PROTECTING PEOPLE AND PROPERTY

A Business Case
For Investing In Flood Prevention & Control

Conservation Ontario
August 6, 2009

Acknowledgements

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EXECUTIVE SUMMARY

Flooding is the leading cause of public emergency in Ontario[1].

The Ministry of Natural Resources (MNR) and Ontario's municipalities, by law, are mandated to manage and respond to flooding. Conservation Authorities and MNR district offices are responsible at the local level, through programs that are now being integrated into a new, provincial emergency management framework that will address all hazards.

Ontario's programs to manage floods and regulated floodplains have proven extremely effective and, indeed, the province has been a leading jurisdiction in flood planning and management. For example, a study of four storms that occurred in Michigan and Ontario in 1986 showed that while flood flows for Ontario were higher, damages were much lower due to floodplain management measures: $640 million in Michigan versus $0.64 million in Ontario in 2008 dollars.

While much has been accomplished, several factors, if not addressed directly and quickly, will significantly jeopardize the province's ability to maintain and improve on this level of management and protection.

Hard Assets

Hard assets include the dams, dykes, and channels that harness flood flows. These structures require ongoing maintenance, repair and replacement to function effectively and safely. A realistic target for infrastructure maintenance, repair and replacement would require $27 million annually; nearly three times the current budget allowance.

Moreover, there is no grant financing for new flood control structures, even in areas experiencing repeated flooding. The cost sharing arrangements that helped build all of the major flood control structures in Ontario no longer exist and funding for new projects is limited. Faced with the need for 100% self financing, few municipalities can afford any new flood control structures.

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[1] Ministry of Municipal Affairs and Housing (May 2007)

Soft Assets

Soft assets include flood plain mapping, rainfall and stream flow monitoring systems and computer models to forecast stream flows. These tools support the entire emergency management framework for flood management; they are indispensable to the effective management of floods.

Flood plain maps maintained by the Conservation Authorities are now on average 22 years old; 39 per cent are more than 30 years old. Old maps are of limited value and complicate the task of administering and enforcing the flood plain regulations since they are difficult to defend on technical grounds.

Flood Frequency and Severity

Flooding in Ontario is escalating. Climate change, together with growing populations, increasing property values and aging urban infrastructure have diminished the capacity of watersheds to cope with storm runoff, exposing growing populations to increased flood risk.

It is clear that storms have become more frequent and powerful. From 2000 to 2005, Ontario experienced ten severe storms that exceeded intensities that are normally expected less than once every 100 years. These storms caused over $360 million in damages.

Climate change ensures that the trend in escalating storm intensity will continue for decades. As currently structured and funded, Ontario’s flood management system does not have the capacity to cope with the resulting changes in flood patterns.

Funding

Fiscal constraints in the 1990s affected all agencies involved in flood management. Under-funding amounted to many millions of dollars every year. As a consequence, flood management systems have not been kept current with new technologies or emerging threats.

Under-funding seriously compromises the ability of the Ministry and the Conservation Authorities to fulfill their statutory obligations under the Planning Act and regulations of the Conservation Authorities Act. It reduces their capacity to contribute to the development of municipal emergency management plans. Most importantly, if the funding deficit continues, it will compromise the Province's ability to protect lives and property during floods.

It will take at least 10 years to catch up—to update flood plain maps, to restore aging flood control infrastructure, to strengthen the technical capacity of line agencies. Ten years that is, if the commitment comes now to renewal of the flood management system.

The Province of Ontario's commitment and leadership is required to forge a critical three-way partnership with municipal leaders and the Federal government in the task of renewal.

The commitment must begin with new and increased funding for:

- Infrastructure maintenance, repair and replacement (hard assets): $27 million annually
- Flood plain mapping, rainfall and stream flow monitoring systems, computer models (soft assets): $78 million over 10 years
- Ongoing flood management programs, including monitoring, regulation and facility operations, as well as studies to plan for climate change and other emerging threats: $16.5 million annually

Introduction

Flooding is the leading cause of public emergency in Ontario.[2] The Ministry of Natural Resources and Ontario municipalities have a statutory obligation to respond to and manage flooding.[3] Conservation Authorities have been delegated flood management responsibilities at a watershed scale throughout most of southern Ontario and where they exist in northern Ontario.[4] Elsewhere district offices of the Ministry of Natural Resources have this responsibility. These agencies cannot continue to effectively manage and mitigate flooding to the degree required under current fiscal arrangements. This report explains why this situation has come about and what must be done to strengthen the capacity for flood management at a watershed scale.

The Evolution of Flood Management

Records of flooding in Ontario go back at least 200 years. Flood management efforts begin in the 1880s with a dyke system along the Thames River in London. This was followed in the 1940s through the 1960s, by the construction of several large dams. In 1954, Hurricane Hazel gave new impetus to flood management efforts. The Province adopted a one zone flood plain planning approach and Conservation Authorities were authorized to acquire flood prone lands and regulate fill and construction activities on floodplains.

Floodplain mapping and modeling, which started in the 1950s, was vigorously pursued once cost sharing arrangements were established under the Canada / Ontario Flood Damage Reduction Program in 1975. These developments established the framework of a best practice approach to flood management now practiced in Ontario—a practice featuring a balanced mix of structural measures like dams and dykes and non-structural measures like flood plain regulations, and warning systems.

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[2] Ministry of Municipal Affairs and Housing (May 2007).
[3] Under regulations of the Emergency Management and Civil Protection Act, RSO 1990.
[4] Conservation Ontario / Ministry of Natural Resources / Ministry of Municipal Affairs and Housing, 2001, Memorandum of Understanding on Procedures to Address Conservation Authority Delegated Responsibility.

The Province is now integrating these existing programs into a new emergency management framework. This approach to emergency management rests on five pillars of emergency planning:

PILLAR OF EMERGENCY PLANNING				
PREVENTION Prevent effects of floods	**MITIGATION** Reduce flooding	**PREPAREDNESS** Develop capacity to respond	**RESPONSE** Take action during a flood	**RECOVERY** Deal with flood aftermath
CORRESPONDING FLOOD MANAGEMENT ACTIVITY				
Planning and regulation to minimise vulnerabilities (e.g. regulate floodplain land use, education)	Evaluate risks and implement mitigation programs. (e.g. flood control structures, flood proofing, flood forecasting & warning systems)	Develop plans for emergency preparedness (e.g. flood contingency planning, partner training, public education)	Implement emergency measures (e.g. monitor storms and stream flows, issue flood warnings)	Help administer relief / recovery programs (e.g. assess overall damage, post-audit of flood response)

Agencies responsible for flood management need resources and tools to meet these responsibilities—experienced professionals, accurate flood plain maps, monitoring networks, flow modeling tools, and infrastructure management systems. Much has been accomplished but there are deficiencies in our current flood management systems that must be overcome if past accomplishments are to be sustained and if we are to meet emerging threats.

A BRIEF HISTORY OF FLOOD MANAGEMENT IN ONTARIO[5]

1791 – 1st written account of flooding by settlers on the Thames River.

1857 –1st severe flood on record in Ontario: roads, buildings and bridges destroyed in Brampton, 5 five feet of water covered downtown streets.

1883 - A severe flood on the Thames River kills 17 people in London and causes extensive damage. The City responds by building a dyke system.

1932 – Grand River Conservation Commission Act passes in 1932; the Commission receives its letters Patent in 1934.

1937 – The worst flooding ever seen on the Thames River kills 5 and destroys 1,100 homes in London and areas to the north. The City's dyke system is over topped by flood waters that are 20 feet above normal summer flows.

1942 – Grand River Commission completes Shand Dam, the 1st in Canada built for flood control. Funding by Federal-Provincial-municipal cost sharing.

1946 – Conservation Authorities Act is passed; 8 Conservation Authorities are established by 1948.

1950s – Initial efforts to map floodplains by Conservation Authorities and the Province. Fifteen new Conservation Authorities are established. Fanshawe Dam is commissioned in 1952, and Conestogo Dam in 1958.

1954 – Hurricane Hazel strikes. Conservation Authorities Act is amended so Conservation Authorities can acquire flood plain lands. Flood Control and Water Conservation plan for Toronto is finalized in 1959.

1960s – Clairville dam commissioned in 1964, in 1967 Pittock and Wildwood Dams follow. The Lands Acquisition Program set up in Toronto to acquire flood plain lands. Thirteen new Conservation Authorities are established.

1975 – Canada/Ontario Flood Damage Reduction Program starts promoting an integrated approach to flood management. FDRP supports floodplain mapping and other flood management measures.

1976 – Guelph Lake dam, the last dam for flood control in Ontario, is completed. Milne and G. Ross Lord dams are completed a year earlier. Four new Conservation Authorities in the 1970s.

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[5] Based on Appendix A and: UTRCA, 2009; TRCA (a); Wianecki and Gazendam, 2004; and D. Shrubsole, 2000.

1978 - Ontario joins FDRP; Provincial Flood Plain Management Policies issued in 1979. Over the next decade, 318 communities are mapped and many CAs begin enforcing floodplain regulations. The Ministry of Natural Resources collects data on flood events and flood damages and publishes Annual Flood Damage Reports.

1984 – Respective roles and responsibilities of the Ministry of Natural Resources and the Conservation Authorities for flood forecasting and warning are clarified.

1988 – New Flood Plain Planning Policy Statement and Guidelines emphasise development controls on floodplains. Many municipalities identify flood hazards in their planning documents and direct development away from flood prone areas.

1990s – Forty per cent budget cuts hit the Ministry of Natural Resources. Transfers to Conservation Authorities are cut 87%. Provincial funding for new structures and land acquisition ends as does flood damage reporting to the Ministry of Natural Resources. Environment Canada also loses expertise and funding as flooding falls off the Federal agenda. The 10-year General and Mapping Agreements are not renewed, and the stream gauge monitoring network was cut back.

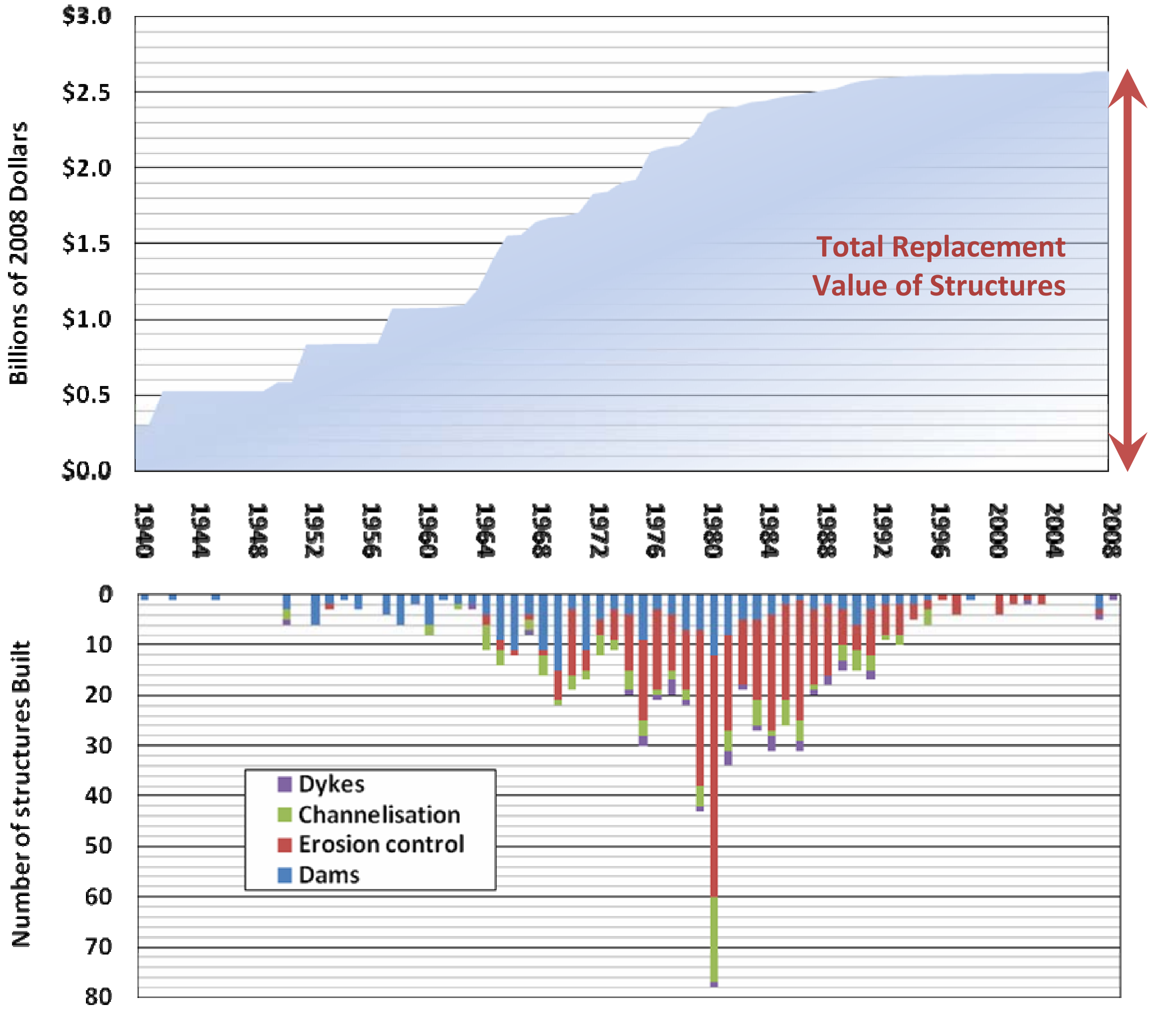
2002 - Efforts to rehabilitate and expand the Stream Gauge network start.

2003 – Province starts a $5 m annual transfer, matched by local funding, to Conservation Authorities for maintenance of flood and erosion control structures. New regulations under Ontario’s Emergency Management and Civil Protection Act call for a risk based approach in emergency management. Management of flooding, one of the top risks, will become more complex but more effective.

2008 - New provincial guidelines for flood forecasting and warning are issued.

Accomplishments

Traditional flood control response relied on structural measures as the initial line of defence against flooding. Over 900 dams, dykes, channels and erosion control structures were built along our rivers and shorelines providing many benefits beyond flood control. The replacement value of these structures is estimated at $2.7 billion in today's dollars. Together they protect more than 46,000 homes and prevent an average of well over $100 million a year in damages.[6] Significant loss of life has not occurred since the establishment of flood management programs in Ontario.



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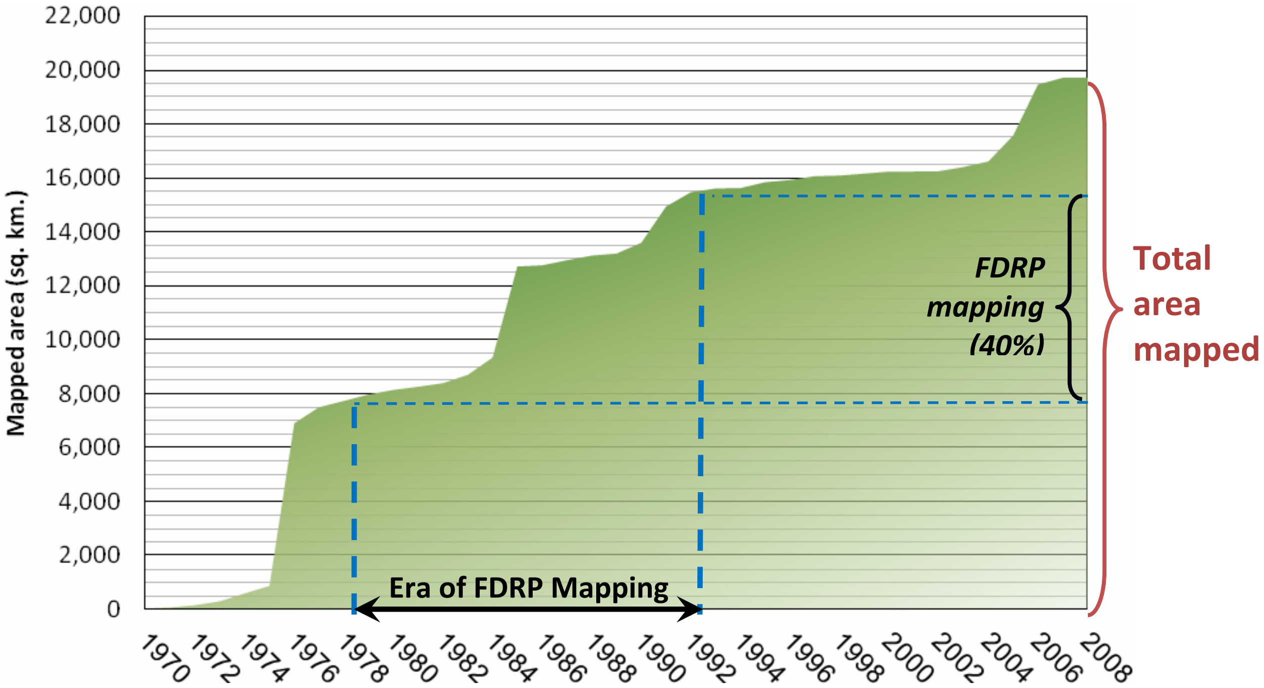
[6] Based on an analysis of flood management infrastructure data base compiled by Conservation Ontario. For details see Appendix C.

Early experiences with structural measures, notably the failure of dykes in London in the 1937 flood, clearly demonstrated the limitations of this approach. By the 1960s, efforts were underway to augment structural controls with non-structural measures to prevent flooding and mitigate flood impacts. New systems were developed to forecast floods, issue flood warnings and regulate flood plain lands. The foundation underlying these new systems was flood plain mapping.

Mapping efforts, which began in the early 1970s, accelerated over the period 1978 to 1992 when agreements under the Flood Damage Reduction Program provided 45 per cent Federal and 45 per cent Provincial funding. In total, 318 communities were mapped under the Federal-Provincial Flood Damage Reduction Program (FDRP).[7] Mapping continued once FDRP ended, and now there are 44,400 km of stream mapped covering almost 20,000 km^2. Forty per cent of this area was mapped under the auspices of the FDRP.



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[7] D. Shrubsole, G. Brooks, R. Halliday, E. Haque, A. Kumar, J. Lacroix, H. Rasid, J. Rousselle, S. P. Simonovic, January 2003.

Supported by flood plain mapping, today's non-structural flood management activities range from monitoring through to public education. These activities include:

- Stream flow, rainfall and snow pack monitoring;
- Modeling and forecasting of floods, issuing flood warnings;
- Contributing to municipal emergency planning and preparedness activities;
- Regulating development in flood plains in cooperation with municipalities;
- Providing planning support and advice to municipalities to minimize flood impacts;
- Acquiring selected flood plain lands and flood vulnerable structures;
- Protecting significant Natural Heritage features such as wetlands and forests and promoting ecological restoration to help control floods;
- Informing and educating the public on flooding.

The effectiveness of these measures is indisputable. More than 75 per cent of development on urban flood plains occurred prior to implementation of land use regulations and limited encroachment has occurred since then.[8] In the Toronto region, 13,400 hectares (32,000 acres) of flood plain lands have been acquired.[9]

The combination of structural and non-structural measures used by the Ministry of Natural Resources and the Conservation Authorities represents best practice as advocated by proponents of an integrated approach to flood management. For this reason, existing programs to manage floods and regulate floodplains have been extremely effective. The benefits of these programs were demonstrated in a study that estimated flood damages if the devastating 1996 Saguenay River flood had occurred on the Grand River. Reservoirs, dykes and land use regulations in the basin reduced potential damages from this flood by $160 million ($2008). An earlier study of four storms that occurred in Michigan and Ontario in 1986 delivered a similarly positive message. Although flood flows for Ontario were higher, damages were much lower due to our floodplain management measures: $640 million in Michigan versus only $0.64million in Ontario ($2008).[10]

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[8] A. Kumar, I. Burton, D. Etkin, 2001
[9] TRCA (b)
[10] Shrubsole, D., 2000

Flood Frequency and Severity

Is Flooding Getting Worse? Will we once again experience flooding on the scale of Hurricane Hazel in 1954 which caused damages of $810 million in today's dollars? [11] Climate change research provides an unequivocal answer to these questions:[12]

> *The precipitation occurring in extreme events has increased 1.5% per decade from 1910 to 1970, and by a much larger 14.1% per decade from 1970 to 1999.*
>
> *The Intergovernmental Panel on Climate Change concluded that the climate of coming decades will be driven overwhelmingly by greenhouse gases and that a continuing trend of greater and more frequent intense rain events is "very likely".*
>
> *The Union of Concerned Scientists estimates that the frequency of heavy rain events is expected to double by the end of the century for the Great Lakes region.*
>
> *Storm runoff is magnified as rain intensities increase. A 20 per cent increase in annual precipitation leads to a 39 per cent to 50 per cent increase in runoff.*

The intensity of a storm is indicated by its 'return period' measured in years: a 100 year storm is a storm that is expected on average no more than once every 100 years. The recent history of flooding in Ontario suggests that such large storms are now far too frequent:[13]

Events	Maximum Rain (mm)	Damages ($2008 million)	Rainfall Return Period*
1989, Jul 19-20, Harrow	450	$50 to $125	exceeded regulatory storm*
2000, July 31, Muskoka district	274	Data not available	> 100 year return period
2000, July 9, Stratford area	175	Data not available	> 100 year return period

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[11] See Appendix E

[12] See Appendix B

[13] See appendix E for more detail. Only storms in Appendix E with information on return periods are included in this table.

Events	Maximum Rain (mm)	Damages ($2008 million)	Rainfall Return Period*
2000, June 11, London area	145	Data not available	> 100 year return period
2000, May 12, Saugeen River Valley	> 150.	Data not available	> 100 year return period
2002, June 11, Peterborough	> 200	Data not available	100 year return period
2002, June 9-10, 49th Parallel Storm, N. Ontario	360	$35	exceeded regulatory storm*
2004, July 14-15, Peterborough	240	$109	exceeded regulatory storm*
2004, June 13-14, Grand River	200	Data not available	>>100-year return period
2004, September 9, Hurricane Frances, E. Ontario	150	$63	>>100-year return period
2005, August 19, Toronto	175	$155	>>100-year return period

* Regulatory storms are historical storms that, because of their extreme nature, are now used as the design standard in flood management planning. The regulatory storm for S. Ontario is Hurricane Hazel (October 14, 1954, max. 285 mm rain) and for N. Ontario the August 31, 1961 Timmins storm (max. 193 mm rain).

It is striking that 10 of the 11 flood events listed in the preceding table occurred in the period since 2000. It is even more striking that all but one of these storms exceeded the 100 year storm and that three exceeded the regulatory storms that are used as standards to guide flood management planning in Ontario. The lesson from this recent history is not that the 100 year storm is becoming more frequent; rather it is that storms are getting bigger just as our scientists have warned us. What is considered a 50 year storm today will likely be the 20 year storm by the 2050s.[14]

Urban development is compounding the damaging effect of the forecast increase in rainfall intensity. Urbanization has diminished the capacity of watersheds to slow storm runoff and ease flood flows. While Conservation Authority staff promote the use of modern principles of stormwater management to control flood hazards in urban areas, the implementation of these principles is incomplete especially in older urban areas. Consequently, growing populations, increasing property values and aging urban infrastructure are making us increasingly vulnerable to flooding. In the Toronto region, these factors will contribute to a projected increase in flood damage costs of between 20 per cent and 60 per cent.[15]

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[14] Dr. Paulin Coulibaly, 2008.
[15] Wianecki and Gazendam (March 31, 2004) and D. Shrubsole (2000).

Responding to Future Risks

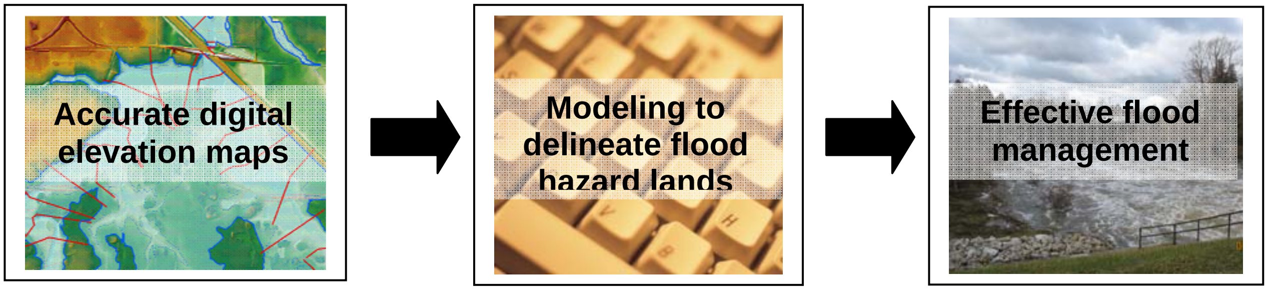
Accurate flood plain mapping, rainfall and stream flow monitoring systems, computer models to forecast stream flows—these are indispensible to effective management of floods. Consider how these tools contribute to emergency management:

Flood Management Responsibility	How We Fulfill this Responsibility
PREVENTION - Prevent effects of floods	Program planning and structural design: Accurate flood plain maps, monitoring data (stream flow, rainfall, snow pack), and stream flow modeling tools are all needed to delineate flood prone areas, regulate land use in those areas, and help plan and design flood control structures. Maintain existing structures: Adequate asset management plans and budgets are needed to assure the safety and effectiveness of existing flood control structures.
MITIGATION - Reduce flooding	
PREPAREDNESS - Develop capacity to respond	Emergency planning: Accurate mapping and stream flow modeling tools are needed to identify vulnerable populations and assets in the flood plain, develop flood warning protocols, plan access routes for emergency vehicles, and prepare other elements of emergency plans. Public information: Technical analysis based on reliable data and tools generates the information and maps that are needed in effective public information campaigns.
RESPONSE - Take action during a flood	Forecasting and warning: Real-time rainfall and stream flow monitoring systems are used to track storms and flood flows. Stream flow modeling tools then allow staff to forecast flood flows hour by hour, prepare timely flood warnings and operate flood control dams during a flood event.
RECOVERY - Deal with flood aftermath	Post-flood assessments: Flood monitoring data, floodplain maps and inventories, and stream flow models are needed for post-flood evaluation of flood management operations. They can also be used to produce estimates of total flood damages to assist with damage relief programs.

Ambitious investments in flood plain mapping and related activities helped Ontario become a leader in flood management in the 1980s. Fiscal constraints affected all agencies involved in flood management in the 1990s so that flood management systems could not keep abreast of new technologies or emerging threats. Since 2000, some flood plain mapping has occurred, often with municipal funding, and programs were initiated to support work on stream gauge networks and the maintenance of flood control structures. These new programs are a promising start, but more is needed.

Flood plain mapping

The first priority is flood plain mapping and the associated hydrologic and hydraulic modeling of flood flows to delineate flood prone areas. Accurate digital flood plain maps are the foundation of effective flood management, helping to save lives, prevent property damage, and reduce emergency response and recovery costs.



Most maps have not been kept up-to-date and existing efforts by agencies to update or extend mapping are piecemeal and inefficient. Existing flood plain maps maintained by the Conservation Authorities are now on average 22 years old and 39 per cent of these maps are over 30 years old. Old maps are of limited value:[16]

- They are out of date due to land use changes, changes in channel morphology, etc
- They were developed from base maps with inaccurate topographical contours and missing information such as culverts and bridges
- They are not compatible with current analytical techniques for flood forecasting

Outdated mapping complicates the task of administering and enforcing the flood plain regulations since they are difficult to defend on technical grounds.

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[16] A. Kumar, I. Burton, D. Etkin, 2001.

By area, 80 per cent of existing maps need to be updated. The maps that need updating encompass 44 per cent of the people residing on flood plains (over 150,000 people), 72 per cent of the buildings and 76 per cent of the bridges located on mapped flood plains.[17]

Digital elevation model (DEM) mapping is the current standard for mapping technology. Unlike the old analogue maps, DEM maps are easier to update in response to new construction, new bridges, land clearance, deforestation, etc. Moreover they fulfill many planning needs in the public and private sectors other than flood management planning.

Agencies responsible for flood management should move to comprehensive DEM mapping in partnership with affected municipalities which can also use such mapping for their planning work. The cost of updating existing flood plain maps is estimated to be $78 million.[18]

Flood Plain Mapping in the Rideau Valley

The Rideau Valley Conservation Authority (RVCA) estimates that it has accurate, defensible information on flood levels and associated flood hazard areas for less than 10% of the streams in the Rideau Valley (22% of the main branch plus second and third order tributaries). However, the regulations require Conservation Authorities to regulate development in all areas that are subject to flood hazards, whether they are described in the regulation limits maps or not.

RVCA recently completed Kemptville Creek Flood Plain Mapping. High quality base mapping was contracted out and the flow modeling analysis was done in-house. Approximately 43 km of watercourse was covered by the project at a cost of about $150,000. Flood lines were updated for nine km of stream and new flood lines were developed for the remaining 34 km which had never been mapped before.

On the nine kilometres of watercourse where flood lines were updated, the overall area of the flood hazard zone decreased from 85 to 67 hectares. The older mapping was overly conservative. It over-estimated the extent of the hazardous lands by 28%, causing development on 18 hectares of valuable riparian land to be “frozen” for 25 years. While this might be defended on the grounds of precaution, a 25 year update cycle is simply too long in the face of dynamic populations and changing land use priorities.

On the other hand, while the flood plain on these 9 km of watercourse was being regulated in an overly conservative fashion, hazardous areas in the adjacent upstream area along the 34 km of previously unmapped stream were under no flood hazard designations or regulatory constraints.

B. Reid, Director, Watershed Science & Engineering
April 9, 2009**,** Rideau Valley Conservation Authority

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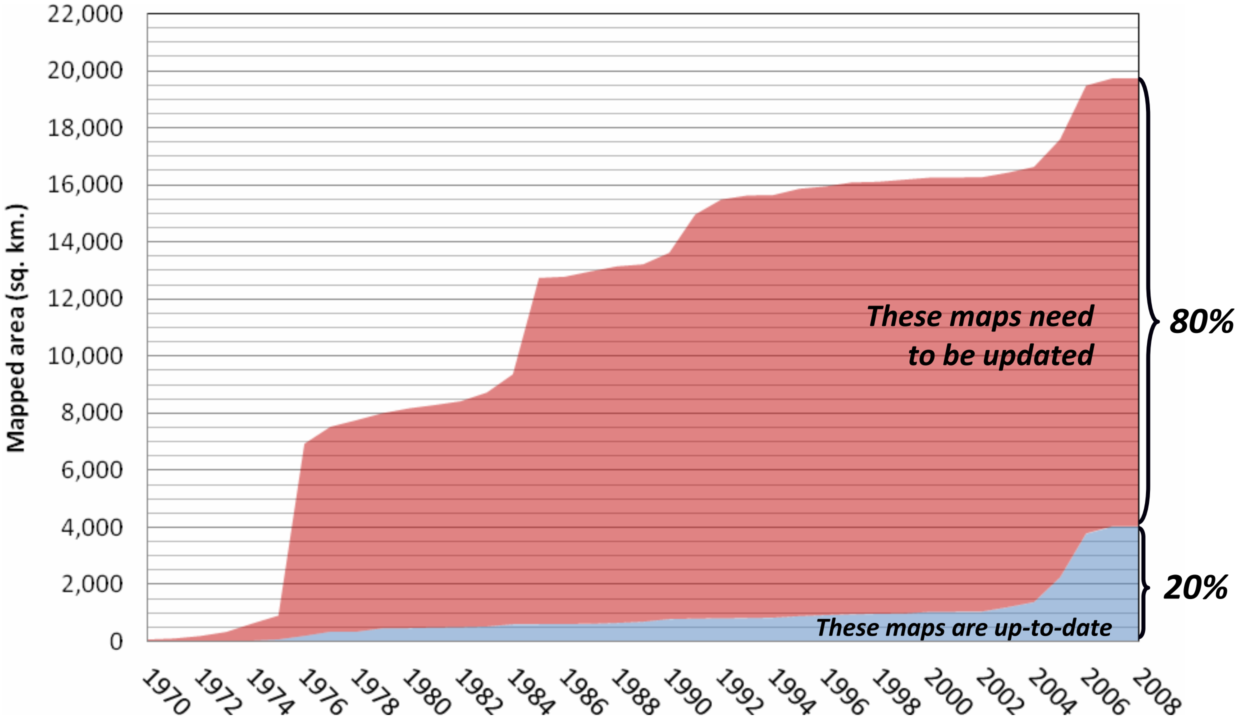
[17] See Appendix D for details of the analysis of flood plain mapping.

[18] Mapping cost at a scale of 1:2000 is approximately $1,700/1.0 km^2. When the associated cost of hydrologic and hydraulic modeling is factored in, the cost increases to $5,000/1.0 km^2. This scale provides approximately 1 meter quality control on mapping contour lines in keeping with original FDRP guidelines. (personal communications C. Wilkinson, Conservation Ontario, 9 Mar 2009 and D. Haley, TRCA, 1 April 2009)



Modeling and analysis tools together with DEM mapping are used to accurately designate flood hazard zones. These zones change in response to changes in land use, channel configuration and the magnitude of design storms[19] and should therefore be reassessed periodically. The best estimates of flood zone boundaries can only be made if flood management agencies have access to analytic techniques that use first-rate science and the growing database of historical stream flow and rainfall records. Budget constraints have meant that for the most part, only the Conservation Authorities and Ministry of Natural Resource districts with larger urban populations have achieved some mapping at this level of technical capacity.

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[19] The magnitude of design storms is changing as historical stream flow records accumulate over time and the statistical analysis of these records allows us to refine the estimates of our design storms.

Flood control structures

While shortcomings in our mapping, modeling and monitoring activities compromise our ability to maintain and improve existing flood management programs, any shortcoming in the maintenance of flood control structures directly threatens the safety of the people and property they are meant to protect.

Conservation Authorities have over 900 structures including 256 dams, and numerous engineered channels, dykes, and erosion control works. These have an estimated replacement value of $2.7 billion. The Ministry of Natural Resources operates an additional 391 dams. Only a small number of the Province’s dams are actively operated to control flooding. All of them, however, must be properly maintained to prevent flooding caused by dam failure.

Elora's Grand dam is a potential risk, 11 Mar 2009

The residents of the village of Elora will no longer see the water about to spill over the Drimmie Dam as a calm, idyllic pond. Instead, they now have reason to fear the water in the pond could come driving through the dam, creating a wave up to two metres high.

The reason for this fear rests with the Grand River Conservation Authority, which is responsible for this dam and many others along the Grand River. The conservation authority decided this week it would use 1,035 tonnes of rock to strengthen the Drimmie Dam in May, but until then the dam remains a potential risk.

Just look at the report the authority received on the dam. It said that according to a draft of the Ontario Dam Safety Guidelines the Drimmie Dam should be classified as a "significant dam hazard." The dam, it concluded, is susceptible to a "sunny day" failure -- meaning it could break apart even if there are no unusual pressures on it, such as ice.

THE RECORD,
http://news.therecord.com/printArticle/501205

Water control structures require ongoing maintenance, repair and replacement if they are to continue to function effectively and safely. Provincial and municipal funding sources together contribute $10 million annually to Conservation Authorities for this purpose, an amount representing only 0.4 per cent of the total replacement value of the Conservation Authority assets. A more realistic target for infrastructure

AGAIN and AGAIN and AGAIN!

Jan 16, 2008 ***Flooding comes early*** The Nith River spilled over its banks last Wednesday, flooding Norm Hill Park and several backyards and basements along Grace and Asmus streets in New Hamburg. At its peak, the river flow reached about 130 cubic metres per second.

Apr 02, 2008 ***Nith River flooding the worst in over two decades*** Bloated from Monday’s rain, unprecedented snow pack and rapid melt, the Nith River spilled its banks late Tuesday and early Wednesday, washing out roads, carrying away property and flooding basements in what some are calling the worst flooding in over 50 years.

Dec 29, 2008 ***New Hamburg submerged as Nith rages*** Heeding the Grand River Conservation Authority's flood warning, residents in New Hamburg's floodplain did what they could to get valuables out of basements, but nothing could stop the river flow from creeping up Jacob Street, Grace, Asmus and Seyler Streets. Mill and Union streets were covered by a lake of water that engulfed the Sobeys plaza. The river raced across Huron Street at the library where firefighters worked frantically to fill sand bags and divert the flow.

Feb 18, 2009 ***Flooded again!*** Although the Nith didn’t come as high as it did in December, New Hamburg is once again bailing out basements as the result of a flood Feb. 12.

New Hamburg Independent, http://www.newhamburgindependent.ca maintenance, repair, and replacement of 1 per cent would imply an annual budget requirement of $27 million, more than twice the current budget allowance.

While funding is limited for maintenance of existing assets, there is absolutely no grant financing for new flood control structures even in areas experiencing repeated flooding (see '**AGAIN**'). The cost sharing arrangements that helped build all of the major flood control structures in Ontario no longer exist and funding for new projects is limited under existing infrastructure grant programs. Faced with the need for 100 per cent self financing, few municipalities can afford any new flood control structures beyond minor erosion control works.

Operations

The Province has traditionally provided funding to Conservation Authorities for recurrent flood management activities including, in part, the operation of flood and erosion control structures, flood forecasting and warning, the preparation of watershed and technical studies and input into official plans. Originally, this funding was intended to cover 50 per cent of eligible expenditures; however, a recent analysis indicates total eligible expenditures of $50.7 million and a provincial funding of $8.8 million, resulting in a $16.5 million shortfall.

Achieving Operational Efficiencies in the Grand River Conservation Authority

A New Hamburg pilot project demonstrates how inundation maps and associated warning lists can be organized to support the effective use of resources during an emergency. Police play a critical role in the watershed warning system, but since police personal change regularly, information must be organized in a straight forward manner (a map and a list) so that the task of warning the public can be effectively delegated during an emergency.

The same project created a database of floodplain roads that identifies which roads need to be closed as flood conditions worsen. The resulting information on frequency of road flooding allows municipalities and the Province to determine how to best allocate available funds to reduce the frequency of flooding on specific roads in order to maintain serviceability of critical transportation routes during a flood.

Unfortunately, resources are not available to turn this pilot into a basin-wide program.

D. Boyd, Director, Flood Operations
Nov. 6, 2008, Grand River Conservation Authority

Operational activities relating to flood management are diverse and include:

- the operation and inspection of flood control structures;
- monitoring of stream flow, weather conditions and snow accumulations;
- maintaining, updating and applying flood forecasting and warning systems;
- undertaking watershed, infrastructure and other planning studies; and
- administering the flood fill regulations

This work calls for professional staff supported by policies that build and maintain core competencies through succession planning. The importance of succession planning is widely recognised given that 28 per cent of public service executives will be ready to retire in five years and 55 per cent in ten years.[20] But local flood management agencies assert that succession planning is difficult if not impossible when they are forced to rely on contract staff and summer students for critical operational activities.

Reliance on temporary staff to deliver important aspects of flood management programs is symptomatic of a gradual erosion of resources for these programs since the demise of the Canada-Ontario Flood Damage Reduction Program.

Summary

Flood management agencies experience chronic underfunding of flood management programs and activities, amounting to several million dollars every year. This continues to compromise the ability of these agencies to fulfill statutory obligations under the Planning Act and the Conservation Authorities Act; and it impairs their ability to contribute to the development of municipal emergency management plans. Continuation of insufficient funding will eventually compromise our ability to protect lives and property during floods.

Costs and Benefits of Improvements

Ontario’s flood management programs need to significantly improve in order to continue to protect life and property and to assure that flood emergencies can be managed effectively now and in the future. The requirements range from updated mapping and improved maintenance of flood control structures to upgrades of our flood forecasting and warning capabilities. The costs of these improvements have not been fully quantified for this study. Cost estimates that are provided for certain items suggest a need to significantly increase annual funding for the Province’s flood control programs and activities.

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[20] Preparing for the Demographic Revolution: How is Today’s Public Service Preparing for Tomorrow’s Workforce? IPAC Toronto Regional Group, May 27, 2008. http://www.ipac.ca/documents/may27summary.pdf

As well, benefits from increased flood management program funding have not yet been estimated because flood damage statistics have not been systematically compiled in the Province since 1990.[21] But, as with the costs, the available evidence suggests a significant social and economic benefit:

- Damage estimates for the severe storms identified for the period from 2000 to 2005 in Chapter 4 suggest an annual average damage of $60 million—this value does not include damages from smaller floods such as the three floods experienced in new Hamburg in 2008.
- An assessment of insurance claims for flooding and sewer backup in four of Ontario's larger cities suggests that an annual average damage of $100 million—this estimate covers about one half of the Provincial population, and omits damages to public infrastructure.

In light of these data, we can reasonably assume that average annual flood damages in Ontario are well in excess of $100 million. The evidence presented in Chapter 3 indicates damages would likely be an order of magnitude higher were it not for past efforts to manage floods and reduce the damages caused by flooding. The cost-benefit of those past efforts is positive and significant, not only in terms of reduced damage to property but in terms of avoided losses from economic disruption and, most importantly, increased public safety. Chronic underfunding threatens to erode the current level of protection and reverse the gains we have made.

A consideration of the risk posed by climate change serves to raise the stakes. In Chapter 4 we saw just how many floods were caused by storms that exceeded the 100 year and even the regulatory rainfall levels in recent years. A recent study for the upper Thames River indicates that the existing flood control structures on this system are ineffective in the face of such floods.[22] The experience in Peterborough with the 2004 flood attests to this. Reinforcement of our current flood management programs is a necessary adaptation to climate change.

Finally, it is important to recognize that improved flood management will have a direct and positive fiscal impact on the government by virtue of the opportunity

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[21] Wianecki and Gazendam (March 31, 2004).

[22] Personal communication, Rick Goldt, Supervisor, Water Control Structures, Upper Thames River Conservation Authority, 8 Jan 2009

provided to control payments under the Ontario Disaster Relief Assistance Program and the Federal-Provincial Disaster Financial Assistance Program.

Conclusion

In the past, investment in structural and non structural flood management systems made the Province a leader in reducing flood damages. However climate change, continuing development, and underfunding of programs now impair our ability to maintain existing levels of flood protection or deal with emerging threats. Several flood management tools need to be updated and improved to meet new challenges.

The top priorities are:

Updating flood plain mapping: Accurate flood plain maps identify where floods are expected. Most of the existing maps are outdated and need to be replaced. To replace them, we must prepare new digital maps showing the riparian topography, then complete engineering modeling analysis to determine flood flows and flood levels. The cost of updating existing flood plain maps is estimated to be $78 million. This cost would be spread over a decade.

Maintaining existing dams, dykes, and channels: These assets are owned by the Ministry of Natural Resources, the Conservation Authorities and, to a lesser extent, individual municipalities. Conservation Authorities have over 900 flood and erosion control structures with an estimated replacement value of $2.7 billion. Proper maintenance of these assets requires annual funding in the order of $27 million, more than twice the current expenditure level. This level of funding can only be achieved through a commitment by the Province and other funding partners to adequate management for these critical assets.

Ongoing flood management programs: Ongoing programs range from monitoring, regulation and facility operations to periodic planning studies in support of emergency management strategies and infrastructure asset management. Without the full support of the Province and its partners in flood management, these programs cannot be delivered in a manner that assures their continuity and the sustainability of past achievements.

APPENDIX A: Time Line for Establishment of CAs

NAME OF CA	DATE FOUNDED	REFERENCE
Ausable Bayfield CA	1946	http://www.abca.on.ca/
Ganaraska Region CA	1946	http://www.grca.on.ca/history.htm
South Nation Conservation	1947	http://www.nation.on.ca/Reports/Annual_Report_2007.pdf
Upper Thames River CA	1947	http://www.thamesriver.on.ca/About_Us/about.htm
Quinte Conservation	1947	Formed by amalgamation of three local conservation authorities in 1995: Moira River, Prince Edward Region and the Napanee Region. Of the three that amalgamated, Moira and Napanee are the oldest, formed in 1947 (Prince Edward Region formed in 1965) http://quinteconservation.ca/site2/index.php?option=com_content&task=view&id=340
Grand River CA	1948	Grand River Conservation Commission Act was passed in 1932. Letters Patent for the Commission were obtained August, 1934 http://www.grandriver.ca
Long Point Region CA	1948	http://www.lprca.on.ca/
Catfish Creek CA	1950	http://www.naturallyelgin.org/springwater.shtml
Saugeen Conservation	1950	http://www.svca.on.ca/about.htm
Lake Simcoe Region CA	1951	http://www.lsrca.on.ca/AboutUs/History.html
Maitland Valley CA	1951	http://www.mvca.on.ca/
Credit Valley Conservation	1954	http://www.creditvalleycons.com/
Lakehead Region CA	1954	LRCA formed in 1963 by an expansion of the Neebing Valley Conservation Authority, which was constituted in 1954 http://www.lakeheadca.com/aboutus.htm
Conservation Halton	1956	1956 as the Sixteen Mile Conservation Authority followed by the formation of the Twelve Mile Conservation Authority in 1957. In 1963 these conservation authorities amalgamated as Conservation Halton http://www.hrca.on.ca/
Conservation Toronto & Region	1957	http://www.trca.on.ca/ The amalgamation of four existing CA's following the creation of Metropolitan Toronto in 1957
Grey Sauble CA	1957	Formed by Order in Council on January 1, 1985 following amalgamation of the North Grey Region and Sauble Valley Conservation Authorities. The two former conservation authorities were created in 1957 and 1958, respectively http://www.greysauble.on.ca/about.html
Central Lake Ontario CA	1958	http://www.cloca.com/
Crowe Valley CA	1958	http://www.crowevalley.com/
Hamilton Region CA	1958	http://www.conservationhamilton.ca/corporate/aboutus/history.asp

Niagara Peninsula CA	1959	http://www.conservation-niagara.on.ca/thenpca/default.htm
Otonabee Conservation	1959	http://www.otonabee.com/index.htm
Nottawasaga Valley Conservation	1960	Personal communication, K. Wynder, NVCA, 4 Mar 2009
Lower Thames Valley CA	1961	http://www.lowerthames-conservation.on.ca/aboutus.htm
St. Clair Region CA	1961	http://www.scrca.on.ca/AboutUs.htm
Mattagami Region CA	1962	http://mrca.timmins.ca/pdfs/2007MRCAAnnualReportFinal.pdf
Raisin Region CA	1963	http://www.rrca.on.ca/about/
Sault Ste Marie Region CA	1963	http://www.ssmrca.ca/Section.aspx?ID=21
Cataraqui Region CA	1964	http://www.cataraquiregion.on.ca/
Kettle Creek CA	1965	http://www.kettlecreekconservation.on.ca/About_Main.htm
Rideau Valley CA	1966	http://www.rvca.ca/about/files/2006_annual_report.pdf
Lower Trent CA	1968	http://www.ltc.on.ca/
Mississippi Valley Conservation	1968	http://www.mvc.on.ca/index.html
North Bay-Mattawa Conservation	1972	http://www.nbmca.on.ca/site/home.asp?id=12
Essex Region CA	1973	http://www.erca.org/
Nickel District CA	1973	http://www.nickeldistrict.ca/ndca/index.php?option=com_content&view=article&id=2&Itemid=74
Kawartha Conservation	1979	http://www.kawarthaconservation.com/

APPENDIX B: Impact of Climate Change on Flooding

J.P. Bruce, Dec. 8, 2008

Part I - Extreme storm and flood events in S. Ontario with climate change

"Stationarity is Dead: Whither Water Management?"
P.C.D. Milly, et al., Science 319:573-4, 1 Feb. 2008

1. INTRODUCTION:

Two main aspects of the changing climate, due to increasing atmospheric concentrations of greenhouse gases, are:

1 Warming surface layers of the oceans, and
2 Greater precipitable water available in a warming atmosphere.

The first affects the storm mechanisms, hurricanes that might from time to time affect southern Ontario. The second affects the amount of rain that could be produced by remnants of a hurricane interacting with extra-tropical weather systems.

Hurricane "Hazel" 1954, the often=used design storm, occurred before anthropogenic forcing of climate became dominant. Prior to about 1970, natural forcing factors, changes in sun's energy, earth's orbit, volcanic emissions were responsible for the large scale variations in climate. However, by the late 1960s, the additional energy from the greenhouse effect became the dominant force resulting in significant global warming and other related weather effects (IPCC 2007). This effect will continue to dominate climate changes for a century or even longer. What does this mean for the frequency and intensity of a "Hazel"-type design storm? Should "probable maximum" storms and floods be adjusted?

2. WARMING OCEANS AND ATLANTIC TROPICAL CYCLONES:

Globally, sea surface temperatures have risen on an average of 0.5ºC from 1970 to 2000 (IPCC 2007). A detailed analysis of the observed and modeled changes in heat content of the upper oceans – from the surface to 700m depth, shows that areas of greatest warming include the east coast of U.S.A. south of Nova Scotia and the Gulf of Mexico. This has been especially pronounced since about 1990 (Carton and Santorelli, 2008). Other analyses have shown that the south Atlantic region in which tropical storms develop into hurricanes also saw significant increases in sea surface temperatures more than 0.3 to 0.4ºC, especially since about 1990 (Bell, et al., 2006).

Hurricanes derive their energy from the latent heat of evaporation from the surface of the ocean and require temperatures of 26-27ºC to develop – well exceeded since 1990. However, atmospheric dynamics also affect hurricane development. For example, a too strong vertical wind shear can inhibit storm development. Projections to 2090 by an ensemble of climate models suggest that ocean temperatures in the region of hurricane development and movement northward will increase by about 2ºC from 1990 levels – that is about 4 times as much as has occurred to date.

Webster, et al., (2006) has shown that over the period since the early 1970s, the annual number of Atlantic hurricanes has not changed much, but the frequency of category 4 and 5 storms has risen sharply. The steepest increase corresponds to the rapid ocean warming since 1990. The IPCC, in its usually conservative way, indicated that increases in intense tropical cyclone activity is “likely” (>66 per cent probability) over this century (IPCC 2007).

The movement northward, towards Canada, of hurricane-generated storms has also been increasing as Ocean temperatures rise. A notable example was hurricane “Juan” of 2003 which was still a well-formed hurricane when it hit Halifax. “Hanna” in 2003 also reached Nova Scotia (S. Fisk and P. Shilts, 2008). Most remarkably, hurricane “Noel”, which earlier devastated Dominican Republic, tracked north to Baffin Island in the Arctic, on Nov. 5, 2007, still retaining a tropical storm structure (J. Hanasiuk, 2008). Several hurricanes which affected Gulf of Mexico communities have moved northward and caused heavy rains in Ontario.

3. EXTRA-TROPICAL TRENDS:

However, to be as intense a storm over Ontario as hurricane “Hazel”, some distance from the ocean, requires conversion into an extra-tropical storm by an encounter with a strong cold front or an existing extra-tropical storm. It is difficult to tell if cold fronts will strengthen with climate change. Climate models (Lambert, 2004) and observational data (McCabe, 2001) suggest that there have been and will be more frequent intense events south of 60ºN, especially in winter but slightly lower frequency in total storm numbers. While these results were mainly for winter storms, the increased frequency of intense storms was related to increased release of latent heat because of more water vapour in the atmosphere. Thus, the trends in these results likely apply in autumn months as well, in the hurricane season, especially the latter part of it (see next section).

More intense extra-tropical storms do not necessarily require stronger cold fronts, but this would usually be the case.

4. PRECIPITABLE WATER:

As the atmosphere warms, it can hold more water vapour (precipitable water). Theoretically, by the Clausius-Clapeyron equation, this is at the rate of 7 per cent per degree C., and in observations since 1974 this has occurred at a rate close to this (Dai, 2006). It has been shown (Trenberth, et al., 2003) that the increased water vapour is manifest primarily in more intense precipitation, when atmospheric dynamics produce a precipitation event.

Data from radiosondes over North America show that 850 mb dew points and specific humidity along with precipitable water from the surface to 500mb have risen along with temperature since 1973 (Ross & Elliott, 2001). For 850 mb dew point, this has exceeded 0.25ºC/decade over the Great Lakes basin region or >3 per cent /decade in precipitable water. This would suggest an increase in precipitable water since 1973 of 10 per cent or more.

Dai, (2006) showed that annual values of specific humidity at the surface increased at 1.2 to 2.4 per cent per decade over southern Ontario, significant at the 5 per cent level, a slightly lower rate of increase.

A recent analysis of humidity trends in Canada 1953 to 2005 (Vincent, et al., 2007) suggests that the greatest upward trends in dew point are in summer, 0.5ºC with a national positive trend in fall being 0.4ºC over the whole period of study. The annual average was also 0.4ºC. However, dew points fell on average from 1953 to 1970 and rose about 1ºC nationally from 1970 (when greenhouse gases began to dominate) to 2005.

5. CONCLUSIONS:

Available evidence points to a record of intensification since 1970 of factors such as those that led to hurricane Hazel's impacts in Ontario. Climate models with rapidly increasing greenhouse gas concentrations indicate a continuation or strengthening of these trends towards more intense events, at least until mid 21st century. The frequency of hurricane and cold front events appear to be not changing in the warming climate. However, increasing atmospheric water vapour (precipitable water) indicates that when the atmosphere's dynamic mechanisms such as tropical and extra-tropical storms do occur, precipitation intensities will usually increase.

For selection of a design storm, these conclusions present something of a dilemma. However, the warming oceans, by perhaps twice as much by 2050, as observed so far, and four times as much by 2100, strongly suggest that more intense hurricanes will be sustained as they move north to affect eastern Canada more frequently. A storm such as "Hazel" would produce more rain, with precipitable water increasing by 2 to 3 per cent per decade (since 1973). This suggests a 6 to 10 per cent increase to date and another approximately 10% to 2050.

This also suggests that the "Hazel" design storm should be increased by the order of 16 to 20 per cent if designing for 2050. For estimates of Probable Maximum Precipitation, similar adjustments upward should be made for increased maximum precipitable water.

Part 2 - Factors affecting watershed flooding in S. Ontario with climate change

1. INTRODUCTION

In the Phase 1 report on extreme storm events, the conclusion was noted that changes in climate prior to the mid-1960s were due significantly to natural forces. However, since about 1970, the greenhouse gases (especially CO2) had become so concentrated in the global atmosphere, that the warming and related climatic events since then have been due almost exclusively to human-induced forcing factors (Bates, et al., 2007). The rapid rise in CO2 and other greenhouse gas concentrations will undoubtedly dominate the climate system this century. The average rate of increased CO2 concentration since 1980 has been 1.6 ppm/year, but since 2000 increased to 1.9 ppm/year (Levinson, 2008).

Since the greenhouse effect has dominated changes in climate for the past four decades, and continued greenhouse effects will dominate the coming four decades and more, trends in climatic factors measured since about 1970 should be good indicators of future trends. If the projection of such factors through extension of trends of last four decades is consistent with climate model projections, there is added assurance that the future estimates are reasonably correct. This analysis will take advantage of these considerations.

2. FACTORS AFFECTING FLOODS

The main aspect of climate change in southern Ontario, which is likely to result in more frequent flooding due to heavy rain events, is the increase in water vapour (precipitable water) in a warming atmosphere. In the head waters of the Grand River and in the Upper Thames, increased lake effect snows may well affect winter and spring floods.

3. PRECIPITABLE WATER (See Section 4 in Phase 1 Report)

Heavy rain events can increase at a greater rate than humidity or precipitable water since strong low level convergence into a storm can feed additional moisture to the event. In addition, the latent heat release in the rain producing process can itself reinforce rain intensities.

4. SEASONAL TOTAL PRECIPITATION

The century long trends in precipitation for the Lake Huron and lower lakes drainage basin has been analyzed by Mekis and Hogg, 1999. The results for rain and snow are shown in the following table. This shows that total rain amounts in spring, summer and fall have increased by statistically significant amounts. In winter, there has been a trend over the whole area towards slightly less snow and more rain, consistent with observed warming. However, the reduced snowfall is average over a large area and may not reflect the experience of regions in the lake-effect show belt, such as the Upper Thames basin (see section 6).

SEASONAL PRECIPITATION TRENDS,
GREAT LAKES / ST. LAWRENCE REGION*

		Change in precipitation ÷ 10 year mean precipitation
Winter	Snow	**-1.50%**
	Rain	**2.60%**
Spring	Snow	**-3.8%****
	Rain	**+2.6%****
Summer	Snow	
	Rain	**+1.6%****
Autumn	Snow	**-0.10%**
	Rain	**+2.9%****

***** Lake Huron plus Lower Lakes basins
** significant trend (1895-1995)
Source: *Mekis and Hogg, 1999*

5. INTENSE RAINFALL EXPERIENCE

In USA, amounts of one day “extreme” events (<0.1 percentile for the location) rose 3.3 per cent per decade from 1910 to 1999. The percentage of annual precipitation occurring in extreme events showed a linear upward trend of 1.5 per cent per decade from 1910 to 1970, but a much larger 14.1 per cent increase per decade from 1970 to 1999 (SWCS, 2003)

Several global analyses which included southern Canada (Alexander, et al, 2006), indicate for the period 1951 to 2003, trends towards more heavy precipitation days, greater contributions to total precipitation from heavy events and greater increases in five day amount in spring (MAM) than in other seasons. Groisman, et al., 2005, showed southeastern Canada as a region of significantly increasing rain intensities, especially in recent decades.

Kunkel, et al., (1999) showed that seven day rain events over Canada as a whole, greater than the one-year recurrence interval amount for 1931 to 1993 rose only slightly in annual amounts and in three seasons, but in spring showed a substantial increase.

A Canada-wide analysis of frequency of one day rain events in several intensity ranges was undertaken by Stone, Weaver, and Zwiers (2000). For southeastern Canada, including the Canadian portion of the Great Lakes watershed the study found that increases in total accumulation observed in spring and summer (April, May, June, July) were driven mainly by an increase in heavy event frequency. The average increase per decade in heavy rain frequency in May, June, July was 7 per cent from 1960 to 1990. The frequency of April-May-June heavy events increased by 5 per cent /decade on average and March-April-May rains by 4 per cent /decade. There is much greater impact on erosion and runoff of intense rain events in spring is discussed in section 10. A smaller increase in total accumulation in autumn (Sept., Oct, Nov.) was driven by events of both intermediate and heavy nature according to Stone, et al., 2000. Heavy rain events were defined as ≥ (5.0 + 5.0 x n) mm/day where n is the highest amount that results in at least 5 heavy events per year over the 1960 to 1990 period of the study.

An analysis for the Soil and Water Conservation Society was undertaken of trends in amounts of maximum annual one day rainfall amounts from 1970 to 1996, and for three stations where records had been abstracted to 2002. These annual maximum values were provided by Meteorological Service, Environment Canada (Robert Morris 2005, personal communication). These data were fitted with least squares trend lines. For 14 stations in the basins of Lakes Huron, Erie and Ontario, only three had negative trends. The latter were all due south of Georgian Bay in a pattern similar to that noted in figure 16 of Mekis and Hogg (1999). Average results for all 14 stations gave an upward trend of 2.6 mm per decade. When expressed as a percentage of the initial amounts of the trend lines, averaging 49mm, this represents about a 5 per cent increase per decade, as an average value over the study area (SWCS, 2007).

A further analysis of monthly variations in trends of extreme rainfall data for seven stations in southern Ontario (SWCS 2007) reveals little change or slightly negative trends in intensity for durations of 5 minutes to 24 hours in July and August (1970-2003). However, in June, the intensity trend was about +5 per cent per decade and in May +15 per cent per decade. This is also suggested in the study by Stone, et al.

Other analyses of 30 minute extreme events over southern Ontario (Adamowski, et al., 2003, Bruce, et al., 2007) found 14 stations with positive annual trends in amounts from 1970 to 1996, and 6 with negative trends (all but one slightly so). Averaging over all stations indicated a 5 per cent per decade increase over the period.

The analysis by Cheng, et al., 2007, indicates that while frequency of high rain intensity may have increased more rapidly in spring than those in summer

(>25mm/day), the frequency of summer high intensities remain the greatest in the year (analysis for 1955-2002). That study also shows that sewer flood insurance claims from 1992 to 2002 are slightly higher in April than May and higher again in summer months. This suggests that in April, some snow melt may be lingering to increase the small watershed flood effects. However, if rain intensity trends since 1970 continue as expected into coming decades, then May and eventually spring events are likely to increase more rapidly than at other times of the year.

6. A NOTE OF CAUTION

It should be noted that the standard rain gauge for Canada was changed, in my view unfortunately, in the 70s. On the basis of gauge catch comparisons the newer gauge appeared to catch more annually by about 5 per cent, so in the Canadian daily rainfall studies reported here, the earlier data were adjusted upward through the procedures described by Mekis and Hogg, 1999. These may be over-adjustments for heavy one-day falls where wetting losses in the gauge are insignificant. If so, southern Canadian trends would be closer to the larger trends observed across the border in northern U.S.A.

7. FUTURE PROJECTIONS – HEAVY RAIN EVENTS

In its 2007 review of the world's scientific literature on climate change, the IPCC (Intergovernmental Panel on Climate Change) expressed its confidence in the finding that "more intense precipitation events" have "likely" occurred over many areas and are becoming "very likely" in future. The period of most significant increase in recorded rain intensity in several regions (1970 to date) coincides with the period in which greenhouse gas concentrations have dominated global climate change. The climate of coming decades will also be driven overwhelmingly by greenhouse gases with concentrations increasingly on the increase. Thus a continuing trend of greater and more frequent intense rain events is "very likely," as IPCC has phrased it.

There were a number of climate projections into the future, as well as the trends of recent decades, which IPCC cited to support their assessment of likelihood of future heavier rainfalls. Among these were studies by Dessens (1995) which linked rising night-time temperatures, observed and predicted in a warming climate, to more intense convective activity and rainfall. Continued increases in short duration, convective rain intensities would require greater instability over land and greater water vapour content of the atmosphere as discussed above.

Global Climate Models have been used to project changes in annual precipitation over the Great Lakes basin between now and the period 2040 to 2060. For 30 different models and various future greenhouse gas global emission scenarios, the great majority of results show 2 to 6 per cent increases in annual precipitation (including snow) by the time of the two decades about 2050 (Bruce et al., 2003).

Increases for one day and shorter period intense rainfalls have been and are projected to be greater than for changes in annual or seasonal totals. There have been a number of attempts to use Global Climate Models to project future shorter duration (i.e. one day) rain events as well as annual and seasonal changes. These have concentrated on one day rain events since data are insufficient, and models not of fine enough scale, to address intensities in convective rainstorms for hourly periods or less.

The Union of Concerned Scientist, (Kling, et al., 2003), estimates for the Great Lakes region (heavily biased towards U.S. parts) that frequency of heavy rain events is expected to double by the end of the century.

In summarizing the results of some 16 climate models in projecting future 24 hour rain intensities, Kharin , et al., 2007 indicated a consensus value on annual extremes for a 20 year return period of +6 per cent per degree C of warming. The range was 4 to 10 per cent. Agreement was good in temperate zones, but a substantial range of values was obtained for the tropics. Southern Ontario was close to the consensus value 6 per cent /ºC. With a projected temperature change over southern Ontario of 3 to 4ºC (above 1961-1990 values) by 2050 an increased intensity of 18 to 24 per cent in the 20 yr-24 hour rainfall could be expected.

8. SUMMARY ON RAIN INTENSITIES

Observed changes in annual extremes to date: (for 30 min to 24 hour duration) +3 to 5 per cent per decade – with some shift towards greater rate of increases in spring (esp. May), but still most intense rains in summer.

Projected change by climate models would be ~4.5 to 6 per cent per decade to 2050 for 20yr-24 hr. maxima.

9. LAKE-EFFECT SNOWS

An analysis of trends in lake effect snows in Ontario could not be found but:

i) Increasing trends in such snowfalls on US side of the Great Lakes has been documented (Burnett, et al., 2003).

ii) Ice cover has been declining and surface water temperatures of Lakes Superior and Huron have been increasing more rapidly than air temperatures in the region (Austin & Colman, 2007) leading to greater lake effect snows in cold weather outbreaks.

Much of the Upper Thames basin and to a lesser extent headwaters of the Grand have been and will experience, with winds off Lake Huron and Georgian Bay, an increase in winter snowfall. The study by Burnett, et al., 2003, showed that for 15 US locations subject to lake effect shows a marked upward trend in October to April snowfall is evident from 1923 to 2001. However, for stations in the same region, but not subject to lake-effect snow, no significant trend is evident. The increase in lake effect snows has been most pronounced in the last four decades, increasing at Syracuse downwind from Lake Ontario in the period 1961-2001 by 67 cm over the period 1923 to 1960, an increase of 32 per cent between the two periods.

10. POTENTIAL IMPACTS ON FLOODS

Cheng, et al., have summarized some of the flood effects, especially for urban watersheds. Runoff and erosion effects on cropland have been considered by Soil and Water Conservation Society 2003 and 2007. Estimates of increased runoff and erosion were based on analyses by Pruski and Nearing, 2002, of behaviour of a number of instrumented small watershed and runoff plots, in USA of varying slopes, soils and cover.

One key conclusion was that runoff is magnified as rain intensities increase. For example, a 20 per cent increase in annual precipitation due to increase only in intensity of events leads to a 50 per cent increase in runoff. If the 20 per cent increase in annual rainfall is due equally to more rain days and higher intensities then the runoff increase estimate averaged 39 per cent. These values apply to total runoff, but with increased rain intensities they might also be approximations for peak flow increases. At the same time, unless very effective erosion control measures are undertaken, increases in erosion of 48 per cent and 33 per cent were estimated for the two cases for runoff. While the changes in rain intensity indicated here, are reasonably consistent with those modeled by Cheng, et al., the increased runoff from small cropped watersheds is greater. Of course, the watersheds used in the Pruski and Nearing analysis are very small and changes in runoff and peak flows would be somewhat attenuated and smaller for larger natural watersheds of 500km² or so. There is no evidence that the areas of intense rain events are getting larger (or smaller) in a warming climate.

The time of peak discharges in the Upper Thames basin may be somewhat different from the trend towards more frequent warm season peak flows in other basins under study. The Thames is likely to experience a continuing increase in lake effect snows with warming surface water in Lake Huron and Georgian Bay. This basin's distance from Lake Huron is not dissimilar to the distance from Lake Ontario to Syracuse where a 32 per cent increase has already been observed. With some signs of spring rain intensities increasing, a major rain on snowmelt event in this basin is increasingly likely.

11. POLICY IMPLICATIONS:

The threat of more frequent rain-induced floods is evident, with about a 40 per cent increase in peak flows projected for small agricultural watersheds by mid-century. Such an increase would be attenuated in larger basins.

For flood damage reduction, the data and projections suggest the need for:

i) Improved flood forecast-warning systems
ii) A revisit of flood plain land designations to take into account climate change and in some basins upstream urban development.
iii) Review of operational plans for upstream dams and reservoirs to provide for changes in timing and intensity of floods.
iv) Improvement in capacity of urban drainage systems.
v) Greater efforts at erosion control, and surveillance of culverts and drainage facilities to prevent siltation with greater upstream erosion.

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APPENDIX C: Analysis of the Flood Control Infrastructure Database

Introduction

The Water & Erosion Control Infrastructure (WECI) database, was compiled by Conservation Ontario in 2007 to manage, store, and rank water and erosion control structures and projects. Information in the database was provided by Conservation Authority staff in response to a web based questionnaire. The database is maintained by staff of the Grand River Conservation Authority on behalf of Conservation Ontario and the Ministry of Natural Resources.

Four types of structure are described in the database: dams, dykes, channelization structures and erosion control structures. Information provided for these include physical dimensions, construction dates and costs, replacement values, flood and erosion control functions, and other data. The following analyses were completed with this data:

- Update replacement value data for all structures to account for inflation and for key structures using information from current bids for structural work
- Analysis to fill in missing replacement cost data
- Summarize key data series for reporting

Replacement Value Update

Total reported replacement values of assets described in the Conservation Ontario database amounted to $0.8 billion at 2007 dollar prices. These data were incomplete covering only 37 per cent of structures in the database. In certain cases the values were biased in a downward direction because valuations did not account for the rapid increase in construction and material costs in recent years.

Reported replacement values and historic construction costs were updated to 2008 dollar values using a price index for engineering works built by local, municipal and regional public administrations.[23]

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[23] The price index used for this purpose is the implicit index linking asset values measured at constant and current dollar prices reported by Statistics Canada in their CANSIM database for stocks

The large flood control dams in the database were originally assigned replacement values ranging from $10 to $50 million. A recent quote for two new gates for one of these structures came in at $66 million. Based on this information, replacement values for the large dams were increased, with the revised estimates ranging from $50 to $250 million.

Replacement Value Fill-in

Missing replacement values in the database were estimated using structure cost curves estimated from the available replacement values in the data base. The cost curves were estimated using regression analysis. Estimated cost curves are outlined below (t-statistics in brackets; confidence intervals denoted by asterisks: 90 per cent - *, 95 per cent - **, 99 per cent - ***:

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of non-residential capital goods: Table 031-0002 - Flows and stocks of fixed non-residential capital, by North American Industry Classification System (NAICS), annual (dollars) (table), CANSIM, accessed on September 18, 2008 at: http://cansim2.statcan.ca/cgi-win/cnsmcgi.exe?Lang=E&CANSIMFile=CII\CII_1_E.htm&RootDir=CII/

EROSION CONTROL STRUCTURE (ECS)
Ln(Replace Cost) = 7.151 + 0.567 *Ln(ECS Height) + 0.921* Ln(ECS Length)
(9.917***) (1.802*) (6.680***)
F = 26.027 ***
R^2 = 50.026%
Observations = 54

DYKES AND FLOOD WALLS (DYK)
Ln(Replace Cost) = 7.412 + 1.114 *Ln(DYK Height) + 0.791* Ln(DYK Length)
(6.912***) (1.799*) (5.476***)
F = 22.766 ***
R^2 = 71.668%
Observations = 20

DAMS
Ln(Replace Cost)
= 9.410 + 1.105 *Ln(DAM Height) + 0.589* Ln(DAM Length) + 0.241* Ln(DAM gates)
(32.63***) (8.181***) (7.346***) (4.098***)
F = 113.24 ***
R^2 = 62.828%
Observations = 204

CHANNELS (CHN)
Ln(Replace Cost)= 8.032 + 0.888 *Ln(CHN Length) + -4.84E-09 * (CHN Length)^2
(8.122***) (5.520***) (-2.550**)
F = 15.240 ***
R^2 = 42.641%
Observations = 43

Results

Summary results of the analysis are as follows:

Type of structure	Number of structures	Replacement value of structures ($\$10^6$)	Number of Houses protected	Average annual damages avoided	
				Flooding ($\$10^6$)	Erosion control ($\$10^6$)
DAM	281	$1,802	29,574	$23.62	$0.35
ERO	507	$427	1,681	$6.43	$9.16
CHA	122	$180	3,554	$24.40	$5.16
DYK	46	$265	11,522	$3.86	$0.86
TOTALS	956	$2,674	46,331	$58	$16

Avoided flood damages are only reported for one-third of the houses that are protected by structures. Actual avoided flood damages are therefore potentially three times as large as reported, or $174 million per year.

APPENDIX D: Analysis of the Flood Hazard Inventory Database

Introduction

The Flood Hazard Inventory Database was compiled by Conservation Ontario in 2007 to:

1. "Define the status of flood plain mapping in the Province, including the date, type and method of flood line definition and extent of hydraulic information.
2. "Secondly, define the extent of information that exists related to the existing risk of flooding. The intent is to determine what information is currently available in terms of the number, type, risk level, and potential numbers of people that are at risk to flooding in the Province." (Final CA Hazard Digitizing Questionnaire (vs 12).doc)

Information in the database was provided by Conservation Authority staff in response to a web based questionnaire. The database is maintained by staff of Conservation Ontario.

Information in the database covers the following topics:

- General information (project name and type, location, date of mapping and update status...)
- Base mapping (type and date of original base mapping, contour intervals...)
- General hydraulic and hydrologic modeling (links to hydraulic/hydrologic models, regulatory standard, flood line calculations, people and assets below the flood line)
- Details on floodplain delineation methods (estimate or modeled, applicable standards, modeling details...)
- Regulatory and policy status of the delineated flood plain (flood damage areas, flood vulnerable area, special policy area, two zone approach, emergency planning...)

Treatment of Data Omitted from the Database

Data for several Conservation Authorities were not included in the original database because they were submitted as MS Excel or Word files rather than the prescribed database format. All of these omitted data were compiled in a single Excel spreadsheet and combined with the original database date using Excel software.

Treatment of Missing Values

The data provided by Conservation Authority staff were incomplete. Various methods were employed to fill in missing values as described the following table:

<table>
<tr><th>Data Item</th><th>% Incomplete</th><th>Approach to Fill-in of Missing Data</th></tr>
<tr><td>Project Date</td><td>10%</td><td>No fill-in attempted. Forty-nine observations coded as 1905 or 1899 were assumed to erroneous entries and were assumed to be missing data.</td></tr>
<tr><td>Total Area
Total Length</td><td>25%
25%</td><td>All entries coded zero were assumed to be missing data. The following algorithms are used to estimate missing data:
1. Total area of a mapping project:
If total length was provided for the project, total area was estimated as:
[total length ÷ median of the length/area ratio]
If area and length were missing, total area was estimated as:
[median of reported area data]
2. Total length of a mapping project:
If total area was provided for the project, total length was estimated as:
[total area X median of the length/area ratio]
If area and length were missing, total area was estimated as:
[median of reported area data]
Mean and median values of the data are:
<table>
<tr><th></th><th>Median</th><th>Average</th></tr>
<tr><td>Total area</td><td>3.5 km^2</td><td>38.6 km^2</td></tr>
<tr><td>Total length</td><td>8.4 km</td><td>53.9 km</td></tr>
<tr><td>Length/area ratio</td><td>5.99</td><td>7.96</td></tr>
</table>
These statistics suggest a positive skew to the underlying distributions. Assuming missing values are more likely to represent smaller projects, the median values will result in more a more reasonable estimate of fill-in data. These estimates will also be more conservative.</td></tr>
<tr><td>Susceptible Population</td><td>22%</td><td>Zero entries were assumed to be true zeros if the variable ‘Residential Damage’ was coded ‘false’ or was left blank. If the entry was zero or blank and ‘Residential Damage’ was coded ‘true’ the following algorithm was used to estimate the missing value:
If total area was available for the project, the missing data was estimated as:
[total area X mean ‘susceptible population per km^2’]
If no area data were available, the missing data was estimated as:
[mean of ‘susceptible population’]
Mean values are:
Susceptible Population per project = 135.4 persons
Susceptible Population Per km^2 = 72.5 persons</td></tr>
<tr><td>Estimated Crossings</td><td>21%</td><td>Zero entries were assumed to be true zeros if the variables “Rural Damage’, ‘Residential Damage’, ‘Commercial Damage’, ‘Industrial Damage’, or ‘Institutional Damage’ were all coded ‘false’. If an entry</td></tr>
</table>

Data Item	% Incomplete	Approach to Fill-in of Missing Data
Estimated Culverts	21%	was zero or blank and one of the 'Damage' variables was coded 'true' the following algorithm was used to estimate the missing value: If total area was available for the project, the missing data was estimated as: [total area X mean per km^2 of reported data] If no area data were available, the missing data was estimated as: [mean of reported data] Mean values are: Estimated Crossings = 15.0, Estimated Crossings Per km^2 = 1.2 Estimated Culverts = 14.3, Estimated Culverts Per km^2 = 1.1 Estimated Buildings = 141.4, Estimated Buildings Per km^2 = 23.3 Estimated Structures = 0.3, Estimated Structures Per km^2 = 0.1
Estimated Buildings	19%	
Estimated Structures	23%	

Summary Statistics

Variable	Sum	Count	Missing Values	Median	Average
Original data					
Project year		606	10%	1989	1990
Project year – area weighted		606	10%	n.a.	1986
Total Area	19,358	501	25%	3.54	38.64
Total Length	27,046	502	25%	8.40	53.88
Length/area		452	33%	5.99	7.96
Susceptible Population	70,932	524*	22%	0.0	135.4
Estimated Crossings	7,929	530*	21%	0.0	15.0
Estimated Culverts	7,649	534*	21%	0.0	14.3
Estimated Buildings	76,637	542*	19%	0.0	141.4
Estimated Structures	176	519*	23%	0.0	0.3
Susceptible Population/km^2		367	45%	0	72.51
Estimated Crossings/km^2		373	44%	0	1.22
Estimated Culverts/km^2		377	44%	0	1.08
Estimated Buildings/km^2		383	43%	0	23.29
Estimated Structures/km^2		362	46%	0	0.09
After Fill-in of missing values					
Total Area	19,962	672	0%	3.54	29.70
Total Length	44,374	672	0%	21.17	66.03
Susceptible Population	344,402	597*	11%	260.0	1,383.1
Estimated Crossings	11,649	597*	11%	2.0	35.3
Estimated Culverts	17,459	597*	11%	2.0	53.1
Estimated Buildings	146,947	600*	11%	80.0	456.4
Estimated Structures	1,136	597*	11%	0.0	3.6

* Original data includes many zeros which represent blank entries. These zeros are replaced in the data after fill-in by estimated values or true blanks.

Variable	Count	Missing Values	TRUE / YES	FALSE / NO
Update Required	670	0.3%	413	257
Rural Damage	597	11%	236	361
Residential Damage	597	11%	223	374
Commercial Damage	597	11%	168	429
Industrial Damage	597	11%	99	498
Institutional Damage	597	11%	94	503

Total mapped area by year

Year	Maps that need to be updated now		Maps that are up-to-date		Total mapped area		
	Mapping done in the year (km^2)	Cumulative area mapped (km^2)	Mapping done in the year (km^2)	Cumulative area mapped (km^2)	Mapping done in the year (km^2)	Cumulative area mapped (km^2)	Cumulative area mapped (%)
Before 1970	0.0	49.5	0.0	0.0	49.5	49.5	0.3%
1970	0.0	49.5	0.0	0.0	0.0	49.5	0.3%
1971	34.0	83.5	0.0	0.0	34.0	83.5	0.4%
1972	75.0	158.5	11.0	11.0	86.0	169.5	0.9%
1973	143.7	302.2	0.0	11.0	143.7	313.2	1.6%
1974	295.7	597.9	0.0	11.0	295.7	608.9	3.1%
1975	236.7	834.5	39.8	50.8	276.5	885.3	4.5%
1976	5,898.8	6,733.3	125.5	176.3	6,024.2	6,909.6	35.1%
1977	451.4	7,184.7	145.0	321.3	596.4	7,506.0	38.1%
1978	229.8	7,414.6	1.1	322.4	231.0	7,736.9	39.3%
1979	124.9	7,539.5	118.8	441.2	243.7	7,980.7	40.5%
1980	158.7	7,698.2	8.3	449.4	167.0	8,147.7	41.3%
1981	100.1	7,798.4	18.4	467.8	118.5	8,266.2	41.9%
1982	116.5	7,914.9	13.9	481.7	130.4	8,396.6	42.6%
1983	285.7	8,200.6	21.8	503.5	307.6	8,704.1	44.2%
1984	557.9	8,758.5	82.3	585.8	640.2	9,344.3	47.4%
1985	3,373.2	12,131.8	2.0	587.8	3,375.2	12,719.5	64.5%
1986	39.0	12,170.8	5.5	593.3	44.5	12,764.0	64.8%
1987	185.0	12,355.8	4.7	597.9	189.7	12,953.7	65.7%
1988	139.3	12,495.1	32.5	630.5	171.8	13,125.5	66.6%
1989	30.1	12,525.2	42.4	672.9	72.6	13,198.1	67.0%
1990	311.8	12,837.0	91.4	764.3	403.2	13,601.3	69.0%
1991	1,327.6	14,164.6	16.6	780.9	1,344.2	14,945.5	75.8%
1992	510.1	14,674.8	15.5	796.3	525.6	15,471.1	78.5%
1993	136.2	14,810.9	4.2	800.6	140.4	15,611.5	79.2%
1994	2.6	14,813.6	13.7	814.3	16.4	15,627.9	79.3%
1995	163.3	14,976.8	54.3	868.7	217.6	15,845.5	80.4%
1996	43.2	15,020.0	37.4	906.1	80.6	15,926.1	80.8%
1997	114.0	15,134.0	28.4	934.5	142.4	16,068.4	81.5%
1998	4.2	15,138.2	17.6	952.1	21.8	16,090.2	81.6%
1999	66.5	15,204.7	6.8	958.8	73.3	16,163.6	82.0%
2000	14.2	15,218.9	58.7	1,017.6	72.9	16,236.5	82.4%
2001	0.0	15,218.9	5.0	1,022.6	5.0	16,241.5	82.4%
2002	3.5	15,222.5	6.1	1,028.7	9.6	16,251.2	82.4%

Total mapped area by year

Year	Maps that need to be updated now		Maps that are up-to-date		Total mapped area		
	Mapping done in the year (km^2)	Cumulative area mapped (km^2)	Mapping done in the year (km^2)	Cumulative area mapped (km^2)	Mapping done in the year (km^2)	Cumulative area mapped (km^2)	Cumulative area mapped (%)
2003	2.5	15,224.9	155.1	1,183.8	157.5	16,408.7	83.2%
2004	28.7	15,253.6	175.3	1,359.1	204.0	16,612.7	84.3%
2005	94.8	15,348.3	868.9	2,227.9	963.6	17,576.3	89.2%
2006	349.6	15,698.0	1,537.8	3,765.8	1,887.4	19,463.7	98.7%
2007	0.0	15,698.0	248.1	4,013.9	248.1	19,711.8	100.0%
2008	0.0	15,698.0	0.0	4,013.9	0.0	19,711.8	100.0%
2009	0.0	15,698.0	0.0	4,013.9	0.0	19,711.8	100.0%
Sub-Total	15,698.0		4,013.9		19,711.8		
Records with no date	114.5		135.3		249.8		
Total	15,763.0		4,149.1		19,961.6		

APPENDIX E: History of Flooding in Ontario

EVENTS	MAXIMUM RAIN, IMPACT AND DAMAGES ($2008)*	RAINFALL RETURN FREQUENCY	REFERENCE**
1954, October 14, Hurricane Hazel, Toronto	285 mm of rain fell on Toronto area watersheds; Humber river flows were four times greater than previously recorded; over 20 bridges destroyed, 81 lives lost, 4000 families left homeless; damages - $810 million	Extreme event used as a 'regulatory' storm for design of flood control infrastructure in Southern Ontario	Canadian Disaster Database, Public Safety Canada http://ww5.ps-sp.gc.ca/res/em/cdd/search-en.asp Hurricane Hazel 50 Years Later, http://www.hurricanehazel.ca/
1961, August 31, Timmins	193 mm of rain; destroyed roads and homes; five deaths	Extreme event used as a 'regulatory' storm for design of flood control infrastructure in Northern Ontario	Canadian Disaster Database, Public Safety Canada http://ww5.ps-sp.gc.ca/res/em/cdd/search-en.asp D. Bonin, Hatch Acres, March 3. 2006. "The 49th Parallel Storm and its Impact on Regional Flood Estimates 49th" Environmental Commissioner of Ontario. 2007. "Flooding Hazards:Prevent and Mitigate, or Compensate and Rehabilitate?." Reconciling our Priorities, ECO Annual Report, 2006-07. Toronto: The Queen's Printer for Ontario. 197-201.
1974, May 17-21, Grand River	Many roads and businesses closed, 3 small dams were damaged, utility services disrupted; damages - $37 million	n.a.	Canadian Disaster Database, Public Safety Canada http://ww5.ps-sp.gc.ca/res/em/cdd/search-en.asp
1976, Aug 27, Toronto	roads closed; damages - $12 million	n.a.	Canadian Disaster Database, Public Safety Canada http://ww5.ps-sp.gc.ca/res/em/cdd/search-en.asp

EVENTS	MAXIMUM RAIN, IMPACT AND DAMAGES ($2008)*	RAINFALL RETURN FREQUENCY	REFERENCE**
1977, Mar 13, Southern and central Ontario	Flooding on the Saugeen and Maitland Rivers and in Sault Ste. Marie; roads closed; damages - $9 million	n.a.	Canadian Disaster Database, Public Safety Canada http://ww5.ps-sp.gc.ca/res/em/cdd/search-en.asp
1979, Apr 24, Lake Nipissing area	Several roads closed; damages - $112 million	n.a.	Canadian Disaster Database, Public Safety Canada http://ww5.ps-sp.gc.ca/res/em/cdd/search-en.asp
1979, May 12, White River	Roads and businesses closed, utility services disrupted; damages - $17 million	n.a.	Canadian Disaster Database, Public Safety Canada http://ww5.ps-sp.gc.ca/res/em/cdd/search-en.asp
1985 and 1987, Lake Huron, Lake St. Clair, Lake Erie	1985 spring runoff 20% to 65% above normal, the highest in 20 years; record high water recorded on all lakes; severe storms caused shoreline damages of $181 million One storm on Dec 2 1985 had winds gusting up to 100 km/hr. It severely affected shorelines with western exposures; erosion occurred on Lake Huron; on the eastern end of Lake Erie, cottages were destroyed; property and shore protection structures were damaged.	n.a.	Environment Canada. Flooding events in Canada - Ontario, http://www.ec.gc.ca/Water/en/manage/floodgen/e_ont.htm Canadian Disaster Database, Public Safety Canada http://ww5.ps-sp.gc.ca/res/em/cdd/search-en.asp
1986, May 16, Winisk River	Spring ice jam caused flood waters to reach six kilometres inland. The village was destroyed; 2 deaths.	n.a.	Canadian Disaster Database, Public Safety Canada http://ww5.ps-sp.gc.ca/res/em/cdd/search-en.asp Environment Canada. Flooding events in Canada - Ontario, http://www.ec.gc.ca/Water/en/manage/floodgen/e_ont.htm

EVENTS	MAXIMUM RAIN, IMPACT AND DAMAGES ($2008)*	RAINFALL RETURN FREQUENCY	REFERENCE**
1989, Jul 19-20 Harrow and Colchester South, Essex County ON	Widespread flooding due to 450 mm of rain in a 30-hour period. Many evacuated from areas of extreme flooding and erosion; a few injuries were reported, no deaths; utility service in some areas was disrupted. Kent and Leamington counties were also affected. Damage estimates - $50 to $125 million	Rainfall exceeded the Hurricane Hazel Storm	Canadian Disaster Database, Public Safety Canada http://ww5.ps-sp.gc.ca/res/em/cdd/search-en.asp Ministry of Natural Resources, 2001. Understanding Natural Hazards Part 2, River and Stream systems. http://www.mnr.gov.on.ca/en/Business/Water/Publication/MNR_E002317P.html Environment Canada. Flooding events in Canada - Ontario, Harrow storm damage costs millions. http://www.ec.gc.ca/Water/en/manage/floodgen/e_harrow.htm
1992, Jul 31, Toronto	Damages - $7 million	n.a.	Canadian Disaster Database, Public Safety Canada http://ww5.ps-sp.gc.ca/res/em/cdd/search-en.asp
1992, Aug 28, Elmira	Damages - $6 million	n.a.	Canadian Disaster Database, Public Safety Canada http://ww5.ps-sp.gc.ca/res/em/cdd/search-en.asp
1994, Jan 16-17, Southern ON	Damages - $19 million	n.a.	Canadian Disaster Database, Public Safety Canada http://ww5.ps-sp.gc.ca/res/em/cdd/search-en.asp
1996, July 8, Atikokan	Over 600 homes flooded; damages - $6 million	n.a.	K. Wianecki and E. Gazendam, March 2004. Flood Damages in Ontario 1996 1997 1998 1999 2000 2001 2002 2003, Lands & Waters Policy Branch, Ministry of Natural Resources
1996, August 2, Kanata	100s of homes flooded.	n.a.	K. Wianecki and E. Gazendam, March 2004. Flood Damages in Ontario 1996 1997 1998 1999 2000 2001 2002 2003, Lands & Waters Policy Branch, MNR

EVENTS	MAXIMUM RAIN, IMPACT AND DAMAGES ($2008)*	RAINFALL RETURN FREQUENCY	REFERENCE**
1996, August 8, Ottawa-Hull	Over 1700 homes flooded; damages - $26 million. Damages - $27 million	n.a.	Canadian Disaster Database, Public Safety Canada http://ww5.ps-sp.gc.ca/res/em/cdd/search-en.asp K. Wianecki and E. Gazendam, March 2004. Flood Damages in Ontario 1996 1997 1998 1999 2000 2001 2002 2003, Lands & Waters Policy Branch, Ministry of Natural Resources
1998, Mar 28-Apr 15, Eastern Ontario and Québec	Flooding on the Clyde, Ottawa, Mississippi Rivers, rivers entering Lake Nipissing, lower Trent System from Rice Lake to Bay of Quinte. States of Emergency declared in 7 communities. More extensive flooding in Québec. Estimated Cost: $40 million	n.a.	Canadian Disaster Database, Public Safety Canada http://ww5.ps-sp.gc.ca/res/em/cdd/search-en.asp
1998, May, Mississippi River system	Ten flood emergencies declared; several roads and bridges affected; 400 to 500 homes evacuated	n.a.	K. Wianecki and E. Gazendam, March 2004. Flood Damages in Ontario 1996 1997 1998 1999 2000 2001 2002 2003, Lands & Waters Policy Branch, Ministry of Natural Resources
2000, May 12, Saugeen River Valley (Walkerton flood)	Rainfall amounts on May 12 were in excess of 90 mm in the southern Saugeen and peaked at 115 mm locally in Halton Region. Accumulated rainfalls in these areas were in excess of 150 mm. Grand, TO, Halton, Simcoe ... SW ON, SC ON	> 100 year return period	J. Klaassen, et. Al, 2003
2000, June 11, London area	125-145 mm of rainfall during a 10-14 hour period	> 100 year return period	J. Klaassen, et. Al, 2003 Personal communication, M. Helston, Senior Water Resources Engineer, Upper Thames river Conservation Authority

EVENTS	MAXIMUM RAIN, IMPACT AND DAMAGES ($2008)*	RAINFALL RETURN FREQUENCY	REFERENCE**
2000, June 26, all along the Grand River.	Major to severe flooding	n.a.	K. Wianecki and E. Gazendam, March 2004. Flood Damages in Ontario 1996 1997 1998 1999 2000 2001 2002 2003, Lands & Waters Policy Branch, Ministry of Natural Resources
2000, July 9, Exeter, St. Mary's, Stratford and Woodstock, London	Up to 175 mm of rain over an 8-12 hour period. Severe flash flooding.	> 100 year return period	J. Klaassen, et. Al, 2003
2000, July 31, Muskoka district	Over 150 mm of rain during a 6-hour period; a rainfall gauge at the Muskoka Airport measured 274 mm of rain	> 100 year return period	J. Klaassen, P. Ford, H. Auld, G. Li, Q. Li, 2003. Ontario Heavy Rainfall Study for Spring and Summer, 2000. Meteorological Service of Canada – Ontario Region, Environment Canada Prepared for: Ontario Conservation Authorities and Ontario Ministry of Natural Resources
2001, Oct-Nov, Lake Nipissing	500 mm of rain since late October; high lake levels led to flood conditions for North Bay, West Nipissing, French River and Jocko Point; 250 property lots damaged in Jocko point; 225 homes impacted in other communities.	n.a.	K. Wianecki and E. Gazendam, March 2004. Flood Damages in Ontario 1996 1997 1998 1999 2000 2001 2002 2003, Lands & Waters Policy Branch, Ministry of Natural Resources
2002, June 11, Otonabee River	202.5 mm of rain impacted 800 homes; 15 families evacuated; 400 basements flooded. Damage - $1 million	n.a.	K. Wianecki and E. Gazendam, March 2004. Flood Damages in Ontario 1996 1997 1998 1999 2000 2001 2002 2003, Lands & Waters Policy Branch, Ministry of Natural Resources

EVENTS	MAXIMUM RAIN, IMPACT AND DAMAGES ($2008)*	RAINFALL RETURN FREQUENCY	REFERENCE**
2002, June 11, Peterborough	Over 200 mm of rain; 800 homes flooded and 15 families evacuated near the Otonabee River	100-year return period	Joan Klaassen and Mark Seifert. "Extreme Rainfall in Ontario: The Summer 2004 Storms Study." Meteorological Service of Canada, Environment Canada UMA Engineering Ltd., 2005. City of Peterborough Flood Reduction Master Plan, Peterborough
2002, June 9-10 49th Parallel Storm, Northwestern Ontario	360 mm of rain—"the most devastating flood in Ontario's history..."; widespread disruption in Rainy River and Atikokan from extensive flooding. Estimated total damages exceed $35 million.	Rainfall exceeded the probable maximum storm Exceeded the Timmins design storm by a factor of 2 to 3.	D. Bonin, Hatch Acres, March 3. 2006. "The 49th Parallel Storm and its Impact on Regional Flood Estimates 49th" J. Klaassen, 2008. Climate Change Implications for Stormwater/Water Resources Infrastructure, OGRA-ROMA Conference, February 25, 2008. Environment Canada – Ontario J. Cummine, B. P. Murphy, R. P. Ford, 2002. The 49th Parallel Severe Rainstorm - An example of elevated thunderstorms and their impact. June 8 to 11, http://ams.confex.com/ams/pdfpapers/81208.pdf
2003, August 10, Pembroke	Flooding of 100 homes; 100s of thousands of dollars in damages.	n.a.	K. Wianecki and E. Gazendam, March 2004. Flood Damages in Ontario 1996 1997 1998 1999 2000 2001 2002 2003, Lands & Waters Policy Branch, Ministry of Natural Resources

EVENTS	MAXIMUM RAIN, IMPACT AND DAMAGES ($2008)*	RAINFALL RETURN FREQUENCY	REFERENCE**
2004, June 13-14, Grand River Watershed Storm	Localized rainfall of 200 mm northwest of Kitchener-Waterloo; significant flooding in small communities and rural regions; temporary road closures, downed trees and hydro wires, flash floods, significant soil erosion and road washouts. If the event had occurred over Kitchener or Waterloo Cities, flooding impacts would have been similar to those in Peterborough in 2004.	>>100-year return period	Joan Klaassen and Mark Seifert. "Extreme Rainfall in Ontario: The Summer 2004 Storms Study." Meteorological Service of Canada, Environment Canada UMA Engineering Ltd., 2005. City of Peterborough Flood Reduction Master Plan, Peterborough
2004, July 14-15, Peterborough	Unprecedented rainfall amount and intensity in records dating back to 1866; Rainfall amounts elsewhere varied from 150 mm to 240 mm; flood damage exceeded $109 million in direct physical damages to private and public property. Approximately 4500 homes had flood damage.	290-year return period Exceeded Hurricane Hazel design storm	J. Klaassen, M. Seifert. Extreme Rainfall in Ontario: The Summer 2004 Storms Study. Meteorological Service of Canada, Environment Canada UMA Engineering Ltd., 2005. City of Peterborough Flood Reduction Master Plan, Peterborough Environmental Commissioner of Ontario. 2007. "Flooding Hazards:Prevent and Mitigate, or Compensate and Rehabilitate?." Reconciling our Priorities, ECO Annual Report, 2006-07. Toronto: The Queen's Printer for Ontario. 197-201. J. Klaassen, 2008. Climate Change Implications for Stormwater/Water Resources Infrastructure, OGRA-ROMA Conference, February 25, 2008. Environment Canada – Ontario

EVENTS	MAXIMUM RAIN, IMPACT AND DAMAGES ($2008)*	RAINFALL RETURN FREQUENCY	REFERENCE**
2004, September 9, Hurricane Frances, Eastern Ontario	100-150 mm of rain; widespread flooding across eastern Ontario; significant damage to private property and public infrastructure in Kanata where a senior's residence and fifty homes were evacuated; transportation, sewage treatment and electrical infrastructure were directly impacted; insurance claims were $63 million.	>>100-year return period	Joan Klaassen and Mark Seifert. "Extreme Rainfall in Ontario: The Summer 2004 Storms Study." Meteorological Service of Canada, Environment Canada
2005, August 19, Toronto	175 mm of rain in less than one hour across the northern sections of the City of Toronto and York Region. Over 9,000 reported basement claims with damages of $155 million	Exceeded Hurricane Hazel design storm	Conservation Ontario Representation at Provincial Urban Flooding Meeting(s), August 10, 2007 J. Klaassen, 2008. Climate Change Implications for Stormwater/Water Resources Infrastructure, OGRA-ROMA Conference, February 25, 2008. Environment Canada – Ontario

* Values updated to $2008 using the CPI.

** Damage values from the Canadian Disaster Database, Public Safety Canada are generally insurance claim figures and are low estimates of total damage.

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