18-inch diameter turbine flowmeters, one 4-inch diameter turbine flowmeter and one digital shaft encoder for water level measurements. The flowmeters are used to measure the outflow from the lift station and the water level data obtained for the sump are used to determine the storage volume. Inflow is determined from the station outflow and storage data. Processing of data is fully computerized. Data stored by the minicomputer is transmitted over telephone lines to an IBM 370 computer and processed. The quality of storm water is not studied.

Several years of high quality precipitation-runoff data have been produced so far and are available from the Engineering Division (Saskatoon). These data consist of maximum rainfall intensities, the total inflow onto the catchment, the total outflow, an average time of concentration and the runoff coefficient.

10. Les Saules Catchment (Quebec City, Quebec)

The catchment has been established and monitored by Institut National de la Recherche Scientifique (INRS-Eau) of Université du Québec, Québec. The project is co-sponsored by Services de Protection de l'Environnement, Québec, and Office de Développement de l'Est du Québec. The objectives of this project are to monitor time-varying sanitary flows, infiltration into sanitary sewers, and composition of wet and dry weather sanitary flows.

The catchment represents a modern single family residential development of 10.2-hectares served by separate sewers. The area was developed during the period from 1955 to 1968. There are 476 people living within the catchment boundary.

The following phenomena are measured: precipitation, sanitary flow rates, quality of sanitary flows, sewage temperature, and water table levels. Precipitation is measured by a single tipping-bucket raingauge. A vertical slot weir is used as a primary flow measuring device. Weir head is measured by a Manning Dipper and converted into flow rate by a Manning Flow Computer. For collecting sewage samples, a Manning or SEIN sampler can be used. Water table levels are measured in up to five boreholes. Collected sewage samples are analyzed for a number of parameters, such as BOD, Kjeldahl nitrogen, ammonia, suspended solids and volatile suspended solids.

Three types of recorders are used: in-situ analog recorders for visual control; a central magnetic tape recorder; and some information is transmitted over leased telephone lines to the INRS-Eau offices where it is recorded.

So far, only some preliminary observations have been published. The project holds great promise to provide good data on the variation of sanitary flows and their quality, and the effects of precipitation and high groundwater levels on sanitary flows.

11. Malvern Catchment (Burlington, Ontario)

The Malvern data represent a good source of data for detailed modeling of runoff.

The Malvern catchment has been established, instrumented and monitored by the Hydraulics Research Division of the Canada Centre for Inland Waters.[35] The project has been co-sponsored by the Urban Drainage Subcommittee. The catchment was established in 1973. Hydrological studies pertinent to the catchment are expected to continue until 1978. Main objectives of these studies are to collect urban precipitation-runoff data, to verify the SWMM on the catchment, to test various urban runoff models, and eventually to develop a simplified urban runoff model.

The Malvern catchment represents a modern residential development of 23.1-hectares with a total imperviousness of 34%. The roof drains are connected to the separate storm sewers. The catchment is well defined and documented.[35]

The catchment instrumentation has been continuously refined and the description below refers to the latest version. Precipitation is measured by two tipping-bucket raingauges. Runoff flows are measured by means of a rectangular weir which was calibrated on a scale model (for high flows) as well as in the prototype. The weir is located at the drainage outfall. Weir head is measured by a float placed in a stilling well. Stormwater quality is monitored by collecting and analyzing stormwater samples. The samples are collected by two automatic samplers which are activated by the water level rise inside the weir box. The samples are collected sequentially at 5 to 10 minute intervals. A modified Stevens water level recorder, Type A, is used as a central, in-situ recorder. The output of one precipitation gauge, weir head and operation of both samplers are recorded on the same chart.

So far, only the 1973 data have been fully analyzed and published.[35] These are precipitation and runoff quantity data for eight medium-intensity storms. The data collected in 1974 and 1975 are presently being analyzed and their publication is scheduled for late 1976. A preliminary analysis indicates that about thirty quantity-only events and twenty quantity and quality events will be suitable for publication. The Malvern data appear to be of a good quality. All the published data have been checked and verified.

The 1973 and 1974 Malvern data were used for the testing of the SWMM. A close agreement between the runoff quantity simulations and observations was reported.[35,36] Such agreement was not found for the runoff quality.

Other studies are in progress, involving simulation of runoff quality and development of new runoff models.

12. Rigaud Catchment (St. Foy, Quebec)

The catchment has been established and monitored by Institut National de la Recherche Scientifique (INRS-Eau) of Université du Québec, Québec.[8] The project is co-sponsored by Services de Protection de l'Environnement, Quebec, and Office de Developpement de l'Est du Québec. The objectives of this project are to identify and characterize various inputs to sewer systems, such as stormwater, sanitary sewage, and groundwater, and the total pollutional loadings carried by sewer flows.

The Rigaud catchment is a 20-year old residential development served by combined sewers. The catchment area is 15.7-hectares with a total imperviousness of 44%. The total population of the area is about 800 persons.

The data acquisition system is fully integrated and consists of a tipping-bucket raingauge, a 24-inch Palmer-Bowlus flume, air bubbler, thermometer and automatic sampler. Dry weather flows are monitored by means of a 3-inch

Parshall flume. Combined sewage samples are collected by an automatic sampler activated by the raingauge. Three types of automatic samplers have been acquired and can be used alternately: a French sequential APAE 241F sampler (collects up to 24, 2000-ml samples); an ISCO sampler (model 1392); and a Manning sampler (S 4000). The samples are analyzed for five parameters.

Three types of recorders are used: analog in-situ recorders for visual control; an in-situ magnetic recorder (made by SEIN, Alfortville, France); and a remote recorder at the INRS-Eau offices. The data are transmitted over leased telephone lines. The following information is recorded: precipitation, sewage flows, sewage temperature, and sampler operation.

So far, only some preliminary data have been published. The project holds great promise to provide high quality data for modeling of combined sewer flows.

13. Saint Pascal Catchment (Saint-Pascal de Kamuraska, Quebec)

The catchment has been established and monitored by Institut National de la Recherche Scientifique (INRS-Eau) of Université du Québec, Québec.(8) The project is co-sponsored by Services de Protection de l'Environnement, Québec, and Office de Développement de l'Est du Québec. The project objectives are to characterize dry and wet weather flows in sanitary sewers and to characterize quantity and quality of surface runoff in a semi-urban community of Saint-Pascal de Kamuraska (2,500 inhabitants). The catchment serves for two types of investigation: surface runoff is studied for the entire storm drainage area of 81-hectares; and a subarea of 39.3-hectares served by sanitary sewers is used for the study of sanitary flows.

The 39.3-hectare subarea is a predominantly residential area (71% residential lots, 14.5% streets), with some commercial establishments (7.3%) and open space (7.2%). There are 1,100 persons living in the subarea. The data acquisition system for the subarea is similar to that installed on the Les Saules catchment noted earlier. Precipitation, sanitary flow rate, sanitary flow composition and temperature, and ground water level are monitored. Sanitary flow rates are measured by a Palmer-Bowlus flume with a built-in capacitance water level sensor (manufactured by UES, Pleasanton, Ca.). Composite sewage samples are collected sequentially by a SEIN sampler.

The storm drainage area of 81-hectares consists of the sanitary subarea described immediately above plus agricultural land and open space, having a total imperviousness of 13%. A single tipping-bucket raingauge is common to both districts, runoff flow rates are measured by means of a calibrated vertical slot weir and an air bubbler. A Sigmamotor instrument is used to convert weir head into flow rate. An ISCO automatic sampler is used to collect sequential composite samples of stormwater. The sampler is activated by the raingauge. Samples are analyzed for 10 to 15 parameters. In-situ analog recorders and an in-situ magnetic tape recorder are used.

Only some preliminary observations have been published so far. The project holds great promise to provide useful information on sanitary flows and good data for hydrological modeling of surface runoff in a semi-urban community.

14. West Toronto Study Area (Toronto, Ontario)

The West Toronto data appear to be suitable for the study of overflow frequencies and demonstration of urban runoff models. The area is well documented for such purposes. The data do not appear to be suitable for general testing or evaluation of urban runoff models because of uncertainties in field observations described below.

The catchment has been established and monitored by the City of Toronto.[42] Project objectives are to monitor the frequency of combined sewer overflows and to provide data for a demonstration study of an urban runoff model. The project has been active for the last seven years.

The West Toronto Study Area is a 944-hectare residential development served by combined sewers. The total imperviousness of the area is 54%.

Precipitation is measured by a single tipping-bucket raingauge located on the catchment and other precipitation data are available for a nearby Atmospheric Environment Service (AES) raingauge. Combined sewage flows are determined approximately by measuring the depth of flow in an overflow sewer and applying the Manning equation. To obtain the total runoff from the area, interceptor flows and diverted flows (by several diversion weirs) had to be estimated and added to the measured flows in the overflow pipe.[42] No quality observations have been made.

The data collected contain some appreciable uncertainties. Considering the size of the catchment, it would be desirable to have more raingauges on the catchment. Estimated runoff flow rates may be in error by 15 to 20%.

15. Windsor Catchment (Windsor, Ontario)

The Windsor data are useful for estimating pollutional loads in stormwater. The data do not appear, however, to be suitable for detailed hydrological modeling. Large uncertainties in the precipitation and runoff measurements are the main reasons.

The Windsor catchment has been established and monitored by the Department of Civil Engineering, University of Windsor, with some financial support from the National Research Council. The primary study objective was determination of the composition of stormwater.[10] The project has been completed.

The Windsor catchment is a 12-hectare residential development served by separate storm sewers. The housing units are mostly single family units, 25 to 30 years old, generally in good repair. The street asphalt cover is fairly worn, which may lead to high wash-off of solids.

Precipitation data were obtained for five raingauges (weighing type) located in the City of Windsor. None of these was located within the catchment boundary. Runoff flow rates were measured approximately by calibrating a measuring section and monitoring the stage at this section. No checking of the precipitation versus runoff volumes has been reported. For some of the published events, the runoff coefficient approached or exceeded unity.[10] Runoff quality was monitored by collecting and analyzing stormwater samples. A Testing Machines International Sampler was used to collect hourly grab samples. Nineteen analyses were performed on the samples. In total, 25 storms were monitored on the catchment.

URBAN RUNOFF FIELD STUDIES OF LIMITED SCOPE

In this section, urban runoff studies designed to provide limited data for engineering or planning studies are briefly listed. Some of these projects could develop in the future into comprehensive studies providing data for urban hydrological research. The projects are listed alphabetically.

Aldershot catchment(33) is a 6.9-hectare commercial plaza that is 100% impervious. Limited observations of precipitation, runoff flow rate and runoff quality were made on the catchment. The feasibility of using this data for hydrological modeling is presently being studied.

In the Dartmouth project(46) storm water quality was monitored in several commercial plazas for several storms.

At Edmonton(55) a large-scale urban runoff study was initiated. Field data are collected in support of a modeling study of the entire combined sewer area.

At Guelph(40) some observations of precipitation, runoff flow and runoff quality were made on two test catchments. Steps were taken recently to refine the catchment instrumentation.

In another major study,(4) the effect of municipal pollution on the Grand River is being studied. For this purpose, water quality upstream and downstream of the city of Guelph (about 60,000 inhabitants) is being studied.

At Halifax(48) performance of a combined sewage retention tank was studied.

McKittrick drainage area is a small drainage district on which some precipitation and runoff measurements were made. The data were used for calibration of an urban runoff model.(41)

At Merivale(3) a runoff retarding device ("Hydro-brake") is being tested on a small catchment. Runoff from the area enters a small underground storage tank and the outflow from the storage is controlled by the Hydro-brake. Also, some water quality aspects are being studied.

At Midland the water budget of a small urban lake receiving urban runoff is being studied.(11)

At Montreal(42) combined sewage flows have been measured at a number of locations. The best documented are the measurements carried out on the Papineau-Curotte Catchment (1166-hectares) in 1973.

Pollutional Significance of Sanitary Bypasses(45) was a field study of sanitary flow bypasses at four Ontario towns: Aurora, Brantford, Dundas and Waterloo. The study was carried out by the Waste Treatment Section of the Ontario Ministry of the Environment. Over a period of twelve months, precipitation, bypass quantity, and bypass quality were monitored. The data will be used to determine the pollutional loads in wet weather bypasses of waste treatment plants.

At Port Dalhousie and Port Weller(32) wet weather sanitary flows at a pumping station and pollution control plant were studied.

In the Sawmill Creek Project,[3] a suburban catchment partially served by sewers will be monitored. The study objective is to determine the feasibility of storage and treatment of stormwater runoff.

At Toronto[25] the City has proceeded with the installation of an automated raingauge network. Eight raingauges have been installed so far. Flow monitors and automatic samplers will be added in the near future.

At Toronto[55] quantity and quality of surface runoff from an oil terminal site was investigated.

At Toronto International Airport[55] quantity and quality of airport runoff was investigated. Several catchments were monitored for various time periods.

At Vancouver[38] the City initiated the installation of an automated raingauge network. Eighteen raingauges have been installed so far and others may be added. Six water depth sensors will be installed in storm sewers to obtain data for hydrological modeling. The project objective is to develop a computer-oriented monitoring system.

In the Whitemud Creek Study[4] the impact of urban drainage and recreational activities on a rural stream will be studied.

In the Willet Creek Project,[55] dry and wet weather flows in sanitary sewers are being studied.

At Winnipeg[55] water quality of stormwater detained in ponds is being studied.

APPENDIX II

INSTRUMENTATION CONSIDERATIONS

A summary of "Instrumentation for Field Studies of Urban Runoff," by J. Marsalek, Research Report No. 42, Hydraulics Research Division, Canada Centre for Inland Waters, Burlington, Ontario, 82 pp., 1976. (Reference No. 34).

INSTRUMENTATION FOR FIELD STUDIES OF URBAN RUNOFF

ABSTRACT

Instrumentation and monitoring techniques for field studies of urban runoff were examined. In particular, the following types of instruments were studied: recording precipitation gauges; sewer flow measurement instruments; and automatic wastewater samplers. After reviewing the literature and surveying equipment, some of the more promising instruments were acquired, tested in the laboratory, and operated in the field for various time periods.

Individual instruments are discussed with regard to their technical data, accuracy and reliability. Recommendations for the selection, interfacing and installation of the instruments are given.

CONCLUSIONS

Assessment of the environmental impact of urban runoff on receiving waters requires detailed data on precipitation-runoff processes. Such data is also needed for further development and application of urban runoff models. Precipitation, runoff flow rate and runoff quality are of major interest.

Precipitation data consists of point precipitation and of the areal distribution of precipitation. Such information can be obtained from a network of several recording rain gauges installed within the studied area. The tipping bucket rain gauge of 0.01-inch (0.25-mm) per tip capacity is particularly suitable for this purpose. A good time resolution, frequently 5-minutes or shorter, is required. Two gauges are sufficient for catchment areas up to 10-km^2 (4-square miles), and for up to 50-km^2 (20-square miles) three gauges are recommended. Time resolutions of rainfall data recommended for urban runoff studies are given in Table 1.

TABLE 1. RECOMMENDED TIME-RESOLUTIONS OF RAINFALL DATA FOR URBAN RUNOFF STUDIES

WATERSHED TYPE	WATERSHED SIZE		TIME RESOLUTION
	Acres	Hectares	(Minutes)
Small experimental watersheds (for model development or calibration)	10-300	4-120	1-2
Large Experimental Watersheds	500-3000	200-1200	5
Data Serving for Design	up to 3000 > 3000	up to 1200 > 1200	5-10 10-15
Data Serving for Planning	> 3000	> 1200	60

Runoff flow rates should be recorded continuously at one or more points. Whenever feasible, runoff flows should be measured at the outfall, outside the sewer system. Conventional constriction flowmeters such as weirs or flumes can be used.

If it is necessary to measure inside the sewer system, and the sewer pipe is not frequently surcharged, an inexpensive vertical slot weir or a flume (e.g., Palmer-Bowlus flume) are applicable. For frequently surcharged pipes, a dual free-pressurized flowmeter such as the U.S. Geological Survey Sewer Flowmeter or an acoustic flowmeter should be used.

The acceptable accuracy of runoff flow measurements is 5 to 10%.

Characteristics of selected liquid level sensors and an overview of sewer flow measurement techniques are given in Tables 2 and 3, respectively.

TABLE 2. CHARACTERISTICS OF SELECTED LIQUID LEVEL SENSORS

TYPE OF LIQUID LEVEL SENSOR	APPLICATION		TYPICAL INSTALLATION			INPUT POWER OPTIONS (SENSOR ONLY)		
	FREE FLOW	PRESSURE FLOW	DIRECTLY IN SEWER	IN SEWER BUT WITH SOME PROTECTION	IN A STILLING WELL	DC	AC	OTHER
Capacitance Probe	X	-	-	X	X	X	X	-
Dipper Probe	X	-	X	-	-	X	X	-
Floats	X	-	X (Scow float)	-	X	-	-	none required
Pneumatic Probe	X	X	X	X	-	X	X	X (compressed gas)
Acoustic Probe	X	-	X	-		X	X	-

Runoff quality is commonly determined from the laboratory analysis of grab samples collected in the field. Such samples are collected sequentially by automatic samplers. A sampling interval as short as 5 to 10 minutes may be required. The first sample should be collected as closely to the beginning of runoff as practicable. In the currently common approach, a constant sampling interval is selected on the basis of experience and the size of the studied area. A review of ten urban runoff studies (i.e., storm water runoff as well as combined sewer overflows) indicated the sampling intervals shown in Table 4.

Other factors to be considered in the selection of a sampling interval is the precipitation time-distribution and the watershed hydrologic response. These two factors influence the runoff flow rates to which the stormwater quality seems to be related. Consequently, high intensity and low duration summer storms on fast responding watersheds will call for shorter sampling intervals and vice versa.

The first sample should be collected as closely to the beginning of runoff as feasible. This can be achieved by activating the sampler by the first impulse from the precipitation sensor, or better, by the rise of the water level in the sewer by a preselected increment.

Some electronic liquid level sensors (e.g., capacitance probes, Manning Dipper, ultrasonic probes, etc.) can be equipped with alarm relays and these are then used to close the power supply circuit of the sampler when flow reaches the selected level.

TABLE 3. OVERVIEW OF SEWER FLOW MEASUREMENT TECHNIQUES

TECHNIQUE	FREE FLOW	FREE AND PRESSURE FLOW	APPLICABLE			ESTIMATED ACCURACY	COST RANGE*	RECOMMENDED
			AT OUTFALL	MANHOLE	SEWER PIPE			
Depth Measurement only	X	X**	X	X		20%	L	No
Depth and point velocity	X		X	X		5%	H	Yes
Specific energy	X			X		20%	L	No
Depth and chord velocity	X	X	X	X	X	3%?	H	Yes
<u>Weirs</u> —								
Rectangular	X		X			5%	L	Yes
V-Notch	X		X			5%	L	Yes
Trapezoidal	X		X	X	X	5%	L	Yes
Vertical slot	X		X	X	X	5%	L	Yes
<u>Flumes</u> —								
Leopold-Lagco	X		X	X		5%	M	Yes
Parshall	X		X			5%	M	Yes
Palmer-Bowlus	X		X	X	X	5%	M	Yes
U.S.G.S.	X	X	X		X	5%	M-H	Yes
Univ. of Illinois	X	X	X		X	5%	M-H	Yes
Tracers	X	X		X		5%	M	No

*: L = Low cost; H = High cost; and M = Medium cost.

**: Measuring pressure drop between two manholes.

TABLE 4. SAMPLING INTERVALS IN URBAN RUNOFF STUDIES

WATERSHED SIZE (Acres)	(Ha)	SAMPLING INTERVAL (Minutes)	24 SAMPLE CYCLE DURATION (Hours)
10	4	5	2
50	20	5-7.5	2-3
100	40	5-10	2-4
500	202	5-15	4-6
1000	455	5-15	4-6
2000	809	15	6
3000	1214	20	8
5000	2023	25-30	10-12

The desirable size of samples is about 1000-ml. Great care has to be devoted in order to avoid systematic errors in the sampling. The first step in this direction is to locate the sampler intake at a cross-section where the sampled medium is rather homogeneous. The capability of the sampling apparatus to collect solids should be evaluated, mainly with regard to the intake orientation and the intake nozzle and line velocities.

To reduce the loss of quality data owing to sampler malfunctions, two samplers may have to be installed and operated in parallel.

The list of water quality parameters usually investigated in urban runoff studies is presented herein in Section 2 (Table 2).

A good time synchronization between the recordings of precipitation, runoff flow and sample collection can best be ensured by recording all this information on the same chart or tape.