IMPACTS & ADAPTATION OF
DRAINAGE SYSTEMS,
DESIGN METHODS & POLICIES

Presented to

NATURAL RESOURCES CANADA

Climate Change Action Fund: Impacts & Adaptation

Contribution Agreement A330

Presented by

Kije Sipi Ltd

In Partnership with

City of Edmonton
City of Ottawa
Mississippi Valley Conservation Authority

June 2001

Kije Sipi Ltd

P.O. Box 47064, Gloucester ON K1B 5B0

☎ (613) 830-1029 🖷 (613) 830-4026 www.kijesipi.com

June 2001

Mrs. Pamela Kertland
Adaptation Liaison Office
Natural Resources Canada
601 Booth Street, Room 381
Ottawa, Ontario
K1A 0Y8

Re: **Report submitted under the Climate Change Action Fund:**
Contribution Agreement A330:
IMPACTS & ADAPTATION ON DRAINAGE SYSTEMS,
DESIGN METHODS & POLICIES

Dear Ms. Kertland:

We are pleased to submit our final report related to the above mentioned climate change study.

We look forward to receiving your comments however, should you have any questions or require clarifications please feel free to give me a call more directly at 797-7000 or via email at Daniel.Jobin@KijeSipi.com.

Sincerely yours,

Kije Sipi Ltd.

Daniel Jobin

Daniel Jobin, M. Eng., P. Eng.
Hydrologist – President

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City of Edmonton	Chris Ward
City of Ottawa	Adrien Comeau Eric Tousignant
Kije Sipi Ltd.	Daniel Jobin, <u>Project Leader</u> Jean-François Sabourin Peter Jolly Jean-Guy Zakrevsky Tim O'Brien
Mississippi Conservation Authority	Paul Lehman

Letter of submittal

Acknowledgements

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GLOSSARY OF SELECTED TERMS IN THE REPORT

A glossary of frequently used terms is presented below to avoid conflicts in terminology and improve interpretations. The definitions assume the reader has a technical background but not necessarily versed in water resources.

Convective Storm: This term defines a specific type of rainfall. Convective storms are associated with the local heating and rising of humid air masses with condensation at higher altitudes to create usually high precipitation rates and much spatial variability of rainfall totals. Severe thunderstorms and hail are often present with this type of storm.

Conveyance: This word refers to the transport or, the movement of water (to convey). Examples of conveyance systems include channels such as ditches and conduits, such as sewers.

Detention Pond: Refers to an open storage facility whereby storm water is detained in order to allow settling of sediments plus decrease downstream flow rates. Detention ponds are sometimes equipped with other types of storm water treatment processes such as ultraviolet light bacteria control systems to reduce the total pollution loadings in the downstream water bodies.

Deterministic: In this report this term refers to a hydrologic modeling approach. Deterministic models attempt to simulate the discrete physical processes. For example, a deterministic model might consider all major hydrologic cycle components such as evaporation, while lumped models would use a single loss coefficient to compute surface runoff.

Distributed: This word is taken from the field of hydrology and specifically refers to a type of hydrologic model that attempts to simulate the high spatial variability of physical variables. In essence, "distributing" the inputs such as precipitation over an area of interest.

Distributed models are typically grid oriented and offer the highest spatial resolution for using remotely sensed raster data.

Evapotranspiration: This term refers to a combination of two hydrologic processes that both transfer water from the earth surface back to the atmosphere in gaseous form. The evaporation process is defined by heating water to the point of transformation into vapor while the plant transpiration process essentially achieves the same results through the life sustaining processes of plants.

Hydrograph: This term refers to a graph depicting the variation of flow with time.

Hyetograph: This term refers to a graph depicting the variation of precipitation with time.

Imperviousness: This hydrologic variable establishes the degree to which water can potentially penetrate into the ground at any given location. One hundred percent imperviousness means no water can infiltrate while zero percent indicates all precipitation can infiltrate. The actual infiltration rate is governed by factors such as the state the soil's saturation level and the type of land cover.

Level of Service: This expression is a water resources design criteria used to establish the conveyance capacity of drainage systems. It is often expressed in terms of “Return Period” (Years). Higher “Levels of Service” translate into larger flow conveyance capacities.

Model: In this document, a model is a mathematical representation of real world processes in a computer form. Hydrologic models for example, simulate the hydrologic cycle. There is a plethora of hydrologic models available today ranging from simple mathematical abstractions of the real world to highly detailed renditions of the hydrologic cycle.

Retention Pond: Refers to an open storage facility whereby storm water is “retained” within the structure in order to allow settling of sediments. As with detention ponds, retention ponds are sometimes equipped with other types of storm water treatment processes in an effort to reduce the total pollution loadings in the receiving water bodies. However, retention ponds constantly release storm water, albeit slowly, and in a controlled fashion to facilitate optimum water quality treatment.

Return Period: This expression is commonly used in water resources to describe the capacity (actual or design) of drainage systems. It can loosely be interpreted as meaning the average time period, at any given time to experience one meteorological event that would generate hydrologic conditions approaching the system's capacity. The return period is typically expressed in units of years; for example, storm sewers are often designed the safely convey flows generated by a 5-year storm. Accordingly, these storm sewers would surcharge on the average once every five years.

Sensitivity Analysis: A method of analysis aimed at assessing hydrological models and, indirectly, the physical world they represent. This is accomplished by evaluating the impacts (sensitivity) on model outputs (typically flows) when changing either the model input data or the state variables. For example, the modeler can ascertain the potential impact on simulated evaporation when the air temperature is increased by 10%.

Simulator: In this document this word is synonymous to the word model.

State Variables: This expression refers to the different elements that comprise the hydrologic cycle; for example, the soil moisture content.

Transformations: This word is used to represent algorithms and a collection of algorithms (models) that change state variables such as the ozone concentration. A computational model "transforms" the input data using process formulations.

EXECUTIVE SUMMARY

Drainage systems have always been designed based on the premise that the climate is not changing and that historical climate data can be effectively used to predict future drainage design requirements. Consequently, there is a real potential for more frequent drainage system failures and increases in the resulting flood damages and related health problems. The study examines these issues by completing a sensitivity analysis using hydrologic simulations. Hypothetical surface areas of multiple land use types were assessed along with existing urban and rural drainage basin models.

The climate change impacts were evaluated mainly in terms of changes to the drainage system peak flows and runoff volumes. However, the incremental construction cost and the variations in the drainage system level of services (frequency of flooding for example) were also analyzed.

Generally, the simulation results indicated increases in peak flows and runoff volumes equal to, or greater than the given increase in precipitation and irrespective of the drainage design and analysis method used. In certain situations, the proportional increase in peak flows is almost twice the projected increase in precipitation. The resulting impacts of these findings indicate future increases in drainage infrastructure costs and a reduction in the level of service of existing systems. However, the likelihood of flooding in municipal wastewater systems could either increase or decrease depending on the relative change in frequency of certain types of storm events and the composition of each sewer system. Simulation results on an existing natural watershed system drainage system also indicated that increases in precipitation yielded an almost direct increase in flow volumes and peak flows.

A review of the regulatory framework of water resources in Canada reveals a complex web of plans, regulations and policies administered by three, sometimes four levels of government. This has resulted in inconsistent application of rules within provinces and across the country. As a result, the current legislative situation makes the implementation of adaptive measures to deal with the impacts of climate change a significant challenge.

As the study findings point to a significant increase in the magnitude and frequency of flood and, costs to provide additional drainage system capacities due to the reduced level of service of existing systems, there is a need for changes in the way stormwater activities and supporting policy and legislative instruments are administered across Canada. A review of drainage design methods, their applicability and usage in the context of climate change should be completed within a larger framework establishing national guidelines on drainage design and analyses methods.

TECHNICAL SUMMARY

Background

An important function of a drainage system is to collect excess runoff from surface areas such as buildings, roads and fields and, to convey it safely and economically to a suitable receiving water body. Drainage infrastructures such as sewers, culverts and ditches have always been designed based on the premise that the climate is not changing and that historical climate data can be effectively used to predict future drainage design requirements. Unfortunately, recent studies on climate change point to increases in rainfall intensities that would most likely result in adverse effects on existing drainage systems. Consequently, there is a real potential for more frequent drainage system failures and increases in the resulting flood damages and related health problems in areas subjected to increased precipitation.

If global warming increases the occurrence of damage causing rainfall intensities, then the cost savings obtained from maintaining current design standards will be outweighed by the costs of future damages. We may only need to look at our recent past to predict what could happen in our not-too-distant future. In the last ten years alone, 25 major flooding events in Canada accounted for almost $1,000,000,000 in losses. Municipalities, under criticism by citizens and insurance companies for the apparent lack of drainage conveyance capacities, have responded that they are the victims of extraordinary natural events beyond their control.

Objectives

In an effort to shed light on these significant issues the study looked into quantifying the impacts of climate changes on the water resources systems, specifically the urban and rural drainage systems. The validity of maintaining current infrastructure design methods, policies and regulations was also reviewed while seeking viable adaptive solutions.

Study Approach

A work plan was developed to achieve the objectives and accordingly, this study is divided into three parts; one that evaluates the climate change impacts, one that reviews the current water resources engineering regulatory framework and, one that explores potential adaptation alternatives. A discussion forum was also organized within the scope of this study to increase the exposure of the proposed solutions and gain additional input.

A sensitivity analysis approach was used as a convenient means of evaluating the climate change impacts on drainage design methods. The climate change impacts on different types of drainage systems were also investigated. Hypothetical unit land areas was used for the former analyzes while hydrological models of actual drainage systems were used for the latter. This included two urban drainage systems and one rural watershed model. Simulations of the hypothetical unit areas had the advantage of allowing the assessment of many physiographic conditions, such as different land uses, whereas simulations using existing drainage systems extend the assessments to real world conditions.

Selection of Precipitation & Temperature Data

As previously mentioned, the technical analyses were completed using a sensitivity analysis approach. Accordingly, a reasonable range of precipitation and temperature values were required for input to the hydrological models. Following a review of recent and pertinent research, it was felt that hydrological simulations based on increases of up to 20-percent in rainfall intensities would be realistic and justifiable. Also, an increase in the air temperature range from 2 to 4 degrees Celsius was also deemed adequate for this study.

Analyses and Results

Prior to initiating the analyses, a review of drainage design and analyses methods was completed to determine the appropriate engineering tools to assess. Two of the most prevalent design models were identified and retained. They include: the Rational Method and the Hydrograph Methods that include both single rainfall event hydrograph simulations and continuous time series hydrograph simulations. All of these drainage design methods require input precipitation and in the case of the continuous method, temperature data is also required. All of these methods with the exception of continuous simulation models (use time series) require precipitation from historical precipitation records. Typically, this information is obtained using Intensity-Duration-Frequency data that was last published by Environment Canada in 1990.

Impacts of Increased Rainfall Intensities on Peak Flows With Respect to Several Variables of Interest Using Two Different Models

Variable	Expected Impacts
Return Periods	For any given Return Period (2 to 100 years), using either the Rational Method (RM) or the Hydrograph Method (HM), peak flows do not vary significantly. However, peak flows computed by both methods increased proportionately more than the increases in rainfall intensities (~1.1:1 for RM and ~1.8:1 for HM)
Size of Drainage Area	For any given Drainage Area (10 to 100 ha), using either method, the peak flows do not vary significantly. However, peak flows computed by both methods increased proportionately more than the increases in rainfall intensities (~1:1 for RM and ~1.8:1 for HM)
Infiltration Rate (CN)	For any given Infiltration CN value (60 to 80) used in the HM (Single Event), the peak flows do not vary significantly. However, peak flows increased proportionately more than the increases in rainfall intensities (~1.8:1 for HM).
Imperviousness	For any given Coefficient (20 to 80 %) used in the RM method the peak flows do not vary significantly. Also, the peak flows generated by the RM method increase at a 1.1 rate to the increase in precipitation. Hpwever, using the single event HM, peaks flows decrease with the Imperviousness ratio and increase with increases in rainfall intensities. For 20% Imperviousness the peak flow increase is 1.12 over the observed value for 5% rainfall increases and up to 1.47 for a 20% rainfall increase. Considering a 80% imperviousness the values are 1.07 and 1.27 for the same increases in rainfall. Using a Continuous Simulation Method (CSM) the analyses also indicate proportional reductions of the peak flow with increases in Imperviousness. However, ratios are slightly lower than those obtained by the HM. . For 20% Imperviousness the peak flow increase is 1.08 over the observed value for a 5% rainfall increases and up to 1.34 for a 20% rainfall increase. Considering a 80% imperviousness the values are 1.06 and 1.24 for the same increases in rainfall.

* - Curve Number (CN)

The first set of analyses examined the sensitivity of the drainage design and analysis methods to climate changes with respect to return period, size of drainage area, infiltration parameters and the level of imperviousness. Approximately 360 simulations were completed when considering the permutations of parameters required to generate a reasonable range of land cover types. This was accomplished by using the currently available precipitation information that reflect the period of record up to 1990 and creating four additional precipitation datasets by incrementally increasing the intensities by 5% up to 20% above the existing dataset. In a similar fashion, temperature records were created by increased the observed dataset by 2 and 4 degrees Celsius. The previous table summarizes the impacts on peaks flows using the Rational Method, the single event unit hydrograph method as well as the continuous simulation method.

A second set of analyses investigated the relative impact on runoff volume with rising values of rainfall intensities. Using the Hydrograph Method with standard Design Storms, the analyses indicate that the increases in runoff volumes stay approximately the same, that is 6 to 7 percent, for every 5 percent increase in rainfall intensity independent of the values chosen for the return period, drainage area or Curve Number (Infiltration Rate). However, as rainfall intensities increase, the runoff volume from areas with low imperviousness ratios will be proportionally higher than those for areas with larger imperviousness ratios. Results for increases in rainfall intensities ranging from 5 to 20% and imperviousness ratios of 20 and 80%, respectively, obtained from simulated design storms, are given in the following table:

Increases in Runoff Volumes as a Function of Imperviousness for Various Simulated Increases in Rainfall Intensities

Increases in Rainfall Intensities	**Imperviousness and Ratio of Future to Existing Runoff Volumes**	
	20%	**80%**
5%	1.08	1.06
10%	1.15	1.11
15%	1.23	1.17
20%	1.31	1.22

Results from a statistical analysis of annual runoff volumes obtained from a series of continuous simulations conducted with 39 years of hourly rainfall data show that areas with lower imperviousness will be more impacted by future increases in rainfall. However, the effects, when examined on an annual basis, are less dramatic as shown in the following table.

Sensitivity of Future Annual Runoff Volumes with Respect to Imperviousness for a 20% Increase in Rainfall Intensity

Imperviousness Ratio	Ratio of Predicted-to-Current Return Period of Annual Mean Runoff Volumes		
	2-year Return Period	25-year Return Period	100-year Return Period
20%	1.08	1.10	1.11
40%	1.05	1.07	1.08
60%	1.04	1.06	1.06
80%	1.03	1.05	1.05

While the expected increase in drainage geometry to accommodate the expected increases in rainfall depend on the computation method used, the fact remains that, regardless of the technique used for sizing, the future impacts of increasing rainfall intensities on the average pipe sizes and associated costs will be quite significant. The simpler design method, the Rational Method, yield less of a proportional increase than the more rigorous methods. The following table summarizes the impact on drainage pipe sizes and costs for different design methods.

Sensitivity of Pipe Sizes and Associated Costs with Respect to Rainfall Intensity and Design Method

Variable	Expected Impacts of Increased Rainfall Intensities on Variable of Interest
Average Pipe Sizes*	Computed average pipe sizes are smaller with the Rational Method (RM) than with the Hydrograph Method.
Increase in Average Pipe Sizes	The increases in required pipe sizes vary from 2% for a 5% increase in rainfall intensity to 8% for a 20% increase in rainfall intensity for the 2, 5, and 10-year return period service level using the RM method. Using the HM method, the required increases in pipe sizes ranged from approximately 5% for a 5% increase in rainfall intensity to 15% for a 20% for any of the three service levels.
Associated Average Cost	The increases in costs associated with larger pipe sizes vary from 4% for a 5% increase in rainfall intensity to 15% for a 20% increase in rainfall intensity for the 2, 5, and 10-year return period service level using the RM method. Using the HM method, the incremental costs increase by approximately 8% for a 5% increase in rainfall intensity to 15% for a 300% for any of the three service levels.

* - diameter in mm

A similar set of analyses was completed to evaluate the impacts of increasing rainfall intensities on stormwater storage facilities. The table below lists the results for a typical control scenario whereby the 100-year flows are controlled to a maximum outflow of

25L/sec/ha. Similar observations would result from the study of facilities originally designed to handle a 5-year storm.

Selected Examples of Impacts of Increased Rainfall Intensities on Storage-Related Variables

Variable	Expected Impacts of Increased Rainfall Intensities on Variable of Interest
Required Storage Volume	To control the runoff from a 100-year storm, a 5% increase in rainfall intensity will require approximately 11% more storage volume for the Rational Method (RM) and 16% for Hydrograph Method (HM) and 17% for the Continuous Simulations Method (CSM). A 20 % increase in rainfall intensity will require approximately 48% more storage volume for RM, 45% for HM and 66% for CSM. The proportional increases in required storage volume are even higher for 2 and 5-year return periods.
Service Level	The capacity of an existing storage facility, sized to control the runoff rate from a 100-year event would be exceeded by a future 1:50 year event if rainfall intensities increase by a mere 5%. Its capacity would also be exceeded by a future 1:15 year event if rainfall intensities increase by 20%.
Probability of Overtopping Storage Facility	Expressed another way, the impacts on storage capacity would be such that the probability of overtopping an existing storage facility designed to handle a 100-year event would be increased by a factor of two for an increase in rainfall intensities of 5%. For a 20% increase in rainfall intensities, the probability of overtopping the same facility would increase by a factor of almost seven.

In order to provide a more holistic insight on the sensitivity of existing drainage systems, two different existing urban sewer systems were assessed: 1) a relatively small sewer system conveying only storm water and, 2) a rather large sanitary sewer collector system that includes some storm water and infiltration. Also, an existing natural rural drainage system was also evaluated for sensitivity to climate changes.

Simulations on an existing storm sewer network in a residential subdivision in Hull, Québec consisting of approximately 4km of pipes and draining 27ha validated the previous analyses results. Considering the 5-year design level, the peak design flows at the outfall would increase by 5.3, 12.3, 16.9 and 23.4% under increases in precipitation of 5, 10, 15 and 20% respectively. Although yet-to-designed drainage systems could be sized to accommodate these increases, existing systems will face a reduction in their intended level of service as the precipitation intensities increase. The analyses for this existing area indicated that, assuming it was constructed for a 5-year level of service, a 5% increase in precipitation would reduce the level of service to 4-years while a 20% increase will reduce the level of service to 2.5-years. If this subdivision was originally designed to convey 10-year flows, the level of service would be reduced to just over 4-year under a 20% increase in precipitation.

A second existing urban drainage model was used to test the reaction of a large wastewater collection system under climate changes. The calibrated hydrological/hydraulic model of the West Nepean collector sanitary trunk sewer was used for this purpose. It serves a population of 112,000 within the City of Ottawa. The total collection area is approximately 2,440ha while the system is comprised of 71% separated sewers, 28% partially separated sewers and only 1% of the area is serviced by combined sewers. Key storm event swere used to evaluate the climate change impacts by merely increasing their intensities up to 20% as in the previous simulations. The simulation results indicated that increasing the intensities of short duration, high intensity events had a minor impact on the system. However, for long duration, low intensity storm events of roughly similar precipitation volume there was a greater impact. Also, the effective precipitation volume (volume that is not surface runoff) that impacted the system was much greater. Based on findings the following table lists expected impacts depending on the anticipated changes in climate.

Climate Change	**Expected Climate Change Impact**		
	Combined Systems	**Partially Separated Systems**	**Fully Separated Systems**
Increased rainfall event peak intensities, similar event type and annual volume	Increased risk of basement flooding. Lower level of service.	Minor impact on peak flows and available capacity.	Minimal impact on peak flows and available capacity.
Increased frequency of large volume and high intensity rainfall events, same annual volume	Increased risk of basement flooding. Lower level of service. Potential increase in CSO volume but reduced CSO frequency.	Increased risk of surcharge and basement flooding. Lower level of service.	Potential impact on available capacity for growth. Increased risk of sewer surcharge and risk of flooding.
Increased rainfall event frequency and annual event volumes, minimal increase in peak intensities or frequency of large volume events	Minimal impact on system capacity. Increase in CSO volumes and frequencies.	Potential increase in risk of system flooding. Potential impact on wastewater treatment costs (volume and quality).	Potential impact on wastewater treatment (volume and quality).

Simulated increased rainfall intensities were also applied to the Clyde River sub-catchment, a rural area located west of Ottawa, in order to assess changes in peak flows, flow volumes and surface water elevations resulting from predicted climate change on an existing rural drainage system. The calibrated distributed hydrological model of this 880km^2 basin was subjected to the same increases in precipitation as the previous simulations except temperature was also modified in this case. Increases in precipitation yielded an almost direct increase in flow volumes and peak flows when temperature was not changed from the observed values. However, increasing the temperature by 4 degrees Celsius caused decreases in peak flows and water surface elevations (1%) and also flow volumes (2%) were compared to those of the 1992 base year.

The more evident consequences of an increase in flow volume, peak flow and the related water surface elevation on this natural stream will be increased flooding (magnitude, extent and frequency) and erosion. As a result, rural drainage system infrastructures such as culverts and bridge openings will experience a reduction in their level of service under a climate change scenario similar to those previously identified in this report. For example, a culvert designed in 1980 to safely convey a 25-year storm flow will perhaps be able to carry only a 10-year storm in 2015. Also, dam and reservoir operations will require updating to ensure the climate change impacts are incorporated within the design variables including operating rules.

Regulatory Framework

The management of water in Canada is set within a complex web of plans, regulations and policies administered by three, sometimes four levels of government. This has resulted in inconsistent application of rules within provinces and across the country.

Local governments are generally responsible for land use planning and regulation of new developments. As a result, stormwater management is generally under the authority of municipal governments but provincial governments, under the Constitution Act, may still exert significant powers over the design and construction of related works. However, provincial statutes and regulations regarding flood prevention and control as well as their means of application and the degree of provincial supervision and intervention vary widely. In fact, few provincial governments appear to take a pro-active stance regarding the management of stormwater.

The Flood Damage Reduction Program (FDRP) allows the federal government to play a guiding role in stormwater management in geographical areas normally under provincial jurisdiction. FDRP policies are intended to discourage future development in designated flood risk areas. Unfortunately, the FDRP design criterion, based on flood frequency, is a moving target as a result of climate change. Floodplain design specifications derived from current statistics will be different from ones done 20 years from now.

Adaptive solutions

The current legislative situation makes the implementation of adaptive measures to deal with the impacts of climate change a significant challenge. As a result, there is a need for changes in the way stormwater activities and supporting policy and legislative instruments are administered across Canada.

There is an opportunity for the federal government to take the lead in fostering the creation of a coherent planning framework to guide stormwater management in Canada. A revised federal water policy developed with provincial assistance could provide the appropriate initial discussion framework. The next phase would be an expanded consultation process involving the municipalities, other major stakeholders and the public.

Changes at the policy level must translate into improvements to the drainage design methods and their applications as well as construction procedures used by local governments. Where possible, relevant national standards and guidelines should be adapted to deal with the new drainage design requirements resulting from climate-induced changes to hydrologic regimes.

The provinces should aggressively pursue the development of comprehensive provincial water policies and a formal watershed-based planning process, such as the one developed by Alberta, with stormwater management as an integral element of these initiatives. As a complementary measure, the provincial authorities should consider making the creation of ‘Master Drainage Plans’ or ‘liquid waste management plans’ a mandatory requirement for local/regional governments. Canadian municipalities should also carefully examine the 3-level administrative approach promoted by the Greater Vancouver Sewerage and Drainage District (GVSDD) for dealing with stormwater management for it has the potential to generate long-term cost savings for those municipalities that are located within high risk flood-prone areas.

Drainage regulations, sparse at best in some provinces, will need to be upgraded while taking into account revised national standards. Regulations cannot be effective without means to ensure their application. Enforcement must however strike the right balance between the threat of legal action against non-complying local authorities and the reward of economic incentives to those municipal governments that are pro-active and diligent in the conduct of their drainage design and construction activities.

Provincial governments, in conjunction with their municipalities, should lead awareness and educational campaigns directed at its citizens to better inform them on the issues of stormwater management, the expected impact of climate change and the projected costs of dealing with potential consequences such as recurring floods.

A second avenue for adaptive solutions deals with the current design philosophies. Drainage design criteria should be reviewed and revised based on a cost-benefit analysis and risk assessment considering the threat of climate change. Life-cycle implications must be built in to the resulting design criteria.

Local governments should also move away from the ‘level of service’ approach that, under global warming conditions, entails ever-changing design levels. A sliding index anchored to a reference year, similar to the Consumer Price Index, could be explored as a means of determining appropriate design criteria. This would allow for an adaptive process that will be applicable for a relatively long time period.

A third area that can potentially yield adaptive solutions is changing current methods of analysis and design. Instead of using simplistic methods such as the “Rational Method” which is reliant on historical data (IDF-based), deterministic modeling, which is based on using projected meteorological time series might be a more appropriate analysis & design method. There will be a need to adopt simple but adaptive design approaches to counter potential increases in complexity of the design methods due to the changing climate. This review process should take place within a larger framework establishing national guidelines on drainage design and analyses methods.

INTRODUCTION

Past and current water resources design philosophies, standards and methods of analysis are based on the premise that <u>the climate is not changing and that historical climate data can be effectively used to predict future trends and drainage design requirements.</u> Drainage infrastructures such as sewers and culverts have always been designed according to this philosophy. Unfortunately, the expected changes in the climate regime could result in our current water resources design approach being rendered inappropriate to maintain the desired level of service and protection (Bruce et al, 1999). Furthermore, since many drainage systems do not incorporate formal "safety factors" in sizing structures, their ability to safely convey flow increases beyond their original design level is limited. As a result, there is a real potential for more frequent drainage system failures, such as increased flooding in areas subjected to increased precipitation.

The direct economic impact of increases in flooding, including the litigation costs, can quickly be expressed in millions of dollars per event in urban areas. A recent compilation by the Insurance Bureau of Canada indicates that in the last ten years, 25 major flooding events in Canada accounted for almost one billion dollars in losses (adjusted for inflation and in 1999$). Frustrated citizens and insurance companies facing huge remediation bills often claim there is a lack in the level of drainage conveyance capacities while municipalities retort the drainage systems were only designed to provide a "reasonable" level of service and, they are the victims of extraordinary natural events beyond their control. Central to this issue is the previously discussed assumption that the existing drainage systems were designed to safely convey flows using long-term meteorological statistics that are perhaps no longer valid, due to the changing climate. Disclosure and adequate articulation of the basic tenets in water resources designs could educate the public in understanding the design limitations but would not provide mitigating solutions.

In areas of increasing precipitation, the existing drainage infrastructure will likely no longer provide its citizens with the original and intended level of service and flood protection. This would invariably lead to increases in the frequency of drainage system failures such as flood damages and related health problems. Adaptations to this potential situation, that are within the scope of this study, include changes in the design methods, upgrades to the drainage systems, public awareness campaigns and, revisions to policies, regulations and insurance practices to reflect the local changes.

OBJECTIVES

The objectives of this project are: 1) to quantify the impacts of climate changes on the water resources systems, specifically the urban and rural drainage systems, 2) evaluate the validity of current infrastructure design methods, policies and regulations and, 3) seek viable adaptive solutions.

STUDY APPROACH

This study is divided into three parts; one that evaluates the climate change impacts, one that reviews the current regulatory framework and, one that explores potential adaptation alternatives. Specifically, the first major section of the study encompasses all technical analyzes and includes hydrologic model simulations to evaluate the climate change impacts on drainage systems and methods of computations. The second major section of the study reviews to existing regulatory framework including water resources management policies at the Federal, Provincial and Municipal levels of government. The third and last major section of the study carries forward the technical findings to explore holistic and viable adaptive solutions within the current regulatory framework. A local workshop was organized to broaden the exposure of the study findings in an effort to obtain input from a larger group of stakeholders that included representatives in water resources engineering, operational water resources management and, the insurance industry.

This document reports all findings and articulates adaptive solutions as well as pertinent recommendations. The layout of this document reflects the three-part breakdown whereas three main sections, A, B & C are provided and the language adopted throughout the report assumes the reader has a technical background, but is not necessarily an expert in water resources. The study team has also briefly documented the evolution of North American drainage design practices as a primer to the project and in order to educate the reader on past and current philosophies. This will undoubtedly prove helpful when evaluating the merits of various recommended alternatives.

Although this study uses local data for efficiency, a focus on broad and generic conclusions was adopted to extend the reach of the findings.

1. Analyzing the Impacts

One of the first technical tasks is to inventory the different methods of design and analysis currently being used in water resources management practice. This is not meant to be an exhaustive compilation however; the inventory will identify current methods used in engineering practice.

Following this task, a sensitivity analysis will be completed and based on using hydrological models to assess the impacts of climate change on the drainage design methods. Subsequently, the impacts of climate change on different types of drainage systems will also be investigated. Hypothetical unit land areas will be used for the former analyzes while models of actual drainage systems will be used for the latter. Simulations of hypothetical unit areas has the advantage of allowing the assessment of many physiographic conditions, such as different land uses, whereas simulations using existing drainage systems extend the assessments to real world conditions.

Rural and urban drainage type infrastructures will be assessed in order to ascertain the existing of critical thresholds within the water resources systems (analysis & design). The sensitivity of various land use changes such as urbanization and deforestation is also evaluated.

Before initiating the sensitivity analysis, a reasonable range of values for precipitation and temperature must be determined to represent the extent of climate changes. A literature review of current findings on anticipated changes in the climate was completed to select an appropriate range of values for the sensitivity analyzes. Since this study is focused on assessing impacts and alternatives at the “Drainage System or Network” level, rather than at the “Pipe” level, highly accurate changes in precipitation and temperature is not warranted.

2. Selection of Increased Rainfall Values for Hydrologic Simulations

Based on the current body of knowledge, rainfall statistics are changing. In some locations the average rainfall totals for various durations is increasing while, in others, it is decreasing. However, there is strong evidence that in either case the intensities of heavy rainfall events are on the rise. This finding is particularly important since in urban areas these increases will likely impact the performance of existing storm sewer systems and could force municipal lawmakers to upgrade sizing requirement for future drainage works.

Accordingly, the selection of climatic values that are to be used as inputs to the hydrological simulations is of paramount importance. There are two general approaches for selecting the input values. The first approach is based on either increasing values of recorded rainfall statistics at a particular location or, extrapolating values based on these given statistics. The second approach is based on selecting rainfall values generated by General Circulation Climate Models (GCM) that assume CO_2 doubling in the atmosphere. Recent findings from both approaches were reviewed.

Two studies that examined rainfall observations, one conducted in Yokohama, Japan, the other in Ottawa, Canada, show increased rainfall intensities for return periods longer than five years and ten years, respectively. The first study was reported by Asada et al (1999) while the second was conducted as part of this project. These results are based on a recording period of less than two hours in the Yokohama case and more than two hours for the Ottawa study.

Analysis of the Ottawa data reveals that the increase in large rainfall intensities (return periods of ten years or more) is not correlated to a currently discernible increase in the annual mean of the maximum rainfall intensity. It is rather associated with an increase in the standard deviation or, the spread of the annual maximum intensity values about the mean. The Yokohama data indicates an increase in rainfall intensity of up to twenty percent from one twenty-year period to the next. The Ottawa data shows increases in the ten-year return period rainfall intensity of between 17 and 30 percent for event durations of two or more hours.

The interpretation of the modelled rainfall outputs, as it pertains to drainage systems design and operation, is difficult due to the poor temporal resolution (24 hours or higher) of the GCM models used to simulate the effects of atmospheric CO_2 doubling. Modelling by Gordon *et al* (1992) and Whetton (1993) shows increases in the frequencies of occurrence of heavy 24-hour rainfall intensities (greater than 6.4mm/day) and decreases in the frequencies of occurrence of light 24-hour rainfall intensities (less than 6.4 mm/day) compared to the climatic conditions that existed under the CO_2 concentrations observed in the early 1990s. Since the heavy 24-hour rainfall intensities are expected to occur more often with climatic warming, one would expect that the rainfall intensities over shorter duration periods would also increase. This would likely have an adverse effect on urban storm drainage systems and future design requirements.

As well, Hengeveld’s research has revealed that, since the 1950's in North America, the percentage of the annual precipitation occurring in the heaviest 10 percent of a year’s rainfall totals has increased from 46 to 48 percent (Hengeveld, 1991). Moreover, both Gordon *et al* (1992) and Noda and Tokiola (1989) have observed an increase in convective rainfalls (high intensities) at the expense of non-convective rainfalls (low intensities). The above findings concur with the results of the station rainfall analyzes and the GCM modelling. Also, an examination of the Intensity Duration Frequency (IDF) graph for any location reveals that the curves for the various return periods are, in general, parallel and would remain so for a stationary climate. This means that any increase in rainfall intensity over a long duration (for the same return period) will also translate into increased rain intensities over shorter durations.

Based on the above findings, it is felt that hydrological simulations based on increases of up to 20-percent in rainfall intensities would be realistic and justifiable in this project.

3. Developing Adaptation Alternatives

Prior to engaging the alternatives seeking process, a review of the current regulatory framework was completed to understand the *environment* in which drainage systems are being designed, managed and regulated. This review serves two purposes: 1) It might in itself identify current regulatory impediments or shortcomings and, 2) It will ensure potential adaptive solutions are cognizant of the regulatory framework.

The alternatives seeking process is mainly based on assessing the response of current drainage analysis and design methods under simulated climate changes. Furthermore, potential changes in drainage design philosophies, policies and regulations will also be put forward for consideration if deemed appropriate. The study team members, consisting of municipal & water resources engineers as well as hydrologists, will formulate potential adaptive solutions based on the technical findings and their combined knowledge and experience in water resources. These potential alternatives will subsequently be presented to a larger audience of stakeholders, via a hosted workshop, in order to ascertain their validity and acceptability.

A. IMPACTS ON DRAINAGE SYSTEMS

This section of the report documents the majority of the technical analyzes completed within this study and includes all simulation findings. It is divided into four sub-sections. The first sub-section presents a discussion on the evolution of drainage systems and design methods. The second sub-section presents study findings related to the sensitivity of the different drainage analysis and design methods while the third sub-section presents the impacts of climate change on existing drainage systems. Finally, the last sub-section discusses the impacts on the design of drainage systems.

1. Standard Methods Used to Analyze & Design Drainage Systems

The art and science of hydrology may be considered to have begun with the works of Pierre Perrault (1608-80), Edmé Mariotté (1620-84), as well as other French physicists and those of the English astronomer, Edmund Halley (1656-1742). For the first time, these scientists gave hydrology a quantitative reference.

> I can foretell the way of celestial bodies, but can say nothing of the movement of small drops of water
>
> *- Galileo Galilei*

Perrault took rainfall measurements over a period of three years. By estimating the drainage area of the Seine River above a point in Burgundy (France), he estimated the runoff from the basin. He calculated that the volume of annual precipitation exceeded the river flow by a factor of six. Mariotté computed the discharge of the Seine at Paris by measuring its width, depth and flow velocity. In doing so, he essentially verified Perrault's results. Halley demonstrated that the evaporation from the Mediterranean Sea was sufficient to supply the quantity of water returned to that sea by rivers flowing into I

Over the next centuries, several researchers devoted their time to improving the methods used to measure, or estimate, rainfall amounts, flows along watercourses, and rainfall losses.

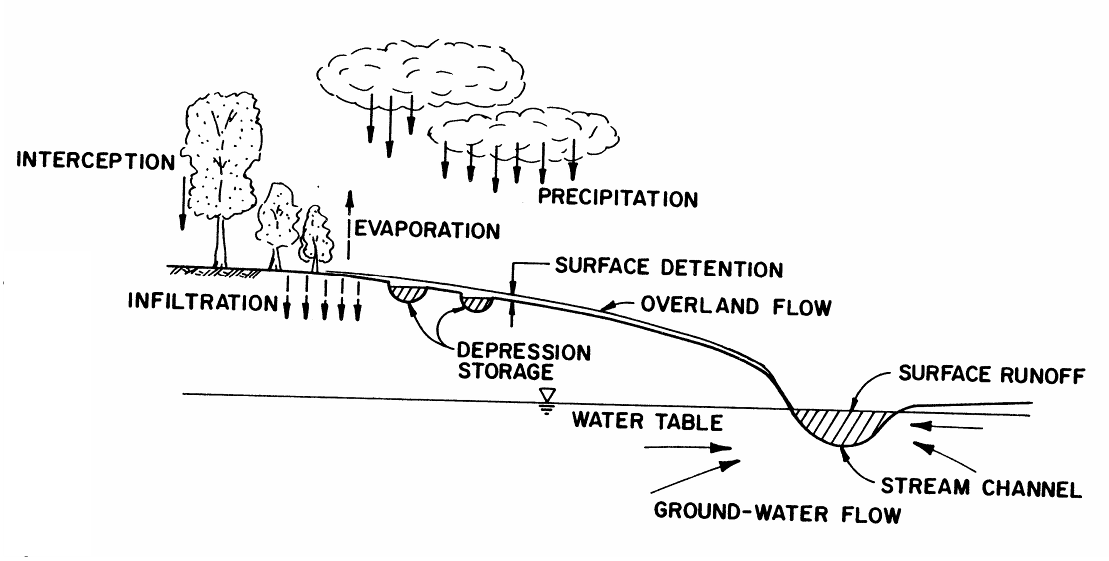


Figure A1.1: Components of the hydrologic cycle

It is from these simple initial efforts and the development of computerized simulation techniques that the methods used in today's designs of storm water infrastructures eventually emerged. As a result, there exist today two general approaches in designing and analyzing drainage systems; one approach uses statistical manipulation of observed hydrological data while the other uses hydrological simulations to explicitly characterize components of the hydrologic cycle (Figure A1.1).

Urban & Rural Drainage Systems

Drainage systems found in rural areas generally differ from those in urban areas and can be classified as either being rural or urban in nature. Rural areas for instance are for all intent and purposes entirely pervious while urban areas have a significant percentage of their surfaces that are hardened and impervious (Typically 30-40% of the total area). Also, open channels such as ditches and streams typically characterize rural area conveyance systems while closed underground conducts, such as sewers, typifies the urban drainage infrastructure. These differences explain in part why the recognized hydrologic behavior of rural and urban areas is quite dissimilar. Runoff in urban areas, for example, reacts quickly to rainfall as compared to rural areas due to the significant impervious fraction. Nevertheless, the methods of analyzing and designing either of these drainage systems are generally similar and applicable to both cases with one noteworthy exception:

- Rural drainage infrastructures on large streams are often designed using statistical methods that rely on historical flow data rather than on hydrologic simulation. However, this technique is usually not used for sizing urban type drainage systems.

Considering these issues, attention will be given to identify and document any findings that uniquely apply to either rural or urban drainage system.

Origins and Types of Urban Drainage Systems

Initially, storm water drainage systems were installed during the development of older cities to relieve street flooding and to permit the transportation of goods and services. At the same time, backyard privies and cesspools provided the means for wastewater disposal (Figure A1.2). Eventually, odors from these septic systems became discernible from several miles away and reinforced the need to transport wastes elsewhere. It was found that storm water drainage pipes were the most convenient means of resolving the problem - thus, the origin of combined sewers (Figure A1.3a).

Figure A1.2: Backyard privy (Syracuse, 1800s)

The capacities of combined sewers were generally based on some multiple of the dry weather sewage rate carrying only domestic flows. For the most part, the combined sewers provided only minimal capacities for storm water rates. Combined trunk sewers were often designed to convey maximum storm runoff of approximately one-year frequency. Interceptor sewers, constructed to divert wastewater from the receiving streams to treatment plants, were commonly designed for two to four times the average dry-weather rates. It therefore became necessary to design structures that would allow the redirection of flows along the interceptor sewers when storm water exceeded the capacity of the pipe; consequently, these structures are now known as “combined sewer overflows” (CSOs). Excess flows in period of surcharge were usually redirected to a nearby stream.

As urbanization continued to expand, so did the occurrence of CSOs. The thought of having raw sewage flowing into our streams and the resulting impact on surface water quality became unacceptable and some rethinking became necessary - thus, the origin of partly separated and separated sewers.

In areas with partly separated sewers (Figure A1.3b), only the surface drainage from streets and surrounding areas are collected by a specific storm drainage sewer. Plumbing fixtures (domestic waste water, weeping tiles and sometimes roof drains) are connected to the sanitary sewer.

In separated sewer areas, one pipe collects and transports the waste water from nearby buildings while a second pipe collects all other sources of rainfall runoff and groundwater (Figure A1.3c).

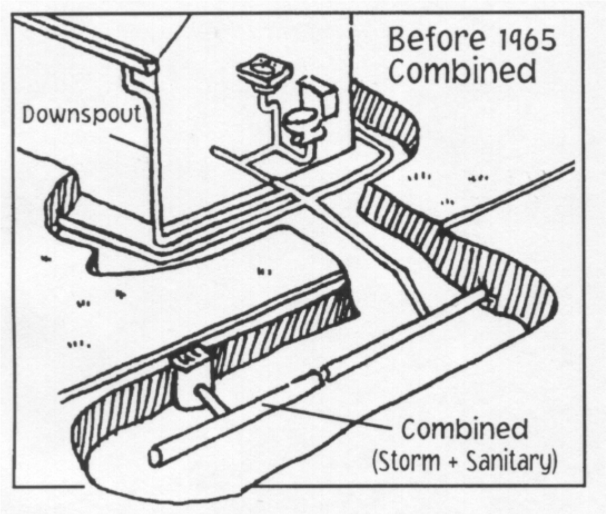


Figure A1.3a: Combined sewer system

All domestic wastes and surface runoff flows are collected and transported by one sewer pipe.

Although such systems are no longer built, they can be found in older parts of our cities.

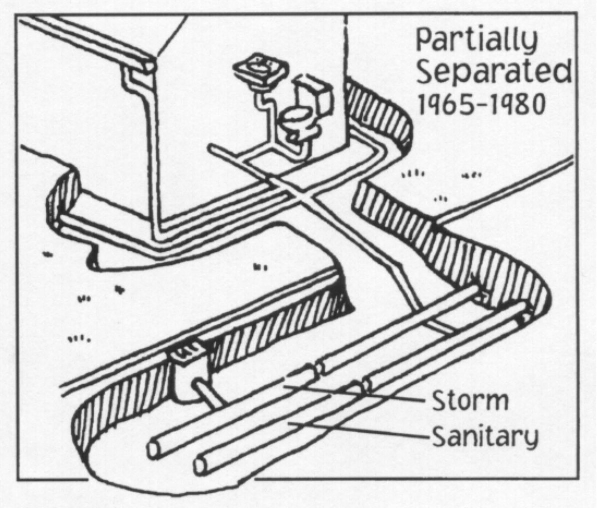


Figure A1.3b: Partially separated sewer system

All domestic wastes and weeping tile flows and, potentially, surface runoff from rooftops are collected and transported by the *sanitary sewer*.

Surface flows from the roadway and surrounding areas are collected and transported by the *storm sewer*.

Such systems were constructed from the mid-sixties to the eighties. The single pipe connection to the house was thought to be economical and simpler to install. However, weeping tile flows and roof runoff were often greatly underestimated and, over the years, were found to be the cause of basement flooding.

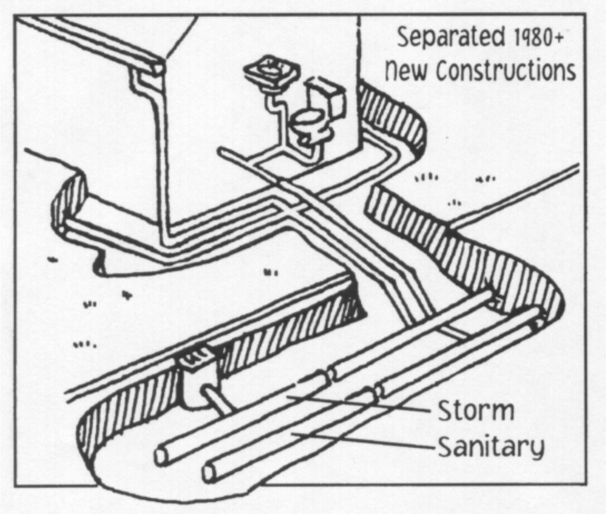


Figure A1.3c: Separated sewer system

Only the domestic wastes are collected and transported by the *sanitary sewer*.

All other surface flows are collected and transported by the *storm sewer*.

Objectives of Modern Urban Drainage Systems

As previously mentioned, urban drainage systems were initially provided to mitigate street flooding and allow unrestricted transportation of goods and services. Although this is still true today, the objectives of providing surface drainage have evolved to meet the needs of the watershed as a whole rather than the local drainage requirements. These “needs” are now usually identified by multi-disciplinary studies that define the overall stormwater management objectives of current and future developments within the area of interest. Some of the most common objectives of modern drainage systems can include some, or all, of the following:

i) Prevent local and downstream flooding for up to the 100-year storm generated flows by providing on-site and off-site storage facilities;

ii) Minimize local and downstream erosion by providing source and conveyance controls and, off-site storage facilities;

iii) Reduce the degradation of surface and groundwater quality (bacteriological and chemical) by providing source, conveyance and off-site controls;

iv) Prevent changes in surface water temperatures by promoting infiltration and subsurface flows, and by properly designing surface detention facilities to include shade and/or sufficient water depths; and,

v) Maintain groundwater recharge and stream baseflows by promoting infiltration.

Clearly, to design and analyze drainage systems incorporating any of these objectives, drainage engineers and hydrologists have to rely on comprehensive tools rather than simple rule-of-thumb methods.

Methods of Designing Urban Drainage Systems

Millions of dollars are spent each year in Canada on the design and construction of drainage systems to carry runoff from small watersheds. These structures range in size from eaves troughs, for roof drainage, to large multi-million dollar storm sewer systems for urban areas.

The basic function of a drainage system is to collect excess runoff from near buildings, roads, pavements and other areas associated with urban development and to convey it safely and economically to a suitable receiving water body. A storm drainage system must be designed to also produce social benefits and minimize environmental degradation so as to: a) maintain public health, b) provide protection from the physical damage and economic losses caused by flooding, c) create an urban environment acceptable to the community, and d) make land available for development. To meet the stringent requirements of today's integrated watershed management plans, the design of storm drainage systems must also account for the potential impacts on groundwater recharge and quality, stream bank erosion, surface water quality (biological, chemical, thermal), and the maintenance of stream baseflows.

Although systems to provide urban drainage have been in existence for centuries, it is mostly during the last twenty-five years that analytical methods to design drainage systems have sufficiently evolved to effectively address today's stormwater management objectives.

Pre-1900

Design methods to size drainage pipes and culverts were often based on experience and rules of thumb. One of the simplest design methods known involved sizing the diameter of culverts based on at a rate of 1 inch per acre of contributing area. That is, a culvert acting as a drainage outlet for a 15-acre area would have had a 15-inch diameter. This method does not take into account on-site precipitation, land use and soil characteristics. Furthermore, there is no explicit quantification of the level of service to reach failure.

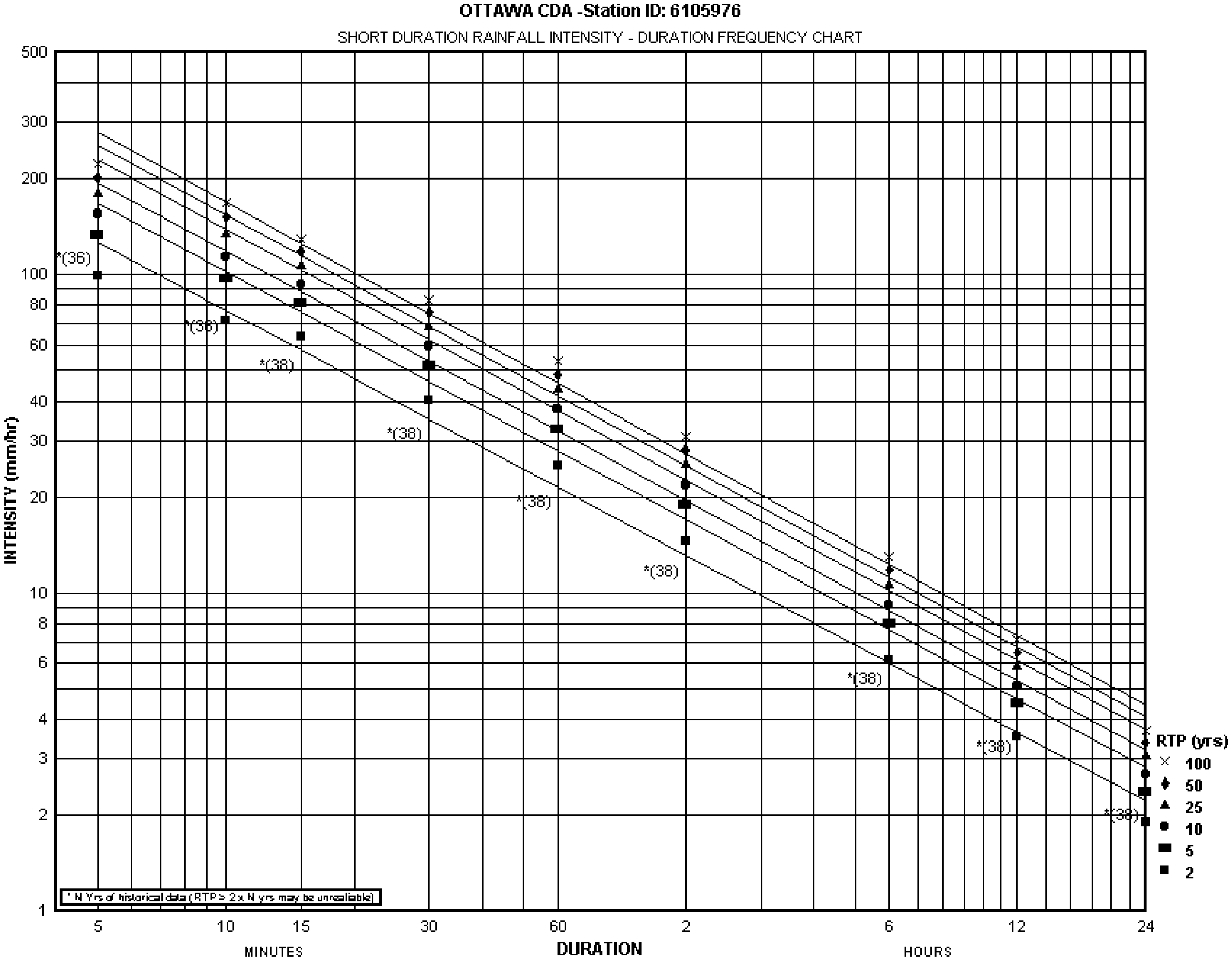
1900-Today (Rational Method)

The Rational Method for estimating peak flows was introduced in the United States by Emil Kuichling in 1889. Since then it has become the most widely used method for designing drainage facilities for small urban areas (i.e. less than 40 ha). With this method, peak flows are found with the following equation:

$$Q_P = C\ i\ A$$

where Q_p is the peak discharge, in cfs; C is a non-dimensional runoff coefficient; i is the average rainfall intensity, in in/hr, for a given return period over a duration equal to the time of concentration for the contributing area; and A is the contributing area, in acres. Rainfall intensities are most often obtained from Intensity-Duration-Frequency (IDF) curves derived from local precipitation statistics. Figure A1.1 presents the currently available IDF curves for the Ottawa CDA meteorological station. Typical values for runoff coefficients ‘C’ are usually selected from textbook tables such as those presented in Table A1.1.

Figure A1.1: Ottawa CDA Station IDF Curves



The choice of the design storm return period should ideally be selected on the basis of economic efficiency. In practice, however, the notion of economic efficiency is typically replaced either partly or wholly by the concept of level of protection also referred to as “level of service”. The selection of this level of protection (or return period), which actually refers to the exceedence probability of the design storm rather than the probability of failure of the drainage system, is largely based on local experience. Typical return periods for the design of various drainage systems types are given in Table A1.2.

Table A1.1: Typical Composite Runoff Coefficient, by Land Use*

Land Use	Runoff Coefficient
Business	
Downtown	0.70 to 0.95
Neighborhood	0.50 to 0.70
Residential	
Single Family	0.30 to 0.50
Multi-units, detached	0.40 to 0.60
Multi-units, attached	0.60 to 0.75
Residential, bungalow	0.25 to 0.40
Apartment	0.50 to 0.70
Industrial	
Light	0.50 to 0.80
Heavy	0.60 to 0.90
Parks, cemeteries	0.10 to 0.25
Playgrounds	0.20 to 0.35
Unimproved (natural)	0.10 to 0.30

* The range of "C" values presented are typical for return periods of 2 to 10 years. Higher values are appropriate for large design storms. Imperiousness ratios and "C" values can be related with, C= 0.9 IMP + 0.2 (1-IMP).

Table A1.2: Typical Design Storm Frequencies

Land Use	Design Storm Return Period
Minor Drainage Systems (storm sewers)	
Residential	2 to 5 years
High value general commercial area	2 to 10 years
High value downtown business	5 to 10 years
Major Drainage System Elements (overland flow paths, detention ponds, etc..)	up to 100 years

Experience has shown that, when properly applied, the Rational Method can provide satisfactory estimates of peak discharges for small catchments where storage effects are insignificant. The method is however not recommended for drainage areas much larger than 40 hectares or where ponding of stormwater within the catchment might affect peak discharges, or where the design as well as operation of large drainage facilities is to be completed.

If the local rainfall statistics are affected by climate change, so will the given IDF curves. Therefore, these changes will directly impact the computed peak flows, whether they are calculated with the Rational Method or any other method using the IDF curves.

1975-Today (Hydrograph Methods)

With the development of computers, it has become possible to undertake more complex analyzes that allow for a better representation of the rainfall-runoff processes of the hydrologic cycle. Typically, with such methods (often called simulation models), a rainfall hyetograph is first produced. Then abstraction and interception losses, as well as infiltration and surface detention are taken into account to produce a discharge hydrograph that can then be used to determine sewer sizes and to design more complex drainage structures such as detention ponds.

Although models are not a substitute for field-gathered data, they can be used when direct measurements are either impossible or impractical (e.g. analysis of future flow conditions). Furthermore, the use of models can help answer ‘what if’ questions and assist in the evaluation of various design alternatives.

There are numerous hydrological computer models now available to engineers for the analysis and design of drainage systems, including: HYMO, OTTHYMO, SWMHYMO, VisualOTTHYMO, QUALHYMO, SWMM, OTTSWMM, HEC-1, SCS-TR55, ILLUDAS and STORM. Of these, SWMHYMO, QUALHYMO, SWMM, ILLUDAS and STORM offer continuous simulation capabilities while the other models are used for single rainfall event analyzes.

Although there is a wide variety of model from which to choose, the basic simulation approach is quite similar for each model: A storm profile and the physiography are specified and the model produces a hydrograph at the outlet of the watershed. The rainfall to runoff transformation is carried out in several simulation steps, namely: obtain the excess rainfall by removing the initial and infiltration losses from the input rainfall hyetograph, transform the rainfall excess to a runoff hydrograph by convolution with a unit hydrograph and finally, route the runoff hydrograph along any given channels and ponds.

Standard temporal distributions of rainfall, commonly known as “Design Storms”, are often used in models for the design of drainage systems. Typical design storms include the AES-12hr, AES-1hr, SCS-24hr, SCS-6hr, Huff, Chicago, etc. With the exception of the Chicago design storm, only the total rainfall volume (selected from a local IDF curve) is required to compute the design storm intensities since their temporal distributions are provided by the given pre-established mass curve. The Chicago design storm is entirely derived from local IDF curves, that is, for any duration, the storm’s average rainfall intensities is equal to the corresponding selected IDF curve intensity. Consequently, the Chicago design storm is the only design storm that incorporates, within its duration, all rainfall statistics of the selected IDF curve. Consequently, the Chicago design storm is often selected for urban drainage design projects in Canada as it also yields results comparable to those obtained with the Rational Method when it is properly applied.

A key assumption that is implicitly used by drainage engineers when applying single-event hydrologic models is that rainfall of a given frequency produces peak flows of the same frequency. This underlying assumption is often violated given that the variability of the antecedent soil moisture conditions and the time distribution of rainfall events are not taken into account in transforming rainfall to runoff. The potential errors of this assumption can be can be avoided by establishing design flows from frequency analysis of simulated peak flow records. With current computing technology, available hourly precipitation data can be efficiently converted into hourly flow records by means of continuous hydrologic simulations. Subsequently, statistical analyzes can then be completed on the simulated annual peak flows to yield appropriate hydrologic frequency design data.

Intensity-Duration-Frequency Curves

It is now perhaps more obvious that the statistical information obtained from IDF curves plays an important role in water resources engineering as was presented in the previous discussions on the different drainage design and analysis methods. Consequently, a closer review of this important source of information is clearly warranted to better establish potential impacts and identify any basis for change or improvement.

IDF curves are calculated from rainfall data recorded during many independent storms and for periods of time. Extrapolation of frequency curves for return periods greater than twice the length of record will result in unacceptable inaccuracies. The most recent set of IDF curves published by the Meteorological Service of Canada (MSC) – Environment Canada are based on rainfall recorded up to and including 1990.

An intensity-duration-frequency (IDF) curve yields the intensity of rainfall corresponding to a specific storm duration and frequency at a given station. To prepare these curves, meteorological agencies such as the MSC determine the largest rainfall for each of various durations for each year of record from the rain gauge charts and rank them in order of magnitude for each specified duration value. A frequency analysis is then performed on the annual maximum values to determine the return periods of different intensities for each duration value. The results can then be plotted on a graph showing the relationships between rainfall intensity, duration and frequency for a particular station as shown on Figure A1.1. Curve fitting techniques can be used to generate a smooth fitting function that can subsequently be use to interpolate rainfall intensities across the entire range of durations.

MSC also publishes the 95% confidence limits for the 5-minute to 24-hour intensities of the various return periods, but engineers rarely use this information. The confidence limits vary from station to station based on the historic recording period and measurement errors. The Ottawa CDA Station IDF curves for example, can have a 95% confidence limit of ±10% to 20% of the average intensity value for the 2-year and 100-year return periods, respectively.

It is important to point out that changes in climate due to global warming will modify the statistics underlying local IDF curves and will therefore impact the distribution of the Chicago design storm. Other design storms, such as the SCS-24 hr and AES-12 hr storms will only be affected by changes to the 24-hour and 12-hour rainfall volumes respectively.

Design Return Period / Level of Service

The selection of a design return period is largely made on economic and level of service basis rather than on meteorological considerations. Longer return periods will give systems with greater capacities, providing higher level of services at higher costs. Many factors influence the selection of the best balance between expenditure and the level of service to be provided. These include factors such the local meteorology and the physiography (soils versus rock trenching) for example.

The design return period is usually selected by the municipality to provide a certain level of protection against flooding. Typically, sewer systems are sized to convey runoff for storms having return periods from 2-years to 10-years. Overland flow routes, the major drainage system, as well as stormwater storage facilities are typically designed to hold flows from precipitation events having return periods as high as 100-years. Ideally, the return period should be selected to yield an optimum design whereby the total costs, investment plus damage, would be minimized.

Liabilities and Responsibilities Associates with Drainage Systems

Under English common law, a “cause of action” is a right to sue an individual or group - that is, to bring a complaint before a judge and ask for compensation or an injunction to stop the offense. There are numerous common-law causes of action. With respect to water and environmental management, the most common of these are nuisance, riparian rights, strict liability, trespass, and negligence.

Court decisions concerning liability for damages associated with drainage works are far from uniform. However, some principles appear to be commonly accepted. According to McGhee (1991) a city cannot be required to provide sewerage works, nor can it be held liable if it is not provided. Once such service is furnished, however, the community and its officials assume certain responsibilities for damages to health, property and the environment that may result from unsatisfactory design, construction, or operation of the system. In addition to local damages, cities can also be held liable for adverse downstream impacts, such as flooding and erosion, from uncontrolled stormwater flows.

The need to review society's approaches in designing both stormwater conveyance and stormwater control works is becoming increasingly clear as shown by the escalating number of legal actions to determine who should pay for damages resulting from a significant rainfall event. If global warming increases the occurrence of damage causing rainfall intensities, as has been suggested in recent literature, then the cost savings in design and the inadequate safety factors in hydrologic computations will likely be outweighed by the costs of future damages.

2. Impacts on Methods Used to Analyze and Design Drainage Systems

As a first step in assessing climate change impacts on drainage systems, a sensitivity analysis will be completed on the different groups of drainage analysis & design methods. A reasonable range of parameters will be established for this analysis based on literature reviews and, the study teams experience in water resources engineering. The sensitivity analysis will be conducted on unit areas of simple drainage networks with watersheds of different land use covers. Deforestation and urbanization scenarios will also be assessed. This component of the project will provide the study team with a feel for the level of sensitivity, or critical threshold levels that are to be anticipated from changes in precipitation. This is particularly important considering the more complex quantitative assessment that follows. Keeping in mind that the focus is on infrastructure, engineering practices such as safety factors will be addressed.

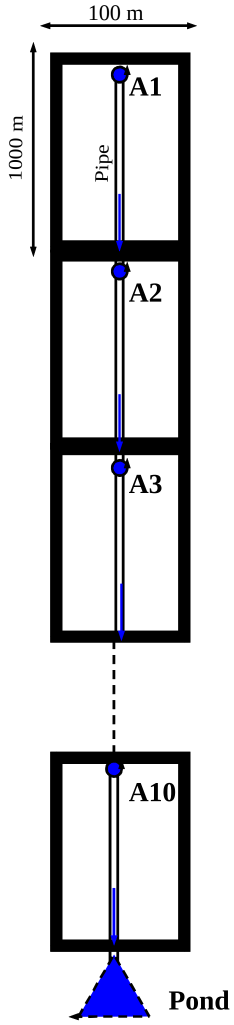
Sensitivity Analysis

General Approach

To assess the sensitivity of the simulated results to changes in precipitation, the Rational Method and the Hydrograph Model SWMHYMO, both accepted hydrologic design methods, were used to compute peak flows, pipe sizes and end of pipe storage requirements for areas of various characteristics. As depicted by Figure A2.1, the areas consist of ten subcatchments, each being 10.0ha in size and linked by 1,000m pipes. Using this multiple unit watershed schematization, various drainage scenarios were simulated by varying hydrologic parameters on each surface area. For example, imperviousness and infiltration parameters were set to different values on each unit area in order to simulation a range of land cover types. Simulations were completed with existing design precipitation data plus precipitation values increased by 5, 10, 15 and 20 percent to represent the postulated change in rainfall statistics resulting from climatic change.

Using the Rational Method, peak flows at the outlet of each of the ten sub-catchments were obtained for four imperviousness ratios. For each scenario, the existing 2 to10 year Ottawa CDA station IDF curves were used for sewer pipe sizing and the 2 to 100 year IDF curves were used to compute the end-of-pipe storage requirements. The costs associated with the resulting storm sewer pipes and pond volumes were also computed. These results were then compared with those obtained from similar IDF curves but with increased rainfall intensities. This resulted in a total of 120 simulations. The combination of conditions represents the domain of today’s typical urban drainage designs.

Using a series of synthetic design storms, a similar exercise was conducted with the hydrologic model SWMHYMO. In addition to varying the imperviousness of the sub-catchments, the Curve Number (CN) value for the pervious portion of each area was also varied to simulate varying degrees of soil infiltration capabilities. As such, CN values of 60, 70 and 80 were used that represent soil types such as sand, loam and clay. As with the Rational Method analyses, storm sewers were sized for the 2 to 10-year storms while end-of-pipe storage requirements were evaluated for the 2 to 100-year events. This resulted in a total of 360 simulations when considering all the permutations of different parameters.



<u>Unit Area Characteristics</u>

A1=A2=A3=...A10 = 10 ha
Imperviousness(1 = 20%, 40%, 60%, 80%
Curve Numbers for pervious surfaces(2 = 60, 70, 80
Model default values(3 used for Depression Storage, Surface Slopes, Surface Roughness and Lengths

<u>Pipe Characteristics</u>

Length = 1000 m
Slope = 0.15%
Manning=s roughness coefficient = 0.013
Diameter = varies based on computed peak flow

<u>Pond Characteristics</u>

Volumes obtained from the following release rates:
!Qrel = 0.5 m^3/s
!Qrel = 1.0 m^3/s
!Qrel = 1.5 m^3/s
!Qrel = 2.0 m^3/s
!Qrel = 2.5 m^3/s
!Qrel = 5.0 m^3/s
!Qrel = 10.0 m^3/s
!Qrel = 15.0 m^3/s
!Qrel = 25.0 m^3/s

Notes:1) For the Rational Method the Runoff Coefficient is computed fro
the Imperviousness based on RC= 0.9 x Imp + 0.2 x (1-Imp).
2)CN values are only used with the Hydrograph Model and applies
only to pervious surfaces.
3)Applies to Hydrograph Model only.

Figure A2.1: Description of Unit Areas

In addition to the design storm analysis conducted with the hydrologic model, continuous simulations with thirty-nine years of hourly precipitation data was used to further evaluate potential changes in peak flows, runoff volumes, and end-of-pipe storage requirements when using a continuous simulation design approach. For these simulations, the continuous existing rainfall record was modified to study the effects of increasing rainfall intensities caused by climatic change. The modifications are described in the following section. The results obtained from the thirty-nine years of continuous simulations were subsequently interpreted by means of frequency analyzes.

The sensitivity of the simulated results (i.e. peak flows, pipe sizes, end-of-pipe storage requirement and costs) to changes in rainfall intensities were evaluated based on the various input parameters (i.e. size of the drainage areas, imperviousness, Curve Number and return period)

Finally, the results obtained from the two design methods, for any given scenario, were also compared to identify relative sensitivity between the design methods.

Rainfall Data Used in the Simulations

Rainfall data from the Ottawa CDA climatic station was used as meteorological inputs to the various design methods. Based on a literature review, global warming can be expected to increase short-term rainfall intensities, in some areas, by as much as 20%. For the applications of the Rational Method and the Hydrograph Model as well as the derivation of design storms, the rainfall intensities of the Ottawa CDA IDF curves were increased by 5% to 20% in increments of 5%. For the application of the continuous Hydrograph Model SWMHYMO, hourly rainfall intensities that were above the mean hourly rainfall intensity of 1.6 mm/hr (based on 39 years of record) were increased by 5% to 20% of the difference between the actual value and the threshold value. In order to maintain the same average rainfall volume over the period considered, rainfall intensities that were below the average value of 1.6 mm/hr were reduced by 5% to 20% of the difference between the actual value and the average.

Results

The simulations results were summarized with respect to impacts on:

1) Peak flows;
2) Runoff volumes;
3) Required pipe sizes and associated costs and;
4) Control storage requirements and associated costs.

For both design methods (ie. Rational Method and Hydrograph Method) each of the above aspects were compared to other design parameters such as: i) return period, ii) drainage area, iii) percentage imperviousness and, vi) soil infiltration (for Hydrograph Method only)

Impacts on Peak Flows

Impacts of Increased Rainfall Intensities on Peak Flows of Various Return Periods

A review of the results shown in Table A2.1a, shows that the peak flows computed with the Rational Method increase almost directly with the rise in rainfall intensities. The slightly larger proportional increase in peak flows resulting from the higher rainfall intensities is linked to the reduction in the travel time that is associated to higher flows. Also, based on the simulation results presented in Table A2.1b, it can be concluded that peak design flows computed with the Hydrograph Method are more sensitive to increases in rainfall intensities than the Rational Method. This can be explained by the fact that, unlike the Rational Method, the Hydrograph Method simulates the runoff contribution from pervious land surfaces. Pervious areas can infiltrate significant fractions of the rainfall until they reach their saturation state. However, as rainfall is increased, these areas reach their saturation level sooner, thereby contributing proportionately more runoff.

Table A2.1a: [Rational Method] Sensitivity of Future Peak Flows with Respect to the Return Period

Increases in Rainfall Intensities	Return Period and Ratio of Future to Existing Design Flows*			Averages
	2 yr	5 yr	10 yr	
0%	***1.78***	***2.39***	***2.81***	***2.33***
5%	1.06	1.06	1.06	1.06
10%	1.11	1.11	1.11	1.11
15%	1.17	1.17	1.16	1.17
20%	1.23	1.23	1.22	1.23

* sample size = 40, represents the average of results obtained for four imperviousness ratios x ten sub-catchment areas

- italics/bold values represent the simulated peak flows in m^3/s

Table A2.1b: [Hydrograph Method] Sensitivity of Future Peak Flows with Respect to the Return Period

Increases in Rainfall Intensities	Return Period and Ratio of Future to Existing Design Flows*						Averages
	2 yr	5 yr	10 yr	25 yr	50 yr	100 yr	
0%	***2.23***	***3.30***	***4.04***	***5.16***	***6.02***	***7.03***	***4.63***
5%	1.09	1.08	1.08	1.08	1.10	1.10	1.09
10%	1.17	1.16	1.16	1.16	1.19	1.19	1.17
15%	1.27	1.24	1.27	1.27	1.30	1.27	1.27
20%	1.36	1.33	1.36	1.36	1.36	1.36	1.35

* - sample size = 120, represents the average of results obtained for four imperviousness ratios x ten sub-catchment areas x three CN values

- italics/bold values represent the simulated peak flows in m^3/s

Impacts of Increased Rainfall Intensities on Peak Flows of Various Size of Drainage Areas

The analyses results presented in Tables A2.2a and A2.2b show that the relative increase in design peak flows with respect to the increase in rainfall intensities, and computed with either the Rational Method or the Hydrograph Method, are not very sensitive to the size of the drainage area. That is, for a given increase in rainfall intensity, the increase in peak flows are practically constant, in terms of percentage, for any size of drainage area between 10 and 100 ha.

Table A2.2a: [Rational Method] Sensitivity of Future Peak Flows with Respect to the Drainage Area (ha)

Increases in Rainfall Intensities	Drainage Area (ha), Existing Peak Flows and Ratio of Future to Existing Design Flows*										Averages
	10 ha	20 ha	30 ha	40 ha	50 ha	60 ha	70 ha	80 ha	90 ha	100 ha	
0%	***1.19***	***1.66***	***1.97***	***2.20***	***2.38***	***2.54***	***2.66***	***2.78***	***2.89***	***2.99***	***2.33***
5%	1.05	1.05	1.06	1.06	1.06	1.06	1.06	1.06	1.06	1.06	1.06
10%	1.10	1.11	1.11	1.11	1.12	1.12	1.12	1.12	1.12	1.12	1.11
15%	1.15	1.16	1.17	1.17	1.17	1.17	1.17	1.17	1.17	1.18	1.17
20%	1.20	1.21	1.22	1.22	1.23	1.23	1.23	1.23	1.24	1.24	1.23

* - sample size = 12, represents the average of results obtained for three return periods and four imperviousness ratios
- italics/bold values represent the simulated peak flows in m^3/s

Table A2.2b: [Hydrograph Method] Sensitivity of Future Peak Flows with Respect to the Drainage Area (ha)

Increases in Rainfall Intensities	Drainage Area (ha) and Ratio of Future to Existing Design Flows*										Averages
	10 ha	20 ha	30 ha	40 ha	50 ha	60 ha	70 ha	80 ha	90 ha	100 ha	
0%	***1.78***	***2.63***	***3.39***	***4.13***	***4.69***	***5.16***	***5.58***	***5.98***	***6.32***	***6.62***	***4.63***
5%	1.09	1.09	1.09	1.09	1.09	1.09	1.09	1.09	1.09	1.09	1.09
10%	1.16	1.16	1.17	1.17	1.17	1.17	1.17	1.17	1.17	1.17	1.17
15%	1.27	1.27	1.27	1.27	1.27	1.27	1.27	1.27	1.27	1.27	1.27
20%	1.35	1.35	1.36	1.36	1.36	1.36	1.36	1.36	1.36	1.36	1.36

* - sample size = 72, represents the average of results obtained for six return periods x four imperviousness ratios x three CN values
- italics/bold values represent the simulated peak flows in m^3/s

Impacts on Peak Flows with Respect to Curve Number

The Curve Number (CN) is used in the Hydrograph Method to compute rainfall losses over pervious land surfaces. In theory, CN can have values from 0 to 100. However, typical values in an urban environment can range from 60 to 80. The higher the value of CN, the lower the infiltration losses and consequently the surface runoff is higher. This is demonstrated by the simulation results provided in Table A2.3 whereby the peak flow for a CN of 80 and a zero percentage increase in rainfall is almost 24% larger than the peak flow generated for a CN of 60 (ie. 5.15 m^3/s .vs. 4.16 m^3/s). Nevertheless, as demonstrated by these same results, the relative increases in peak flows with respect to the higher rainfall intensities, are not very sensitive to the selected CN value. That is, a 20% increase in rainfall intensities raises, on average, the surface runoff peak flows by approximately 36%, irrespective of the CN value.

Table A2.3: [Hydrograph Method] Sensitivity of Future Peak Flows with Respect to Infiltration Parameter, CN

Increases in Rainfall Intensities	CN Values and Ratio of Future to Existing Design Flows*			Averages
	CN=60	CN=70	CN=80	
0%	***4.16***	***4.58***	***5.15***	***4.63***
5%	1.09	1.10	1.08	1.09
10%	1.17	1.18	1.16	1.17
15%	1.28	1.28	1.26	1.27
20%	1.36	1.37	1.34	1.36

* - sample size = 240, represents the average of results obtained for four imperviousness ratios x ten sub-catchment areas x six return periods
- italics/bold values represent the simulated peak flows in m^3/s

Impacts on Peak Flows with Respect to Imperviousness

The results presented in Table A2.4a, shows that the relative increase in peak flows simulated by the Rational Method are not sensitive to the selected imperviousness ratios. That is, for a given increase in rainfall intensity, the computed peak flows are practically the same for any of the selected imperviousness ratios.

Table A2.4a: [Rational Method] Sensitivity of Future Peak Flows with Respect to the Imperviousness

Increases in Rainfall Intensities	Imperviousness and Ratio of Future to Existing Design Flows*				Averages
	20%	40%	60%	80%	
0%	***1.34***	***1.98***	***2.64***	***3.34***	***2.33***
5%	1.06	1.06	1.06	1.05	1.06
10%	1.11	1.11	1.12	1.11	1.11
15%	1.17	1.16	1.17	1.17	1.17
20%	1.22	1.22	1.23	1.23	1.23

* - sample size = 30, represents the average of results obtained for three return periods x ten sub-catchment areas
- italics/bold values represent the simulated peak flows in m^3/s

However, results obtained with the Hydrograph Method are different. As presented in Table A2.4b, the lower the selected imperviousness, the larger is the relative increase in peak flows for any given rainfall intensity increase. This can be explained by the fact that as pervious surfaces become more saturated their runoff contributions, relative to the amount of rain, also increase. A similar trend can be observed in Table A2.4c where the results of the statistical analysis of continuous simulations conducted with 39 years of hourly rainfall data are presented.

Table A2.4b: [Hydrograph Method] Sensitivity of Future Peak Flows with Respect to the Imperviousness

Increases in Rainfall Intensities	Imperviousness and Ratio of Future to Existing Design Flows*				Averages
	20%	40%	60%	80%	
0%	***3.26***	***4.07***	***5.05***	***6.13***	***4.63***
5%	1.12	1.09	1.08	1.07	1.09
10%	1.22	1.18	1.15	1.13	1.17
15%	1.35	1.29	1.24	1.20	1.27
20%	1.47	1.38	1.32	1.27	1.36

* - sample size = 180, represents the average of results obtained for six return periods x ten sub-catchment areas x three CN values
- italics/bold values represent the simulated peak flows in m^3/s

Table A2.4c: [Continuous Simulations] Sensitivity of Future Peak Flows with Respect to Imperviousness

(results shown are for 39 years of continuous simulations and for the total area of 100 ha)

Increases in Rainfall Intensities	Return Period and Peak Flows (m^3/s) (Imperviousness = 20%, CN=70)											
	2 yr		5 yr		10 yr		25 yr		50 yr		100 yr	
0%	1.59	Ratio	2.81	Ratio	3.63	Ratio	4.66	Ratio	5.42	Ratio	6.18	Ratio
5%	1.71	1.08	3.05	1.09	3.94	1.09	5.06	1.09	5.89	1.09	6.72	1.09
10%	1.85	1.17	3.28	1.17	4.23	1.17	5.43	1.17	6.32	1.17	7.20	1.17
15%	1.98	1.25	3.51	1.25	4.52	1.25	5.80	1.24	6.75	1.25	7.69	1.24
20%	2.13	1.34	3.75	1.33	4.83	1.33	6.19	1.33	7.19	1.33	8.19	1.33

Increases in Rainfall Intensities	Return Period and Peak Flows (m^3/s) (Imperviousness = 40%, CN=70)											
	2 yr		5 yr		10 yr		25 yr		50 yr		100 yr	
0%	2.08	Ratio	3.32	Ratio	4.14	Ratio	5.18	Ratio	5.94	Ratio	6.71	Ratio
5%	2.23	1.07	3.57	1.08	4.45	1.07	5.57	1.08	6.40	1.08	7.23	1.08
10%	2.37	1.14	3.80	1.14	4.74	1.14	5.94	1.15	6.82	1.15	7.70	1.15
15%	2.52	1.21	4.05	1.22	5.06	1.22	6.34	1.22	7.29	1.23	8.23	1.23
20%	2.68	1.29	4.29	1.29	5.36	1.29	6.72	1.30	7.72	1.30	8.71	1.30

Table A2.4c (cont.): [Continuous Simulations] Sensitivity of Future Peak Flows with Respect to Imperviousness

(results shown are for 39 years of continuous simulations and for the total area of 100 ha)

Increases in Rainfall Intensities	Return Period and Peak Flows (m^3/s)										(Imperviousness = 60%, CN=70)	
	2 yr		5 yr		10 yr		25 yr		50 yr		100 yr	
0%	2.67	Ratio	3.94	Ratio	4.78	Ratio	5.84	Ratio	6.62	Ratio	7.41	Ratio
5%	2.83	1.06	4.19	1.06	5.10	1.07	6.23	1.07	7.08	1.07	7.92	1.07
10%	2.99	1.12	4.44	1.13	5.40	1.13	6.61	1.13	7.51	1.13	8.40	1.13
15%	3.16	1.18	4.70	1.19	5.72	1.20	7.00	1.20	7.95	1.20	8.90	1.20
20%	3.35	1.25	4.96	1.26	6.03	1.26	7.39	1.27	8.39	1.27	9.40	1.27

Increases in Rainfall Intensities	Return Period and Peak Flows (m^3/s)										(Imperviousness = 80%, CN=70)	
	2 yr		5 yr		10 yr		25 yr		50 yr		100 yr	
0%	3.34	Ratio	4.67	Ratio	5.55	Ratio	6.66	Ratio	7.49	Ratio	8.31	Ratio
5%	3.53	1.06	4.95	1.06	5.89	1.06	7.07	1.06	7.94	1.06	8.82	1.06
10%	3.72	1.11	5.22	1.12	6.21	1.12	7.46	1.12	8.38	1.12	9.30	1.12
15%	3.91	1.17	5.50	1.18	6.55	1.18	7.88	1.18	8.86	1.18	9.84	1.18
20%	4.11	1.23	5.78	1.24	6.89	1.24	8.30	1.25	9.33	1.25	10.37	1.25

Impacts on Runoff Volumes

Runoff volumes computed with the Rational Method are directly proportional to the selected runoff coefficient and the rainfall intensities. Since the runoff coefficient for a given land use is generally taken as a constant for most drainage designs, it can be concluded that the Rational Method computed runoff volumes will be proportional to the increase in rainfall volumes. Therefore, for a 5 percent increase in rainfall intensity, the computed runoff volume would also increase by 5 percent, and so on. However, with hydrograph models which account for depression storage and variable infiltration rates, the computed runoff volume from a given surface area varies throughout the storm. This is reflected in the analyses findings presented in this sub-section of the report.

The design storms used for these simulations were derived from the Ottawa CDA IDF curves using the Keifer & Chu temporal distribution (also known as the Chicago Design Storm) having the 24-hour volumes which are given in Table A2.5 for various return period values.

Table A2.5: Design Storms and Associated 24-hour Volumes

(as per current rainfall statistics)

Storm Return Period (years)	24-hour Storm Volume (mm)
2	46.7
5	58.7
10	66.7
25	76.9
50	84.7
100	92.3

Note: For future rainfall conditions, storm intensities and volumes are increased by 5% to 20%.

Impacts on Runoff Volumes with Respect to Return Period, Drainage Area and Curve Number

As expected, increases in design storm intensities will also lead to increases in runoff volumes that must be considered in designing various stormwater management facilities (e.g. end-of-pipe storage). The results presented in Tables A2.6, A2.7 and A2.8, shows that the relative increase in runoff volume with respect to higher rainfall intensities is not sensitive to either the return period, the drainage area, or the soil infiltration. That is, for any given return period, drainage areas or Curve Numbers considered, the increases in simulated runoff volume is relatively constant and equal to 6 to 7 percent for every 5 percent increase in rainfall intensities.

Table A2.6: [Hydrograph Method] Sensitivity of Future Runoff Volumes with Respect to the Return Period

Increases in Rainfall Intensities	Return Period and Ratio of Future to Existing Runoff Volumes*						Averages
	2 yr	5 yr	10 yr	25 yr	50 yr	100 yr	
0%	***28.61***	***38.75***	***45.70***	***54.90***	***62.00***	***69.10***	***49.84***
5%	1.07	1.07	1.07	1.06	1.06	1.06	1.06
10%	1.13	1.13	1.13	1.13	1.13	1.12	1.13
15%	1.20	1.20	1.20	1.19	1.19	1.19	1.20
20%	1.27	1.27	1.26	1.26	1.25	1.25	1.26

* - sample size = 120, represents the average of results obtained for four imperviousness ratios x ten sub-catchment areas x three CN values
- italics/bold values represent the simulated runoff volumes in mm

Table A2.7: [Hydrograph Method] Sensitivity of Future Runoff Volumes with Respect to the Area (ha)

Increases in Rainfall Intensities	Drainage Area (ha) and Ratio of Future to Design Runoff Volumes*										Averages
	10 ha	20 ha	30 ha	40 ha	50 ha	60 ha	70 ha	80 ha	90 ha	100 ha	
0%	***49.80***	***49.80***	***49.80***	***49.80***	***49.80***	***49.80***	***49.80***	***49.80***	***49.80***	***49.80***	***49.80***
5%	1.06	1.06	1.06	1.06	1.06	1.06	1.06	1.06	1.06	1.06	1.06
10%	1.13	1.13	1.13	1.13	1.13	1.13	1.13	1.13	1.13	1.13	1.13
15%	1.20	1.20	1.20	1.20	1.20	1.20	1.20	1.20	1.20	1.20	1.20
20%	1.26	1.26	1.26	1.26	1.26	1.26	1.26	1.26	1.26	1.26	1.26

* - sample size = 72, represents the average of results obtained for six return periods x four imperviousness ratios x three CN values
- italics/bold values represent the simulated runoff volumes in mm

Table A2.8: [Hydrograph Method] Sensitivity of Future Runoff Volumes with Respect to Infiltration Parameter CN

Increases in Rainfall Intensities	CN Values and Ratio of Future to Existing Runoff Volumes*			Averages
	CN=60	CN=70	CN=80	
0%	***46.30***	***49.70***	***53.50***	***49.83***
5%	1.07	1.07	1.06	1.06
10%	1.13	1.13	1.13	1.13
15%	1.20	1.20	1.19	1.20
20%	1.27	1.26	1.25	1.26

* - sample size = 240, represents the average of results obtained for four imperviousness ratios x ten sub-catchment areas x six return periods
- italics/bold values represent the simulated runoff volumes in mm

Table A2.9: [Hydrograph Method] Sensitivity of Future Runoff Volumes with Respect to the Imperviousness

Increases in Rainfall Intensities	Imperviousness and Ratio of Future to Existing Runoff Volumes*				Averages
	20%	40%	60%	80%	
0%	***40.50***	***46.70***	***53.00***	***59.20***	***49.85***
5%	1.08	1.07	1.06	1.06	1.06
10%	1.15	1.13	1.12	1.11	1.13
15%	1.23	1.20	1.18	1.17	1.20
20%	1.31	1.27	1.24	1.22	1.26

* - sample size = 180, represents the average of results obtained for six return periods x ten sub-catchment areas x three CN values
- italics/bold values represent the simulated runoff volumes in mm

Impacts on Runoff Volumes with Respect to Imperviousness

As demonstrated by the results presented in Table A2.9, increases in runoff volumes, simulated with the selected design storms, are sensitive to the drainage area's imperviousness. It is seen that as rainfall intensities increase, the runoff volume from areas with low imperviousness ratios (eg. 20%) will be proportionally higher than those for areas with larger imperviousness ratios (eg. 80%). For simulated peak flows, this can be explained by the fact that as pervious surfaces become more saturated their runoff contribution, relative to the amount of rain, also increases. Also, for all imperviousness levels the increase in runoff volume is proportionally higher than the given increase in precipitation.

Table A2.10 shows comparative findings that are obtained from a statistical analysis of annual runoff volumes obtained from a series of continuous simulations conducted with 39 years of hourly rainfall data. Although these results also show that areas with lower imperviousness will be impacted more by future increases in rainfall intensities, the effects on an annual basis are less dramatic. For example, the two-year return period annual runoff from an area with an imperviousness ratio of 20% may increase by only 2% when short duration storm intensities increase by 5%. However, given the same conditions the increase in annual runoff volume could reach 8% when increases in rainfall intensities of 20%. Considering the same conditions, but with an imperviousness ratio of 80%, the increases in annual runoff volumes could be 1% to 3% for respective increases in precipitation of 5% and 20%. Therefore, the runoff volumes increase proportionately less than the increased rainfall intensities.

Table A2.10: [Continuous Simulations] Sensitivity of Annual Future Runoff Volumes with Respect to Imperviousness

(results shown are for 39 years of continuous simulations and for the total area of 100 ha)

Increases in Rainfall Intensities	Return Period of Annual Runoff Volumes (mm) (Imperviousness = 20%, CN=70)											
	2 yr		5 yr		10 yr		25 yr		50 yr		100 yr	
0%	123.80	Ratio	169.30	Ratio	199.50	Ratio	237.50	Ratio	265.80	Ratio	293.90	Ratio
5%	126.10	1.02	172.90	1.02	204.00	1.02	243.20	1.02	243.20	0.92	272.30	0.93
10%	128.30	1.04	176.80	1.04	209.00	1.05	249.70	1.05	279.80	1.05	309.80	1.05
15%	129.80	1.05	179.40	1.06	213.30	1.07	253.80	1.07	284.50	1.07	315.10	1.07
20%	133.10	1.08	184.40	1.09	218.50	1.10	261.40	1.10	293.20	1.10	324.90	1.11

Increases in Rainfall Intensities	Return Period of Annual Runoff Volumes (mm) (Imperviousness = 40%, CN=70)											
	2 yr		5 yr		10 yr		25 yr		50 yr		100 yr	
0%	184.20	Ratio	240.80	Ratio	278.30	Ratio	325.70	Ratio	360.81	Ratio	395.70	Ratio
5%	186.50	1.01	241.40	1.00	282.70	1.02	331.30	1.02	367.30	1.02	403.30	1.02
10%	188.80	1.03	248.40	1.03	287.90	1.03	337.70	1.04	374.70	1.04	411.40	1.04
15%	190.40	1.03	250.90	1.04	291.10	1.05	341.80	1.05	379.90	1.05	416.80	1.05
20%	194.00	1.05	256.30	1.06	297.60	1.07	349.80	1.07	388.40	1.08	426.90	1.08

Increases in Rainfall Intensities	Return Period of Annual Runoff Volumes (mm) (Imperviousness = 60%, CN=70)											
	2 yr		5 yr		10 yr		25 yr		50 yr		100 yr	
0%	244.50	Ratio	312.80	Ratio	358.10	Ratio	415.20	Ratio	457.60	Ratio	500.00	Ratio
5%	246.80	1.01	316.40	1.01	362.60	1.01	420.90	1.01	464.10	1.01	507.10	1.01
10%	249.20	1.02	320.40	1.02	367.60	1.03	427.20	1.03	471.40	1.03	515.30	1.03
15%	250.80	1.03	323.00	1.03	370.90	1.04	431.40	1.04	476.20	1.04	520.80	1.04
20%	254.70	1.04	328.60	1.05	377.70	1.05	439.60	1.06	485.50	1.06	531.20	1.06

Table A2.10 (continued) [Continuous Simulations] Sensitivity of Annual Future Runoff Volumes with Respect to Imperviousness

(results shown are for 39 years of continuous simulations and for the total area of 100 ha)

Increases in Rainfall Intensities	Return Period of Annual Runoff Volumes (mm)										(Imperviousness = 80%, CN=70)	
	2 yr		5 yr		10 yr		25 yr		50 yr		100 yr	
0%	304.70	Ratio	385.00	Ratio	438.40	Ratio	505.60	Ratio	555.50	Ratio	605.10	Ratio
5%	307.00	1.01	388.70	1.01	442.90	1.01	511.30	1.01	561.90	1.01	612.40	1.01
10%	309.50	1.02	392.70	1.02	447.90	1.02	517.50	1.02	569.10	1.02	620.40	1.03
15%	311.10	1.02	395.40	1.03	451.30	1.03	521.80	1.03	574.10	1.03	626.10	1.03
20%	315.30	1.03	401.30	1.04	458.40	1.05	530.40	1.05	583.70	1.05	636.80	1.05

3. Climate Change Impacts on the Drainage Systems

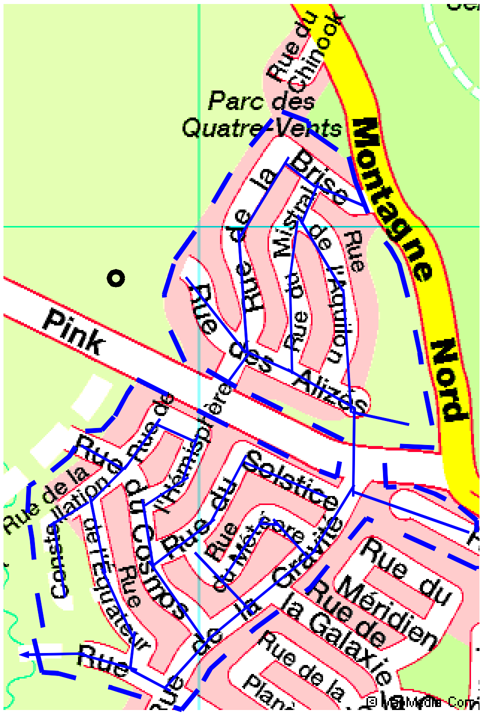
This section of the project involves completing a quantitative sensitivity analysis by simulating variations in precipitation on existing drainage systems of both urban and rural land use composition. Existing urban and rural drainage deterministic hydrologic/hydraulic models are used for this purpose. Urban areas will focus mainly on pipe flows (sewers) while rural areas will focus on open water flows (watercourses). The hydrologic and hydraulic impacts under varying precipitation will be documented. Pertinent comments on public health and safety (pollution, sewer backups, flooding, etc.) will also be reported. Specific attention will be given to determine the existence of certain critical thresholds.

Urban Drainage Systems

As previously discussed, urban drainage systems can often convey a sanitary component as well as surface storm water and/or groundwater infiltration from openings (cracks) along the pipe segments. In order to provide a more holistic insight on the sensitivity of urban drainage systems, two different existing urban sewer systems are assessed: 1) a relatively small sewer system conveying storm water only and, 2) a rather large sanitary sewer collector system that includes some sources of storm water and infiltration.

Impacts on Peak flows of a Small Urban Storm Sewer System

Peak flows in urban hydrology are very sensitive to rainfall intensities. It can therefore be expected that increases in peak flows will increase almost proportionally with higher rainfall intensities. This was confirmed by simulating peak flows for an existing urban drainage area of approximately 26.7 ha (see Figure A3.1 for other system characteristics) located in Hull, Québec.



Characteristics of Existing Drainage System

Characteristics of Drainage System

Location:	Hull, Qc
Type:	Storm
Total Area:	26.7ha
Imperviousness:	0 to 45%
Number of Pipe Segments:	62
Total Length of Pipes:	3,948m
Range of Slopes:	0.12 to 3.3%
Inlet Time:	15mns

Figure A3.1: Description of Existing Small Urban Storm Sewer System

Rainfall runoff peak flows were computed for the 2, 5 and 10-year return period events (typical level of service for sizing storm sewer pipe sizes) based on the existing Ottawa CDA IDF curves and with increases of 5, 10, 15 and 20% in rainfall intensities. A summary of the resulting peak flows at the outlet is presented in Table A3.1. It can be observed that the increases in peak flows are practically proportional to the increases in rainfall intensities.

Table A3.1: Peak system outflows based on choice of IDF curves

Design Level	IDF curves used and associated peak outflows and increases (m^3/s / %increase)				
	CDA IDF	**IDF + 5%**	**IDF + 10%**	**IDF + 15%**	**IDF + 20%**
2 year	1.30	1.37 / +5.4%	1.44 / +10.8%	1.51 / +16.1%	1.59 / +22.3%
5 year	1.71	1.80 / +5.3%	1.92 / +12.3%	2.00 / +16.9%	2.11 / +23.4%
10 year	2.00	2.14 / +7.0%	2.23 / +11.5%	2.34 / +17.0%	2.44 / +22.0%

Note: Total drainage area is 26.7 ha with an average runoff coefficient of 0.43.

Although urban drainage systems could be designed to accommodate future increases in peak flows, the consequences of increased rainfall intensities on existing drainage systems would translate to a reduction in the level of service by increasing the frequency of surface ponding and sewer backups. This is illustrated in Figure A3.2 where the peak flows of Table A3.1 are plotted against the return period.

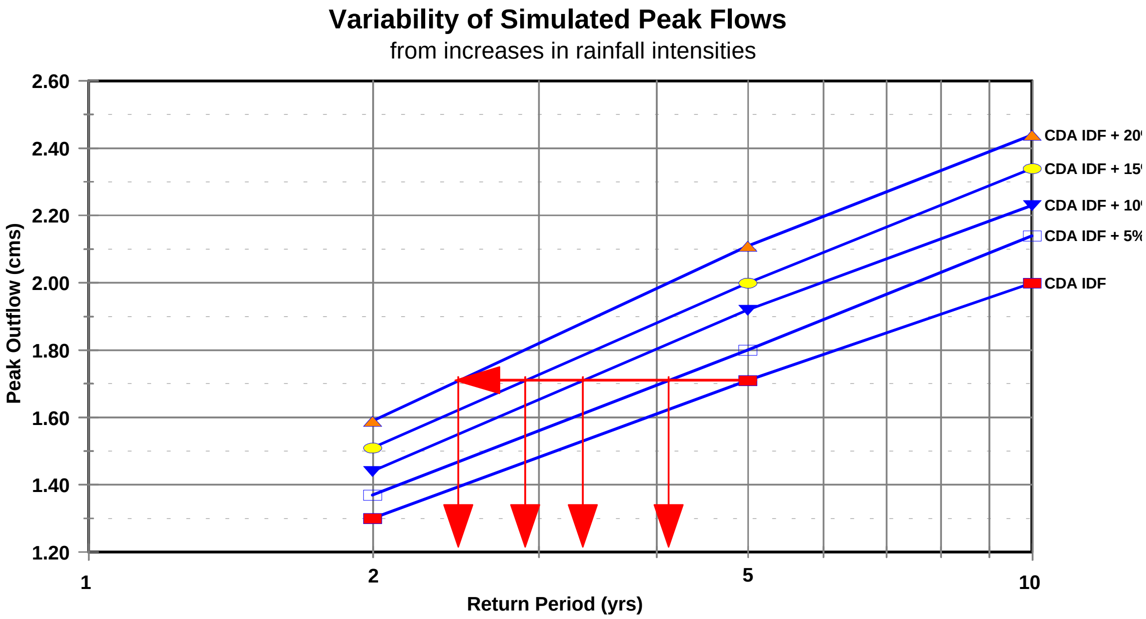
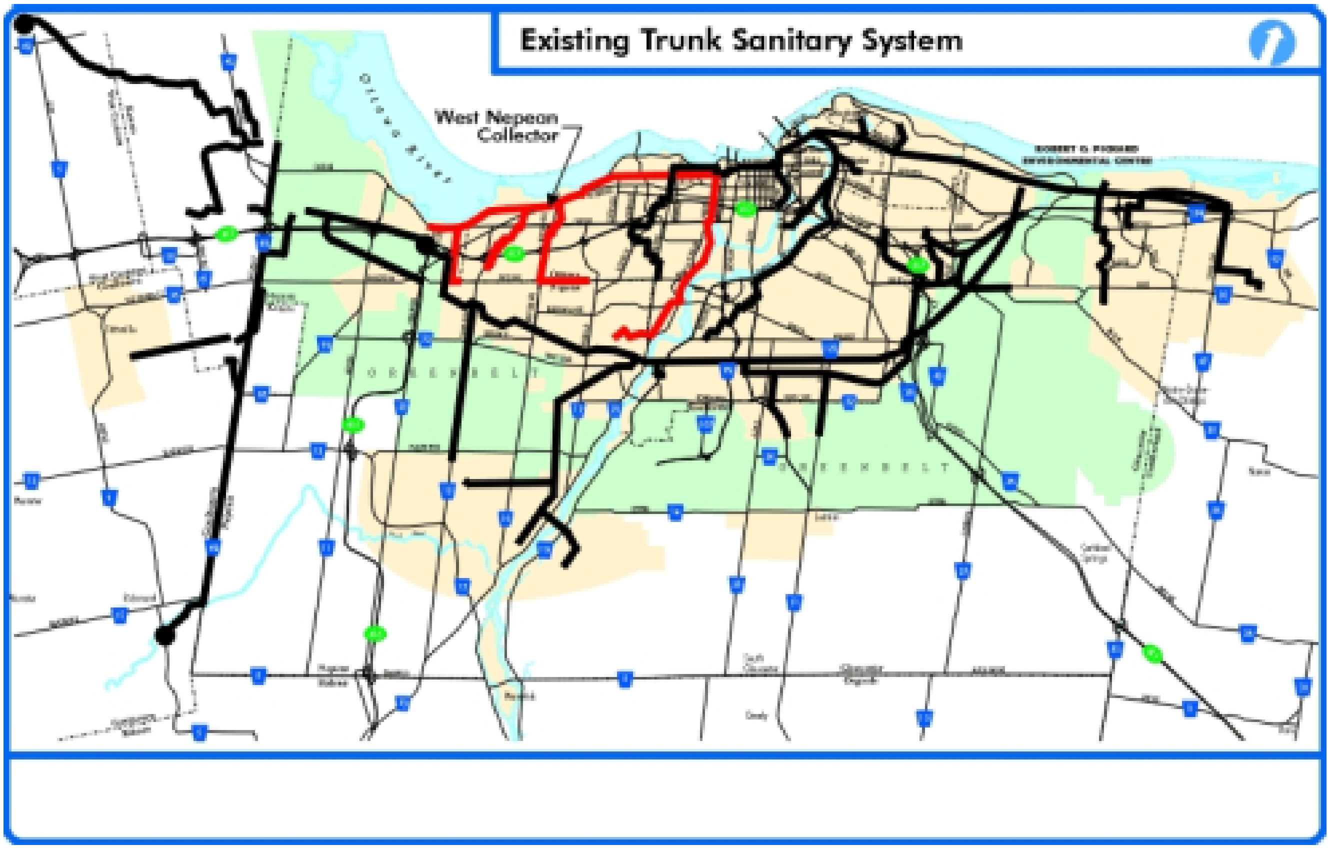


Figure A3.2: Impact of increases in rainfall intensities on peak flows and the level of service for an existing drainage system.

Using Figure A3.2 as a reference, it can be observed that an existing storm drainage system, designed to convey a 5-year design storm could only safely carry a 4-year design storm if rainfall intensities were to increase by only 5%. This represents a 20% reduction in the original level of service. Similarly, if rainfall intensities were to increase by 20%, an original 5-year design could be effectively reduced to approximately a 2.5-year design, thereby increasing the level of system failure by a factor of two. For systems originally designed for a 10-year event the outcomes is more dramatic. An increase of 20% in rainfall intensity will reduce a system's level of service to just over 4 years.

Impacts on the City of Ottawa Sanitary Sewer Collector System

The West Nepean Collector, located in the City of Ottawa, is primarily a sanitary trunk sewer that services a population of approximately 112,000 people in the northwestern portion of the city as shown on the following map. The West Nepean Collector sewer is



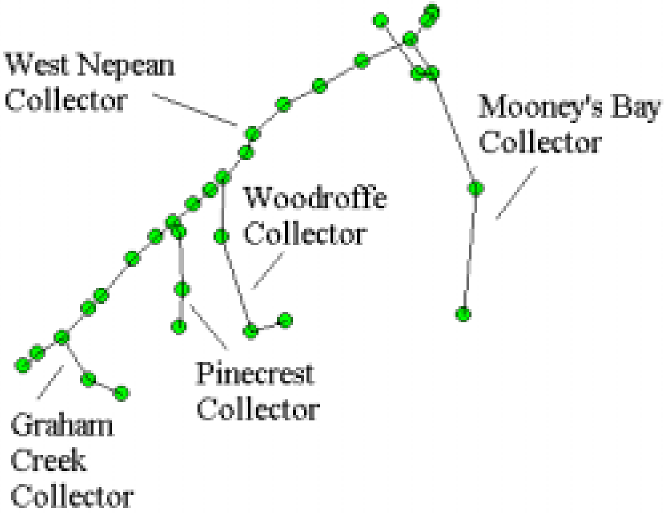
identified in red on the map while the remaining black lines depict the other collector sections draining the City of Ottawa. The total effective drainage area (not including open spaces) for the West Nepean Collector section of the system is approximately 2,440 ha, and is comprised mainly of separated (71%) and partially separated (28%) sewer drainage areas.

Approximately 1% of the drainage area also consists of combined sewers. It is important to note that a significant portion of the study area was constructed prior to 1961 when engineering practices allowed for the connection of foundation drains to the sanitary sewers. As previously discussed, these systems are referred to as partially separated. The West Nepean Collector discharges its flows to an interceptor sewer in the downtown area of the city. Flows are subsequently conveyed to the Robert O. Pickard Environmental Centre in the east end of the city for treatment.

During storm events, the West Nepean Collector is often operating under surcharge (pressure flow) amounts of extraneous flow. The source of these extraneous flows is groundwater infiltration, house foundation drains and roof eaves troughs as well as combined sewer runoff. The larger storm events can surcharge the collector such that surface breakout and overflow occur. During critical events, certain properties may be at risk of flooding. To address these problems and recommend various remedial measures, a proper understanding of the system's behavior under various input conditions was required. Consequently, the City of Ottawa has developed over the course of several years a hydrologic and hydraulic model of the drainage system. The engineering personnel are actively using this model as an analytical tool to optimize the system.

City of Ottawa Sanitary Sewer Collector System Model

The City of Ottawa Sewer Collector System Model was developed using the generic drainage modeling algorithms and modules from the XP-SWMM2000 software package developed by XP Software Inc. The software's hydraulics module (Extran) is used for the hydraulic analysis of the pipe system while the Runoff module is used to generate the extraneous flows and combined sewer runoff input flows. To adequately simulate the effect



of extraneous flows on the system, the Soil Conservation Service (SCS) method is used for the separated and partially separated areas while the runoff method, based on using Horton's infiltration equation, is used to simulate extraneous flows from the combined sewer areas. The domestic sanitary flows (dry weather flows) are added directly to the Extran module as a constant flow based on the contributing population.

The adjacent schematic shows in more detail the conceptualized City of Ottawa Sewer Collector System Model that has one main branch with three major sub-branches and twenty-eight input nodes. Each sub-branch has historical flow monitoring data that is used in the calibration process.

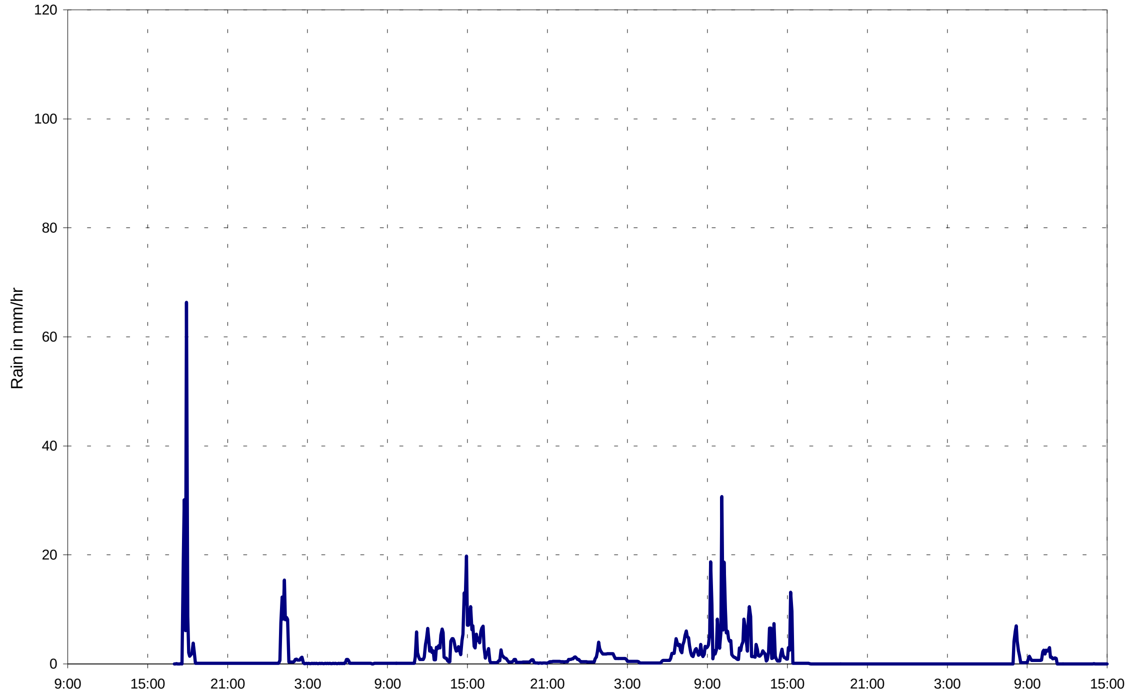
The City of Ottawa has developed, for operational and system planning purposes, a rainfall and flow monitoring program with permanent monitoring sites located at key points throughout its system. The resulting monitoring data is used for the calibration and validation of the model parameters. The availability of the long-term monitoring data allows for the determination of the optimum parameters for various antecedent soil moisture conditions and different types of rainfall events. The precipitation data that is required for the simulations is obtained from a network of approximately ten rain gauges located within the municipal boundaries. This rainfall data is used to calibrate the weather radar information in order to generate the most accurate spatial-temporal distribution of precipitation for application in the model.

Impacts on the City of Ottawa Collector System

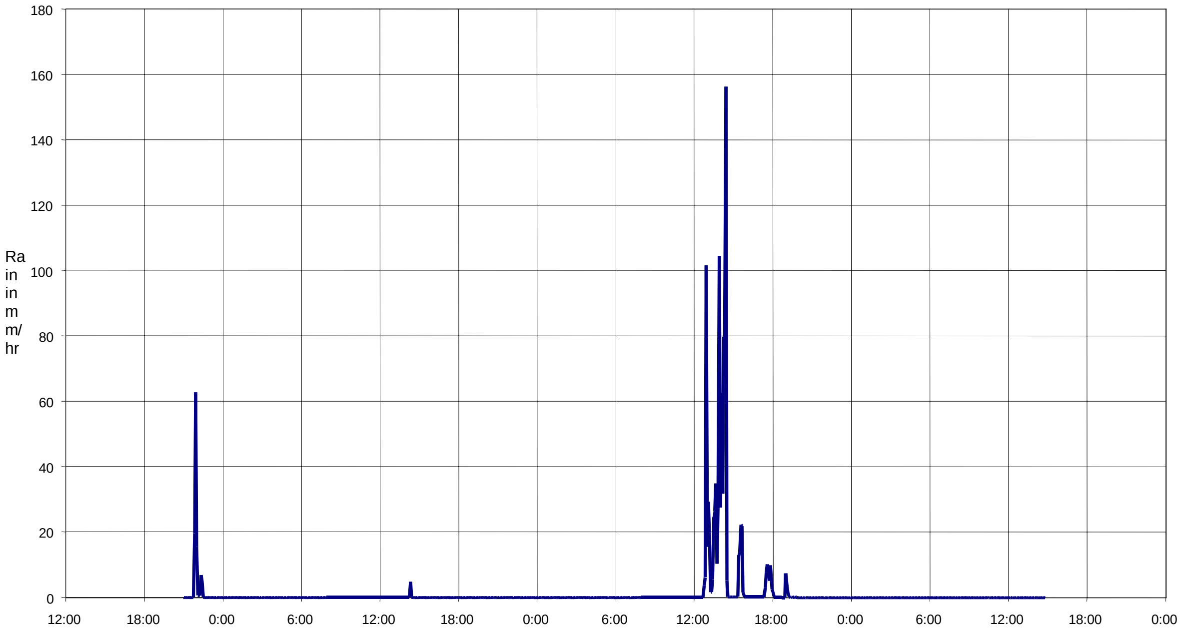
The calibrated model was used to assess the impacts of increasing rainfall intensities for several observed large rainfall events that serve as test events to evaluate the drainage system's behavior as well as obtain technical assessment of potential design changes. For this particular study, four rainfall events were analyzed and were found to have either one of two different types precipitation distributions. The Type 1 precipitation distribution has a high volume, high intensity but short duration storm profile while the Type 2 precipitation distribution has a high volume, low intensity and long duration storm profile. The table below presents general statistics for these four events while the next two pages show the storm hyetographs.

Precipitation Type	Date	Total Precipitation (mm)	Maximum Intensity (mm/hr)	Duration (hrs)
Type 2	May 18, 1986	90.4	66	24
Type 1	August 4, 1988	91.7	156	7
Type 2	June 3, 1995	80.8	40	12
Type 2	June 25, 2000	58.5	20	16

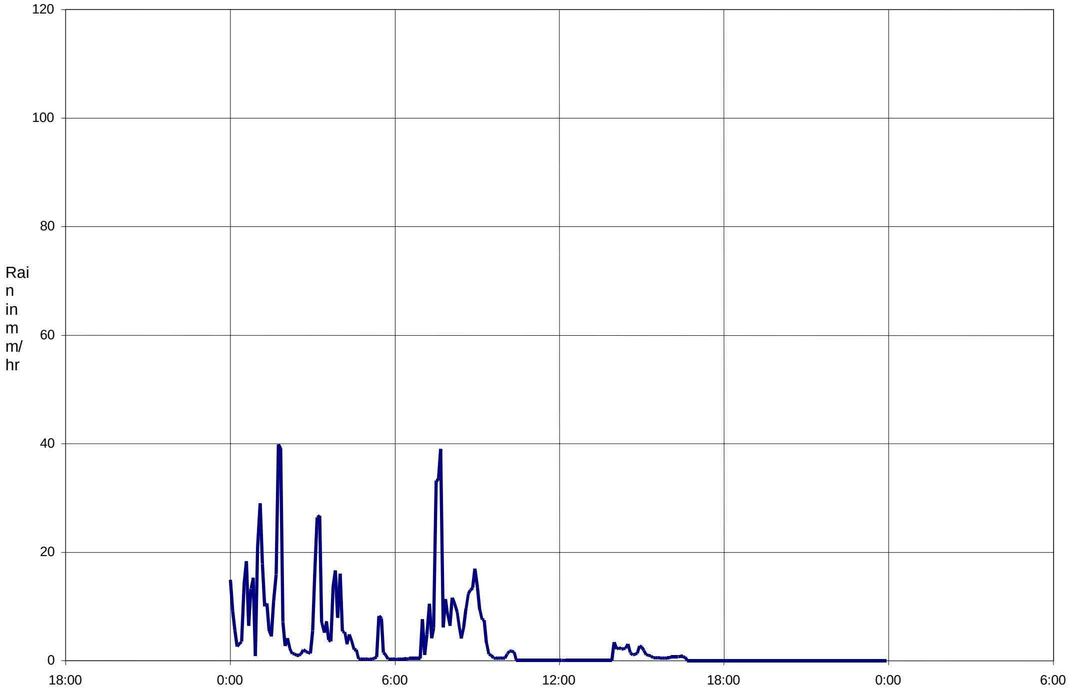
May 18, 1986: Total rain = 90.4 mm

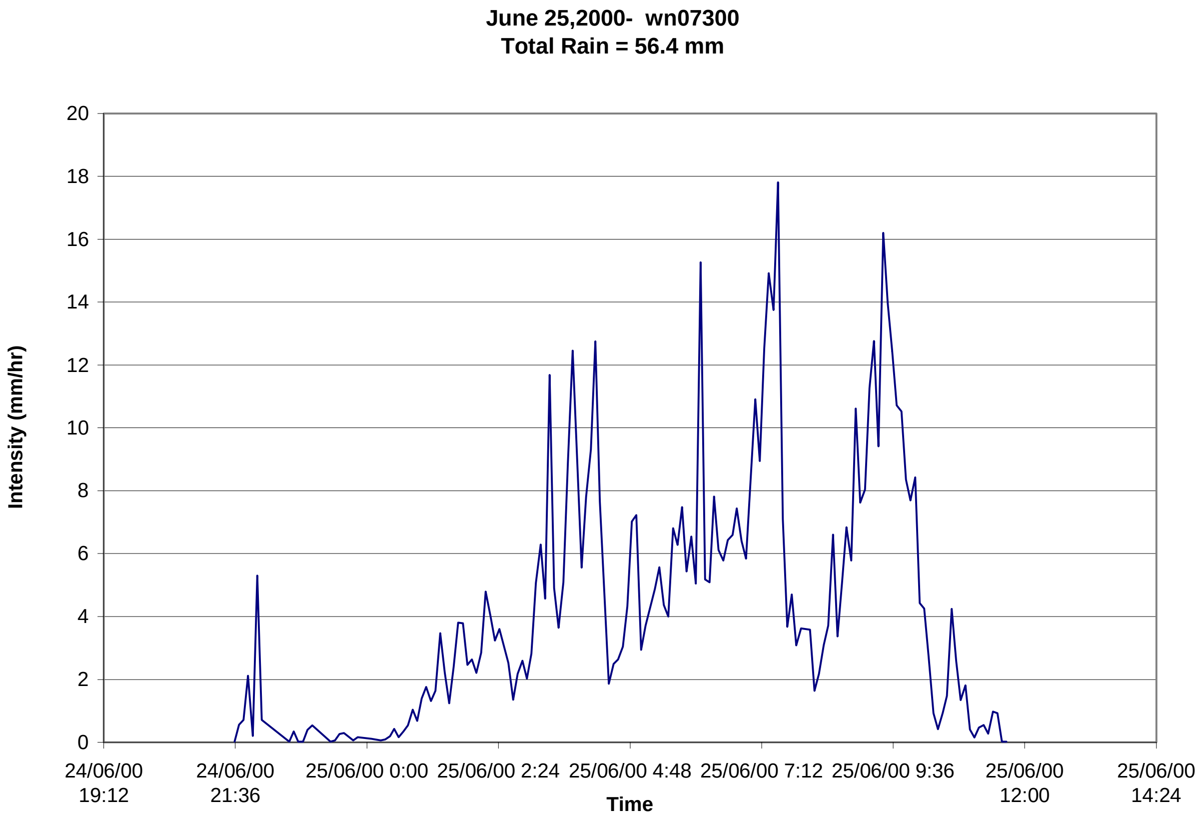


August 4, 1988: Total rain = 91.7 mm



June 03, 1995: Total rain = 78.0 mm





June 25,2000- wn07300
Total Rain = 56.4 mm

A set of four new storms was created for each of the four storm events, by increasing the observed rainfall intensities by 5, 10, 15 and, 20% in order to simulate the effect of climate changes. Simulations were subsequently completed using this precipitation dataset as input to the model. The resulting simulated flows were evaluated at two locations within the basin. The first location is known as the Carruthers Station. This station receives flow from a 1,878ha sanitary drainage area that is 70% separated and 30% partially separated sewers. The second location is from the Mooney's Bay Collector that drains an area of 550ha and has 75% separated, 20% partially separated and 5% combined sewers. Since this latter station has a combined sewer component, it was anticipated to be more reactive to the changes in precipitation.

During the original model calibration efforts, it was found that high intensity short duration events had less of an impact on sanitary sewer extraneous flows than did long duration low intensity events. This is most likely due to the fact that during short duration high intensity events, most of the input precipitation drains as surface runoff and does not enter the collector since access to the sanitary sewers via cracks and foundation drains is limited. However, during long duration, low intensity events (of similar total rainfall), more of the precipitation is able to enter the system since the total infiltration is proportionately higher thereby causing an increase in groundwater water along the sewers cracks and along the house foundation drains. This aspect of the model was successfully calibrated by limiting the maximum hyetograph intensities to 12 mm/hr.

The simulation findings are tabulated below while the impacts on flow are graphically presented on the following pages. There is one graph for each of the four storm events and each of the two sewer locations. Also, each graph presents a simulated flow hydrograph for the observed storm event plus four other simulated flow hydrographs resulting from using the modified storms. The percent increases in simulated peak flows and total flow volumes are also presented as compared to the simulated values using the observed rainfalls.

West Nepean Collector (Carruthers Station)

	18-May-86		04-Aug-88		June 3 1995		25-Jun-00	
	Peak Flow	**Volume**	**Peak Flow**	**Volume**	**Peak Flow**	**Volume**	**Peak Flow**	**Volume**
Observed	**1.9**	**210 184**	**0.87**	**6 527**	**2.75**	**174 675**	**2.71**	**93 452**
5%	1.05	1.08	1.01	1.03	1.03	1.05	1.03	1.07
10%	1.10	1.17	1.02	1.05	1.04	1.11	1.05	1.15
15%	1.16	1.25	1.03	1.08	1.05	1.16	1.08	1.25
20%	1.21	1.34	1.03	1.11	1.06	1.22	1.10	1.26

West Nepean Collector (Mooney's Bay Station)

	18-May-86		04-Aug-88		June 3 1995		25-Jun-00	
	Peak Flow	**Volume**	**Peak Flow**	**Volume**	**Peak Flow**	**Volume**	**Peak Flow**	**Volume**
Observed	**1.06**	**73 762**	**2.11**	**8 527**	**1.02**	**46 535**	**1.41**	**43 748**
5%	1.07	1.08	1.01	1.05	1.05	1.05	1.07	1.07
10%	1.11	1.16	1.03	1.10	1.09	1.11	1.15	1.13
15%	1.16	1.27	1.05	1.15	1.13	1.16	1.22	1.18
20%	1.18	1.32	1.06	1.20	1.17	1.20	1.27	1.23

Note: Observed peak flows are in cms and volumes in m^3 while 5, 10, 15 and 20% are ratios of observed values

As surmised from the calibration efforts, increasing the intensities of short duration and high intensity events had the smallest impact on the system since most of the intensities in the hyetograph are greater than the 12mm/hr threshold. This observation was verified by the simulation results of the August 4th 1988 event whereby the simulated peak flows increased by only 3% at the Carruthers station and 6% at the Mooney's Bay station when the observed storm event rainfall was increased by 20%. Furthermore, increasing the observed storm rainfall intensities by 5% had barely any noticeable impacts on the simulated peak flows (~+1%). However, the simulated flow volumes at both of these stations, for the same event, did increase significantly; 11% at Carruthers and 20% at Mooney's Bay. The larger impacts (peak flows and volumes) at the Mooney's Bay station, as compared to the Carruthers Station, are likely due to the presence of a storm flow component in this part of the sewer network. Although the system can accommodate the additional peak flows from this type of event without surcharging, more water will end up at the treatment plant thereby increasing operational costs.

When reviewing the impacts of long duration and low intensity events such as the storm of May 18th 1986 that has roughly the same total precipitation volume as the August 4th 1988 event, the simulations reveal more significant impacts. The simulations indicate that the peak flows generated from the simulations of the May 18th 1986 event increase at both stations in an amount approximately proportional to the increase in precipitation. For example, the peak flows at both stations increased by 10% when the storm intensities were also increased by 10%. However, simulated flow volumes increased substantially more when considering the same percentage increase in rainfall intensities. For example, 5, 10, 15 and 20% increases in the storm intensities generated flow volume increases of 8, 16, 27 and 33% respectively. Although the May 18th 1986 and the August 4th 1988 events have similar precipitation volumes, the differences in the temporal distribution of the rainfall intensities and the intensity values themselves result in quite different rainfall-runoff transformations. It is of particular interest to note the May 18th 1986 event has numerous periods below the 12mm/hr threshold. Simulations of the long duration and low rainfall intensity May 18th 1986 storms would result in overflows to the Ottawa River and additional operating costs associated with larger volumes of water at the treatment plant would result from these simulation scenarios.

Based on the study findings of the systems behavior under simulator climate change the following general conclusions can be made regarding the potential impacts on wastewater collection systems.

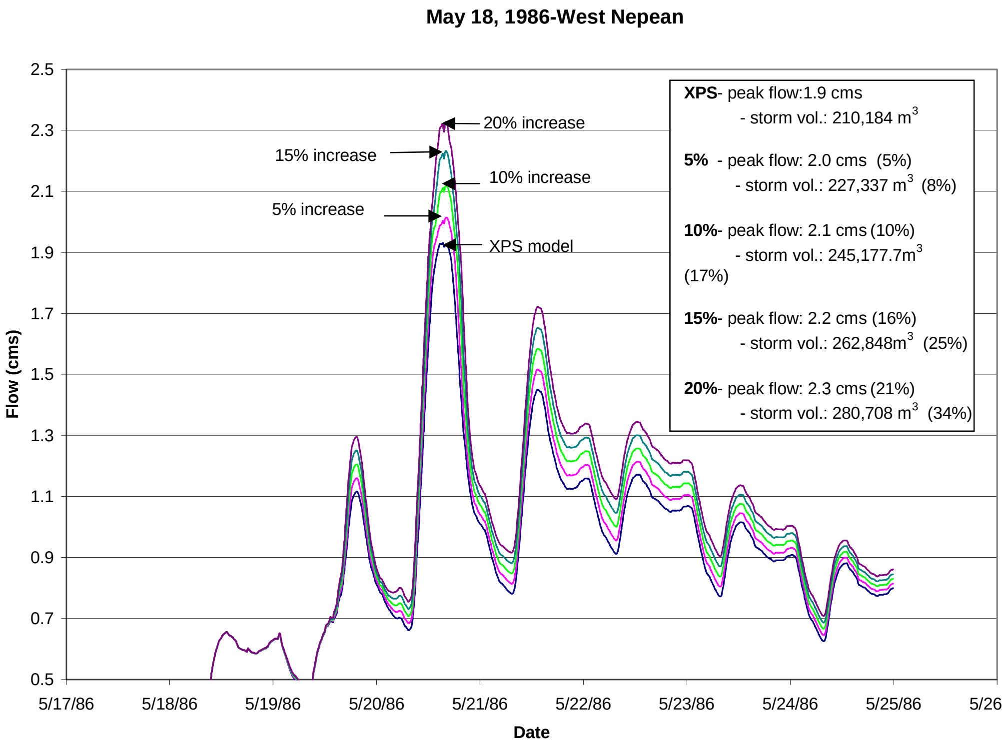
- Higher intensity / short duration events have less of an impact on separated sanitary sewers than long duration/large volume events given that the first type of events produce a large quantity of runoff in a short duration of time, therefore creating more surface runoff and less infiltration into the ground. Longer duration events of similar or larger volume tend to allow for greater infiltration into the ground. This infiltration increases the groundwater level and thus increases the hydraulic head on pipes, allowing more water to infiltrate via cracks and joints. Ultimately, the impact of increased event volumes may be an increase in wastewater treatment requirements and, in some areas, a reduction in available system capacity for additional growth.

- Another source of extraneous flow is from partially separated areas, in which flow enters the sanitary systems via foundation drains. During high intensity/short duration events, the amount of flow entering the sanitary sewers is limited by the capacity of the drain system itself. During long duration/large volume events, the cumulative effects of elevated and sustained foundation drain contributions can lead to an overloading of the system and ultimately surcharging and basement flooding.

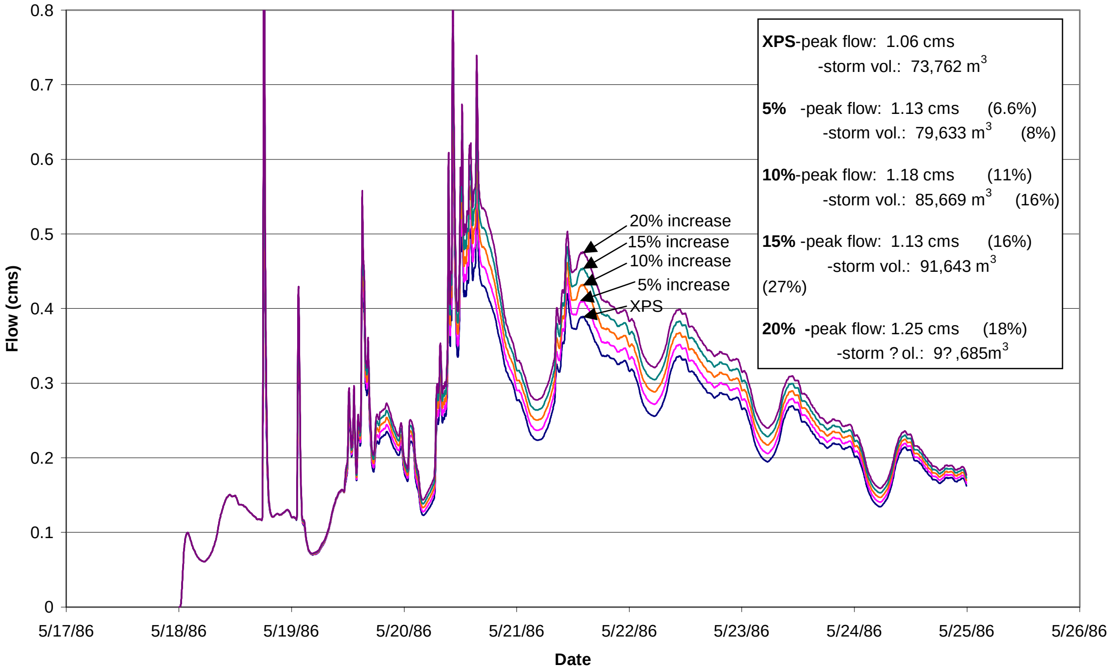
- Combined storm/sanitary sewer systems are impacted by higher intensity / short duration events as they are directly affected by peak flows generated from surface runoff (as opposed to being affected by infiltration). Increased frequencies of higher volume or higher intensity events may also impact on the frequency and volumes of combined sewer overflows (CSO's) and ultimately an increased environmental and health risk.

- Since short duration / high intensity events will increase the peak flow in storm sewer systems, there is a risk that an increase in such events will cause more surface ponding in areas that have stormwater management. This leads to a reduction in the level of service for a given area. Furthermore, as the frequency and level of surface ponding increases, the risk that more flow will find its way to sanitary systems via manhole covers and cross connections also increases. The result may be an indirect impact on sanitary systems.

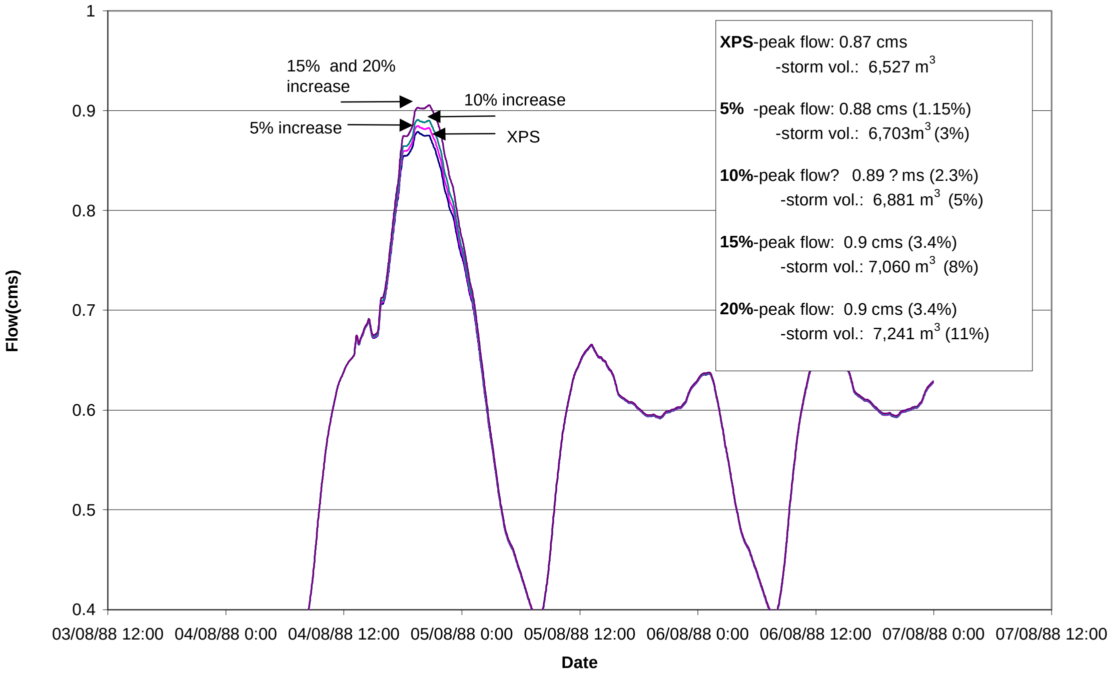
Anticipated Climate Change	Expected Climate Change Impact		
	Combined Systems	Partially Separated Systems	Fully Separated Systems
Increased rainfall event peak intensities, similar event type and annual volume	Increased risk of basement flooding. Lower level of service.	Minor impact on peak flows and available capacity.	Minimal impact on peak flows and available capacity.
Increased frequency of large volume and high intensity rainfall events, same annual volume	Increased risk of basement flooding. Lower level of service. Potential increase in CSO volume but reduced CSO frequency.	Increased risk of surcharge and basement flooding. Lower level of service.	Potential impact on available capacity for growth. Increased risk of sewer surcharge and risk of flooding.
Increased rainfall event frequency and annual event volumes, minimal increase in peak intensities or frequency of large volume events	Minimal impact on system capacity. Increase in CSO volumes and frequencies.	Potential increase in risk of system flooding. Potential impact on wastewater treatment costs (volume and quality).	Potential impact on wastewater treatment (volume and quality).

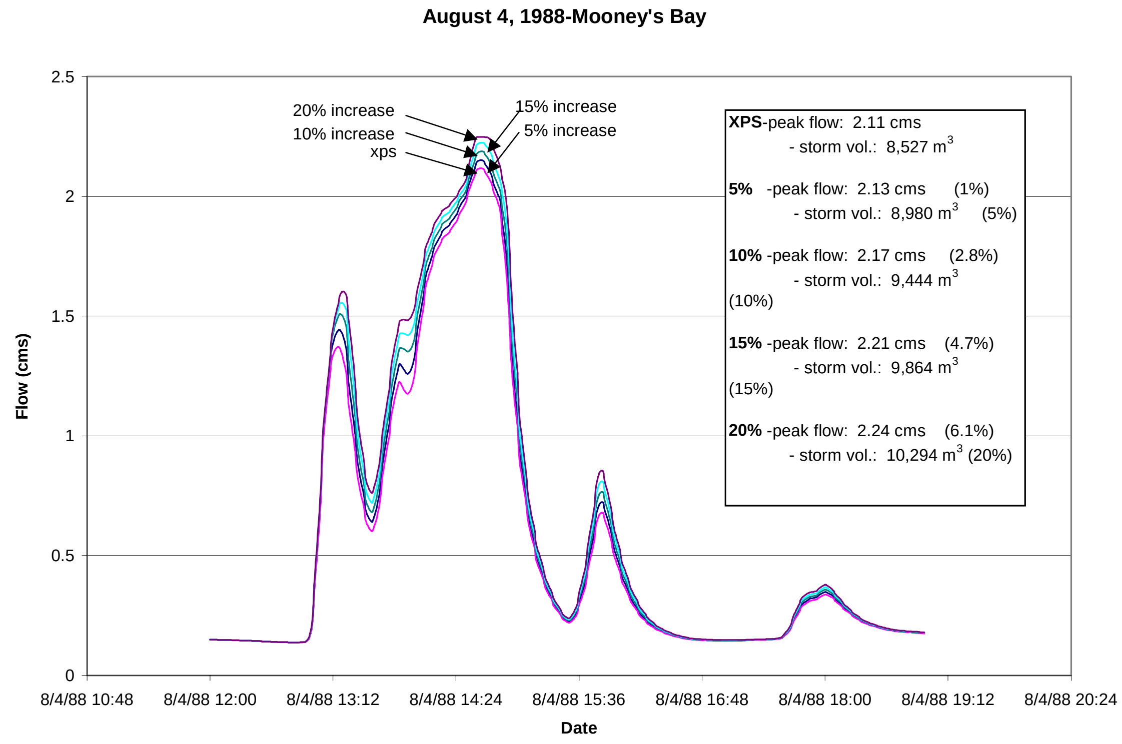


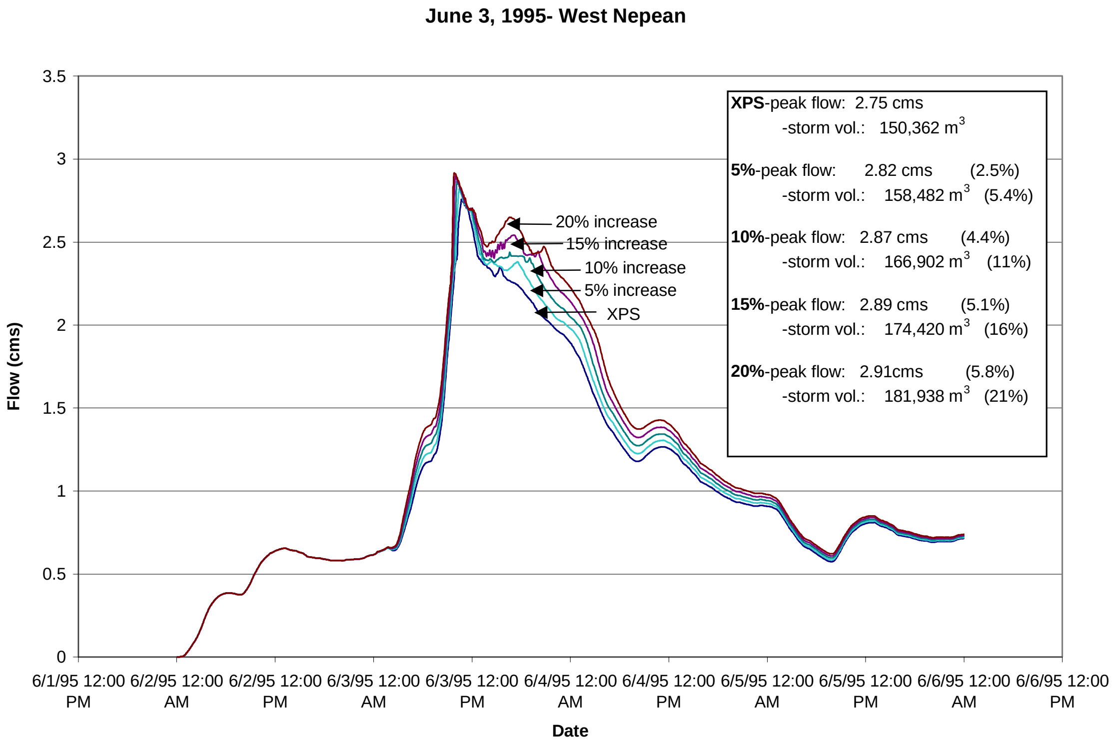
May 18, 1986-Mooney's Bay



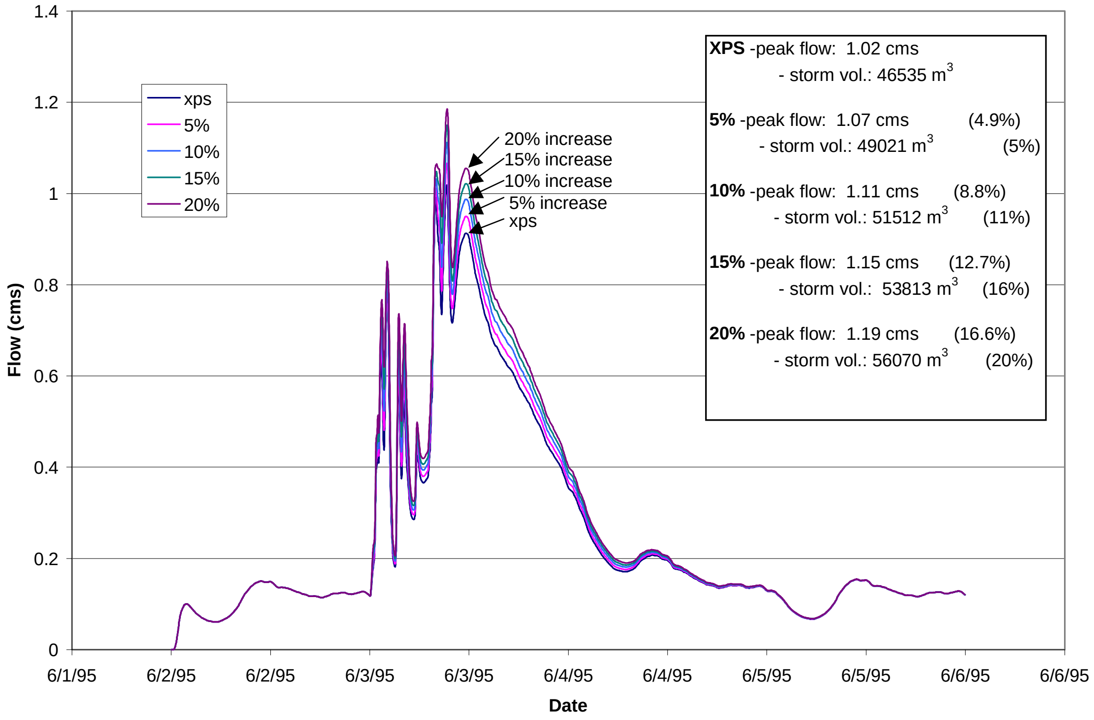
August 4, 1988-West Nepean




August 4, 1988-Mooney's Bay
2.5
2
1.5
1
0.5
0
Flow (cms)
20% increase
10% increase
xps
15% increase
5% increase
XPS-peak flow: 2.11 cms
- storm vol.: 8,527 m3
5% -peak flow: 2.13 cms (1%)
- storm vol.: 8,980 m3 (5%)
10% -peak flow: 2.17 cms (2.8%)
- storm vol.: 9,444 m3 (10%)
15% -peak flow: 2.21 cms (4.7%)
- storm vol.: 9,864 m3 (15%)
20% -peak flow: 2.24 cms (6.1%)
- storm vol.: 10,294 m3 (20%)
8/4/88 10:48
8/4/88 12:00
8/4/88 13:12
8/4/88 14:24
8/4/88 15:36
8/4/88 16:48
8/4/88 18:00
8/4/88 19:12
8/4/88 20:24
Date


June 3, 1995- West Nepean
3.5
3
2.5
2
1.5
1
0.5
0
Flow (cms)
20% increase
15% increase
10% increase
5% increase
XPS
XPS-peak flow: 2.75 cms
-storm vol.: 150,362 m3
5%-peak flow: 2.82 cms (2.5%)
-storm vol.: 158,482 m3 (5.4%)
10%-peak flow: 2.87 cms (4.4%)
-storm vol.: 166,902 m3 (11%)
15%-peak flow: 2.89 cms (5.1%)
-storm vol.: 174,420 m3 (16%)
20%-peak flow: 2.91cms (5.8%)
-storm vol.: 181,938 m3 (21%)
6/1/95 12:00 PM
6/2/95 12:00 AM
6/2/95 12:00 PM
6/3/95 12:00 AM
6/3/95 12:00 PM
6/4/95 12:00 AM
6/4/95 12:00 PM
6/5/95 12:00 AM
6/5/95 12:00 PM
6/6/95 12:00 AM
6/6/95 12:00 PM
Date

June 3, 1995- Mooney's Bay



XPS -peak flow: 1.02 cms
- storm vol.: 46535 m^3

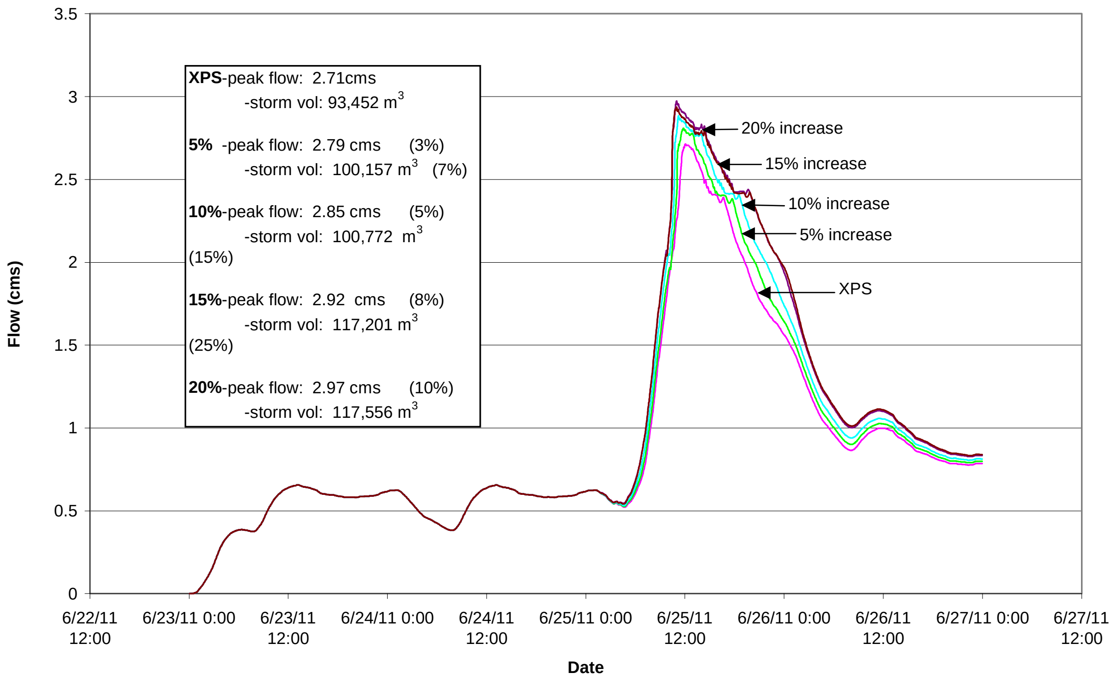
5% -peak flow: 1.07 cms (4.9%)
- storm vol.: 49021 m^3 (5%)

10% -peak flow: 1.11 cms (8.8%)
- storm vol.: 51512 m^3 (11%)

15% -peak flow: 1.15 cms (12.7%)
- storm vol.: 53813 m^3 (16%)

20% -peak flow: 1.19 cms (16.6%)
- storm vol.: 56070 m^3 (20%)

June 25 2000-West Nepean



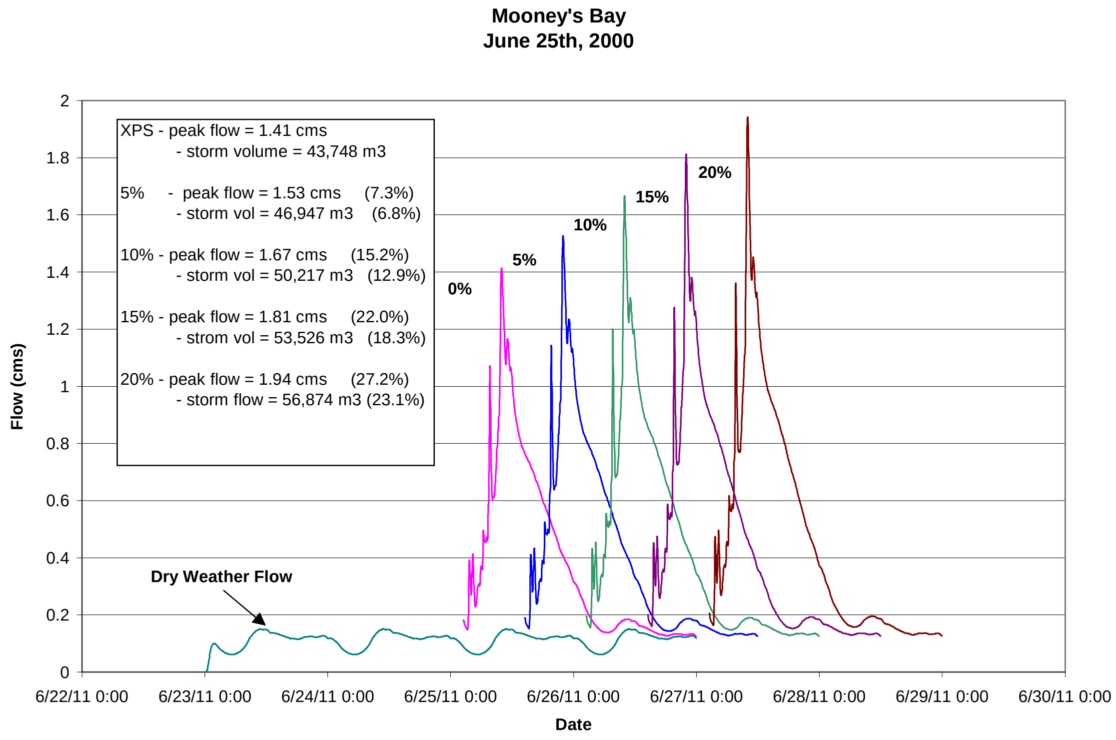
XPS-peak flow: 2.71cms
-storm vol: 93,452 m^3

5% -peak flow: 2.79 cms (3%)
-storm vol: 100,157 m^3 (7%)

10%-peak flow: 2.85 cms (5%)
-storm vol: 100,772 m^3
(15%)

15%-peak flow: 2.92 cms (8%)
-storm vol: 117,201 m^3
(25%)

20%-peak flow: 2.97 cms (10%)
-storm vol: 117,556 m^3

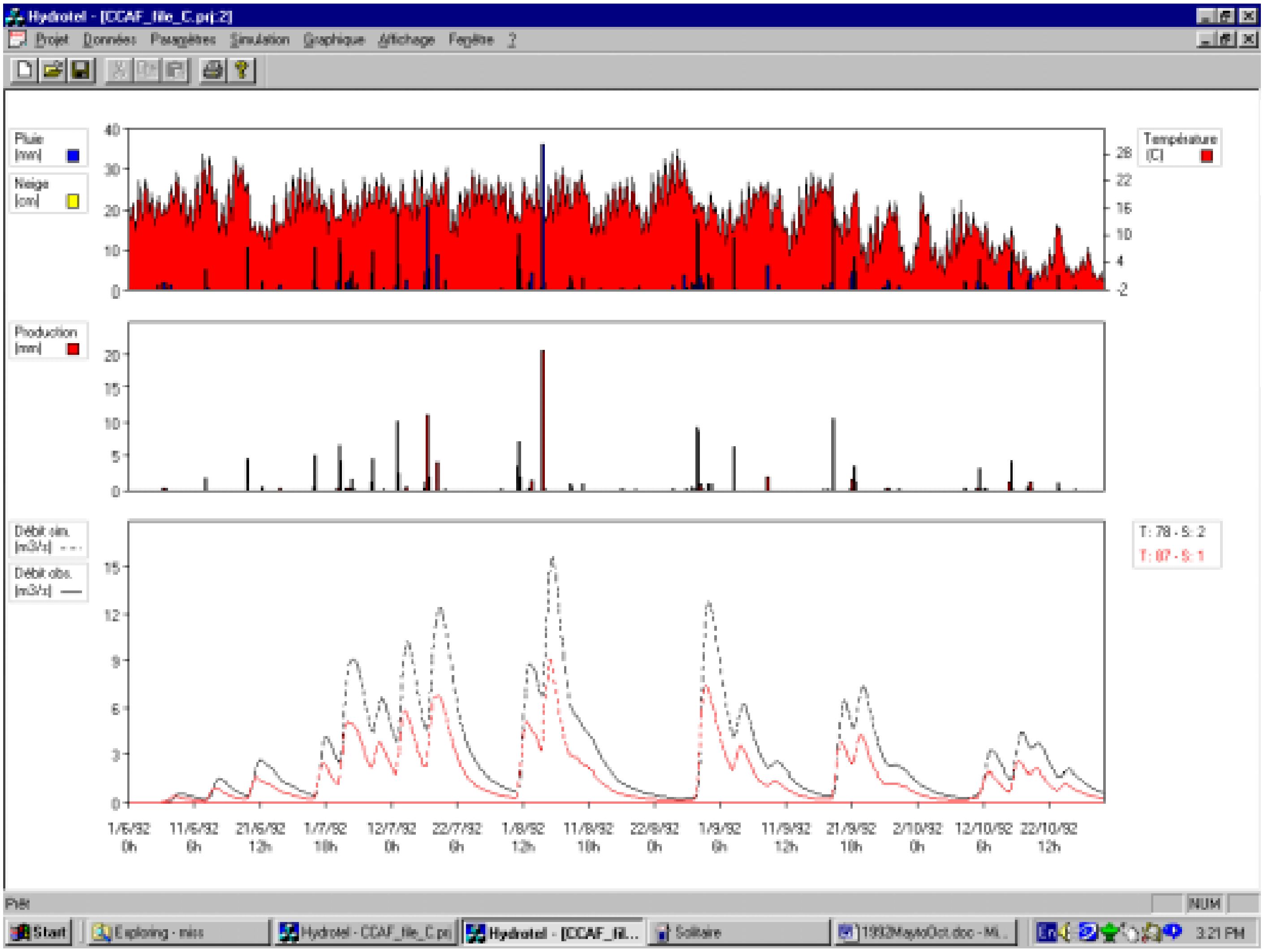


Rural Drainage System

Impacts on the Clyde River Sub-Watershed

Meteorological data series for precipitation and temperature were required in order to simulate the impact of climate changes using the Mississippi River Basin Model. For this purpose, a base year was identified using the long-term daily meteorological data at the CDA station. A year with an average total amount of precipitation during the growing season (June to October) was selected within the entire period of record. The year 1992, which had accumulated a total precipitation of 408mm during the period of June 1st to October 30th, was isolated for simulation purposes. Subsequently, the hourly precipitation and temperature data, for the same year, were extracted from the Environment Canada database and formatted for input into the hydrological model. Using the 1992 base year precipitation data, four precipitation series were created by increasing all rainfall intensities by 5, 10, 15 and, 20%. As discussed in a previous section of this report, predicted increases in precipitation will be the consequence of rising temperatures. Consequently, three temperature series were created by increasing the 1992 base year hourly temperatures by 2, 4 and, 6 degrees Celsius.

Using the Mississippi River Basin Model, eight simulations were completed using the previously described meteorological data series. Flows generated by the increased precipitation and temperatures were compared to those of the 1992 base year. Specifically, increases in peak flows, flow volumes and in water surface elevations at the outlet of the Clyde River sub-catchment were assessed. The following figure is representative of the type of graphical screen displays that is produced by the HYDROTEL model following a successful simulation. The graph shows three stacked charts using a common horizontal time axis (June 1 to October 20) with a 6-hour resolution. The uppermost chart shows the



precipitation as blue vertical bars and the temperature variations as a red backdrop. The middle chart shows the runoff amounts while the bottom charts show the variation in flow for each of two stations along the Clyde River. The black line depicts the variation in flow near the outlet of the sub-watershed that was ultimately used in the analyses. As can be observed, the base year includes many rainfall events throughout the simulation period.

Several rainfall events exceeded 15mm of precipitation during a 6-hour period while the highest 6-hour period was recorded at 36mm and occurred in early August. As can be observed from the graph, the peak flow pattern is highly correlated in time with the occurrence of precipitation. This is a typical of a highly responsive watershed.

The total average basin runoff during the entire period of simulation was relatively constant at approximately 16% of the total precipitation. This average basin runoff value was observed irrespective of the scenario being simulated although it actually varied within a very narrow range from 15.93% to 16.79%. The table below presents the simulation results expressed as deviations from the base year values. Percent changes in the flow volumes, peak flows and the difference in the water surface elevations at the flow gauging station are also shown.

	Change from Base		
Simulation Scenario	**Volume**	**Peak**	**Elevation**
	(%)	(%)	(cm)
Base (Growing 1992)			
Base + 5%	**5.4**	**5.1**	**3**
Base + 10%	**11**	**10.6**	**6**
Base + 15%	**17.3**	**16**	**8**
Base + 20%	**22.2**	**20.8**	**11**
Base + 20% + 2°C	**20.2**	**20.1**	**10**
Base + 20% + 4°C	**18.2**	**19.3**	**10**
Base + 20% + 6°C	**15.9**	**18.5**	**9**

The first four simulation scenarios used the same unmodified temperature series as input. That is, the base year temperature series was not modified for these four simulations. This allowed for verification of the impact of increased precipitation only. As can be observed, increases in precipitation yielded proportionately higher flow volumes and peak flows. Increasing the base precipitation series from 5% to 20% yielded proportional simulated increases in flow volumes from 5.4% to 22.2% and peak flow increases from 5.1% to 20.8%. Also, the water surface elevation at the Clyde River gauging station increased from 3 to 11cm when considering the peak flow during the entire period of record.

The last three simulation results presented in the previous table show the impact of increasing temperature. As can be observed, increases in temperature cause decreases in flow volumes, peak flows and water surface elevations. This is particularly noticeable for flow volumes whereas each 2°C increase in temperature causes a reduction in flow volumes of approximately 2%. Increasing the base year temperature by 2, 4 and 6°C reduced the impact of a 20% increase in the base year precipitation to 20, 18.2 and 15% respectively when considering flow volumes. However, peak flows and water surface elevations were not reduced by as much for identical increases in temperatures. This result is anticipated since the impacts caused by changes in temperature, hence evapotranspiration, are not easily visible at the time scale of storm events, whereas the aggregated effect of evaporation over the total period of simulation is more substantive and represents a proportionately larger fraction of the flow volume. As expected, the changes in peak flows proved to be less than 1% for every 2°C increase. Water surface elevations also show small changes due to temperature variations.

The more obvious consequences of an increase in flow volumes, peak flows and the related water surface elevations on this natural stream will be the more frequent and severe flooding (magnitude, extent and frequency) as well as the increased stream erosion. This is especially true for more reactive watersheds like the Clyde River system where the limited basin and in-stream storage are not sufficient to buffer the additional input in water. The expanded areal extent of flooding under climate change conditions is a function of the local terrain. Flat areas might see substantial increases in flooding while rivers with more entrenched valleys, like the Clyde River, might very well be able to contain a 20% increase in flow. Furthermore, flooding in non-inhabitable areas poses little danger to human life and infrastructure. The flood plain delineation that was completed for the Clyde River under

Flood Damage Reduction Program will be underestimated in low-lying parts of the watershed. However, environmental damages caused by additional stream erosion might affect the aquatic fauna and flora as the river rejuvenates itself under increased flows. Increases in channel erosion could slowly activate and/or accelerate stream development and migration. Also, increases in water column sediments might result in premature mechanical wear of water supply system components. As previously discussed for urban systems, all rural drainage system infrastructures such as culverts and bridge openings will experience a reduction in their level of service under a climate change scenario. For example, a culvert designed in 1980 to safely convey a 25-year storm flow will perhaps be able to carry only a 10-year storm in 2015. Also, dam and reservoir operations will require updating to ensure the climate change impacts are incorporated within the design variables.

4. Climate Change Impacts on the Design of Drainage Systems

The impacts of climate change on the remediation of existing drainage systems and the design of new systems will be evaluated using the previous findings. Generalized costs and related implications will be documented in such a way as to create generic and transferable findings.

Impacts on Pipe Sizes and Costs

Based on the urban storm sewer drainage system previously shown in Figure A2.1, commercially available pipe sizes were computed to convey the 2, 5 and 10-year design peak flows using the Rational and the Hydrograph Methods for 0% to 20% increases in rainfall intensities. The results obtained from both the Rational Method and the Hydrograph Method are presented and compared in Table A4.1. Costs are based on drainage projects in the Ottawa area in 2000. From these results, the following observations can be made: i) computed average pipe sizes are smaller with the Rational Method than with the Hydrograph Method; ii) the relative increases in average pipe sizes for a given increase in rainfall intensity are approximately the same for any return period; iii) the associated pipe costs for a given increase in rainfall intensities are approximately equal to twice the relative increase in the average pipe size. For example, using the Rational Method analyses, the increase in pipe costs are 4% for every 5% increase in rainfall intensities whereas for the Hydrograph Method, the increases in pipe costs are closer to 8% for every 5% increase in rainfall intensities.

Table A4.1: Sensitivity of Nominal Pipe Sizes and Associated Costs with Respect to Design Method*

Increases in Rainfall Intensities	[Rational Method] Average Pipe Sizes (mm) and Associated Average Cost ($/m)											
	2 yr				5 yr				10 yr			
	Davg	$$avg	D/D	$$/$$	Davg	$$avg	D/D	$$/$$	Davg	$$avg	D/D	$$/$$
0%	1324	$417.20	1.00	1.00	1474	$512.41	1.00	1.00	1553	$566.35	1.00	1.00
5%	1350	$432.61	1.02	1.04	1500	$530.00	1.02	1.03	1590	$593.64	1.02	1.05
10%	1376	$450.39	1.04	1.08	1534	$553.09	1.04	1.08	1616	$613.57	1.04	1.08
15%	1399	$465.35	1.06	1.12	1553	$566.35	1.05	1.11	1639	$629.80	1.06	1.11
20%	1433	$485.91	1.08	1.16	1579	$584.71	1.07	1.14	1665	$650.25	1.07	1.15

Increases in Rainfall Intensities	[Hydrograph Method - SWMHYMO] Average Pipe Sizes (mm) and Associated Average Cost ($/m)											
	2 yr				5 yr				10 yr			
	Davg	$$avg	D/D	$$/$$	Davg	$$avg	D/D	$$/$$	Davg	$$avg	D/D	$$/$$
0%	1410	$488.90	1.00	1.00	1709	$701.58	1.00	1.00	1889	$852.74	1.00	1.00
5%	1474	$531.58	1.05	1.09	1763	$747.33	1.03	1.07	1954	$912.92	1.03	1.07
10%	1518	$560.50	1.08	1.15	1834	$804.35	1.07	1.15	2028	$983.06	1.07	1.15
15%	1577	$599.78	1.12	1.23	1894	$856.49	1.11	1.22	2119	$1,071.40	1.12	1.26
20%	1628	$637.34	1.15	1.30	1949	$908.00	1.14	1.29	2181	$1,133.92	1.15	1.33

* Davg= Arithmetic mean of nominal pipe size
$$avg= Cost per m based on total system cost divided by total length of pipes
D/D= Ratio of Davg/Davg_for_0%_increase
$$/$$= Ratio of $$avg/$$avg_for_0%_increase

Impacts on End-of-Pipe Storage Requirements and Associated Costs

In or to attain stormwater management objectives, system storage (on-site or off-site) is an integral part of a drainage system design. The rationale for providing storage is to control post-development flows to natural or other stipulated levels to avert downstream flooding, reduce erosion or prevent water quality degradation. As rainfall intensities increase, new system designs may require more storage and existing systems may fail more frequently.

To assess the impact of future increases in rainfall intensities on the design and operation of stormwater storage facilities, a series of simulations were conducted using the drainage system previously described in Figure A2.1 with 5, 10, 15 and 20% increase in rainfall intensities. Storage volume requirements were computed for maximum storage facility release rates ranging from 5 L/s/ha to 250 L/s/ha (litres per second per hectare).

The results indicated that the changes in storage volume requirements from increases in rainfall intensities were approximately the same for any given sub-catchment imperviousness and end-of-pipe storage release rate. In other words, the increases in storage volume requirements from the changes in rainfall intensities are not sensitive to the imperviousness and release rates. Typical results are presented and compared in Table A.4.2.

Table A4.2: Sensitivity of End-of-Pipe Storage Requirements (m^3/ha) to Control the Runoff of a 100-year Storm with Respect to Increases in Rainfall Intensities, Release Rates and Design Methods*

Increases in Rainfall Intensities	Rational Method			Hydrograph Method with Design Storms			Hydrograph Method with Continuous Simulations		
	10 L/s/ha	25 L/s/ha	50 L/s/ha	10 L/s/ha	25 L/s/ha	50 L/s/ha	10 L/s/ha	25 L/s/ha	50 L/s/ha
0%	***426***	***183***	***54***	***394***	***296***	***117***	***361***	***169***	***42***
5%	1.09	1.11	1.19	1.09	1.11	1.23	1.10	1.17	1.33
10%	1.18	1.23	1.39	1.18	1.22	1.46	1.20	1.33	1.67
15%	1.16	1.36	1.59	1.27	1.33	1.70	1.29	1.49	2.02
20%	1.36	1.48	1.81	1.36	1.45	1.94	1.39	1.66	2.40

* Italics/bold values represent the simulated storage volume requirements in m^3/ha.
All computations are based on a total area of 100 ha with 40% imperviousness.
Hydrograph Method is for average CN value of 70.
Continuous simulations are based on 39 year of rainfall data from May 1st to October 31st of every year.
Results of continuous simulations are extrapolated from a GEV frequency analysis.
Costs of providing end-of-pipe storage can be estimated at \$14/m^3 excluding the cost of land.

A review of Table A4.2 indicates that, for the three design methods, the end-of-pipe storage requirements are greatly affected by future increases in rainfall intensities. Based on a given limiting release rate and design methods, increases in end-of-pipe storage could increase by approximately 10% to 35% per each 5% increase in rainfall intensity. As the costs to provide surface storage is approximately proportional to the required volume (excluding the price of land), it can be concluded that future costs of such facilities will increase by the same amounts.

Storm water storage facilities are typically sized to control the 2, 5 and 100-year storm events to pre-development levels. Increases in rainfall intensities will require the provision of additional storage in order to maintain the same level of service. This is illustrated in Figure A4.1 for a storage facility controlling the release rate to 25 L/s/ha of a hypothetical area of 100 ha in surface area with an imperviousness of 40%. The graph shows storage volumes plotted against the return period for existing and future increases in rainfall intensities. Based on 39 years of continuous simulations, a 5% and 20% increase in rainfall intensities will require approximately 16% and 65% more storage volume, respectively, to control the runoff of a 100-year storm.

Similarly to peak runoff flows, future drainage systems could also be designed to accommodate larger storage volumes. However, the operation of existing end-of-pipe storage facilities will be affected by future increases in rainfall intensities since they will no longer provide their originally intended level of service. That is, existing storage facilities will overflow more frequently and will not provide adequate downstream flood and erosion protection. This can also be assessed using the graphs in Figure A4.1. As shown, an existing storage facility, sized to control the runoff rate from a 100-year event would be exceeded by a future 1:68 year event if rainfall intensities increase by only 5%, and by a future 1:25 year event if rainfall intensities increase by 20%. This means that the probability of overtopping an end-of-pipe storage facility originally sized to control a 100-year event would increase substantially with the onset of climate changes. Similar conclusions can be obtained for facilities originally sized to accommodate flows from smaller-year storm.

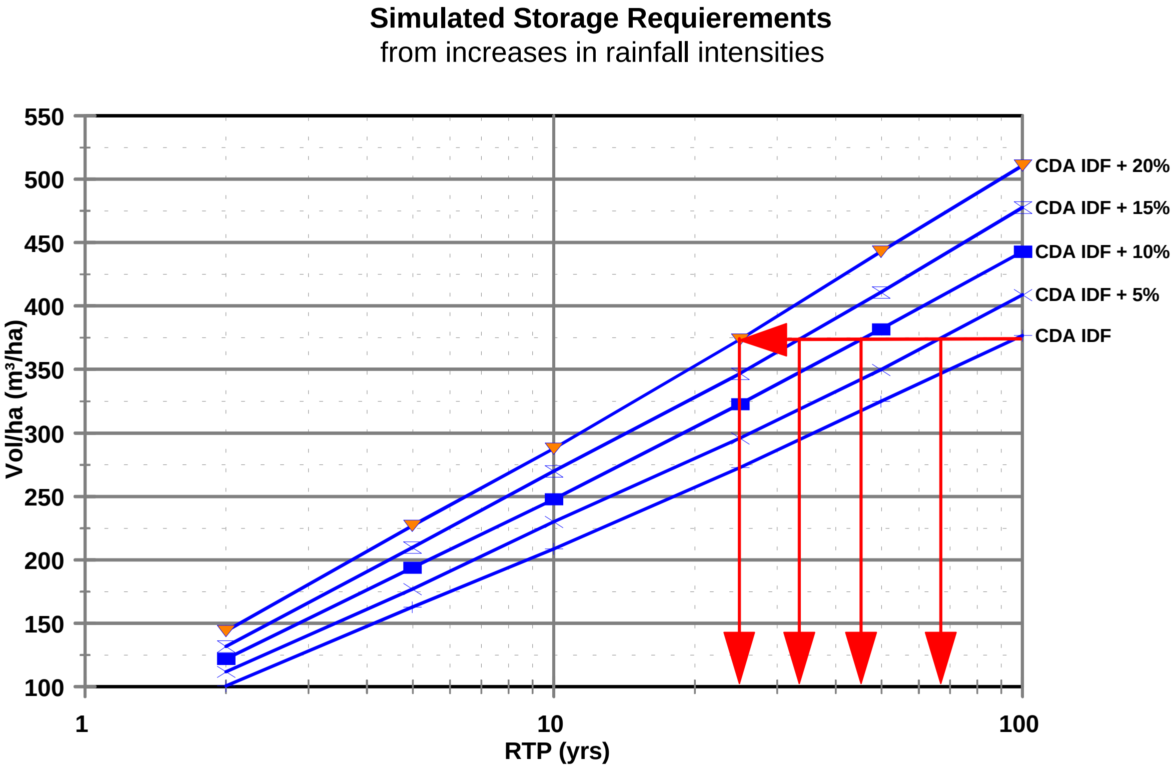


Figure A4.1 Impacts of increases in rainfall intensities on storage volumes and level of service

(for an area of 100 ha with an imperviousness of 40% and a release rate of 25 L/s/ha - Rational Method Design)

B. CURRENT POLICIES AND REGULATIONS

1. Who Has Jurisdiction Over Water?

At the National Level

Division of responsibilities for water is complex and often shared (Environment Canada, 2000) as presented in Table B1.1. Under the *Constitution Act*, the provinces own the water resources within their boundaries, including groundwater, and are responsible for flow regulation and authorization of water use development, both of which are direct relevance to this study. The provinces also have the authority to legislate areas of water supply, pollution control as well as thermal and hydroelectric power development.

Table B1.1 : Division of Jurisdictional Power Related to or Affecting Water Management

Area of Responsibility	Federal	Provincial	Local/Regional
Surface waters (Intra-provincial)		X	**X, X** (Note 1)
Inter-provincial waters	x	X	x
International waters	X	x	x
Stormwater	x	X	X
Groundwater		X	
Hydro power generation		X	
Transportation infrastructure		X	X
Fisheries	x	X	
Pollution control	X	X	
Drinking water	x	X	X
Agriculture		X	

x = minor responsibility

X= major responsibility

Note 1: In some provinces, such as Ontario, authority for water management is largely delegated to or shared with regional governments (conservation authorities, etc.)

The federal and provincial governments share responsibilities on water related issues of national importance. As will be seen later, this has a significant impact on policies and regulations relating to flood prevention and control in Canada. Another area of joint federal-provincial jurisdictional responsibility that is relevant to this discussion is that of inter-provincial waters. However, it must be pointed out that the federal government's role here is mainly a consultative one, acting as a facilitator for negotiations between provinces sharing in the use and management of a transboundary stream or body of water. Also, within the provincial bureaucracies, two or more government departments often share water-related responsibilities.

The construction of dams, diversions and other drainage works that can potentially affect fish requires compliance with the Fisheries Act. Although the Federal Department of Fisheries and Oceans (DFO) normally administers this act, provincial fisheries regulations can be applied instead in jurisdictions where legislative equivalency agreements have been signed.

Irrigation and drainage of agricultural lands is an exclusive area of provincial jurisdiction except in watersheds where farming may cause transboundary water quality or quantity impacts.

The Management of International Waters

Transboundary water related issues are dealt with under the Boundary Waters Treaty of 1909 which 'provides the principles and mechanisms to help resolve disputes and to prevent future ones, primarily those concerning water quantity and water quality along boundary between Canada and the United States.' (IJC, 2000). Water quantity concerns include uses, obstructions, and diversions of waters on one side of the boundary that may affect the level or flow of the waters on the other side. Although the treaty was ratified by His Britannic Majesty (for the Dominion of Canada at the time) and the United States, the provinces and other stakeholders play key roles in the management of international waters.

Delegation of Authority to Municipal Governments

The following text, extracted from the document 'Municipal Spheres of Jurisdiction' (ELG, 2001) describes the somewhat complex and perhaps uneasy relationship between provincial governments and the municipalities under their jurisdiction: 'The Constitution Act, 1867, makes no reference to municipalities except in subsection 92(8) where they are placed under provincial jurisdiction. As a result, municipal governments are considered to be creations of the provinces capable of exercising only those powers delegated to them by provincial governments. In order for a municipal council to enact a by-law dealing with a specific matter, the enabling legislation must either expressly or by necessary implication set out the authority to do so. In effect, in Canada, stormwater management is generally under the authority of local governments but provincial government agencies may still exert significant powers over the design and construction of related works. When applied to drainage issues, the above framework will inevitably lead to an uneven and confusing array of legislative mechanisms at the municipal level unless provincial policies and regulations are explicit and firm on design and construction requirements.

2. Stormwater Management in Practice

According to the North American Commission for Environmental Cooperation (NACEC, 2001), "The provincial legislatures have the authority to create local or municipal governments. These governments have power under provincial legislation to pass bylaws to regulate matters within their own boundaries. The sources of most municipal powers are provincial statutes dealing specifically with municipal governments or with planning legislation. Local governments with law-making power are subordinate to the provincial authority that has delegated its power. The provincial authority can take away, alter, or control the powers transferred at any time."

Keeping mind the above legislative constraints and uncertainties, it can be stated that local governments are generally responsible for land use planning and regulation of new developments. This means that they can potentially play an important role in flood plain management. “In some provinces, local governments are required to incorporate flood hazard information into municipal planning through official plans, zoning bylaws, subdivision plans, and flood and fill regulations” (Environment Canada, 2000c). However, provincial statutes and regulations regarding flood prevention and control as well as their means of application and the degree of provincial supervision and intervention vary widely from one province to another.

Generally, developers defray construction costs of municipal drainage works while the local governments are financially responsible for the long-term maintenance of the resulting infrastructure. In terms of defraying the added incremental cost of infrastructure required to cope with climate change, cost-conscious developers may not be entirely cooperative especially if the case for climate change has not clearly been demonstrated.

Flood prevention and response is, under the Canadian constitution, almost entirely a provincial responsibility. The federal government does have a general mandate to protect the life and property of Canadians and has accepted a moral duty to compensate citizens whose possessions have been damaged by extreme hydrologic events. In the absence of any legal framework to support direct intervention in flood management, Ottawa has sought to influence provincial policy makers to make changes to reduce the social and financial burden of flooding disasters. The Flood Damage Reduction Program (FDRP), which falls under the *Canada Water Act*, allows the federal government to play a guiding role in stormwater management in geographical areas normally under provincial jurisdiction.

The Flood Damage Reduction Program (FDRP) “consists of identifying, mapping and designating flood risk areas, and then applying policies to discourage future flood prone development in these areas” (FDRP, 2000). Individual agreements are signed with the participating provinces and territories. This program is collaborative in nature, aiming to discourage development in flood-prone areas.

Under FDRP, “the minimum design flood criteria is the 100-year flood which is the peak of flood flow with one chance in one hundred of occurring in any given year” (Environment Canada, 2000e). However, some provinces have implemented more stringent standards. To date, 342 areas have been mapped and designated under FDRP, covering approximately 982 communities across Canada (Environment Canada, 2000f). Unfortunately, a criteria based on flood frequency is a moving target as a result of climate change. Floodplain design specifications derived from current statistics would be different from one done 20 years from now. Areas that will experience a future increase in precipitation will end up with spatially underestimated flood-prone designations.

Federal-provincial FDRP agreements are cost-shared. The actual agreements vary from province to province or territory. The two governments apply the following policies to the mapped areas, known as “designated areas”:

1. They will not build, approve or finance flood prone development in the designated area.
2. They will not provide flood disaster assistance for any development built after the area is designated, except for flood-proofed development in the flood fringe.
3. They will encourage zoning authorities under their jurisdiction to zone on the basis of flood risk.

The latter policy captures the essence of the inadequacy of the current legislative framework in setting out the required design criteria to effectively deal with stormwater and in creating the legal instruments to enforce them. Although the provinces have the ability to “control the powers” assigned to the local governments, few provincial governments appear to take a pro-active stance regarding the management of stormwater. As a result, municipalities tend to adopt a reactive approach to dealing with this issue, acting only after repeated flooding and litigation has occurred. This becomes especially critical in the face of a potentially disastrous environmental situation resulting from climate change. Making matters worse, the decision making process of local governments can easily be biased by influential promoters whose priorities are not necessarily focused on the health of the environment. Unfortunately, the size and financial health of a municipality may also directly impact its ability and capacity to adequately manage the design and construction of its drainage works.

Road design and construction also falls under various levels of government. Drainage standards based on FDRP criteria generally apply for works carried out in designated flood plains. Provincial highways usually follow engineering standards prescribed by provincial transportation authorities but compliance with environmental statutes and regulations, some of which contain drainage criteria, is required in some jurisdictions. Municipalities are generally responsible for road construction and all associated drainage works within their boundaries. Mechanisms for provincial control or intervention in drainage matters related to road building vary across Canada.

Under FDRP, within all provinces except for Québec, public works such as bridges and pipeline crossings are automatically exempt from restrictions within FDRP-designated areas.

The Boundary Waters Treaty adds another layer of political complexity when it comes to the management of waters along the Canada-U.S. border. Although the Treaty states that the federal and provincial governments retain “the exclusive jurisdiction and control over the use and diversion… …of all waters on its own side of the line…”, this is only true as long as works on one side of the border does not create the potential for flooding or other “injury” on the other side.

In reality, the International Joint Commission (IJC), created to administer the Treaty, has jurisdiction over all projects that do not meet the latter criteria. A federal government, where it has clear jurisdiction, may submit directly to the IJC an application for the use, obstruction or diversion of waters within its own boundaries. Provincial (state, in the U.S.), individual, private sector and other proponents of such works must first forward their application to the federal government for transmission to the Commission. The federal government can theoretically refuse to transmit such an application if it deems the proposal unacceptable. On the other hand, "transmittal of the application to the Commission shall not be construed as authorization by the [federal] government of the use, obstruction or diversion proposed by the applicant." (Boundary Water Treaty, article 12. (2)). The mechanism for review of an application involves provision for consultation by the IJC with any group, including provincial and municipal government agencies, or individual "interested in the subject matter of an application, whether in favor or opposed to it…" (Boundary Water Treaty, article 20.).

3. The Provincial-Municipal Scene

Newfoundland and Labrador

Sixteen areas have been mapped and designated under FDRP (Environment Canada, 2000f). The 20-year flood was used to designate the floodway and the 100-year flood to designate the flood fringe. These criteria guide stormwater drainage design for municipalities within the designated areas. The province does not currently expect to make changes in policies and regulations as a result of the potential impacts of anticipated climate change.

According to the Highway Design Division, Works, Services and Transportation Department of Newfoundland Provincial (Whittle, 2000), culverts for all provincial roads are designed for a 100-year flood with a high water/diameter (HW/D) ratio of 1.1 and a 10-year flood with a HW/D ratio of 1.0. Storm sewer systems are designed for a 2-year storm. The Government of Newfoundland and Labrador does not anticipate making any policy or regulatory changes regarding road design and construction as a result of the potential impacts of climate change. Meanwhile, the province is drafting a new Urban and Rural Planning Act that will give greater autonomy to municipalities in the area of land use planning.

The provincial *Environmental Assessment Act* applies to undertakings such as "an enterprise, activity, project, structure, work, policy, proposal, plan or program that may, in the opinion of the Minister, have a significant environmental impact…". This includes the construction of dikes, levees, flood control structures, canals and other artificial waterways as well as landfilling and modification of a watercourse. Only structures and affected areas that exceed minimum dimensions (length, area, etc.) specified in the Act are subject to assessment. Project proponents are required to submit an Environmental Protection Plan which, for works involving significant stormwater drainage consideration, would have to include statements regarding flooding potential and the required solution (criteria) in terms of construction design.

Nova Scotia

The *Municipal Government Act* states that a municipal planning strategy may include statement of policy with respect to the protection, use and development of lands within the municipality, including the use and development of lands subject to flooding and regarding stormwater management. The Act requires that a subdivision by-law include "any requirements prescribed by the provincial subdivision regulations applicable to the municipality unless (i) the municipality adopts more stringent requirements, or (ii) the municipal requirements implement the municipal planning strategy", the latter having presumably been previously approved by provincial authorities. Under the Act, a sub-division by-law may also include 'requirements for the design and construction of stormwater systems'. A council may also make by-laws regarding stormwater management such as 'setting standards and requirements respecting the design, construction and installation of stormwater systems and related services and utilities and regulating and setting standards for drainage'.

Under the *Environment Act*, developers, including local governments, must seek approval from the provincial Department of Environment and Labour for[1] :

- The use or alteration of a watercourse
- The construction of a culvert
- The construction of a bridge
- Storm drainage works

[1] Only the activities related to the current discussion are listed here.

The same requirements, which include drainage design criteria, would obviously apply to road construction activities.

Nine communities in Nova Scotia are covered by a General Mapping and Studies Agreement under the FDRP program. The 100-year flood was used to delineate and designate flood plains while the floodway is defined by the 20-year flood (Environment Canada, 2000g).

Prince Edward Island

For PEI, the small watersheds and previous low losses to flooding did not justify an agreement under FDRP (Environment Canada, 2000h). Nevertheless, climate change may increase the amounts and frequency of precipitation events therefore flooding and erosion could become a significant issue in the future for this small island province situated in the Gulf of St-Lawrence.

Similarly to other provinces, local governments receive authority to pass by-laws under a provincial government act. For example, the town of Cornwall operates under the Charlottetown Area Municipalities Act. It is interesting to note that, with respect to stormwater management, at least two municipalities, Cornwall and Stratford, share responsibilities with the provincial Department of Transportation and Public Works. The ‘Town of Stratford Official Plan 1997’ states that ‘all new subdivisions and major developments shall be required to submit a storm water management plan, subject to standards imposed by Council and the Department of Transportation and Public Works.

New Brunswick

Under the *Municipalities Act*, a municipality may provide services contained in the First Schedule. These include drainage, sewerage and roads and streets. The Community Planning Act states that ‘where a municipality requests, the Minister [presumably, the Minister of Environment and Local Government] may designate any area within the municipality to be a flood risk area. There is an apparent overlap in mandates with the provincial department of highways as the *Highway Act* states that ‘the Minister [of

Transportation] may construct, reconstruct, repair a highway that lies within a city, town or village including the storm drainage, catch basins, curbs and gutters associated with the highway…]. Also, the *New Brunswick Highway Corporation Act* specifies that 'all work affecting any highway or road is subject to the supervision, inspection and approval of a person designated by the Minister of Transportation, a local authority or the New Brunswick Highway Corporation and the provisions of the *Highway Act* or the *New Brunswick Highway Corporation Act*…'. However, none of the aforementioned Acts makes any reference to engineering guidelines that may apply to drainage works.

The 'Field Guide on Environmental Practices for Highway Construction and Maintenance' for the province of New Brunswick (Washburn & Gillis Associates Ltd., 1994) contains no information or direction regarding the design of associated drainage works.

The department of Environment and Local Government may also have authority to review drainage projects under its *Clean Water Act*. This Act stipulates that the Lieutenant-Governor in council may make regulations 'regulating, controlling, prohibiting, directing or providing for river diversions, drainage diversions or alterations or diversions of alterations or diversions of all or part of a watercourse or the water flowing in a watercourse' and 'designating or authorizing the Minister [of Environment and Local Governments] to designate an area subject to flooding as a flood hazard area…'. Unfortunately, the Act does not specify which potential environmental concerns related to drainage works are addressed by the legislation. But the reference to the designation of flood hazard areas indicates at least a concern with the negative consequences that engineering works, including drainage projects, may have on a given watershed.

The *Community Planning Act* also authorizes a municipality to enact a flood-risk area by-law. This by-law 'may prescribe engineering standards, designs and techniques to be followed in all development within the flood risk area…'. The Act also makes provision for the issuance of a permit under which 'prescribed engineering standards, designs and techniques' may be specified. However, article 77, paragraph (1)(h.1) the Act gives the Minister a significant level of authority over land use and development policies, including flood plains. It states unequivocally that, where there is a conflict between a local regulation, plan or by-law and a regulation under paragraph (1)(h.1), ‘the regulation under paragraph (10)(h.1) prevails’.

The 1:100 year flood has been used to delineate and designate flood plains in thirteen areas of New Brunswick (Environment Canada, 2000i).

Québec

Flood risk areas have been designated in 245 communities in Québec, covering 50 different streams, using the 100-year flood. The Québec FDRP agreement is unique in that it allows, with Ministerial approval, for a so-called “derogation” or special permission for a specified project to be undertaken within a specified area of the floodway. In a recent planning document (Ministère de l’Environnement, 2000), the provincial ministry of Environment pledges to support municipalities in their tackling of issues related to flood plain management.

In the Montreal Urban Community (Communauté urbaine de Montréal), a by-law was presented to the Standing Commission of Council in 1997 to deal with FDRP-designated areas. Although the content of this proposed by-law is not known, it is clear, that in at least some municipalities, issues relating to designated flood plains are dealt with in a responsible and official manner. But overall, in this province, drainage policies and regulations and the political will required to address stormwater management issues in a pro-active and consistent manner are much weaker than they are in Ontario, Alberta and British Columbia (Sabourin, 2001).

Ontario

This province is one of very few that has drafted very comprehensive legislation dealing with drainage works. The *Drainage Act* defines “drainage works” as ‘a drain constructed by any means, including the improving of a natural watercourse, and includes works necessary to regulate the water table or water level within or on any lands or to regulate the level of the waters of a drain, reservoir, lake or pond and includes a dam, embankment, wall, protective works or any combination thereof'. Under the Act, a local municipality, conservation authority or the Minister of Natural Resources (MNR) may request of a local council that 'an environmental appraisal of the effects of the drainage' be carried out. There is however no definition provided of what 'effects' are to be considered.

The Municipal Act provides that by-laws may be passed by Council of a municipality 'for the purpose of preventing damage to any property within the municipality by floods arising from the overflowing or damming back of a river, stream or creek flowing through or in the neighborhood of the municipality and for constructing such works as may be considered necessary.'

The administration of regulations and policies in Ontario is complicated by both the number and complexity of statutes and policies and the existence of regional municipalities and conservation authorities, both of which create additional layers of government at the regional scale. The regional municipality is considered to be the first level of government while the area municipalities under it constitute the second level. Regional municipalities and conservation authorities, respectively, administer flood plain regulations in areas under their charge. The Niagara Peninsula Conservation Authority's statement on its Web site (NPCA, 2000) regarding 'duplicated and confusing government roles' most likely includes the issue of drainage management.

Provincial regulatory policies for drainage management that regional/municipal governments must deal with include but are not limited to (MTO, 1999).

- Provincial Policy Statement: Natural Heritage, Water Quality and Quantity, Natural Hazards and Human Made Hazards (Planning Act)
- Official Plans, Secondary Plans, and Zoning By-laws (Planning Act, Municipal Act)
- Fill, Construction and Alteration of Waterway (Conservation Authorities Act)

The Ontario Ministry of Transportation, in its discussion on 'Elements of Common Law (MTO, 2000), asserts that 'anyone who interferes with a natural watercourse, must ensure that the works are adequate to carry the flow of water, even that resulting from an extraordinary rainfall'. Although this statement is aimed at MTO staff and engineering firms involved in highway construction projects for MTO, it is most likely applicable to all drainage works, including those designed and implemented under the authority of local governments. This same document specifies that the construction of drainage works by a municipality or other proponent within a highway right of way will need to conform to MTO's engineering standards.

The regulatory situation regarding the construction of highways appears to be very complex. MTO is conferred a regulatory management role mandated by the *Public Transportation and Highway Improvement Act*. However, MTO 'as an agent of the Crown, will not issue an approval that will contravene another regulatory agency's statutory mandate'. And in all, there are 4 federal and 8 provincial statutes, including the *Drainage Act*, that are applicable to highway construction projects, the majority of which clearly have an environmental focus and are very likely to impact on drainage works design and construction. MTO (2000), referring to the "Drainage Management Manual" of 1997, presents a summary of the highway drainage system design criteria. There are criteria based on regulatory storm passage and on design flow frequency, the latter varying according to the road classification (freeway urban arterial, local road, etc.). Adding to the already elaborate planning framework are several other design criteria including one based on requirements for level of control for water quality. Standards of practice are identified through manuals and guidelines issued to implement 'the design criteria and regulatory policy of a provincial agency, local municipality, or local conservation authority' (MTO, 1999).

MTO has established a body, known as OPS for dealing with Ontario Provincial Standards for Roads and Public Works (MTO, 2000b). The OPS has an Advisory Board and over 10 committees to address various issues related to roads and public works on an ongoing basis. The Drainage Committee is responsible for standards related to drainage works including culvert, drainage structures and sub-drain pipes. However, the standards produced by the Committee are limited in that they do not address the quantitative (computational) aspects of drainage works design.

Extensive directives emanating from MTO (1989) and its predecessor, the Ministry of Transportation and Communication (1987, 1989) on flood criteria, the Drainage Act and on MTO drainage management policy and practice also reflect on the complexity involved in dealing with drainage matters, both from technical and legal points of view. It is interesting to note that 'MTO may become liable if the stormwater runoff from the proposed land development is conveyed through a highway drainage system and damages any riparian property located upstream or downstream of the highway right-of-way.' This gives MTO the authority to request that a proponent complete a drainage impact analysis of any proposed land development occurring upstream or downstream of a highway drainage system. Again, drawing a parallel with municipal drainage works, it is likely that the same legal framework applies to the construction of stormwater facilities within the boundaries of urban and rural communities.

The *Lakes and Rivers Improvement Act* gives the Ontario Ministry of Natural Resources (OMNR) 'the mandate to manage watershed activities, particularly in the areas outside the jurisdiction of Conservation Authorities' (OMNR, 1996). This confers on OMNR the authority to require approval for projects such as the construction of bridges, culverts, dams, channels, diversions, agricultural drains and by-pass ponds on the part of proponents depending on the size of the project and on whether the proponent is the Crown, a municipality or a private citizen.

Under FDRP, Ontario defines the flood risk area by the flooding hazard limit. 'Depending on location in the province, the flooding hazard limit is determined by the 100-year peak flow, a regional storm, or the highest observed flood' (Environment Canada, 2000j). Special status, under a Special Policy Areas provision of FDRP, allows controlled development under certain conditions for an area within a community that has historically existed in a flood plain but where adherence to strict policies would result in social and economic hardship to the community.

Nothing on the government of Ontario's websites indicates any intention on the part of provincial authorities to revise the design specifications as a result of the potential impacts of climate change on the frequency and intensity of future rainstorms.

Manitoba

The Manitoba government's Web page listing its acts and regulations affecting surface and groundwater (Manitoba, 1997) sheds very little light on what legislation affects the design and construction of drainage works in that province. Its *Water Resources Administration Act* contains references to designated flood areas. The City of Winnipeg Act deals specifically with the designated floodway fringe for this city situated in the flood-prone Red River valley. Unfortunately, none of these legislative documents were available to the study team.

Following public consultation, this province has also developed the Manitoba Water Policies that were adopted in 1990. These policies are designed to achieve seven distinct objectives, three of which, falling under the headings of 'Conservation', 'Flooding' and 'Drainage', may have relevance to the design of drainage works.

Under FDRP, the 100-year flood was used to designate flood risk areas in 17 communities (Environment Canada, 2000k).

Saskatchewan

In this province, 'SaskWater is responsible for the management, administration, development, protection and control of Saskatchewan's water and related resources as established by The Water Corporation Act…'(Saskatchewan, 2000). SaskWater provides services related to the design and construction of drainage works for a number of municipalities, most likely smaller communities located in rural Saskatchewan.

However, with regards to drainage works, SaskWater's authority does not apply in municipalities that have developed their own regulations. In such cases, any drainage plans must be approved by the province (Anonymous, 2001). For example, the City of Estevan which, under the provincial *Urban Municipality Act*, has established its own by-law ‘for the Management and Regulation of Waterworks, Sanitary Sewage Works and Storm Drainage Works’ (Estevan, 1996). This by-law specifies ‘a five (5) year return or other more frequent event’ as the criteria for the design of storm sewers and ‘a one hundred (100) year return or other more frequent event… or the equivalent combination of more frequent storm events, for surface discharge and conveyance in channels, ditches, gutters, roads, detention ponds, or other such surface conveyances…’.

The Government of Saskatchewan has acknowledged the potential impacts of climate change on future water projects and is taking a pro-active stance. Under its Water Management Framework (Saskatchewan, 2000a), one of its official objectives is stated as: ‘Plan developments in consideration of the potential effects of flood, drought and climate change.’ The accompanying discussion on flooding focuses on the issues of year-to-year variability in precipitation and the need to improve flood forecasts. Its Action Number 35 recommends that criteria used for approving projects subject to flooding, including municipal works, be reviewed and modified so that ‘the level of protection is commensurate with the potential for damage’.

Saskatchewan has adopted a much stricter flood designation criteria than the other provinces under its FDRP agreement with the federal government, using the 500-year flood to delineate flood risk areas in 17 communities (Environment Canada, 2000l).

Alberta

The recently revised *Water Act*, administered by Alberta Environment, imposes legislative requirements for those constructing drainage channels and outfall structures to and on water bodies (Alberta Environment, 2000). All new developments must meet specific design criteria relating to potential flood events. However, there is provision for regional differences in water management to be reflected through the development of water management plans. It is not clear what is implied by this provision in terms of the application of drainage design criteria.

Under the Act, the Minister (of Environment) may designate ‘any area of land in the Province as a flood risk area’ and the Minister may ‘specify any acceptable land uses with respect to the flood risk area’. The Act also specifies that ‘the Minister must consult with the local authority that is responsible for a proposed flood risk area before making a designation…’.

Alberta Environment has issued a ‘Code of Practice for Watercourse Crossings’, applicable to bridges and culverts. This document contains ‘Standards for Carrying Out a Works’ that states that any increase in backwater from one of these structures must not result in flood damage to private and public properties. Works of a certain size are exempted as long as they do not alter the water body characteristic below the 1 in 25 year flood event.

It is not clear how the Water Act applies to municipal stormwater drainage works. It is assumed that, as is the case in other provinces, local governments are authorized to enact their own regulating by-laws but these must respect provincial statutes and regulations.

According to the City of Calgary Web site (Calgary, 2000) the storm sewer systems in most Alberta communities are designed to handle one-in-five-year rainfalls. More modern stormwater systems (including overland flow routes), built in the 1990’s, were designed to handle one-in-one-hundred-year rainfalls.

The City of Edmonton storm drainage design criteria are the 1 in 100 year rainfall event for the major drainage system which consists mostly of the overland drainage conveyance elements and the 1 in 5 year rainfall event for storm mains which service areas of 30 hectares or less (Edmonton, 2000).

This province’s *Drainage District Act* is mostly concerned with the formation of local administrative bodies formed to manage rural drainage works. It contains no legal directives related to the potential environmental impacts of drainage design and construction. The *Water Act* regulations appear to apply to the design and construction of all new rural drainage works.

Alberta's Framework for Water Management Planning (Alberta, 1999), the result of extensive public consultation, provides a framework for water management that aims for a fair balance between environmental sustainability and economic development. Also coming out of this process was the development of new policies designed to guide water management and fresh legislative authority for their implementation in the form of the Water Act.

Together these elements form and Integrated Resource Management (IRM) approach to achieving sustainable development. Planning at the local level and ongoing consultation with the provincial government are key processes for realizing the sustainability objectives. Standard setting, compliance monitoring and environmental impact assessments are additional instruments that the Ministry of Environment has developed or will be implementing to ensure the environmentally responsible development of non-renewable natural resources.

One of Alberta Environment's declared core businesses is flood control. Although it was not specifically intended to do so, the above framework, if properly exploited, has the potential to be an effective legislative toolset for dealing with the new stormwater management planning and design challenges that will be created by climate change.

Although responsibility for water management planning is shared with others, including non-government organizations, the government of Alberta will nonetheless 'retain responsibility for the endorsement and approval of plans and decisions under the Water Act'.

Alberta's comprehensive planning framework may be a suitable model for other provinces to adopt. However, in the context of the new drainage design requirements imposed by climate change, a more definite set of rules and regulations, applied more aggressively and more homogeneously across each of the provinces' municipal landscapes will need to be implemented.

British Columbia

The British Columbia government has mandated a process to be followed by municipal governments to facilitate an integrated and local approach to making decisions regarding liquid waste management. Within the Greater Vancouver Sewerage and Drainage District (GVS&DD), effective management of urban stormwater runoff is a key component of its Liquid Waste Management Plan (GVRD, 2000). It is within this context that GVRD has examined options for local government use of by-laws, permits and other regulations for stormwater management.

The recommendation made by GVRD to its constituent municipalities is based on a 3-level approach:

Level 1- Basic Regulations

In general, the basic regulation, Level 1, is designed to be implemented at minimal effort and cost to the municipality. This normally involves a self-certification program for developers and commerce/industry where designs, plans, O&M programs and site inspections are developed and certified by the private sector, usually by a registered Professional Engineer. This level of implementation is designed to be achieved by the municipality without hiring new staff, although some outside (consultant) assistance may be necessary for specific tasks.

Level 2 and 3 – Comprehensive Regulations

The more comprehensive levels of regulation, Levels 2 and 3, offer potentially greater benefits than Level 1, but they involve a much greater level of effort and cost to the municipality. These two levels of implementation require hiring and training new staff, specialty consultant assistance, and ongoing internal development of technical criteria, O&M programs, site inspections, enforcement activities, and review of designs and plans. While Level 1 provides a basic flat fee rate, the other two levels involve the formation of a more complex, and therefore more expensive to operate, cost-recovery system. Level 3 requires the creation of a self-supporting stormwater utility. While 'Level 1 and Level 2 regulatory tools can be implemented through sewer use bylaws', the Level 3 tool is formed through a separate bylaw.

In terms of flood control, Level 1 provides minimum protection but there is no provision for inspection or enforcement. It typically specifies only general design requirements for the capacity of the drainage systems. Application of Level 1 bylaws comes at a cost of approximately $10,000 to $25,000 a year using existing staff.

Level 2 and Level 3 are much more comprehensive bylaws that include requirements for erosion protection in watercourses and infiltration of surface runoff. Implementing these types of bylaws usually calls for detailed technical standard manuals containing descriptions of responsibility levels, planning needs and required design methods. Annual cost to a municipality can be significant as additional full time staff will be required to review design documents, provide education to developers and carry out inspections. The level of expertise required to support the Level 2 and Level 3 bylaws is significantly higher than for Level 1.

C. ADAPTIVE SOLUTIONS

This section of the report will present adaptive solutions that explore alternative changes in drainage design philosophies, policies & regulations as well as analysis & design methods. The study team, consisting of municipal & water resources engineers as well as hydrologists will formulate potential adaptive solutions based on the study findings and the collective experience of the study team members in water resources. The potential solutions was presented to a larger audience of regional stakeholders including policy makers via a discussion forum (Minutes of Forum included in Annex A) to determine preferable solutions. The following pages document a preferred set of adaptive solutions as well as implementation issues.

1. Changes in Policies & Regulations:

Background

The management of water in Canada is set within a complex web of plans, regulations and policies administered by three, sometimes four levels of government. This has resulted in inconsistent application of rules within provinces and across the country. This makes the implementation of adaptive measures to deal with the impacts of climate change a significant challenge.

In order to be able to react to climate change impacts on drainage works in a nationally consistent manner, revised legislative instruments, i.e. policies and regulations, may have to be developed and applied to bring about the required changes in design and construction practices. This portion of our report focuses on the existing legal framework under which stormwater drainage engineering and implementation activities function. It also makes recommendation towards a more pro-active set of policies and regulations that will help deal with the impacts of climate change on drainage systems in a sustainable manner.

What changes are required?

It is quite evident from the foregoing discussion on policies and regulations that there is a need for changes in the way stormwater activities and supporting policy and legislative instruments are administered across Canada. Ultimately, there must be a comprehensive and integrated (quality: pollutants; waste: sewers; energy: recreation and life sustaining) nationally consistent set of water policies specifically dealing with and a minimum national standard for drainage works design, construction and maintenance.

Federal role

The report ‘Broadening Perspectives on Water Issues’ (Bruce and Mitchell, 1995) calls for the federal government to significantly step up its national leadership role in water management. The views and recommendations of these authors reflect in many instances the results of our own research that is presented below. The reader is referred to the executive summary of ‘Broadening Perspectives on Water Issues’ for contextual information and a very readable treatment of the policy and legislative aspects of water management.

Bruce and Mitchell build a strong case for Environment Canada to re-focus its water activities and to ‘accept responsibility to ensure that federal legislative and other obligations continue to be met in one way or another while harmonizing actions between federal and provincial governments’. Their report also emphasizes the need to understand and prepare for the impacts of climate change on aquatic systems. Several references are made to the need for a strong federal role in the resolution of drainage issues with specific references to the expected impacts of climate change.

Accordingly, there is a unique opportunity for the federal government to become responsible for and take the lead in fostering the creation of a coherent planning framework to guide stormwater management in Canada. Without that leadership, progress will be slow and haphazard as is clearly demonstrated by the current situation as described earlier in this report. The Canadian Council of Ministers of the Environment (CCME) is well positioned to take the first step in improving federal-provincial coordination of activities related to stormwater management. A revised federal water policy could provide the appropriate initial discussion framework. The next phase would be an expanded consultation process involving the municipalities, other major stakeholders and the public.

The Flood Damage Reduction Program is a clear example of a successful federal-provincial process for dealing with an issue of significant national interest. It is strongly recommended that this program be modified with a focus on the development of basin-wide Master Drainage Plans developed within a holistic framework, taking into account climate change issues.

Changes at the policy level must translate into improvements to the drainage design and construction procedures used by local governments. Where possible, relevant national standards and guidelines should be adapted to deal with the new drainage design requirements resulting from climate-induced changes to hydrologic regimes.

Provincial role

The provinces must recognize that stormwater management and how it is being affected by long-term changes in global climate are closely linked issues that transcend political boundaries. Provincial governments should need no further incentive to collaborate with the federal government to establish a national framework for action.

Provincial authorities hold the power to effect the required changes. They should aggressively pursue the development of comprehensive provincial water policies and a formal planning process, such as the one developed by Alberta, with stormwater management as an integral element of these initiatives. Watersheds, not political boundaries, should be the basic geographical unit for planning activities. Obviously, participation in a stepped up Flood Damage Reduction Program would be a natural part of an overall provincial water management strategy.

Drainage regulations, sparse at best in some provinces, will need to be upgraded while taking into account revised national standards. Regulations cannot be effective without means to ensure their application. Enforcement must however strike the right balance between the threat of legal action against non-complying local authorities and the reward of economic incentives to those municipal governments that are pro-active and diligent in the conduct of their drainage design and construction activities.

While the provinces should become and remain pro-active in the area of stormwater management, they should strongly encourage a local approach to dealing with drainage issues. Accordingly, they should consider making the creation of ‘Master Drainage Plans’, which some of the more progressive municipalities are already pursuing, or ‘liquid waste management plans’, such as the ones decreed by the province of British Columbia for its municipalities, a mandatory requirement for local/regional governments.

Provincial governments should lead awareness and educational campaigns directed at its citizens to better inform them on the issues of stormwater management, the expected impact of climate change and the projected costs of dealing with potential consequences such as recurring floods. Such campaigns could be designed and funded jointly with the federal government and involvement from the municipalities.

Municipal role

In a sense, the municipalities are the victims of the current chaotic situation in the area of stormwater management. With little or no sense of purpose or direction conveyed to them by their federal leader and provincial masters, they generally do what they feel is the most appropriate or, in other words, the least costly, when confronted with drainage-related problems. However, with insurance companies and their own taxpayers targeting them for legal action at an ever increasing rate on account of presumably preventable flooding losses, local governments now find themselves in a leadership position by default but more often than not lacking the knowledge, the tools and the funding to meet their due diligence obligations.

The municipalities' best hope is in working closely with their respective provincial governments in coming up with fresh drainage design and construction standards based on risk assessment and cost-benefit analyzes. A federal-provincial consultation forum in which local governments can make their views known would in itself help move the standard-setting process along in the right direction and allow the municipalities to contribute to the design of funding mechanisms for the planning and implementation of 'climate-ready' drainage infrastructure.

All Canadian municipalities should take an in-depth look at the 3-level administrative approach promoted by the Greater Vancouver Sewerage and Drainage District (GVSDD) for dealing with stormwater management in a pro-active and systematic approach (GVRD, 2000). Although it may appear prohibitively costly to implement, the GVSDD strategy, if properly implemented, may actually result in long-term cost savings for those municipalities that are located within high risk flood-prone areas.

Municipal government should also take responsibility for educating their citizens to the risks involved in managing their drainage network and to the benefits and costs of appropriate design and construction standards.

Other Players

The Federation of Canadian Municipalities (FCM) is already active on the issue of climate change, having helped form the 'Partners for Climate Protection' (PCP) program (FCM, 2000). Through PCP, municipalities are actively involved in providing public education and outreach, conducting research, developing model plans, bylaws and ordinances and forming partnerships. However, as its designation implies, PCP is concerned primarily with prevention and has not tackled the other side of the climate change issue that is the subject of this report. This is an obvious gap that FCM should try to fill by being a player in a national discussion on stormwater management, climate change and the need to adapt current policies, legislation and standards to deal with more frequent extreme weather events.

2. Changes in Design Philosophies:

A second avenue for adaptive solutions deals with the current design philosophies. Many drainage systems are designed today to convey flows derived from a given design storm using IDF curves and considering "average soil moisture conditions". Given that the basic IDF information (which is at the heart of the design approach) will vary in the future, the entire design philosophy might require modifications or even replacement. Design philosophies based on using synthetic target IDF information or, those based on a family of acceptable climatic series or, on an "Acceptable Level of Service" or "Dual Drainage" principles might offer viable solutions.

It is recommended that:

- Drainage design criteria be reviewed and revised based on a detailed cost-benefit analysis and risk assessment considering the threat of climate change;
- Local governments move away from the ‘level of service’ approach that, under global warming conditions, entails ever changing design levels;
- A sliding index anchored to a reference year, similar to the Consumer Price Index, be explored as a means of determining appropriate design criteria. This will allow for an adaptive process that will be applicable for a relatively long time period;
- Life-cycle implications must be built in to the resulting design criteria and;

3. Changes in Analysis and Design Methods:

A third area that can potentially yield adaptive solutions is changing current methods of analysis and design. For example, many jurisdictions still use simplistic methods such as the “Rational Method” which is heavily reliant on historical data (IDF-based). Exploration of alternative methods such as deterministic modeling, which is based on using projected meteorological time series might be a more appropriate analysis & design method. There will be a need to adopt simple but adaptive design approaches to counter potential increases in complexity of the design methods due to the changing climate.

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APPENDIX A

Discussion Forum

CCAF Project A330 - DRAINAGE SYSTEMS, DESIGN METHODS & POLICIES

March 27, 2001; 13:30 Ottawa City Hall

Discussion Forum

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Participants

Adrien Comeau	Water Resources Engineer, City of Ottawa
Dave Harvey	Hydrologist, Environment Canada
Daniel Jobin	Water Resources Engineer, Kije Sipi Ltd
Peter Jolly	Water Resources Engineer, Kije Sipi Ltd
Paul Lehman	Water Resources Engineer & General Manager Mississippi Valley Conservation Authority
Daniel Pigeon	Insurance Broker, Pigeon & Fils
Bruce Reid	Water Resources Manager, Rideau Valley Conservation Authority
Eric Tousignant	Water Resources Engineer, City of Ottawa
J. F. Sabourin	Water Resources Engineer, Kije Sipi Ltd
J. G. Zakrevsky	Hydrometric Surveys, Environment Canada

Peter

There have been many studies and analyzes undertaken during the past ten years on the changes to precipitation statistics due to the climatic warming of the earth's atmosphere. For most of North America's geographic regions this warming has caused an increase in annual precipitation totals, although the analysis of some specific precipitation records had indicated a recent decrease in annual precipitation totals. By far the majority of recording stations, however, have shown increases with including the localities situated in

the Great Lakes Basin.

An analysis of the April through October rainfall data recorded at the Ottawa CDA station shows an increase in extreme rainfalls of durations from 2 to 12 hours of up to twenty percent over the period 1959 to 2000.

The doubling of CO2 in the atmosphere will increase the earth's air temperatures by 3.5 degree C, but unevenly spatially. Doubling CO2 modellings have indicated that in the Ottawa Valley the winter air temperatures will increase by seven degrees C and summer temperatures by three degrees.

Warmer air temperatures will cause more evaporation. Also hotter air masses will have larger capacity to hold vapour. These two phenomena will result in more annual precipitation to occur as well as higher rainfall intensities.

Two examples of the occurrence of increased rainfall intensities are: one from 1935 to 1999 the intensity of the annual maximum 15 minute rainfall at Torino, Italy, has increased from 5 to 30 mm - a definite trend; two, at Yokohama, Japan, from the twenty year interval 1955 to 1974 to the next twenty year interval, 1975 to 1994, the magnitude of both the 5 and 10 year return period rainfalls for durations less than 2 hours have increased . In the latter case, for both return periods the maximum increase is for the twenty minute duration - twenty percent.

An analysis of Ottawa's CDA station April through November rainfall records for the period 1959 to 2000 was made. During the first 21 years, the one-hour rainfall exceeded 20 mm 10 times and exceeded 30 mm once; during the next 21 year period, the one-hour rainfall exceeded 20 mm 15 times and 30 mm 3 times. Thus the station intensities of short-duration rainfalls are increasing.

The annual maximum rainfall intensity occurring over duration ranging from 5 minutes to 12 hours for the two recording periods were also analyzed. There are not much differences in the average intensities between the two periods; however, the annual intensities have larger standard deviations for most durations. For all durations except one, the larger of the recorded annual maximum occurred in the later period.

When the 5, 10, 25 and 50 year average return periods were calculated from this data, the second period had the larger rainfall intensities - by between 15 and 33 percent.

The preceding has shown that the intensities of short duration rainfall have increased during the past sixty years and will get larger if global warming continues. This will have adverse effects on the operations of existing drainage systems and the designs and costs of future ones.

JF

The most common analytical approaches to design and analyze urban drainage systems include the Rational Method and Hydrograph Models. Both approaches require rainfall data that is usually taken from IDF curves that represent the rainfall statistics observed at a given station.

As global warming will change local rainfall patterns and trends thus statistics, it can be expected that the results obtained from the use of the Rational Method and Hydrograph Models will also be affected. The questions are: i) how will design peak flows change?, ii) how will design runoff volumes change?, iii) how will this affect sewer sizes and associated costs?, iv) how will this affect the end-of-pipe storage requirements and associates costs?, and finally, v) how will this affect the operation of existing drainage systems?

To answer the above questions, a hypothetical drainage system was analyzed with both the Rational Method and a Hydrograph Model (SWMHYMO) using the existing Ottawa CDA station IDF curves. In the analyzes, the rainfall intensities for the 2, 5, 10, 25, 50 and 100 year return period were increased by 5, 10, 15 an 20%.

It was demonstrated that the effects on computed peak flows with the Rational Method were practically proportional to a selected increase in rainfall intensity. That is, a 5% increase in rainfall intensity generated a 5% increase in the computed peak flow. This was true for all tested scenarios (ie. Drainage areas of 10 to 100 ha, with imperviousness ratios of 20 to 80% and for return periods of 2 to 100 year). In terms of pipe sizes and associated costs, the larger peak flows translated to a 2% and 4% (respective) per 5% increase in rainfall intensity.

When using the Hydrograph Model Approach, the sensitivity of the results were generally similar to those obtained with the Rational Method except, that the increases in simulated peak flows were approximately 1.8 times larger than the selected increase in rainfall intensity. That is, for a 5% increase in rainfall intensities, simulated peak flows increased by 9% (1.8 times 5%). Similarly, for a 20% increase in rainfall intensities, the simulated peak flows increased by approximately 36%. This result highlights the computational difference between the Rational and Hydrograph drainage design methods, but more importantly brings forth the impact that the simulated runoff from pervious surfaces is more sensitive to increases in rainfall intensities than the runoff from impervious surfaces. Pervious areas generated proportionately larger increases in peak flows as compared to impervious areas. In terms of pipe sizes and associated costs, the Hydrograph Model simulated peak flows translated to respective increases of approximately 4% and 8% for each 5% increase in rainfall intensities.

Simulated runoff volumes obtained from the Hydrograph Model, with the use of design storms, increased on average by approximately 6.5% for each 5% increase in rainfall intensities. Larger increases of 8% per 5% increases in rainfall intensities were noted for the lower imperviousness ratio of 20% while lower increases in runoff volumes of 6% per 5% were noted for the higher imperviousness ratio of 80%.

For the design of end-of-pipe storage to control the runoff of a 100 year storm, the volume requirements could, depending on the release rate, increase by as much as 35% for each 5% increase in rainfall intensities. That is, based on 39 years of continuous simulations, an area of 100 ha with an imperviousness ratio of 40% could require 2.4 times more storage volume in an end-of-pipe facility in order to control the runoff of a 100 year storm to a target release rate of 50 L/s/ha.

Although future drainage systems could be designed to accommodate future increases in peak flows, the consequences of increased rainfall intensities on existing drainage systems would translate to a reduction in the level of service by increasing the frequency of surface ponding nuisance and sewer backups. It was demonstrated that an existing drainage system design for a 5-year level could have a reduced level of service of just over the 4-year level if rainfall intensities were to increase by only 5%; this represents a 20% reduction in the level of service. Similarly, if rainfall intensities were to increase by 20%, an original 5-year design could see its service level reduced to approximately a 2.5- year design thus potentially increasing the frequency of surface or basement flooding by 200%. For systems originally designed for a 10-year event an increase of 20% in rainfall intensities will reduce the systems level of service to just over 4-years.

As with peak runoff flows, future drainage systems could also be designed to accommodate future increases in storage volume requirements. However, the operation of existing end-of-pipe storage facilities will be affected by future increases in rainfall intensities in that they will no longer provide their originally intended level of service. That is, existing storage facilities will overflow more frequently and will not provide adequate downstream flood or erosion protection. It was demonstrated that for an area of 100 ha with an imperviousness ratio of 40%, where the target release rate is set to 25 L/s/ha, an existing storage facility sized to control the runoff rate from a 100-year event would have a reduced design level in the future down to a 1:50 year event if rainfall intensities increased by only 5%, and down to a 1:15 year event if rainfall intensities increased by 20%. This means that the probability of overtopping an end-of-pipe facility originally sized to control a 100-year event would be increased by a factor of 2 (for an increase in rainfall intensities of 5%) and a factor of almost 7 (for an increase in rainfall intensities of 20%).

Similar conclusions can be obtained for smaller facilities originally sized for a 5-year storm.

Implement Major/Minor and other well developed storm water management techniques for new areas. Specify the use of higher (Shift in) IDF curves as a simple method to account for climate changes within drainage designs.

Paul

Has seen paper in Canadian Water Resources journal that summarizes Regulations. Can make it available to Jean-Guy. In Ontario, no integrated water policy – such a policy is needed and federal government should get involved.

Fears impact on reservoir operations since they are difficult to change due to extensive consultative process.

Adrien

Suggest moving away from “Level of Service” drainage design concept and adopt more risk management base approach where benefit costs on a local basis should be used. Solutions must be flexible.

Eric

Existing areas with house lead for example are at risk but municipalities need funds to systematically optimize mitigation of flood risk for each area such as appropriate use of Inlet control devices.

Daniel P.

Insurance companies winning more court cases involving flooding. Industry generally reactive and likely respond by simply excluding coverage on a local basis or a minimum raise premiums and deductible (Both household & Municipalities). For example, Orleans, majority of Hull, parts of Gatineau are excluded from coverage by insurance companies. Can no longer insure against floods, only against sewer backups. However, the industry would likely remove coverage restrictions in areas where municipalities implement storm water management. The industry is highly competitive therefore apt to adopt positive changes and evaluate the risk on a year by year basis.

Daniel J.

Daniel brought up the idea for a public awareness campaign. There was a bit of defensiveness on the part of one or two participants on the idea of a public awareness campaign. Property devaluations were mentioned as an issue if a high risk targeted campaign is mounted. However, the hesitation was likely due to a narrow interpretation of 'public awareness' defined as simply telling homeowners what the risk of their home getting flooded is. A broader perspective is needed. There could be new pieces or documentaries aired on national television to help the public at large understand the issues involved. In other words, an education campaign that makes people not only aware but also educated enough to ask politicians the right questions. A public consultation exercise, at the national level, that would get citizens engaged should be considered

All on design criteria

Design decisions (5-year *vs* 10-year design) – who made them? Cost-benefit analysis should be done. Risk assessment should be part of process. Could be a recommendation from this group. This is a area where the Federal Government could play a lead role. This is complex and requires involvement of various disciplines. Establish comprehensive national policy and minimum standards on drainage (basin approach) (Daniel). National standards and policies would help bring consistency in assessment methods (Daniel). Design is a moving target (Daniel). Process should be adaptive – in other words, not subject to constant change but able to respond to needs for a long time (Daniel). Move away from level of service approach (Daniel). There are several 'levels', not just one (Bruce). Even without climate change, engineering practices and design are imperfect (Dave). Use "Best Management Practises" and level of safety that has life cycle management implications built in (Adrien). No need for drastic change as some degree of conservatism built in design process (Bruce).

IMPORTANT

5-yr vs 10-yr Design : Cost-benefit analysis should be done. Could be a recommendation from this group. This is a area where the Federal Government could play a lead role. This is complex and requires involvement of various disciplines.

Dave

Expanded FDRP approach should be used as a vehicle to instill change. Perhaps we could work through the Federation of Canadian Municipalities. Adopt a basin approach *vs* piecemeal (local)

Bruce

Climate change is just one more factor re: floodplain delineation. Currently, there is no financing of mapping activities. Should revise maps – initially were going to revise every 15 years!