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URBAN INFRASTRUCTURE FLOODING IN SOUTHERN ONTARIO: A CASE STUDY APPROACH TO DETERMINE CAUSALITY (PART TWO)

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Résumé de l'article

Dans le cadre d'une étude de cas, trois villes ont été choisies à partir d'un échantillonnage d'événements liés à l'inondation et qui tous ont été rapportés dans les journaux locaux. Les villes de Peterborough, Sarnia et Ottawa ont toutes eu à subir l'expérience d'inondations urbaines au cours d'une même année et dans le même secteur géographique, à savoir le sud de l'Ontario. Une revue sommaire de ces trois événements démontre qu'il peut exister différents facteurs causals pouvant influencer les inondations urbaines. Les villes furent choisies comme cibles de l'étude de cas à cause de leur localisation dans une même région du Canada, de leur localisation dans la même zone climatique et du fait que les événements à l'origine de chaque inondation, quoique similaires, semblent être le résultat de particularités distinctes de l'infrastructure urbaine. On colligea les données de précipitation pour chaque cité cible et on révisa les données régionales climatiques. On prit en compte, dans chaque cas, les éléments relatifs à l'intensité, à la durée et à la fréquence, mais on compara uniquement les averses maxima de pluie de plus de 15 minutes, de plus d'une heure et de plus de 24 heures.

On a mis au point, sur une période minimum de 20 ans pour chaque cité, des cartes sur les changements d'utilisation de terrains environnant les inondations. On mesura approximativement 1 kilomètre carré autour de la zone inondée, et les résultats furent comparés sur différentes périodes. Le changement du col, d'un couvert perméable à imperméable, fut considéré comme un mécanisme propre à augmenter les inondations.

On examina aussi les systèmes d'égoût en vue de déterminer s'ils ont été un facteur causal d'inondation urbaine dans les villes ciblées.

URBAN INFRASTRUCTURE FLOODING IN SOUTHERN ONTARIO: A CASE STUDY APPROACH TO DETERMINE CAUSALITY (PART TWO)

by Tanuja Kulkarni

ABSTRACT

Three case study cities were chosen from a number of urban flood events that were identified through local newspapers. Peterborough, Sarnia and Ottawa all experienced urban floods in the same year and are all located southern Ontario. Cursory review of the three events indicates that there may be different causal factors that influenced the urban floods. They were chosen to be case study cities because they fall in one region of Canada, are in the same climate zone and the flood events, though similar, appeared to be the result of different features of the urban setting. Precipitation data for each case study city was gathered, and the regional climate data was reviewed. Intensity, duration and frequency tables were considered for these cities but only maximum rainfall for 15 minutes, one hour and 24 hours were compared.

Land use change maps in the areas surrounding the flood events were developed over a minimum of 20 years for each city. Approximately 1km^2 was measured around the flooded area and compared over time. The change from permeable to impermeable land cover was considered as a mechanism for increased flooding.

The sewage systems were also examined to determine if they could be a cause for urban flooding in these cities.

RÉSUMÉ

Dans le cadre d'une étude de cas, trois villes ont été choisies à partir d'un échantillonnage d'événements liés à l'inondation et qui tous ont été rapportés dans les journaux locaux. Les villes de Peterborough, Sarnia et Ottawa ont toutes eu à subir l'expérience d'inondations urbaines au cours d'une même année et dans le même secteur géographique, à savoir le sud de l'Ontario. Une revue sommaire de ces trois événements

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démontre qu'il peut exister différents facteurs causals pouvant influencer les inondations urbaines. Les villes furent choisies comme cibles de l'étude de cas à cause de leur localisation dans une même région du Canada, de leur localisation dans la même zone climatique et du fait que les événements à l'origine de chaque inondation, quoique similaires, semblent être le résultat de particularités distinctes de l'infrastructure urbaine. On colligea les données de précipitation pour chaque cité cible et on révisa les données régionales climatiques. On prit en compte, dans chaque cas, les éléments relatifs à l'intensité, à la durée et à la fréquence, mais on compara uniquement les averses maxima de pluie de plus de 15 minutes, de plus d'une heure et de plus de 24 heures.

On a mis au point, sur une période minimum de 20 ans pour chaque cité, des cartes sur les changements d'utilisation de terrains environnant les inondations. On mesura approximativement 1 kilomètre carré autour de la zone inondée, et les résultats furent comparés sur différentes périodes. Le changement du sol, d'un couvert perméable à inperméable, fut considéré comme un mécanisme propre à augmenter les inondations.

On examina aussi les systèmes d'égout en vue de déterminer s'ils ont été un facteur causal d'inondation urbaine dans les villes ciblées.

1.0 INTRODUCTION

The events examined in this paper were identified through local newspapers and are important to consider because they may indicate an emerging pattern of floods in southern Ontario.

The case study cities of Peterborough, Sarnia and Ottawa all experienced flooding in the summer of 1996, and were chosen based on apparent differences in the causes of the floods.

Precipitation in the cities was compared over time to determine if these cities have been experiencing an increase in extreme precipitation that may correspond to increased urban flood frequency.

Changes in land use are also analyzed to determine the contribution of permeable surfaces urban floods. The land use surrounding the affected areas was mapped over time to measure changes in permeability. The soil types in the hinterlands of the cities were mapped and the soil type within the city limits was interpolated, indicating the natural drainage that underlay each city.

The sewage systems themselves need to be considered when studying urban floods, as the increasing growth of the sewer network relative to urban development may be a key concern. The sewershed that the flooded area lies in is important to define, and its characteristics, including capacity and density need to be determined.

2.0 VARIABLES OF CONSIDERATION

2.1 Precipitation

Precipitation data for each case study city was gathered, and the regional climate data was reviewed. The data collected for Peterborough was collected at the Peterborough Airport from 1971 to 1990. Data from the Sarnia Airport was collected from 1970 to 1990. The Ottawa data was collected at the Ottawa International Airport from 1967 to 1990. All three sites were located several kilometers from the airport, and likely do not reflect the exact volumes of rain that affected the flood areas. All events occurred in the summer, and due to convective rainfall, any precipitation data collected would be spatially concentrated. Intensity, duration and frequency (IDF) data for each city was evaluated to determine if the trends of the city followed a regional precipitation trend.

2.2 Land Use

Land use change maps in the areas surrounding the flood events were developed over a minimum of 20 years for each city. The change from permeable to impermeable land cover was considered as a mechanism for increased flooding.

An area approximately 1 km^2 in size surrounding the urban floods in the three case study cities was mapped using aerial photos, Ontario Geographic Survey topographic maps and city maps. The time intervals were chosen based on available air photos. Ontario Soil Survey maps were used to determine the soil type and drainage characteristics of lands surrounding the cities. The soil types within the cities were not mapped, due to the unavailability of urban soil maps, but were interpolated from the surrounding land.

An area of approximately 1 km^2 around the flooded streets was mapped, classified and measured. The area surrounding the flooded streets was mapped using three land use classes: urban, forested and field. The urban land class included all homes, driveways, sidewalks, commercial and industrial buildings, and most residential road networks. The forest class included areas with significant tree or shrub density. This determination, using aerial photos, was made based on whether the leaf coverage allowed the viewer to see the surface of the ground. Significant density was defined as an inability to view the ground surface. The field class included all areas that appear to be farmed, sports fields, and large grassed areas.

Appendices 1, 2 and 3 contain tables of data from the airport climate stations that were used to create the intensity, duration and frequency curves for the case study cities. Table 1 lists the maximum rainfall amounts for the durations of 5 minutes to 24 hours for each year the station operated. The summary values for each duration include mean extreme, standard deviation, years of record, coefficient of skewness and coefficient of kurtosis. Table 2 consists of two sections: one showing rainfall durations of 5 minutes to 24 hours, and the precipitation amount for return period values for 2, 5, 10, 25, 50 and 100 years. The first section shows the expected total amount for each duration and return period. The second section lists the value for each duration as a mean hourly rate of rainfall averaged over the corresponding duration. Table 3 outlines the characteristics of the interpolation equation. The values from Table 1 (precipitation value by return period) are fit onto log-log paper (intensity by duration) and the best fit line is the IDF curve for that return period (Hogg and Carr 1989).

The IDF curves for the case study cities can be seen in Appendix 4. These IDF curves cannot be compared over time without comparing these IDF curves with historical IDF curves of these stations. This option was not available, so the undifferentiated values of Table 1 were considered. These graphs (Figures 3, 4 and 5) display precipitation value as the independent variable and thus, are more appropriate for this study.

The most common return period chosen is the 5 year storm, and in fact, Ottawa and Peterborough sewer networks have been constructed with a 5 year return period. The Sarnia sewage network is more variable and sections of it range from the 3 to 5 year return period.

3.0 CASE STUDIES

The three case study cities were chosen from a number of urban flood events that were identified through local newspapers. These cities all experienced urban floods in the same year and are all located southern Ontario. Cursory review of the three events indicates that there may be different causal factors that influenced the urban floods. These factors were explored within the confines of the limited resources.

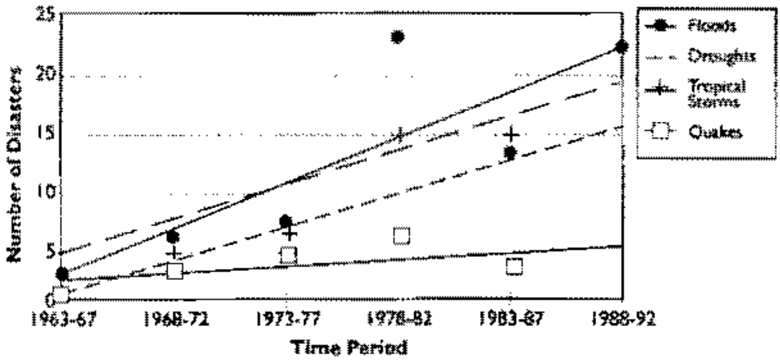
Global flooding has increased in frequency in recent years (Figure 1). In urban areas of the St. Lawrence Basin in Southern Ontario and Quebec, urban floods have caused damage by overland flow and sewer back-up. The cause of the flooding for each case study city is that the rainfall volumes exceeded infrastructure capacity, but the floods may be the result of land cover change, obsolete drainage infrastructure, extreme rainfall or a combination of these factors.

Recent urban floods in Ontario have left affected households and businesses to discover that compensation for flood damages is often not a simple process. The issue of urban floods is a complex one, where the role of insurance companies is generally defined, but the response of government changes for each event, as there is no municipal policy response to infrastructure flooding.

The summer of 1996 brought floods to much of Europe and to the American mid-west. The cities of Peterborough, Sarnia and Ottawa, also experienced flooding, leaving close to 3000 people with damaged property. These floods were unusual because they were flood events that occurred outside the floodplain. They were chosen to be case study cities because they fall in one region of Canada, are in the same climate zone and the flood events, though similar, appeared to be the result of different features of the urban setting. The population of the three cities can be seen in Figure 2.

As Peterborough developed new areas and paved them, the impact may have led to flooding in adjacent properties. Sarnia's

FIGURE 1
GLOBAL NATURAL DISASTERS, INCLUDING FLOODS 1963 TO 1992 (FRANCIS AND HENGEVELD 1998)



combined sewage network is up to 90 years old in some sections, and even moderate rainfall events may have contributed to urban flooding, particularly as the city expanded. Ottawa's sewage system is approaching 100 years old. The volume of flow that it was inundated with that summer was unusually large, leading to floods.

During the summer of 1996, Ottawa experienced large scale urban floods, where the average insurance claim was between $1000 and $1500, but the cost to the insurance industry was over $20 million (Insurance Council of Canada 1998). The cost to service the large number of claims was increased as a result of using out of town adjusters, hotel and car rentals, and the number of support staff required to process the claims.

The case study cities each consider one urban infrastructure flood event, but do not look at the frequency of the floods over time. The value in considering the independent events is the process of collecting relevant urban data for very local areas and determining how these separate events fit into rainfall trends of the city.

☐ 3.1 Peterborough Case Study

Peterborough is a city whose growth has increased steadily since its incorporation in 1905 (Statistics Canada 1998). Its relative location to the other cities can be seen in Appendix 6.

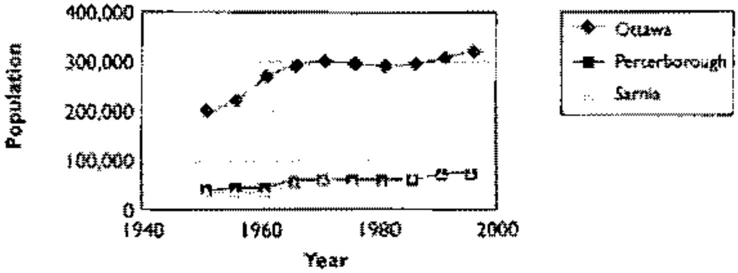
This city is in the midst of a drumlin field, and borders the Mark S. Burnham Provincial Park to the east (Appendix 7). The city recently annexed land on the eastern border extending to Television Road including part of the Provincial Park.

The soils that surround the city are alternating Ontonabee loam, Foxboro silt loam and Brinco loamy sand. The properties and location of these soils are listed in Appendix 8. The drainage in Peterborough is complex as a result of the extensive drumlins. The alternating Ontonabee loam is well drained, and is intermixed with Foxboro silt loam, a poorly drained soil, which may contribute to differential drainage. These are the two soil types surrounding the urban flood sites, but the actual underlying soil characteristics were onavailable.

3.1.1 Peterborough Flood, 1996

The 17.0 mm of rainfall that the City of Peterborough received on September 13,1996 impacted many homes on Meadowview Road (Appendix 9). The residents attribute the flooding in this area

FIGURE 2
POPULATION GROWTH FOR OTTAWA, PETERBOROUGH AND SARNIA



to construction of an uphill subdivision and the paving of an uphill drainage swale. Previous to the subdivisions 1993 construction, there were no flood problems on Meadowview Road. The runoff from the rain event created basement and yard floods, the resulting damage cost one homeowner $17,000 (Tyson 1996). This was not a large volume of rainfall, but the impacts were considerable.

3.1.2 Land Use

The land area of the City of Peterborough is 53 square kilometers. Although the city is primarily urban, it includes a number of wetland sites within its borders. The major waterways, which have been channelized to some degree, are the Trent Canal and the Ontonabee River, which flow south into Little Lake and through to the North Monaghan Township.

The area affected by the September 1996 flood lies to the east of Little Lake and just west of the annexed land and Mark S. Burnham Provincial Park, which is primarily wetland. This subdivision borders North Beavermead Park and includes a tributary of Little Lake.

Approximately a 1 km^2 area was mapped around the affected area from 1954 and 1978 air photos. The change in land distribution can be seen in Table A and in Appendix 10. The areas were chiefly measured using a planimeter, but a grid based integration method was used for very small areas. The 1954 area and the 1978 area are not identically mapped. There is a 0.67 km^2 difference in the areas, which can be attributed to mapping error, relating to scale changes and to estimations of location, as the affected area was not constructed in 1954. The affected street was not identifiable in the 1954 aerial photos, and it location was approximated along with the 1.0 km^2 area surrounding it. The total area mapped for Peterborough may not be identical, but the changes in the land use of the areas mapped form 1954 to 1978 are broadly comparable.

The increase in urban area from nearly zero to 0.5 km^2 may be one of the key determining factors of the flooding experienced in September 1996. The field area decreased by 0.56 km^2, and the forested area changed from 1.02 km^2 to 0.41 km^2. The figures in Table A indicate that the forest area decreased, likely converted to field and to urban areas, and the field areas decreased, likely to the increase in urban area.

3.1.3 Homeowner Reaction

Those who were impacted by the urban floods in Peterborough were not compensated for damage through insurance and looked for support from the City. The homeowners viewed the situation as one where the City was responsible, and needed to take action (i.e. liable for damages), but the City insists that the City is not accountable, and that the citizens should be looking toward the uphill subdivision developer for blame. The homeowners maintain that the City authorized the subdivision, and are therefore liable for the damages. The issue of sewers was not raised in this community, as the sewers that attach the area to the larger trunk sewers are new, and the age and quality of the sewershed it sits in has not been disputed.

3.1.4 Peterborough Precipitation Graph

The IDF curve data for the City of Peterborough from 1971 to 1990 can be found in Appendix 2. The 15 minute, one hour and 24

TABLE A
LAND USE CHANGE FOR PETERBOROUGH 1954-1978

	1954 (km^2)	1978 (km^2)	Difference (km^2)
Total area mapped	4.03	3.36	– 0.67
Forest	1.02	0.41	– 0.61
Field	2.68	2.30	– 0.38
Water	0.33	0.09	– 0.24
Urban	0.0075	0.56	+ 0.55

hour data were plotted (Figure 3). These graphs illustrate that there are not strong trends that were detected using a linear regression.

Although the precipitation graphs do not present an obvious change in precipitation for Peterborough, the land use change in the area was dramatic. If urban flooding in the area of Meadowview road is increasing, the more likely causes include changes in land use or sewer network problems.

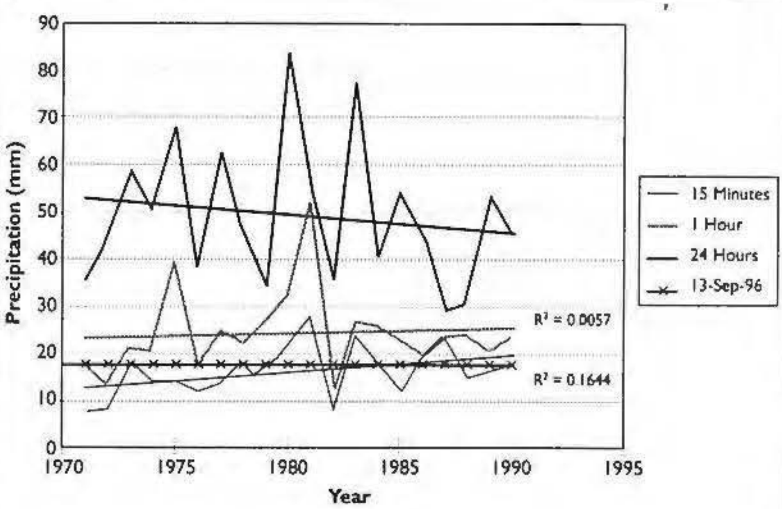
☐ 3.2 Sarnia Case Study

The City of Sarnia, located in the northwest portion of Lambton County, was incorporated in 1914, and has grown to a population of 72 738. Sarnia sits on the east shore of the St. Clair River and the south coast of Lake Huron (Appendix 11).

3.2.1 Sarnia Flood, Summer 1996

Urban floods in Sarnia occurred on June 22, 1996, and affected over 200 homes. The one day, 40 mm rainfall affected homeowners who have combined sewer systems on Bright Street and Conrad Street (Appendix 12). Both were affected by sewer back-up, and are both on combined systems, while homes in the Wiltshire Park subdivision who are on a separate system were also

FIGURE 3
PETERBOROUGH TIME SERIES OF MAXIMUM PRECIPITATION



flooded. These floods caused an estimated $20 million in damage and 2 500 people made insurance claims.

Some residents of Bright Street have experienced urban infrastructure floods up to six times since they moved in. The 1996 event was the second flood in two years. Some residents have since lost their insurance due to the high number of claims (Mathewson 1996).

3.2.2 State of the Sewers

Many Sarnia residents are connected to combined sewers. The City of Sarnia initiated a number of sewer projects in 1989 and has completed 30%-40% of the separation projects, including completion of $5.4 million storage and holding tanks. Some residents believe that the separation issue should be a priority because when they are flooded, it is not with storm water, but with the contents of the combined sewers. The sewer system in Sarnia in parts is over 90 years old. The overflow of the system is a regular occurrence, and untreated sewage is often discharged into the lake (McMichael pers. comm.). The move towards a completely separated system is the preferred option, but is currently not a priority for the municipality. The system is designed for the 3-5 year storm event, but under the anticipated influence of climate change, that return period will likely shrink. New developments in the municipality have drainage networks that are separated, but are built for the 2-3 year storm event. This trend of decreasing the capacity of the sewers, but separating them does not mitigate the possibility of urban floods, but changes the quality of the water that inundates the home.

3.2.3 Land Use

The current land area of the City of Sarnia is 165 km^2. The City has few green spaces and few wetland areas. The waterways in the city are primarily channelized. The water flow direction is either to the east into Lake St. Clair or to the north into Lake Huron.

The soil that surround the city is primarily Brookston clay, although to the northeast of the city lies Brady sandy loam and to the north is Granby sandy loam and Plainfield sand. Appendix 13 contains the properties of these soils. Brookston clay is poorly drained and may explain why most of the natural watercourses are channelized. The poor drainage capacity may contribute to urban floods, as the natural drainage ability is low, the movement of water to sewers from field and forested area is faster than it would be over better drained land.

Bright Street and Conrad Street were both affected by the "flood of '96", and a 1 km² area around them was mapped. Aerial photos were used to map the areas in 1955 and 1978. Due to the scale differences in the aerial photos, the 1955 map contains both streets, while the 1978 maps are separate.

The change in area of forest, field and urban area is detailed in Table B and in Appendix 14. When considered separately, the differences between the 1955 land use information and the 1972 land use appears large, but when considered together, the differences are less dramatic. The key changes is the combined increase is in the forested area. The newly greened area that surrounds major road ways were not planted in 1955, but are furthest away from the areas of interest. The change in water, field and urban areas may be the result of either mapping error, double counting due to overlap, or both.

3.2.4 Sarnia Precipitation Graph

The IDF curve data for the City of Sarnia from 1970 to 1990 can be found in Appendix 3. The 15 minute, one hour and 24 hour data was plotted (Figure 4). The graphs indicate that there has been no detectable increase using a regression analysis in the 20 year period.

TABLE B
SARNIA LAND USE 1955 TO 1978

	1955 km²	1978 Bright St. km²	1978 Conrad St. km²	1978 Bright St. + Conrad St. (combined) km²	Difference 1955 – combined 1978 km²	Difference 1955 – Bright St. km²	Difference 1955 – Conrad St. km²
Total area mapped	10.36	6.44	3.99	10.43	+ 0.07	– 3.92	6.37
Forest	0.03	0.05	0.09	0.14	+ 0.11	+ 0.02	0.11
Field	0.84	0.52	0.33	0.85	+ 0.01	0.32	0.01
Water	0.44	0.09	—	0.09	– 0.35	0.35	—
Urban	9.04	5.8	3.58	9.38	0.34	3.24	5.46

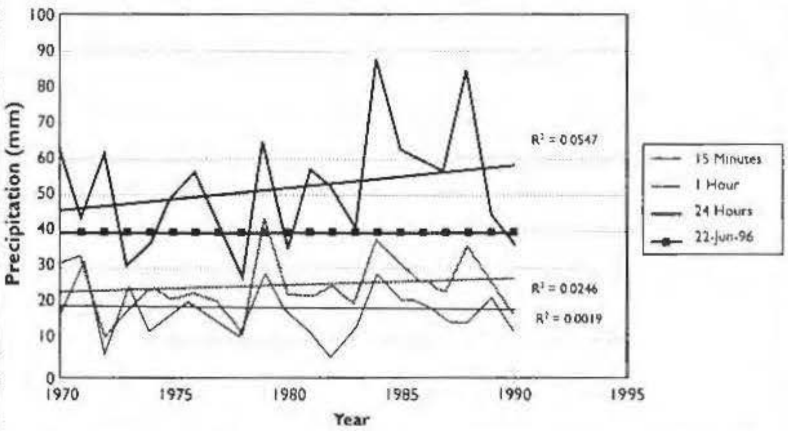
The land use change in the areas surrounding Bright St. and Conrad St. are not extensive, and the precipitation graphs do not indicate a consistent change over the three durations chosen. This leaves the question of the sewers to be resolved. The sewage network of Sarnia consists of different types and capacities of sewers. This may be the primary contributor to urban flooding in the city, but before that can be determined, the complete sewershed for Bright St. and Conrad St. need to be analysed.

3.3 Ottawa Case Study

Ottawa is 110 km² and was incorporated in 1854. It currently has a population of 223 340. The City is bordered to the north by the Ottawa river.

The Municipality agreed to pay for expenses that were caused by *blocked* sewers for the 1996 flood event, but not for damage resulting from total system overload (i.e. they would not be responsible for any natural volume overflows, but for overflowed sewers resulting from blockages would be covered). A by-law passed in 1987 provided the citizens of Ottawa with compensation of up to $3000 for flood damage to homeowners who have installed backwater valves in their basements. These valves were designed to prevent sewage from back washing into basements. After the storm of August 8, 1996, the city claimed that only backwater valves that were installed and inspected under a municipal program would be eligible for this compensation.

FIGURE 4
SARNIA TIME SERIES OF MAXIMUM PRECIPITATION



3.3.1 Ottawa Flood, Summer 1996

On August 8, 1996, 90 mm of rainfall fell, flooding hundreds of basements in Ottawa, Gloucester and Vanier in 24 hours. In the City of Ottawa, it affected over 1200 homes and spawned 1800 insurance claims for resulting property damage.

3.3.2 State of the Sewers

Portions of the sewer system of Ottawa are 100 years old. The City of Ottawa is responsible for storm sewers, while the region manages the larger trunk sewers flowing from municipality. The interceptor, into which stormwater drains, is part of a network of pipes that run across the city collecting sewage. This system was not designed for the type of flow that the City experienced on August 8, 1996. Overflows of this system occur regularly during heavy rainfalls. Improper connections like floor drains in garages that link to sanitary sewers result in numerous leaks in the system. The City needs to upgrade the sewer system, but is unwilling to finance the $40 million project. The Commissioner of Public Works of Nepean stated that, "We have known for 35 years that sanitary sewers designed to take the flow from normal household use... don't have the capacity for the big rainfall" (Marr 1996).

Delmar Drive (Appendix 15), a street in Ottawa's Applewood Acres, flooded twice in two weeks during that summer.

3.3.3 Land Use

Ottawa is primarily underlain with moderately permeable Rideau clay (Appendix 16). The change in its land use can be seen from 1971 to 1991 in table C and in Appendix 17. The small increase of urban land use and of field area may be due to map

TABLE C
OTTAWA LAND USE 1971-1991

	1971 km^2	1991 km^2	Difference km^2
Total area mapped	5.57	5.64	+ 0.07
Forest	0.3	0.19	+ 0.11
Field	1.22	1.33	+ 0.11
Urban	4.04	4.12	+ 0.08

error, but this case study appears to have the least variability between the two years measured. The change in forest cover is most likely converted to both field and urban uses.

3.3.4 Ottawa Precipitation Graphs

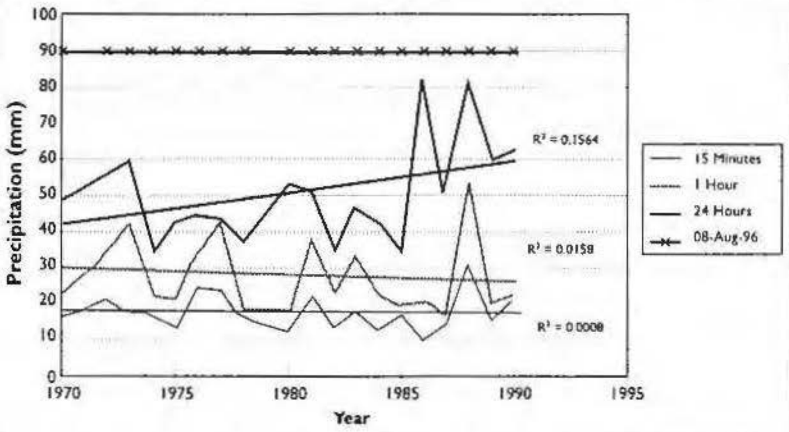
The IDF curve data for the City of Ottawa from 1905 to 1990 can be found in Appendix 4. The 15 minute, one hour and 24 hour data was plotted for 1970 to 1990 (Figure 5). Although there appears to be a higher variance for the last five years of 24 hour data, the regression analysis applied found no strong correlation ($R^2 = 0.16$).

Land use in Ottawa has not changed significantly over the 20 years that were examined. The sewer system and the rainfall extremes both seem to be important when considering urban flooding. The old sewage network combined with the apparent increases in extreme precipitation are mutually exclusive events that may occur independently, but the cumulative impact on homeowners may be significant.

4.0 ANALYSIS AND LIMITATIONS

When considering urban infrastructure floods independently, the first tool that is required is the sewershed map. This data was

FIGURE 5
OTTAWA TIME SERIES OF MAXIMUM PRECIPITATION



unavailable, but efforts to estimate this area included using a 1 km^2 area around the affected sites and considering the natural drainage of the area. Mapping the sewersheds for the areas affected is critical for determining what areas influence the sewers. Since no sewer data was available, a 1 km^2 was used as a surrogate for the infrastructure, rainfall and land use flooding relationship. This assumption is legitimate, as the sewers are influenced by the surrounding land uses (Poof 1999 pers. comm.). Although complete sewer maps were unavailable for the cities, partial ones were available. One problem with using partial maps is that the route for storm and sanitary sewage to the receiving bodies (i.e.,sewage treatment plants) could not be mapped. Other sewer issues including determining the age of specific sections of sewers were not addressed as a result of the incomplete maps, but general information on the systems was collected from personal interviews.

The result of climate change on urban flooding has not been explored in Canada, though its impact may be significant. With expected increases in extreme rainfall events in Canada (Francis and Hengeveld 1998), urban infrastructure flooding will increase correspondingly, especially if the sewer networks are old, or if the land use is changing from permeable to impermeable.

The land use analysis was not as conclusive as expected, as many important data sets were unavailable. According to most topographic maps, soil maps and city maps, urban areas are not treated as part of the ecosystems they are embedded in. The topographic maps display the urban areas as homogenous regions, without contours, small streams or open spaces. There were some spot heights on older maps stored on microfiche, but they did not include true contours, so watersheds could not be defined for the affected areas. For Peterborough, this lack of data was especially important, as the drumlin field in the city introduces planning and drainage obstacles. Soil maps also ignored urban areas and classified them simply as "urban rather than map the soils that underlie the area or the soils that exist in the open spaces or forested areas of the city. Soil data is important for this research because it contributes to the natural drainage of the land. Soils data for cities was interpolated from the surrounding areas, leading to inaccuracy in determining the natural drainage ability.

The case study cities all experienced floods during the same year, but the causes of the flooding may be different. The Peterborough urban flood event may be the result of the increased urbanization of the surrounding area. Peterborough had the largest increase in the urban class, growing from 0.0075 km^2 to 0.56 km^2. The water, forest and field classes all decreased. The area of flooding was recently developed from the field and forested land. The reduction in the area of water may be related to a development pattern of channelizing the streams or burying them. Homeowners identified the creation of a new uphill development to be the cause of the urban floods (Mathewson 1996). This land use analysis can not be used as conclusive evidence that paving is the cause of the downhill urban floods, since the first development was still under construction during 1978, the time of the most recent aerial photos. This type of analysis can be used to determine if paving is a cause of urban floods, but in this case, the analysis done was not sensitive to the critical time period.

The Sarnia analysis encountered some unresolved map problems. The 1971 and 1978 aerial photos were not at the same scale, which in itself is not a problem, but when the surrounding land area of approximately 1 km^2 was measured on the 1971 maps, the areas around Bright St. and Conrad St. overlapped. The difference between the 1955 total land area and the combined total of the two 1978 total areas is not large, and may be accounted for by scale transformation error. The analysis showed a slight increase in urbanization, but the addition of the two land use maps (i.e., Bright St. urban + Conrad St. urban) may be invalid because the overlap led to some double counting of the land. The sewer structure information was critical for Sarnia because one issue identified by homeowners to be a potential cause of urban floods is the aging of the sewage network. This could not be further explored due to the lack of data available on the state of Sarnia's sewers.

Ottawa's land use in the Applewood Acres area showed a slight increase in the urbanization and the field classes. These small increases may be the result of scale transformation error. The decrease in the forested area is less likely to result from mapping error because the difference is significantly higher than the urban and field differences.

The sewer system in the area of Peterborough where urban flooding had occurred is a newer branch of the system. The subdivision in question was constructed in 1978/1979 and is attached to a separate sewer line. As the sewer network increases in density, there is an increased possibility of urban flooding. This aspect of the sewage network could not be pursued, as sewage maps were not available for the City of Peterborough, but municipal engineers stated that the sewers were neither old nor dense in that area.

General conclusions can be drawn from the limited information available.

Older infrastructure may not be adequate for more frequent increased rainfall, which is one expected impact of climate change in Ontario (Francis and Hengeveld 1998). The change in the return period of rainfall would leave both separate sewers and combined sewers at a higher risk of flooding. In Sarnia, where the aging sewer network plays a key role in urban floods, a change in the return period of precipitation events will increase the vunerability of the structures attatched to the sewage network to flooding.

The precipitation literature is inconclusive for southern Ontario, and there are ongoing studies of extreme precipitation analysis. If an increase in extreme precipitation is occurring, then the sewage infrastructure needs to re-examined. If the urban floods are a result of increased impermeable land surface, then the land use planning parameters should recognize the problem of urban infractructure floods. One aspect of the rainfall events that needs to be further addressed is the type of rainfall events that occur that cause extremes in precipitation. This is important to recognize when determining how the flood events occur (i.e. through convective or frontal precipitation).

One of the obstacles to obtaining complete data sets of the land cover, sewage networks, floodplain and precipitation data was the lack of communication among the stakeholders. There are two sets of non-communicating stakeholders; insurers, homeowners and municipal governments, who do not share information on urban floods; and municipal governments and conservation authorities, who do not coordinate efforts when confronted with urban flood events. There is clearly value in establishing communication lines for municipal engineers and conservation area managers, if only to collect the appropriate data sets for studying urban floods. This lack of communication may contribute to the lack of integrated watershed management and the lack of preventative approaches to planning. If communication between these stakeholders was more structured and information about land use was exchanged more readily, land use analysis and urban flood causality research could be more easily facilitated.

The most current data released from the Insurance Council of Canada (1998) details natural disasters and major multiple payment occurrences. The data show how the natural disaster events, of which flooding is one, are categorized and broken down (Appendix 18). The records kept by insurers to date do not classify flood events, recognize the distinction between floodplain and non floodplain events or distinguish urban and non urban floods. Both types of flooding are combined on the chart, as the Ottawa event of 1996 in included. This leaves the study of urban floods at a disadvantage, because the insurance data is not accessible. Insurance issues remain unresolved when causality of the event is not addressed.

5.0 CONCLUSIONS AND RECOMMENDATIONS

The only data that was available to test was the extreme precipitation data sets, which through the literature search was less decisive than expected; and upon testing the maximum annual values of the case study cities, no strong correlations could be drawn.

The land use data was not as conclusive as expected. The lack of physiographic data (i.e. soils, contours, drainage) in the urban areas blocked many routes to determining some potential causes of urban floods. If these obstacles are overcome, a more comprehensive study can be undertaken. The changes in land use data was taken from aerial photos and was not be reproduced using a geographic information system (GIS). Future studies of urban floods may consider using a GIS to measure areas more accurately. Urban land use information is difficult to find, as there are few databases that include the urban and natural systems together. Drainage, soils and slope are topographic features that need to be applied to urban flood research.

Urban infrastructure flooding is best measured by considering the sewer networks that they are attached to and determining the frequency of urban flood occurrence. Sewage data collection was one obstacle to performing this analysis, and the collection of frequency information was equally difficult to determine. There are no databases for urban infrastructure flood events, as no group collects this type of information.

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