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CANADIAN PROGRESS IN URBAN HYDROLOGY RESEARCH (1979-1983)

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INTRODUCTION

Une série d'ateliers sur l'hydrologie urbaine ont été tenus et des rapports faisant le point sur la recherche et la modélisation relatives aux bassins versants urbains ont été rédigés dans le cadre du Programme hydrologique international. Le Canada contribue activement à ce Programme depuis son lancement. Le premier rapport national sur la recherche en hydrologie urbaine au Canada a été préparé en 1976 (Marsalek, 1976) et une mise à jour a été publiée en 1979 (Marsalek, 1979). Le présent rapport décrit les progrès accomplis par le Canada dans la recherche et dans les applications des résultats de cette recherche de 1979 à 1983. Les principaux sujets portent notamment sur les précipitations urbaines, la caractérisation des écoulements d'averse et des trop-pleins d'égout mixtes, l'impact des eaux de ruissellement sur les eaux réceptrices, la modélisation mathématique ainsi que le contrôle et la gestion des eaux de ruissellement. On peut trouver de plus amples renseignements sur ces sujets dans les références énumérées à la fin du rapport. Pour ne pas allonger indûment la liste, seules sont énumérées les références n'apparaissant pas dans les deux premiers rapports nationaux. Une seule publication représentative a été retenue dans le cas des auteurs ayant présenté des communications semblables dans plus d'une publication.

CANADIAN PROGRESS IN URBAN HYDROLOGY RESEARCH (1979-1983)

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INTRODUCTION

Under the International Hydrological Programme, a series of workshops on urban hydrology has been held and the state-of-the-art reports on urban catchment research and modelling have been prepared. Canada has actively participated in these activities since the program inception. The first national report on urban hydrology research in Canada was prepared in 1976 (Marsalek, 1976) and a report update was produced in 1979 (Marsalek, 1979). The report that follows describes the Canadian progress in urban hydrology research and in applications of research findings during the period from 1979 to 1983. The main topics include research on urban precipitation, characterization of stormwater and combined sewer overflows, runoff impact on receiving waters, mathematical modelling, and runoff control and management. Further information on such topics can be found in the references which are listed at the end of the report. For brevity, only the references not included in the two earlier national reports are listed. In cases where authors presented similar contributions in more than one publication, only one representative publication has been selected and included in the list of references.

URBAN PRECIPITATION RESEARCH

Advances in urban runoff computations and modelling have necessitated further research on urban precipitation. The main problems which have been addressed in research studies include rainfall measurement, analysis, and modelling.

Rainfall Measurement. The measurement of temporal and spatial distributions of rainfall over large urban areas requires to establish a network of recording rain gauges. A relatively inexpensive rainfall intensity sensor suitable for this purpose has been developed (James et al., 1982; Haro et al. , 1983).

Analysis of Urban Rainfall Data. Several studies dealt with analysis of point rainfall for the purpose of runoff computations. Investigations of storm volumes and frequencies (Fraser, 1982) showed that such volumes departed significantly from the volumes derived from the intensity-duration-frequency (IDF) curves, as done in many synthetic design storms. Such a finding suggests that synthetic design storms should not be used for design of stormwater storage.

Temporal distributions of rainfall in 1 and 12 hour storms were studied for 35 stations in Canada (Hogg, 1980). Distributions of various probabilities of occurrence were produced and recommended for use in urban drainage design. It was also noted that the Chicago-type distribution (derived from local IDF curves) is totally inappropriate for some Canadian climates and, in other cases, it is not among the most probable distributions.

Distributions of rainfall intensity-duration data were studied by Watt and Nozdryn-Plotnicki(1980). On the basis of such studies, they recommended a procedure for extrapolation of short records.

Areal distributions of rainfall are of interest in the design of drainage systems for large urban areas, particularly when dealing with real-time control of combined sewer systems (Nguyen et al., 1980). The relationship between the point and areal rainfall has been studied in the Montreal area(Nguyen et al.,1981). A theoretical methodology to establish such a relationship has been proposed and areal correction factors have been calculated for various return periods. In another approach, the factor analysis was used to study spatial variations of precipitation (Beaudoin and Rousselle, 1982). A probabilistic characterization of point and areal rainfalls was presented by Nguyen and Rousselle(1982).

Stationary storm rainfall distributions do not describe adequately the actual storm events which are characterized by the movement, development and decay of storm cells of somewhat limited dimensions. Such dynamic and kinematic features of storms are of primary interest in the design of real-time controls for large drainage systems. Studies of storm movement and development have been done in Hamilton (James and Drake, 1980; Robinson and James, 1983) and in Montreal (Nguyen et al., 1981). In the latter study, the tracking of storms for the purpose of automatic control of the Montreal combined sewerage system has been found feasible.

Storm Rainfall Models. Urban runoff computations require storm rainfall models of various nature. The simplest models (stationary point rainfall) are typically synthetic design storms which are common in drainage practice. Experience with various design storms has been summarized by Patry and McPherson (1979).

Wisner and Gupta (1979) compared runoff peaks simulated for the Chicago-type design storms with those simulated for actual storms. Modified synthetic storms of reduced peakedness produced a fair agreement with the actual storms.

Marsalek and Watt (1983) reviewed characteristics of design storms and concluded that the design storm definition should be expanded to include all the storm characteristics, catchment conditions, the computational methods, and the range of applicability. The need for realistic temporal rainfall distributions, such as those produced by Hogg (1980), was stressed.

The shortcomings of design storms of the Chicago type prompted Russell (1979) to derive design discharges from simulations with actual storms for model parameter values derived from probabilistic distributions.

Dynamic and kinematic models of storms were developed from weather-radar data for the Hamilton area (James and Drake, 1980). Such models generate hyetographs for each subcatchment and simulate the spatial distribution as well as the temporal growth and decay of a system of storm cells which move across an urban catchment.

A stochastic model for hourly rainfall depths was developed by Nguyen (1979) and further described by Nguyen and Rousselle (1981). The model determines the probability distribution of rainfall accumulated at the end of each time interval within the total storm duration.

CHARACTERIZATION OF URBAN RUNOFF QUALITY AND OF IMPACTS ON RECEIVING WATERS

The quality of urban runoff has been studied fairly extensively in the earlier phases of research. The studies reported here were conducted for specific purposes of model development or for evaluation of the impact of runoff on receiving waters.

Characterization of Stormwater and Combined Sewer Overflows. Waller and Novak (1981) estimated pollutant loadings from Ontario municipal sources to the Great Lakes. Estimates of urban runoff loadings were based on extensive catchment data. For phosphorus, the runoff loading represented 15% of all municipal source loadings. Higher relative magnitudes of runoff loadings were found for other constituents.

Dick and Marsalek (1979) proposed unit pollutant loads for use in the assessment of urban runoff pollution at the planning level.

The catchment research of urban runoff quantity and quality has been conducted in a number of cities. A brief listing of such studies, many of which are still in progress, follows.

In Burlington, Ontario, two test catchment are studied to determine the effects of urban land use on runoff quality. Field investigations in Edmonton , Alberta (Ahmad, 1983), are conducted to improve the performance of the combined sewerage system and to find cost effective alternatives to sewer separation. Studies in Hamilton, Ontario, are conducted in support of the development of new models (James, 1983). In Kingston, Ontario, a residential test catchment is monitored to support the development of a new runoff quality model (Watt, 1983). The composition of combined sewage and of its overflows was studied in Montreal, Quebec, for the purpose of system modelling (Beaudoin et al., 1981; Coutu, 1980; Lessard, 1981; and Lessard et al., 1982). Water quality conditions in the Montreal area were evaluated (Paradis et al., 1979). Extensive studies of combined sewer overflows are underway in Quebec City, Quebec, in connection with the water quality study of the St.Charles River (Lavalée, 1983). Stormwater quality and urban streams quality are studied in St.John's, Newfoundland, in the study of urbanization in the Waterford River Basin (Technical Committee, 1982). Several urban catchments were monitored in Ottawa, Ontario, in connection with the Rideau River Stormwater Management Study(Gietz, 1982; Gore&Storrie, 1981). Extensive investigations of stormwater and overflows quality are planned in Toronto, Ontario, in connection with the Toronto Area Water Management Study (Zukovs, 1983). Several urban test catchments were monitored in the Grand River Basin (Singer, 1980). A test catchment was monitored in Stratford, Ontario, under the Avon River Study(Novak and Whitehead, 1982; Whitehead and Novak, 1982). Investigations of stormwater and overflows were completed in Vancouver, British Columbia, in connection with the Fraser River Estuary Study (Ferguson and Hall, 1979; The City of Vancouver, 1981).

Other investigations dealt with microbiological characterization of land drainage flows in the Canadian Great Lakes Basin (Qureshi and Rybakowski, 1981). Such sources of bacteria were found to cause only minor water quality problems because of the short duration and a limited spatial extent of elevated microbial levels following runoff events. There are however many water bodies draining into the Great Lakes where high bacterial populations exceed the Ministry of the Environment objectives for recreational activities(Weatherbe et al., 1982). Urban sources of bacteria iclude animal wastes, vegetation and soil contaminated by animal wastes, combined sewer overflows, and illegal connections of sanitary sewers to storm sewers.

While the above studies dealt with traditional aspects of water pollution, new concerns about toxic substances led to extensive investigations of persistent toxic substances in urban runoff in the Canadian Great Lakes Basin. During a 3-year period, more than 50 persistent toxic substances were studied in 12 cities at 72 sites. Preliminary results indicate high levels of toxics in urban sediment and stormwater, particularly in industrial areas (Wong, 1981; Wong and Marsalek, 1981).

MODELLING OF URBAN DRAINAGE SYSTEMS

The modelling of urban drainage systems has been further advanced in a number of research studies and applications. Such advances have been made in various forms, including the development of supporting data and conceptual models, development of new submodels or models, improvements in computer programs, model verifications, and model adaptations to minicomputers. Such developments are further discussed below.

Development of Input Data and Supporting Concepts for Modelling. The activities reported here dealt with investigations of hydraulics of drainage system elements, flow routing through such elements, and preparation of input data.

Joliffe(1981) developed a model for dividing and combining flows at sewer pipe junctions. With the advent of the pressurized flow routing, there is an increased interest in head losses at sewer junctions. The results of experimental investigations of such losses were reported by Marsalek (1981). The flow routing in sewer systems with sideweir diversions was studied by James and Mitri (1982).

Hydraulics of sewer inlets is particularly important for the modelling of dual (surface/subsurface) drainage. The spacing of inlets and their hydraulic characteristics control the inflow of surface runoff into sewers. Two approaches to inlet controls were reported. In the first approach, the controls are achieved by a proper spacing of inlets. Such an approach, which is particularly applicable to highway drainage, has been used in extensive studies of hydraulics of sewer inlets, ditch inlets, and bridge deck drains (Marsalek, 1982). In the second approach, inlet controls are achieved by constriction devices retrofitted into standard inlets. Investigations of such devices were reported by Townsend et al. (1980). The results of the latter study were used in a dual drainage model.

Integrity of rainfall time series for analysis of combined sewer systems was investigated by James et al. (1982).

Model Refinement and Development. The reported advances in modelling development range from modifications of the existing models to the development of new models.

Adams (1983) continued the development of analytical hydrological models in which the rainfall input is transformed to create probability distributions of the system outputs. Verifications of such distributions against the results obtained by continuous simulation are underway.

Further improvements in flow routing models have been made. Kassem and Wisner (1980) and Ahmad et al.(1982) verified and refined the EXTRAN model for pressurized flow routing. Hamam and McCorquodale (1981, 1982) studied transitions from the gravity to pressurized flow. Beron and Richard (1982) developed a simplified flow routing procedure which is particularly suitable for applications in real-time control of flows in combined sewer systems.

In runoff quality modelling, Shivalingaiah and James (1982) reported a new submodel (interfaced with the SWMM model) which quantifies and distributes accumulations of pollutants from atmospheric sources on the catchment surface. Schroeter and Watt (1983) developed a model for solids transport by runoff using a "solids reservoir" concept. This model was added to the earlier reported Queen's University Urban Runoff Model. McBean et al.(1982) studied statistical modelling of bacteria in combined sewer overflows.

Extensive modifications of the HYMO and SWMM models were reported by Wisner (1982, 1983). The OTTHYMO is a modified version of HYMO which reflects special properties of urban catchments. Newly added optional subroutines offer alternatives for hydrograph computations and for flow routing. The OTT-SWMM model was specifically developed for dual drainage design (Kassem, 1982; Wisner and Kassem, 1981). Inlet supply hydrographs, which are simulated by the standard SWMM model, are divided into minor and major drainage system flows and routed.

A new hybrid model, referred to as the Versatile Stormwater Quantity and Management Model (VSQMM) was developed by Lee (1981). The model consists of six basic computational modules and, for most of these, the user may select from several computational options.

Thompson and Sykes (1979) developed a subcatchment runoff model which is applicable to both urban and rural areas for discrete as well as continuous simulation. The model was applied to minicomputer simulations of dual drainage with inlet controls.

For real-time control of flows in combined sewers, simple runoff models were developed by Marchi et al.(1982), Patry et al.(1982), and Patry and

Marino (1982).

Effective implementation of urban runoff models on various computer systems has been also studied. Robinson and James (1981) developed a data preprocessing program for the SWMM model. The program simplifies corrections and editing of input data and expedites execution of simulation runs (James and Robinson, 1982).

The increasing availability and use of minicomputers led to the development of runoff models which can be applied on minicomputers. A minicomputer version of the ILLUDAS model was developed by Patry and Raymond (1979) and further described by Patry and Marchi(1979), and by Marsalek (1981). The modified model, which is also referred to as the SIRDU model (Béron and Marchi, 1981; Béron and Marchi, 1982), has some new features and can be implemented on a minicomputer with 16K memory storage. A similar model is under development at the University of British Columbia (Russell, 1983). Note that the Queen's University Runoff Model(Q'URM) can be also implemented on a minicomputer (Watt, 1983).

Methodology for Modelling Applications. Experience with urban runoff models led to some improvements in modelling applications. James and Robinson (1981a, 1981b) developed standards for urban runoff modelling studies. Wisner (1980) evaluated the Soil Conservation Service procedure TR-55. Model verification studies were reported by Wisner (1983) for OTTHYMO and OTTSWMM, Patry and Raymond (1979) for a modified ILLUDAS model, Patry and Marino (1982) for a nonlinear rainfall-runoff model, and by Ng and Marsalek (1981) for the SWMM model. Numerous refinements of SWMM modelling applications were reported by Ahmad (1980) and Ahmad et al. (1982).

RUNOFF CONTROL AND MANAGEMENT

As urban drainage design progressed from simple sewer sizing to runoff management, considerable effort has been spent on developing and evaluating runoff control technologies. Engineering applications of such technologies are fairly numerous and cannot be discussed here. Only the case studies with distinctive research aspects are included in the discussion. It is expected that further interest in runoff control and management will be generated when the earlier proposed Ontario drainage policy and guidelines are finalized (Weatherbe, 1980).

General Aspects of Runoff Control and Management. A comprehensive report on control of pollution from urban runoff was prepared by the Environment Canada (1982). The report which was compiled by a team led by Mr.D. Hay lists sources and pathways of pollutants in urban runoff, states problems caused by runoff in terms of both quantity and quality considerations, lists runoff control measures, and describes links with policy and socio-economic matters.

Ellis et al.(1983) and McBean et al.(1982) studied urban land use standards and their implications on stormwater management.

Details of runoff control technologies follow.

Runoff Control by Storage. Runoff control by storage is perhaps the most widespread control measure in Canada. Engineering applications are quite numerous and have been described elsewhere (Zukovs et al., 1982). Research aspects of such measures are addressed below.

Schwarz and Adams (1981) further developed analytical models for storage design (see also Schwarz, 1981; and Smith, 1980). Analysis of rainfall intensity-duration-volume, for individual storms, demonstrated that simple design storms, which are derived from the IDF curves, are inappropriate for storage design (Fraser, 1982). Robinson and James (1983) investigated rainfall inputs for storage design and James (1982) pointed out the need for continuous simulation in storage design. Marsalek et al.(1982) surveyed technical and institutional aspects of runoff storage design.

Among the various types of storage, stormwater ponds seem to be the most popular. Various aspects of stormwater pond design for water quality objectives were addressed by Lafleur et al.(1981) and by Fok et al.(1981). McBean and Burn (1983) investigated the thermal modelling in urban runoff and the implications for pond design. The effects of the detention time in ponds on algae blooms were studied by Mulamoottil and McBean (1983). Lafleur and McBean (1981) demonstrated the need for multiple-port outlet structures in ponds, in order to effectively control the pond discharge for storms of various magnitude. Installations of ponds in parks were proposed by Wisner et al. (1981).

Extensive studies of the Kennedy-Burnett pond were conducted in Ottawa, Ontario. The pond was operated in both continuous and batch modes and monitored over a 3-year period (Gietz, 1982). The use of the batch mode was recommended to achieve the required effluent quality. Bacteria were the contituents most difficult to control. Adjunct studies of bacteria in stormwater and the effects of sedimentation on their levels were done by Droste (Gietz, 1982). Attempts to reproduce the observed water quality data by means of the existing simulation models were unsuccessful.

Bench-scale and pilot-scale treatability studies of urban runoff were conducted for the purpose of pond design (Kronis, 1981). Natural settling for about 10 hours was effective in removing the settleable matter, but it did not affect bacteria density levels. Disinfection effectively reduced densities of indicator bacteria.

Public acceptance of stormwater ponds was investigated for 3 ponds in Ontario (Baxter and Mulamoottil, 1981; Switzer, 1981). The major concern of all action groups were the future maintenance problems.

Inlet Controls. Although inlet controls by constriction devices had been introduced by the Borough of East York in the late 1960's, only recently the importance of such measures was fully recognized and their acceptance improved. By partial blockage of inlets, the inflow to the sewer system can be controlled to a selected level and the sewer surcharging can be avoided. The constriction devices proposed by Townsend et al.(1980) were installed in several Canadian cities. Inlet controls, which are achieved by proper spacing of standard inlets, have been proposed by Marsalek (1982) and adopted for highway drainage design in Ontario.

Other Control Measures. Although the demand for runoff quality controls is increasing, there are no significant innovations to report. Besides the control by storage, the control measures are limited to some forms of poorly understood "best management practices", such as street sweeping (Weatherbe et al., 1982; Zukovs et al., 1982). Some quality control aspects of street sweeping were investigated in Ottawa (Pitt, 1982).

Various types of control measures, which are particularly suitable for control of overflows from combined sewer systems, were investigated by Henry and James (1981), and by Marchi (1981). Vatagodakumbura and Choudhry (1982) studied the effects of disconnecting roof-leaders from sewers on basement flooding.

A procedure for evaluating costs and damages for pumped storm sewers was developed by Imam et al.(1979).

RIVER BASIN STUDIES WITH EMPHASIS ON URBAN RUNOFF

Urban runoff is recognized as one of significant sources of pollutants which cause degradation of water quality in streams, lakes, and estuaries. Consequently, the impact of urban runoff on receiving waters has been studied in several studies which are described below.

The highly eutrophic state of the Avon River (Ontario) has been found to result from excessive nutrient inputs from urban and rural sources (Ontario Ministry of the Environment, 1979). In a comprehensive program of monitoring, analysis, and demonstration projects, urban pollutant sources, including urban runoff, have been characterized. The most cost-effective package of rural, urban, and in-stream measures has been developed to achieve the desired stream water quality.

A management plan for the Fraser River Estuary (British Columbia) has been developed. The plan included assessment of pollutant loads in stormwater discharges and combined sewer overflows draining into the Lower Fraser River (Ferguson and Hall, 1979; The City of Vancouver, 1981).

Extensive studies of urban runoff have been conducted in the Grand River Basin (Singer and So, 1980). It was concluded that for the conditions studied, urban runoff did not have a serious impact on dissolved oxygen in the river and urban runoff control measures were not justified. Such controls, however, might be justified in small urban tributaries.

To develop a remedial program for the protection of bathing beaches along the Rideau River in Ottawa, Ontario, stormwater and combined sewage discharges to the river have been studied. Study activities comprized monitoring of runoff quality including bacteria densities, bacterial die-off rates in the river following runoff events, effects of storage on runoff quality, and modelling of urban runoff and of receiving waters quality (Gietz, 1982; Gore&Storrie, 1981). The control measures under consideration include the best management practices and stormwater ponds.

The impact of combined sewer overflows on water quality in the St.Charles River has been studied in Quebec City, Quebec. Observations of overflows and of water quality in the river have been used to calibrate mathematical models which are used to analyze the pollution problems. Cost-effective measures for overflow controls are sought (Lavallée, 1983).

The Toronto Area Watershed Management Study (Ontario) has been initiated recently to control pollution and to improve water quality of streams and of the near-shore zone of Lake Ontario in the Toronto area (Zukovs, 1983). Under this study, extensive investigations of the impact of urban runoff on receiving waters will be conducted. A watershed management plan including runoff control and management will be developed.

In the Waterford River Basin, Newfoundland, the increased incidence of flooding and deterioration of water quality are caused by progressing urbanization (Technical Committee, 1982). To control such problems and to develop guidelines for future development, a comprehensive study of water resources in the basin was initiated in 1980. Study research activities include the monitoring and modelling of urban rainfall/runoff, streamflow, groundwater, and water quality.

FUTURE RESEARCH NEEDS

Significant advances have been achieved in urban hydrology research in Canada during the past four years. In spite of this progress, a number of urban hydrology problems should be investigated further as outlined below.

The research on rainfall inputs for urban runoff modelling is far from being completed. Promising advanced approaches need to be extended from limited local studies to the nation-wide basis. Specific problems requiring further attention include temporal storm rainfall distributions, areal distributions, storm dynamics and the development of rainfall inputs for stormwater storage design.

The modelling of runoff quantity is well established. Further research should address the problems of modelling major storm events for which the catchment moisture and infiltration processes are likely to play a significant role. The adaptation of models to inexpensive and widespread minicomputers should be continued.

For characterization of stormwater and combined sewage overflows, the emphasis should be placed on studies of toxic substances and on further improvements in the modelling of runoff quality processes. Methodologies for investigations of urban runoff impact on receiving waters should be further developed.

Runoff quality controls, particularly stormwater ponds, deserve further research to provide hard data for their design. Evaluations of existing facilities are also needed. Further attention should be paid to real-time control of flows in combined sewer systems. The new microcomputer technology should lead to new advances in this field.

Finally, there is a strong need to continue the collection of urban hydrological data for evaluation of numerous new tools which are used for analysis and management of urban runoff. Such tools include mathematical models as well as runoff management and control measures.

SUMMARY

During the period from 1979 to 1983, a substantial progress has been achieved in the Canadian urban hydrology research and stormwater management. Major advances have been made in the urban precipitation research. New approaches have been introduced for analysis of point rainfall, areal distributions, storm dynamics, and storm rainfall modelling.

Catchment studies of stormwater and combined sewer overflows have been continued to develop or calibrate water quality models and also to study runoff impacts on water quality in receiving waters. The interest in pollutional aspects of urban runoff has been extended from conventional constituents to persistent toxic substances.

New advances have been made in the development of urban runoff and stormwater management models. The newly developed submodels can be readily interfaced with the existing well-established and well-accepted models. Such additions generally extend the scope of the original models. The pertinent examples are new models of storm rainfall, pollutant accumulation, and inlet controls for dual-drainage. Other new models have been developed for minicomputers.

Urban runoff control and management are practiced extensively. While the technology for runoff quantity control is well established and tested, little information is available on the performance of runoff quality controls, such as stormwater ponds and street sweeping. Many such controls are implemented on the basis of insufficient or unreliable data.

The recent river basin studies reflect a comprehensive approach to water resources problems. In this approach, urban runoff is considered as one of many pollutant sources in the basin. Urban runoff control measures are then considered in relation to other pollution source controls in the basin. Such an approach leads to the formulation of cost-effective solutions to water pollution problems.

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