Assessing Vulnerability *to* Climate Change *and* Flooding *in the City of London, Upper Thames River Basin, Ontario*

by Linda Mortsch
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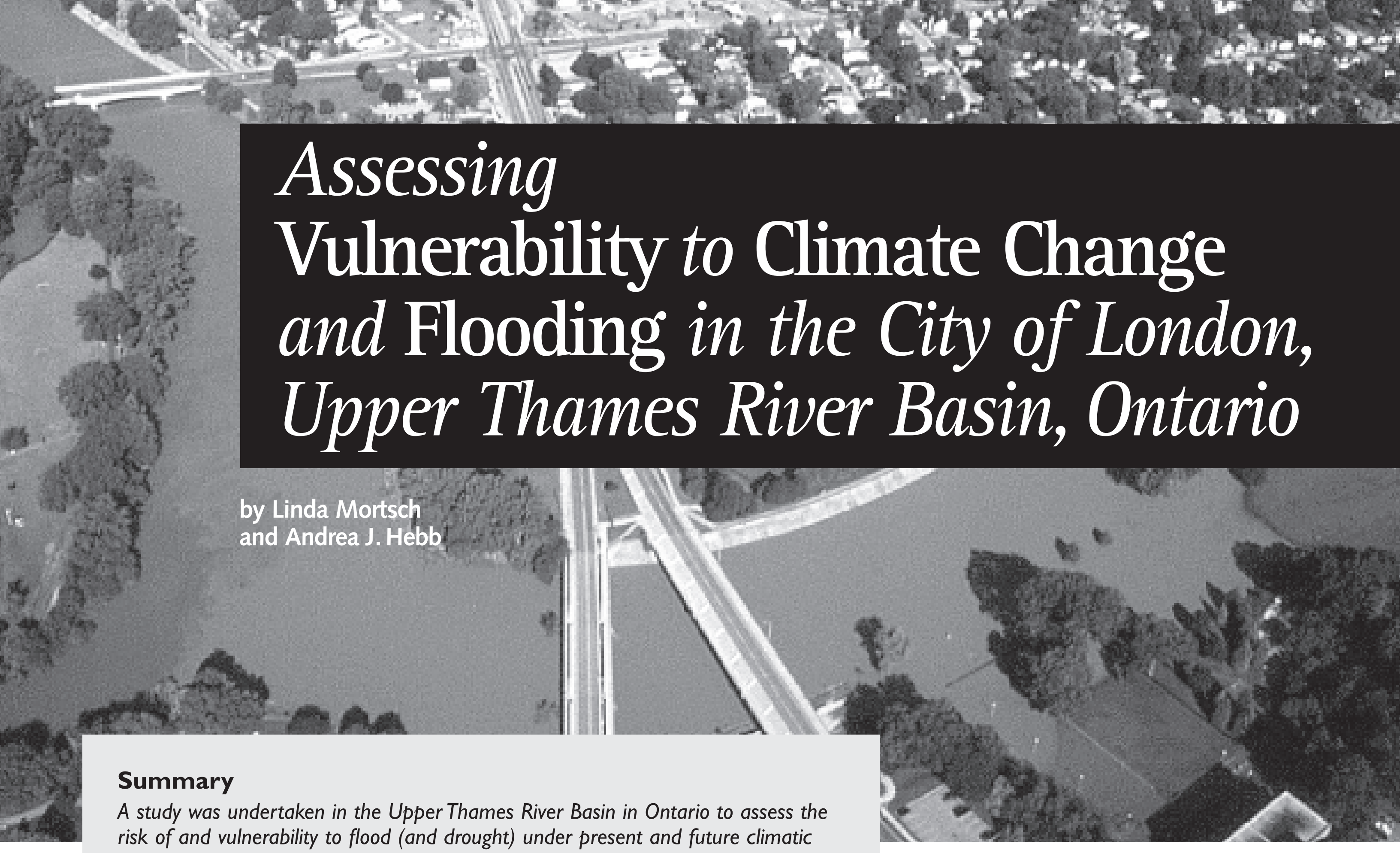


View of the Forks of the Thames in Downtown London. Photo credit: Upper Thames River Conservation Authority.

Summary

A study was undertaken in the Upper Thames River Basin in Ontario to assess the risk of and vulnerability to flood (and drought) under present and future climatic conditions. First, a traditional hazard mapping analysis was conducted in a geographic information system (GIS) to determine the hazard associated with the 1 in 100-, 250- and 500-year floods under historic and two climate change scenarios. Changes in the area affected by the floodlines were calculated, along with estimates of the number of structures affected using overlay techniques in GIS. Second, vulnerability indices were developed to determine the vulnerability of the population, in terms of their "adaptive capacity" or ability to respond to or cope with floods. Socio-economic factors from the 2001 Census Data and physical factors, such as housing type and age, were used to develop indices. Indices maps were created for each factor and combined to create a total socio-economic vulnerability index for each dissemination area. The resulting output identifies areas of vulnerable populations, which can help improve watershed, emergency preparedness and municipal planning. Project details can be found at: http://www.eng.uwo.ca/research/iclr/fids/cfcas-climate.html

Résumé

Une étude a été entreprise dans la région du bassin de la rivière Upper Thames, en Ontario, afin d'évaluer les risques et la vulnérabilité aux inondations (et aux sécheresses) selon les conditions climatiques présentes et futures. Tout d'abord, une analyse classique de cartographie des risques a été menée à l'aide d'un système d'information géographique (SIG) afin d'établir les risques d'inondation de récurrence de 100, 250 et 500 ans selon les données historiques ainsi que deux scénarios de changements climatiques. Les changements aux superficies inondées ont été calculés, tout comme les estimations du nombre de structures touchées, à l'aide de techniques de superposition en SIG. Ensuite, des indices de vulnérabilité ont été établis afin d'évaluer la vulnérabilité de la population au plan de sa capacité d'adaptation ou de son aptitude à réagir aux inondations. Les facteurs socio-économiques, tirés du recensement de 2001, et les facteurs physiques, comme le type et l'âge des habitations, ont servi à l'élaboration des indices. Des cartes indicielles ont été créées pour chaque facteur et combinées pour créer un indice total de vulnérabilité socio-économique pour chaque aire de dissémination. Le produit permet de cerner les aires occupées par des populations vulnérables, ce qui peut aider au processus de planification des bassins hydrographiques, de la protection civile et des municipalités. Les détails du projet peuvent être consultés à l'adresse : http://www.eng.uwo.ca/research/iclr/fids/cfcas-climate.html

Introduction

Extreme events or natural hazards such as floods, droughts, and windstorms are acute examples of climate and socio-economic systems interacting, resulting in lives lost, economic damages, and disruption of lives and infrastructure. The vulnerability profile of a system or community is dependent on the nature of the hazard as well as the characteristics of social groups that affect their response capacity, attributes of the biophysical system that affect susceptibility or sensitivity, and external human system factors (e.g., policies, institutions).[1] Assessing vulnerability, or in broad terms exploring the potential for loss, informs society of who and what are exposed to a natural hazard, and in turn offers insights on the capacity to cope with or adapt to the hazard and where policy and structural responses might be necessary to prevent damage or disaster. Flooding is the most common natural hazard affecting Canada today, and it is also the most costly in terms of property damage.[2,3] Numerous studies have addressed contemporary vulnerability of

Canadian communities to flooding hazard but virtually none explores the effect of climate change on precipitation intensity and flooding hazard,[4,5] and following from that vulnerability and the capacity to cope or adapt. Human-caused climate change, from increasing concentrations of greenhouse gases, is very likely to increase the intensity of precipitation enhancing the potential risk of flash flooding and urban flooding, and increase the exposure of systems and communities to this hazard.[6]

This paper presents the vulnerability assessment component of the research project, "Assessment of Water Resources Risk and Vulnerability to Changing Climatic Conditions". The project's main objectives were to develop water resources risk and vulnerability assessment tools, assess climatic vulnerability of the Upper Thames River basin, and recommend guidelines for vulnerability reduction and hazard mitigation – this to improve the understanding of the processes leading to hydrological hazards, including floods and drought. The assessment focuses on the Forks of the Thames, which is the confluence of the north and south branches of the Thames River near the centre of the City of London. Historically, this area has experienced flooding and associated damages.

Methods

The vulnerability assessment component described herein builds upon climate change scenario-generating techniques and hydrologic modelling developed in this research project and explores the changing flooding hazard due to climate change.[7,8,9]

The 1 in 100-, 250- and 500-year floods were used in the vulnerability assessment. For planning in the Upper Thames River watershed, the 100-year flood separates the flood fringe from the floodway and the 250-year flood defines the flood plain or hazard area. The 500-year floodline coincides with flood damage estimation work completed by the Upper Thames River Conservation Authority for this project, and represents the most extreme condition used for disaster planning.[10]

Two climate change scenarios were used for the vulnerability assessment – dry/warm for drought analysis and wet for flooding assessment; however, if the results were to be applied in a real planning context, a suite of climate change scenarios should be used to explore the vulnerability. Results for these two scenarios are presented. The areas of the 1 in 100-, 250- and 500-year floodlines were calculated for all climate scenarios, and area changes in the floodline between scenarios were determined. The floodlines were overlaid on layers representing the location of homes and buildings to determine the number affected by each floodline.

The vulnerability assessment examines the changing exposure to riverine flooding in an urban area due to climate change scenarios, and the socio-economic and physical attributes of place that influence the capacity to adapt (reduce the impacts of flooding). Adaptation includes undertaking proactive flood-proofing actions prior to an event, responding during the flooding emergency, and recovering after a flooding event. The vulnerability indicator development was based on three thematic areas: ability to cope and respond, differential access to resources, and level of situational exposure. Ten variables from the Canadian Census 2001 Profile Tables at the dissemination area level were used.[11] The selection of variables was based on literature assessing vulnerability to current hazards[12-16] and a changing climate.[17] The contribution of each indicator to vulnerability and the thematic groupings are outlined in Table 1.

Each of the 10 indicators was standardized (from 0.0 to 1.0) by dividing the value for each dissemination area by the maximum value of the variable for all dissemination areas in the study area; higher values indicate greater vulnerability.

TABLE 1: INDICATORS SELECTED FOR THE UPPER THAMES VULNERABILITY ANALYSIS

Indicators	Rationale for contribution to vulnerability
Ability to Cope and Respond: *characteristics that affect ability to cope and respond to flooding*	
Over 65 years of age	• Limited mobility (physical difficulties in evacuation); reluctant to leave homes; health-related problems, longer recovery[16,18]
Under 19 years of age	• Young children, in particular, physically weak; less mobile;[18] legally dependent until age of 18
No Knowledge of Official Languages	• Language barrier; may not understand danger or respond appropriately; may not understand home preparedness measures
Females	• Physically disadvantaged in evacuation or home preparedness; increased emotion, work, stress, physical domestic labour; slower to recover[19]
Differential Access to Resources: *economic characteristics that affect access to resources in order to respond*	
Low Income Households	• Limited resources to prepare or respond (i.e. lack communication devices to stay informed, fewer social or community contacts; rely on public resources)[15]
Single Parent Families	• Limited resources to prepare or respond
Rely on Public Transit	• May lack mobility
Renters	• Landlords lax on disaster preparedness or cleanup[19] • Limited resources and motivation to prepare or respond; less informed, fewer contacts
Level of Situational Exposure: *structural integrity of homes; likelihood of potential damage or failure*	
Housing Type	• Low structures (i.e. one- or two-storey homes) are more susceptible to damage from flooding than apartments[20]
Period of Construction	• Older homes may be constructed in floodplains; regulation not in effect until 1961 (high water mark) and 1973 (regional storm level, i.e. 250-year floodline)[10] • Older neighbourhoods have ageing infrastructure which may be more susceptible to flooding (e.g., water and sewer systems; dykes, dams, etc.)

The thematic vulnerability scores were averages of the standardized vulnerability scores from the appropriate groupings of individual indicators. A total vulnerability score was computed by summing the three individual thematic scores (maximum value of 3.0). The thematic and total vulnerability indicators were mapped into quintiles [e.g., low ($\leq$20th percentile), medium (41-60th percentile) and high (81-100th percentile)] in a GIS.

Results

The climate change scenarios were specifically developed to explore the impact of extremes – wetter conditions with more intense precipitation events, and warmer, drier conditions with more frequent drought. In this community, exposure to flooding hazard increases under the wet climate change scenario (Table 2). The modelled 100-, 250- and 500-year floodlines for the wet climate change scenario are presented in Figure 1. This traditional hazards approach describes the flooding hazard exposure but it does not assess or differentiate the adaptation capabilities of the population exposed to flooding. Using vulnerability indicators and mapping them allows for the analysis of the distribution of adaptive capacity within the community. In Figure 2, the total vulnerability index per dissemination area is presented. The 250-year floodline is shown as it is used for watershed floodplain planning. Mapping reveals that vulnerability to flooding is not evenly distributed throughout the Forks of the Thames River region, "hot spots" emerge that would benefit from additional planning and management attention in order to identify means to reduce flooding vulnerability.

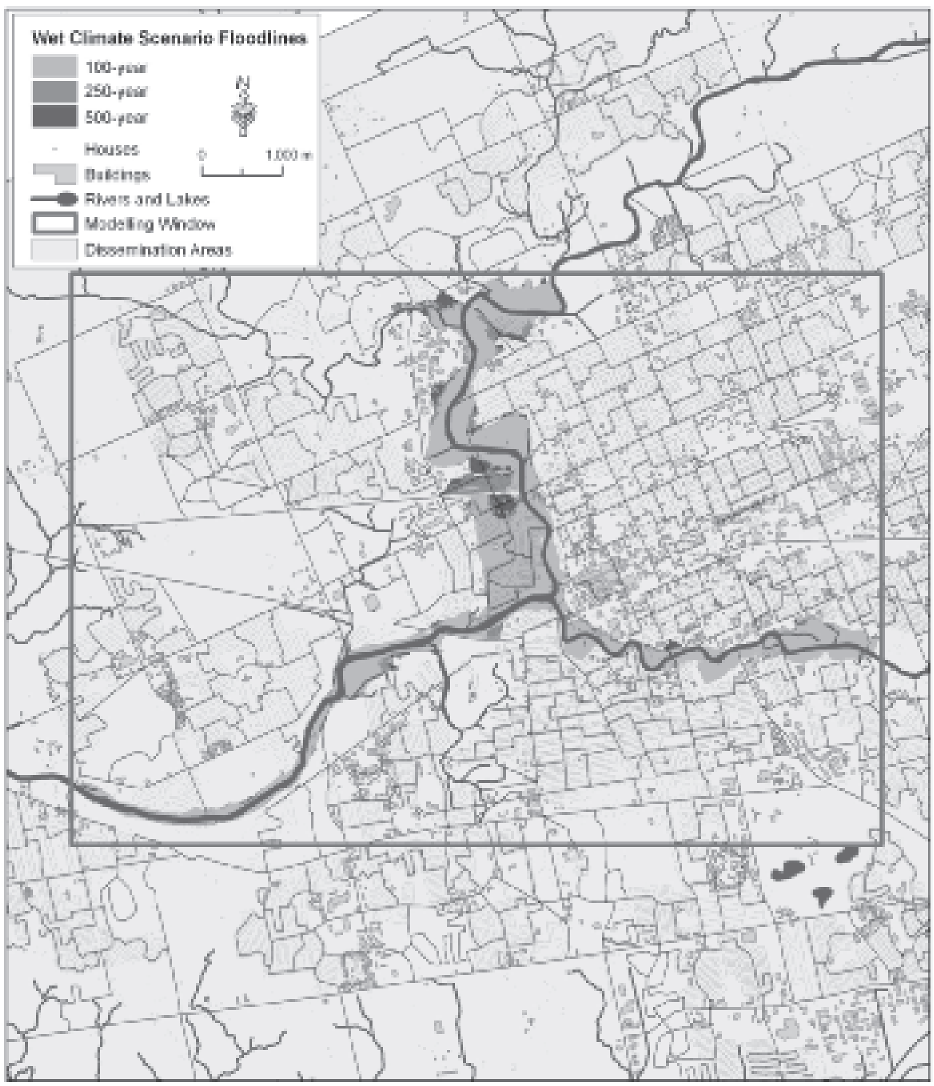
Discussion and Conclusions

The dissemination areas with the highest total vulnerability scores or the "hot spots" are circled in Figure 2. The factor contributing greatest to vulnerability was the "level of situational exposure" indicator (high-medium to high) which identified older areas in the community where houses were built before floodplain restrictions. "Differential access to resources" (medium-high) was the next contributor to vulnerability. It identified areas that might not have the economic resources to invest in adaptation. "Ability to cope and respond" indicator (low-

TABLE 2: Modelled flooded area under historic conditions and two climate scenarios (wet for flooding and dry for drought conditions) and number of homes (all private homes/apartments, etc.) and buildings (commercial, institutional, industrial, etc.) affected

Floodline	Climate Scenario	Area (m^2)	Change in Area	Change in Percent	No. Homes Flooded	No. Buildings Flooded
100-year	Historic	5,291,440			1,141	34
	Dry	3,930,436	-1,361,004	-25.7%	68	18
	Wet	5,595,988	+ 304,548	+ 5.8%	1,249	42
250-year	Historic	5,858,976			1,376	58
	Dry	5,101,848	- 757,128	-12.9%	1,059	33
	Wet	6,116,988	+ 258,012	+ 4.4%	1,486	59
500-year	Historic	6,268,729			1,560	71
	Dry	5,362,852	- 905,877	-14.5%	1,155	36
	Wet	6,567,292	+ 298,563	+ 4.8%	1,690	83

FIGURE 1: MODELLED FLOODLINES FOR THE WET CLIMATE CHANGE SCENARIO



medium) had the lowest impact on the total vulnerability score. This indicator identified members of the community that are likely to have more challenges addressing pre-event vulnerability reduction, emergency response and

FIGURE 2: MAPPING OF TOTAL VULNERABILITY ILLUSTRATING "HOT SPOT" AREAS

post-event recovery because of age, physical capabilities, language barriers or time availability.

The study shows that there is increasing risk from flooding events with the wet climate change scenario that needs to be considered in municipal emergency preparedness and watershed planning in the Upper Thames River watershed. The vulnerability approach builds upon traditional hazard assessment methods and enhances the information provided for planning and management. Since the approach seeks to understand the socio-economic and physical factors that contribute to a differential capacity to adapt, it can inform plans to reduce vulnerability. ■

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References

1. Füssel H-M. Vulnerability: A Generally Applicable Conceptual Framework for Climate Change Research. Global Environmental Change 2007;17:155-67.
2. Public Safety and Emergency Preparedness Canada (PSEPC). Floods. [On-line]. Ottawa, Ontario: Public Safety Canada; 2005. Accessed 14th March 2007 from: http://www.ps-sp.gc.ca/res/em/nh/fl/index-en.asp
3. Institute for Catastrophic Loss and Reduction (ICLR). Understanding Floods/Drought. [On-line]. Toronto and London, Ontario: ICLR; 2007. Accessed 1st February 2007 from: http://www.iclr.org/hazards/flood.htm
4. Cunderlik J, Simonovic SP. Hydrologic Extremes in Southwestern Ontario Under Future Climate Projections. Hydrological Sciences Journal 2005;50(4)631-54.
5. Roy L, Leconte R, Brissette F, Marche C. The Impact of Climate Change on Seasonal Floods of a Southern Quebec River Basin. Hydrological Processes 2001;15:3167-79.
6. Meehl GA, Stocker TF, Collins WD, Friedlingstein P, Gaye AT, Gregory JM, *et al.* Global Climate Projections. In: Solomon S, Qin D, Manning M, Chen Z, Marquis M, Averyt KB, *et al* (editors). Climate Change 2007: The Physical Science Basis. Contribution of Working Group I to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change. Cambridge, United Kingdom and New York, New York, USA: Cambridge University Press; 2007:747-846.
7. Cunderlik JM, Simonovic SP. Inverse Flood Risk Modelling Under Changing Climatic Conditions. Hydrological Processes 2007;21(5):563-77.
8. Prodanovic P, Simonovic S. Inverse Flood Risk Modelling of the Upper Thames River Basin. Project Report VIII. London, Ontario, Canada: Department of Civil and Environmental Engineering, University of Western Ontario; 2006. Accessed 30th May 2007 from: http://www.eng.uwo.ca/research/iclr/fids/publications/cfcas-climate/reports/EventModelReport.pdf
9. Sharif M, Burn DH. Simulating Climate Change Scenarios Using an Improved K-Nearest Neighbor Model. Journal of Hydrology 2006;325:179-96.
10. Personal communication, M. Helsten; 2006.
11. Statistics Canada. 2001 Census Dictionary. Ottawa, Ontario: Ministry of Industry; 2003.
12. Cutter SL, Mitchell JT, Scott MS. Revealing the Vulnerability of People and Places: A Case Study of Georgetown County, South Carolina. Annals of the Association of American Geographers 2000;90(4):713-37.
13. Montz B, Evans T. GIS and Social Vulnerability Analysis. In: Gruntfest E, Handmer J (editors). Coping with Flash Floods. The Netherlands: Kluwer Academic Publishers; 2001.
14. Chakraborty J, Tobin G, Montz B. Population Evacuation: Assessing Spatial Variability in Geophysical Risk and Social Vulnerability to Natural Hazards. Natural Hazards Review 2005;6(1):23-33.
15. Phillips B, Metz W, Nieves L. Disaster Threat: Preparedness and Potential Response of the Lowest Income Quartile. Environmental Hazards 2006;6:123-33.
16. Rygel L, O'Sullivan D, Yarnal B. A Method for Constructing a Social Vulnerability Index: An Application to Hurricane Storm Surges in a Developed Country. Mitigation and Adaptation Strategies for Global Change 2006;11(3):741-64.
17. Wu S-Y, Yarnal B, Fisher A. Vulnerability of Coastal Communities to Sea-Level Rise: A Case Study of Cape May County, New Jersey, USA. Climate Research 2002;22:255-70.
18. Health Canada. Climate Change and Health and Well-Being: A Policy Primer. Ottawa, Ontario: Climate Change and Health Office, Safe Environments Programme, Healthy Environments and Consumer Safety Branch; 2001. Accessed 31st May 2007 from: http://www.hc-sc.gc.ca/ewh-semt/alt_formats/hecs-sesc/pdf/pubs/climat/policy_primer-abecedaire_en_matiere/policy_primer-abecedaire_matiere_e.pdf
19. Rex J. Evaluation of a Literature Review of the Social Impacts of the 1997 Red River Valley Flood. Report submitted to the International Red River Basin Task Force, International Joint Commission. University of Colorado: Natural Hazards Center; 1999.
20. Messner F, Meyer V. Flood Damage, Vulnerability and Risk Perception – Challenges for Flood Damage Research. Helmholtz Centre for Environmental Research (UFZ) Discussion Paper. Leipzig, Germany: Department of Economics, UFZ; 2005.