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PROCEEDINGS OF THE INTERNATIONAL WORKSHOP ON

FLOOD-RESISTANT BUILDINGS

Edited by: A. Attar, M.N. Khaliq, Z. Lounis and M. Armstrong

National Research Council Canada
Conseil national de recherches Canada

Canada

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Proceedings of the International Workshop on FLOOD-RESISTANT BUILDINGS

Ottawa, Canada
26-27 February 2020

Co-sponsored by
National Research Council Canada and
Infrastructure Canada

Edited by
A. Attar, M.N. Khaliq, Z. Lounis and M. Armstrong

Contents

Acknowledgements

On behalf of the National Research Council of Canada (NRC), the organizing committee would like to thank all workshop participants for their contributions and suggestions, and for helping to streamline the impact of flooding on buildings and develop effective design guidelines.

We are especially grateful to all speakers for allowing the distribution of their presentations.

Dr. Bruce Ellingwood (Colorado State University, CO, USA), Dr. Peter Irwin (RWDI, ON), Mr. Marco Civitarese (City of Calgary, AB), Ms. Annick Maletto (City of Montreal, QC), and Dr. Laxmi Sushama (McGill University, QC) are thanked for helping with chairing the workshop sessions.

Mr. Bill Coulbourne (Coulbourne Consulting MD, USA), Dr. Dave Kriebel (Coastal Analytics LLC, MD, USA), Ms. Kimberly McKenna (Stockton University, NJ, USA) and Mr. Randy Behm (Behm Hazard Mitigation LLC, NE, USA) are thanked for their contributions to the development of design guidelines for flood-resistant buildings.

Dr. Dan Healy (Northwest Hydraulic Consultants Ltd., AB), Mr. Raj Mannem (Hatch, MB), Mr. Derek Williamson (Baird & Associates, Ottawa, ON), and Mr. Vincent Leys (CBCL, Halifax, NS) are thanked for leading selected case studies in different regions of Canada.

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Dr. Francis Zwiers (Pacific Climate Impacts Consortium, BC) is also thanked for his presentation on long period return level estimates of extreme precipitation.

We would like to extend our thanks to Infrastructure Canada for making the workshop possible through their support for the Climate-Resilient Buildings and Core Public Infrastructure Initiative (CRBCPI) project, under the Pan-Canadian Framework for Clean Growth and Climate Change.

Finally, we acknowledge NRC staff who contributed towards various phases of the workshop: Ms. Fiona Hill, Mr. Paul Taylor-Sussex, Dr. Matthew Vucko, Ms. Sarah Gagné and Ms. Celia Roy.

A. Attar, M.N. Khaliq, Z. Lounis & M. Armstrong

National Research Council Canada

List of Authors

Name	Institution
Dr. Muhammad Naveed Khaliq	National Research Council Canada
Dr. Ahmed Attar	National Research Council Canada
Ms. Marianne Armstrong	National Research Council Canada
Mr. Bill Coulbourne	Coulbourne Consulting, MD, USA
Ms. Kimberly McKenna	Stockton University, NJ, USA
Dr. David Kriebel	Coastal Analytics LLC, MD, USA
Mr. Randall Behm	Behm Hazard Mitigation LLC, NE, USA
Mr. Bill Brown	Flood Science Center, WI, USA
Dr. Dan Healy	Northwest Hydraulic Consultants Ltd., AB, Canada
Mr. Raj Mannem	Hatch, MB, Canada
Mr. Derek Williamson	Baird & Associates, ON, Canada
Mr. Josh Wiebe	Baird & Associates, ON, Canada
Mr. Vincent Leys	CBCL, NS, Canada
Mr. Mark Peacock	Lower Thames Valley Conservation Authority, ON, Canada
Ms. Sandy Davis	City of Calgary, AB, Canada
Mr. Marco Civitarese	City of Calgary, AB, Canada
Mr. Jesal Shah	Ministry of Forests, Lands, Natural Resource Operations and Rural Development, BC, Canada
Ms. Annick Maletto	Centre de sécurité civile - Ville de Montréal, QC, Canada
Dr. Amir Ali Khan	Municipal Affairs and Environment, NL, Canada
Ms. Paula McLeod	Natural Resources Canada
Dr. Francis Zwiers	Pacific Climate Impacts Consortium, BC, Canada
Dr. Bruce Ellingwood	Colorado State University, CO, USA

List of Participants

Name	Institution
Ms. Marianne Armstrong	National Research Council Canada
Dr. Ahmed Attar	National Research Council Canada
Mr. Randall Behm	Behm Hazard Mitigation LLC, NE, USA
Mr. Bill Brown	Flood Science Center, WI, USA
Mr. David Brown	KGS Group, MB, Canada
Mr. Peter Campbell	Public Services and Procurement Canada
Mr. Marco Civitarese	City of Calgary, AB, Canada
Mr. Bill Coulbourne	Coulbourne Consulting, MD, USA
Ms. Sandy Davis	City of Calgary, AB, Canada
Mr. Stan Dueck	District of Sooke, BC, Canada
Dr. Bruce Ellingwood	Colorado State University, CO, USA
Ms. Laurence Forget-Dionne	Infrastructure Canada
Dr. Jon Galsworthy	CPP Wind Engineering & Air Quality Consultants, ON, Canada
Mr. Jim Hanley	ISL Engineering and Land Services, AB, Canada
Dr. Dan Healy	Northwest Hydraulic Consultants Ltd., AB, Canada
Ms. Fiona Hill	National Research Council Canada
Dr. Han-Ping Hong	Western University, ON, Canada
Dr. Peter Irwin	RWDI, ON, Canada
Mr. Philip Jarrett	Environment and Climate Change Canada
Mr. Clive Kamichaitis	Public Services and Procurement Canada
Dr. Muhammad Naveed Khaliq	National Research Council Canada

Dr. Amir Ali Khan	Municipal Affairs and Environment, NL, Canada
Dr. David Kriebel	Coastal Analytics LLC, MD, USA
Mr. Vincent Leys	CBCL Limited, NS, Canada
Dr. Zoubir Lounis	National Research Council Canada
Ms. Annick Maletto	Centre de sécurité civile - Ville de Montréal, QC, Canada
Mr. Raj Mannem	Hatch, MB, Canada
Dr. Ghyslaine McClure	McGill University, QC, Canada
Mr. Glenn McGillivray	Institute for Catastrophic Loss Reduction, ON, Canada
Ms. Kimberly McKenna	Stockton University, NJ, USA
Ms. Natalia Moudrak	Intact Centre on Climate Adaptation, ON, Canada
Mr. Enda Murphy	National Research Council Canada
Mr. Chad Nelson	Infrastructure Canada
Mr. Mark Peacock	Lower Thames Valley Conservation Authority, ON, Canada
Mr. Joe Rogers	Department of Municipal Affairs and Housing, NS, Canada
Ms. Chris Rol	Insurance Bureau of Canada, ON, Canada
Mr. Jesal Shah	Ministry of Forests, Lands, Natural Resource Operations and Rural Development, BC, Canada
Mr. Kevin Smith	Environment and Climate Change Canada
Dr. Laxmi Sushama	McGill University, QC, Canada
Mr. Hariharasankaran Vaidyanathan	National Defence – Government of Canada
Mr. Derek Williamson	Baird & Associates, ON, Canada
Ms. Adrienne Yuen	Standards Council of Canada, ON, Canada
Dr. Xuebin Zhang	Environment and Climate Change Canada
Dr. Francis Zwiers	Pacific Climate Impacts Consortium, BC, Canada

Introduction

The National Research Council of Canada (NRC) is leading the Climate-Resilient Buildings and Core Public Infrastructure (CRBCPI) project, with funding from the Federal Government of Canada through Infrastructure Canada. The project will develop decision-support tools, including codes, guides and models, to enhance the resilience of Canada's buildings and core public infrastructure against climate change and extreme weather events such as floods.

Over the last two decades, floods in Canada have resulted in major economic losses and hardships for many communities. It is also likely that the frequency and intensity of future flood events will increase due to climate change. Therefore, improving the performance of buildings exposed to flooding is an important research and development need identified within the CRBCPI project.

As part of the CRBCPI project, the NRC—in collaboration with national and international partners—is developing prescriptive and performance-based requirements for the design of flood-resistant buildings, as well as guidelines for improving the flood resistance of existing buildings. The outcome of this effort will address a gap in the current National Building Code of Canada, where there are no provisions for designing buildings against flood loads typically experienced in riverine and coastal environments in different parts of Canada.

A two-day International Workshop on Flood-Resistant Buildings was held in Ottawa on February 26 and 27, 2020. This workshop brought together national and international experts in flood-resistant design and modelling, structural engineering, code development and climate change science. In addition, there were federal, provincial, territorial and municipal stakeholders, and agencies involved in flood-related initiatives, including floodplain mapping and flood mitigation activities.

The workshop consisted of four different sessions: two were held on the first day (Sessions 1 and 2) and two were held on the second day (Sessions 3 and 4). Session 1 was preceded by an introduction to the workshop and an overview of the flood-resistant buildings initiative.

Session 1 was devoted to "Requirements for Flood-Resistant Buildings". In this session, engineers from Coulbourne Consulting presented on six different aspects related to the development of guidelines for the design of flood-resistant buildings and the retrofitting of existing buildings. Six talks were given in this session and each talk was followed by a dedicated period for questions and discussion.

Session 2 was devoted to "Case Studies on Flood Data Generation". In this session, collaborators from Canadian consulting companies presented on the progress and status of their regional case studies. These case studies were from Alberta, Manitoba, Saskatchewan, British Columbia, Ontario, Nova Scotia, New Brunswick, Newfoundland and Labrador, and the Northwest Territories.

Session 3 was devoted to "Federal, Provincial, Territorial and Municipal Initiatives on Flood-Related Issues". In this session, six talks were given, two of which focused on urban environments; that is, the city of Calgary and the city of Montreal. Three talks were given on provincial initiatives related to flooding issues for British Columbia, Ontario, and Newfoundland and Labrador. One talk was given by Natural Resources Canada, which reviewed federal government initiatives related to flooding issues.

Session 4 was devoted to "Extreme Precipitation", which is a topic of great interest for managing urban flood risk. In this session, a single talk was given wherein the issue of estimating long return period precipitation extremes was discussed.

A summary of the key issues and the path forward were also discussed towards the end of the workshop.

Copies of all presentations are included in these proceedings, along with the program of the workshop, the abstract for each presentation, and short biographies of the corresponding presenters, which are provided in Appendix A.

DAY 1
Opening Sessions

NRC's Flood-Resistant Buildings Initiative
Naveed Khaliq and Ahmed Attar
National Research Council Canada

NRC's Climate-Resilient Buildings and Core Public Infrastructure Initiative (CRBCPI) – Flooding Activities
Marianne Armstrong
National Research Council Canada

NRC's Flood-Resistant Buildings Initiative

NAVEED KHALIQ and AHMED ATTAR

National Research Council Canada

Abstract

Within the framework of the Climate-Resilient Buildings and Core Public Infrastructure project, the National Research Council of Canada (NRC) is developing guidelines for the design of flood-resistant buildings and improving the flood-resilience of existing buildings, in collaboration with national and international experts. To support the development of these guidelines, a number of initiatives have been undertaken to generate data on a range of expected and extreme flood-loading conditions in riverine, coastal and large lake environments in Canada. This presentation will provide an overview of these initiatives and associated timelines and various data products.

Biographies

Dr. Naveed Khaliq is a Research Engineer at the Ocean, Coastal and River Engineering Research Center of the NRC. He has a PhD degree in Engineering Hydrology, two Master of Science degrees, one in Hydrology and another in Water Resources Engineering, and over 30 years of professional experience in various settings, ranging from applied research and academics to software industry. At the NRC, his research focus is on advancing innovation and solving applied problems in hydrology and water resources, based on advances in hydrotechnical engineering, hydrologic process modelling and analysis, and multi-disciplinary approaches to water management. His expertise includes stochastic and deterministic modelling, river flow forecasting, environmental change and its impact on water cycle components, hydro-climatology, time series analysis, and applied software development.

Dr. Ahmed Attar is the Lead Technical Advisor for the Standing Committee on Structural Design at Codes Canada. In this role, he provides expertise and guidance to several design standards, regulators and industries, including the National Building Code (NBC) 2015 and its Structural Commentaries. In recognition of his Code expertise, Dr. Attar has been selected by NRC Management to lead the development of climate change provisions, including flood-resistant buildings, for implementation in the NBC and its user's guides. Prior to his functions as a Lead Technical Advisor, Dr. Attar has been an Evaluation Officer at the NRC's Canadian Construction Materials Centre (CCMC) since 2008. In his tenure at the CCMC, Dr. Attar integrated the technological expertise of the NRC, universities and external experts to provide technical opinions on the compliance of innovative construction products to the NBC, aiding more than 70 companies in the development, marketing and acceptance of their products. Dr. Attar also worked with the NRC's Industrial Materials Institute (IMI) for 3 years (1997-2000), where he brought his expertise in composite materials and modelling, and led the development of optimization techniques for plastic processes within two major consortium projects, providing a manufacturing competitive edge to 40 North American plastic manufacturers by adding new performance features in design. Before joining the NRC, Dr. Attar was a Researcher at McGill University (1996-1997) where he led the work on deterioration assessment using non-destructive methods as part of large project on the assessment of Montreal's Dickson Bridge. Dr. Attar was a Research Engineer for five years at France's "Centre Scientifique et Technique du Bâtiment" (CSTB) (1992-1995) working on innovative structural materials and experimental methods, leading to higher performance and robust designs.

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Flood-Resistant Buildings Initiative

M.N. Khaliq and A. Attar

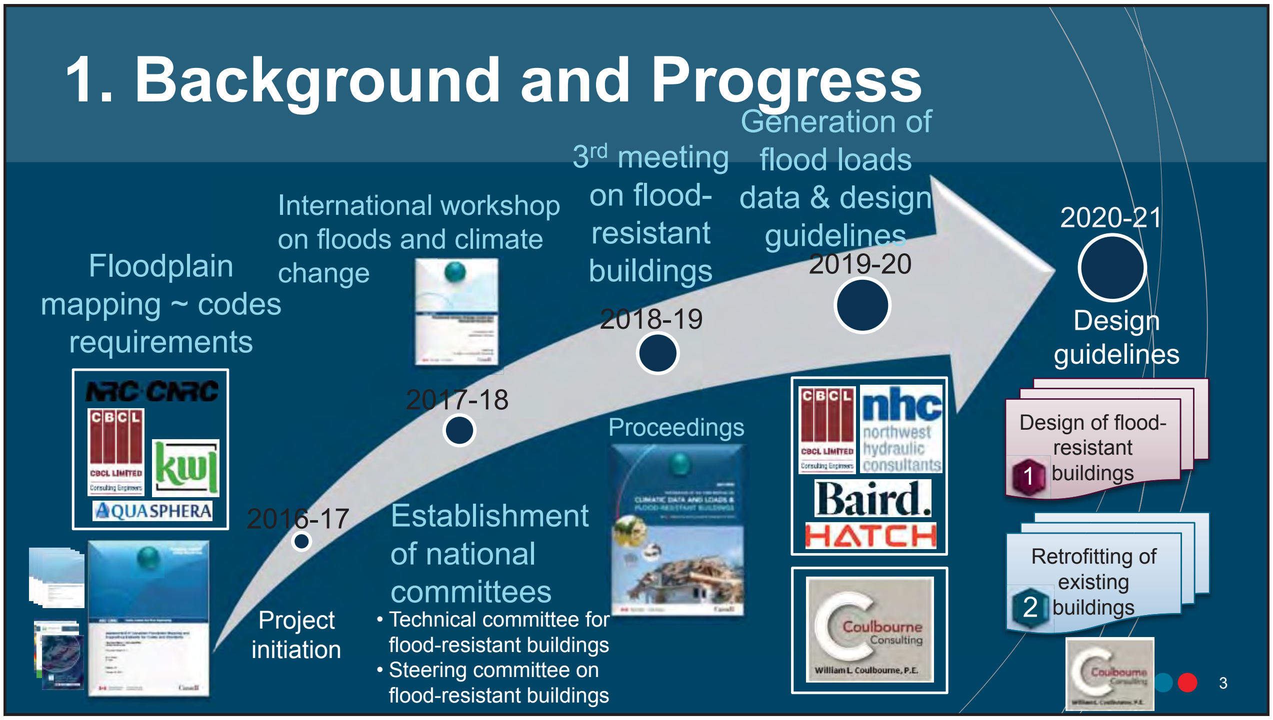
International Workshop on Flood-Resistant Buildings
Ottawa, Ontario, Canada
February 26-27, 2020

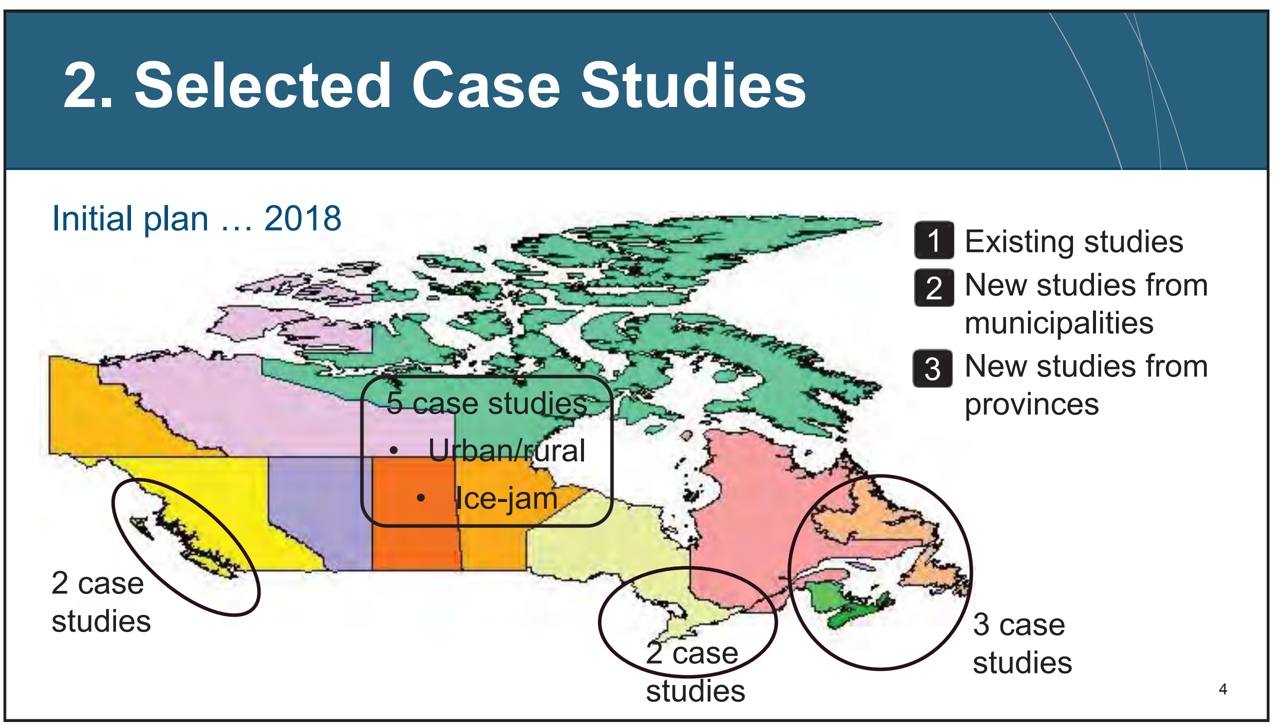
National Research Council Canada | Conseil national de recherches Canada
Canada

Outline

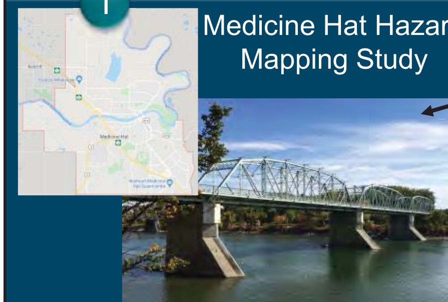
1. Background and Progress
2. Selected Case Studies
3. Other Relevant Studies and National Guidelines
4. Concluding Remarks

2

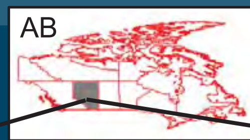

1. Background and Progress
Floodplain mapping ~ codes requirements
International workshop on floods and climate change
3rd meeting on flood-resistant buildings
Generation of flood loads data & design guidelines
2016-17
Project initiation
2017-18
Establishment of national committees
• Technical committee for flood-resistant buildings
• Steering committee on flood-resistant buildings
2018-19
Proceedings
2019-20
2020-21
Design guidelines
1 Design of flood-resistant buildings
2 Retrofitting of existing buildings
3


2. Selected Case Studies
Initial plan … 2018
1 Existing studies
2 New studies from municipalities
3 New studies from provinces
5 case studies
• Urban/rural
• Ice-jam
2 case studies
2 case studies
3 case studies
4

2.1 Selected Case Studies … NHC

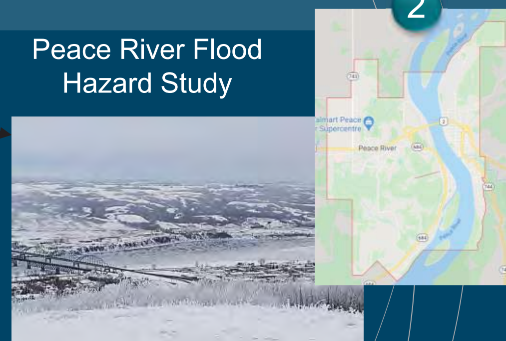


Medicine Hat Hazard Mapping Study



2 Riverine case studies

Peace River Flood Hazard Study



- A 40 km long reach of the South Saskatchewan River
- Completed in 2019 for Alberta Environment and Parks

- A 52 km reach extended from Shaftesbury Ferry crossing to Highway 986 bridge
- Completed in 2019 for Alberta Environment and Parks

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2.1 Selected Case Studies … NHC

City of Vancouver Coastal Flood Risk Assessment Study

2 Coastal case studies

Serpentine and Nicomekl River floodplain inundation study

- To identify and quantify the assets at risk of damage as a result of coastal flooding
- Completed in 2014 for the City of Vancouver

- Mixed inundation – caused by coastal conditions and river outflows
- Completed in 2014 for the City of Surry

[Dan Healy, NHC]

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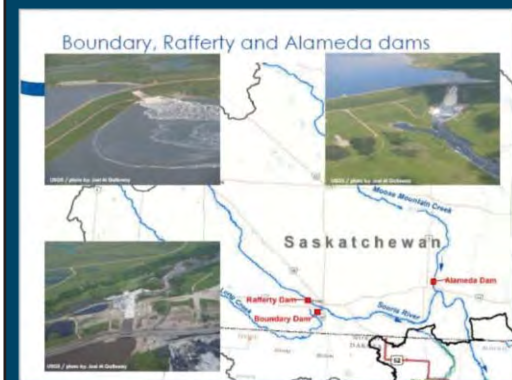
2.2 Selected Case Studies … HATCH

Rafferty and Alameda Inflow Design Flood and Dam Breach Study



- This study was completed for the Saskatchewan Water Security Agency
- HEC-RAS 1-D hydraulic model was used
- The same model will be used to generate flood loads data to support flood-resistant buildings initiative

Source: BARR

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2.2 Selected Case Studies … HATCH

The Souris River Hydrodynamic Modelling Study

- The Souris River study was completed for Manitoba Infrastructure and Transportation in 2019 (273 km river reach)
- HEC-RAS 1-D hydraulic model was used and it can be coupled with hydrologic forecasts for real-time inundation mapping
- The same model will be used to generate flood loads data to support flood-resistant buildings initiative

[Raj Mannem, HATCH]

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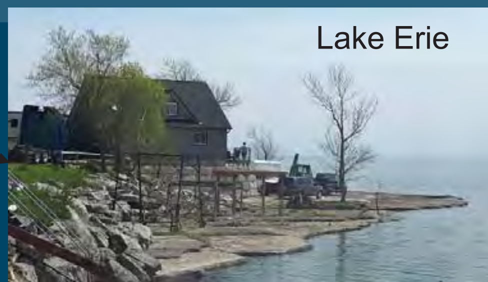
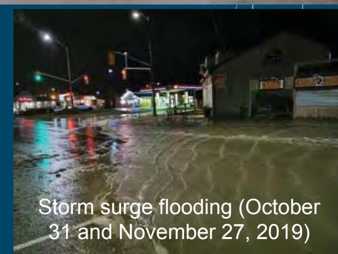
2.3 Selected Case Studies … Baird

ON

Norfolk and Haldimand Counties (2 sites)




Storm surge flooding (October 31 and November 27, 2019)

- These counties have over 200 km of Lake Erie shoreline and over 6,000 buildings at risk of coastal flooding
- This lake is subject to the largest storm surges on the Great Lakes
- Flood and erosion hazard studies were completed in 2019 (funded through the NDMP)

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2.3 Selected Case Studies … Baird

NWT

The hamlet of Tuktoyaktuk, NWT, is vulnerable to coastal erosion and flooding

- In 2019, Baird investigated flood and erosion mitigation alternatives for the community
- This study will be extended to generate flood loads data to support NRC's initiative on flood-resistant buildings

[Derek Williamson and Josh Weibe, Baird]

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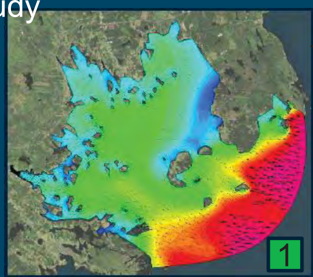
2.4 Selected Case Studies … CBCL

Mahone Bay Flood Prevention and Shoreline Enhancement Study



Coastal flooding

Riverine flooding

Truro Flood Risk Mapping Study

- The Town of Mahone Bay is one of the premier scenic locations in coastal NS
- The study was completed in 2015

- Historically, the city of Truro experienced repeated flooding due to river outflows
- A flood risk mapping study was completed in 2014

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2.4 Selected Case Studies … CBCL

Waterford River Flood Risk Mapping Study

- In 2015, CBCL completed a flood risk mapping study for the province, which later was revisited in 2017 to complement NRCan's climate change case studies
- This study will again be revisited to develop flood loads data to support NRC's initiative on flood-resistant buildings

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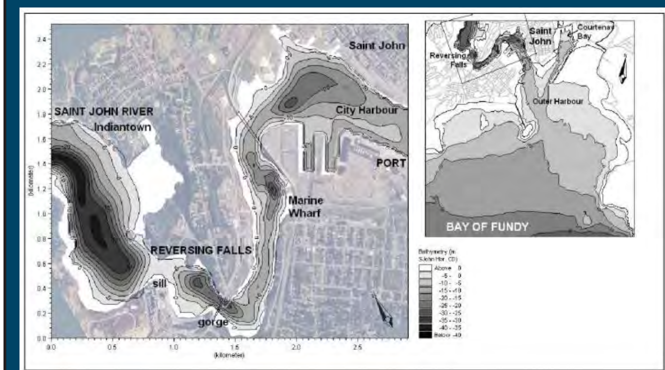
2.4 Selected Case Studies … CBCL

Saint John Harbour Coastal Flood Modelling Study



- Combination of the Saint John River and the Bay of Fundy tides makes this site quite unique for urban flood risk modelling and flood loads data generation.

[Vincent Leys, CBCL]

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3. Other Relevant Studies and Guidelines

1 Federal Flood Damage Estimation Guidelines

[NRCan]

2 Coastal Flood Risk Assessment Guidelines

[Ebbwater Baird NRC]

An Inventory of Methods for Estimating Climate Change-Informed Design Water Levels for Floodplain Mapping

3

Climate Change Adaptation and Impacts Division [NRCan/PSC/NRC]

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4. Concluding Remarks

- A brief overview of various studies that are directly connected with the “flood-resistant buildings” initiative is provided. Additional detail will be available in related presentations.
- Work is already in progress for 12 case studies. Additional studies will be added during the 2020-21 fiscal year.
- An overview of all findings on flood loading parameters will be documented and published in the future.

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Thank you

M.N. Khaliq

Email: Muhammad.Khaliq@nrc-cnrc.gc.ca

Tel: 613-993-6656

A. Attar

Email: Ahmed.Attar@nrc-cnrc.gc.ca

Tel: 613-993-3807

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NRC's Climate-Resilient Buildings and Core Public Infrastructure Initiative (CRBCPI) – Flooding Activities

MARIANNE ARMSTRONG

National Research Council Canada

Abstract

This presentation provides a brief overview of the broad range of flooding-related activities undertaken by the five-year Climate-Resilient Buildings and Core Public Infrastructure (CRBCPI) Initiative in collaboration with Infrastructure Canada, and in support of the Pan-Canadian Framework on Clean Growth and Climate Change. The presentation sets the stage for the International Workshop and the development of national guidelines for flood-resistant buildings, activities enabled by funding under CRBCPI.

Biography

Marianne Armstrong is Director of Stakeholder Engagement and Management with the National Research Council of Canada (NRC), Construction Research Centre. In her current role, she manages research in support of provincial and territorial priorities for building codes, as well as engaging key stakeholders in the transformation of the current national codes system. From 2016-2019, she managed the CRBCPI initiative to integrate climate resiliency into Canadian building and infrastructure codes, standards and guidelines. For over a decade, Ms. Armstrong also conducted residential energy efficiency research at the Canadian Centre for Housing Technology, where she helped to assess the performance of over 60 different housing technologies. Ms. Armstrong is a member of the Professional Engineers of Ontario, holds an MSc in Industrial Design from the University of New South Wales, Sydney, and a BSc in Mechanical Engineering from Queen's University in Kingston, Ontario.

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NRC's Climate-Resilient Buildings and Core Public Infrastructure Initiative (CRBCPI) – Flooding Activities

Marianne Armstrong

February 2020

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Canada

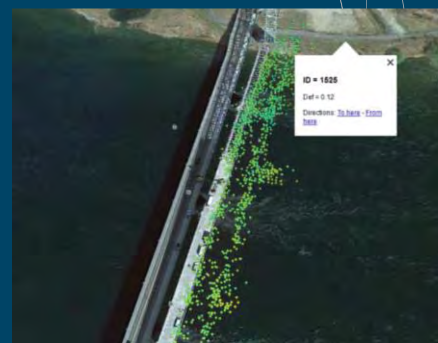
To develop decision support tools, including codes, guides and models for the design of resilient new buildings and Core Public Infrastructure (CPI) and rehabilitation of existing buildings and CPI in key sectors to ensure that climate change and extreme weather events are addressed

Climate Data • Roads
Buildings • Bridges
Water/Wastewater
Transit • Decision Support Tools

2

Responding to Climate Change

- Funding from **Infrastructure Canada**
- $42.5M over 5 years (2016-2021), 30+ projects
- **Pan Canadian Framework on Clean Growth and Climate Change**
- **NRC Expertise**
  - Model Codes
  - Infrastructure, Building Science, Hydrology, Aerodynamics
- **Environment and Climate Change Canada**
  - Historical data
  - Climate modeling and projections
- **Over 150 collaborators**



Monitoring bridge displacement rates with satellite data

3

Developing Future Climatic Design Data

- Partnership with Environment and Climate Change Canada (ECCC) and Pacific Climate Impacts Consortium (PCIC)
- Draft **forward-looking climatic design data** will likely be made public in late 2019. General guidance on how to use this data is currently under development.
- **IDF curves** under development for December 2020.
- The **2019 Canadian Highway Bridge Design Code** (CHBDC) will include a full update to historic data. (some data was from the 1970s).
- The **2020 National Building Code** will include updated wind design data.

Peace tower weather station

4

Flooding

- Best practices for flood risk reduction in **existing residential communities "Weathering the Storm"** was published (Intact Centre and SCC)
- **Four new CSA standards related to flooding** have been published: bioretention systems (2), basement flood protection and risk reduction, and climate change adaptation of wastewater treatment plants.
- CRBCPI has triggered a discussion at the **Canadian Commission on Building and Fire Codes (CCBFC)** on the role of National Construction Codes in addressing flooding.

First prototype buoyant foundation built at University of Waterloo

5

Flooding continued

- NRC established a technical committee to review and advise the development of new guidelines for conducting **coastal flood hazard and risk assessments**. The draft guidelines are nearing completion.
- The University of Waterloo is developing guidelines for the design of **buoyant foundations**. One prototype foundation is complete, an existing cottage will be retrofit this year.
- A **Technical Committee** and a **Steering Committee** on flood-resistant buildings have been established. A contract is in place with Coulbourne Consulting to develop **structural provisions for the design of new buildings to flood-related loads**.

First prototype buoyant foundation built at University of Waterloo

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Design for the Future rather than the Past
https://www.infrastructure.gc.ca/plan/crbcpi-irccipb-eng.html
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THANK YOU
Marianne Armstrong
marianne.armstrong@nrc-cnrc.gc.ca
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DAY 1
Session 1 – Part 1: Requirements for Flood-Resistant Buildings

Chair, Bruce Ellingwood
Colorado State University, CO, USA

Developing Requirements for Flood-Resistant Buildings, Including Execution Plan and Discussion of Data Needs
Bill Coulbourne and Kimberly McKenna
Coulbourne Consulting, MD, USA

Design Flood Conditions and Considerations
Bill Coulbourne and David Kriebel
Coulbourne Consulting, MD, USA

Flood Load Formulas and Provisions
David Kriebel
Coulbourne Consulting, MD, USA

Developing Requirements for Flood-Resistant Buildings, Including the Execution Plan and Discussion of Data Needs

BILL COULBOURNE and KIMBERLY MCKENNA

Coulbourne Consulting, MD, USA

Abstract

This presentation will discuss the scope of the project that Coulbourne Consulting is undertaking to prepare guidance documents for the requirements for flood-resistant buildings that are intended to be used as the basis for eventually developing Canadian building code requirements for flood design of buildings. This presentation will also cover the execution plan developed for this project and the data-needs requirement for successfully developing the guidance documents.

Biographies

Mr. Bill Coulbourne has nearly 50 years of experience as an engineer and manager. His expertise includes building design, methods, materials, and codes. He is experienced in hazard-related design and the construction of wind- and hurricane-resistant structures. He has performed structural inspections and building investigations on thousands of structures to assess past or future performance during a natural hazard event. He is leading the Coulbourne Consulting team effort and is the leader for performance-based design guidelines.

Mr. Coulbourne actively participates in engineering standards development by working on the American Society of Civil Engineers (ASCE) standards ASCE 7, Minimum Design Loads for Buildings and Other Structures, including the Wind Load and Flood Load Task Committees, and ASCE 24, Flood Resistant Design and Construction.

Ms. Kimberly McKenna has over 35 years of experience in coastal geology and is the current Director of Sponsored Programs & Senior Project Manager, Coastal Research Center, at Stockton University in Port Republic, NJ, USA. She has extensive experience in GIS (Geographic Information Systems) and is leading the team’s effort in data collection and manipulation needed for this project. She has led teams of coastal geologists for the Delaware Department of Natural Resources and Environmental Control (DNREC), Division of Watershed Stewardship, Shoreline and Waterway Management Section, Dover, DE. Her roles there included being a coastal processes expert, research coordinator, and a scientific advisor for state policy development and special projects. She was an interagency team leader for studies related to shoreline change, tidal inlet management, beach nourishment design, storm surge impacts and sea level rise, and beach nourishment sediment quality/quantity.

Requirements for Flood-Resistant Buildings: A Contract to Develop Guidance

Bill Coulbourne

Kimberly McKenna

National Research Council Canada Conseil national de recherches Canada

Committee on Flood Resilience of Buildings &
Technical Committee for Flood-Resistant Buildings
Ottawa, ON February 26-27, 2020

Coulbourne Consulting

Outline

- Scope of work
- Technical reports to be developed
- Execution plan
- Schedule
- Data needs

Coulbourne Consulting

Scope of Work

- Develop technical guidance related to flood design that can eventually be placed in the National Building Code of Canada
- Address flooding in riverine and coastal areas that are included in mapped floodplains
- Address future conditions
- Develop guidance that can be used in any province

Contract for Requirements for Flood-Resistant Buildings

Coulbourne Consulting

Technical Reports

- TR No. 2 Design Flood Conditions and Considerations
- TR No. 3 Flood Load Formulas and Provisions
- TR No. 4 Performance-Based Design for Flood
- TR No. 5 Guidelines for Improving Flood-Resistance for Existing Buildings
- TR No. 6 Final Report & Recommendations for inclusion of Flood-Design Requirements in Canadian Codes or Standards

Contract for Requirements for Flood-Resistant Buildings

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Execution Plan

- Execution Plan was accepted by NRC in August, 2019
- Covered the reports to be delivered
- Included a standard report outline for authors to follow
- Included a development plan for each technical report including possible references and resources to use
- Included a schedule

Schedule

Deliverable	Description	50% Draft		90% Draft		Final
		Team	NRC	Team	NRC	NRC
1	Execution Plan	---	---	7/19/19	8/1/19	9/1/19
2	Design Flood Conditions	9/1/19	10/1/19	4/1/20	5/1/20	9/1/20
3	Flood loads	11/1/19	12/1/19	5/1/20	6/1/20	10/1/20
4	Performance-based Design	12/1/19	1/1/20	7/1/20	8/1/20	12/1/20
5	Existing Bldgs	10/1/19	11/1/19	6/1/20	7/1/20	11/1/20
6	Codes	9/15/20	10/1/20	12/15/20	1/1/21	3/1/21

Completed

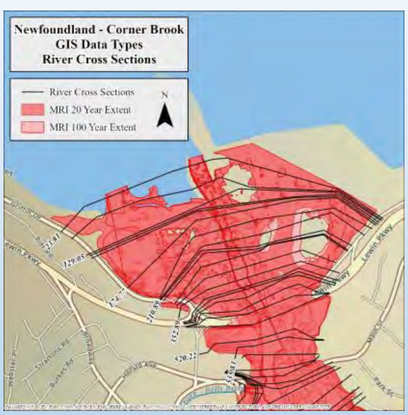
Data Needs

- Need data that leads to development of flood depth and velocity in a study location
- Need data that leads to development of future conditions including depth and velocity for long term return periods
- Data has been difficult to find/retrieve as much of it is not in public domain
- Selected Provinces: Alberta, British Columbia, Newfoundland, Ontario, Quebec

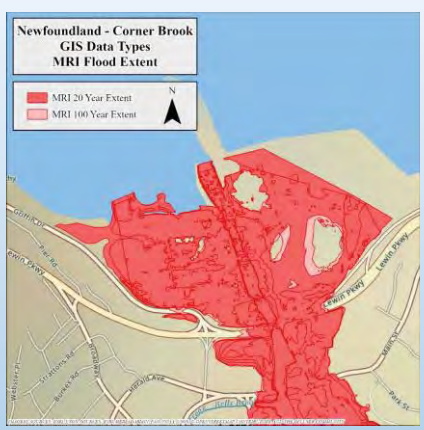
Technical Report No. 1 – Execution Plan: Requirements for Flood-Resistant Buildings

Development of flood depth and velocity in a study location

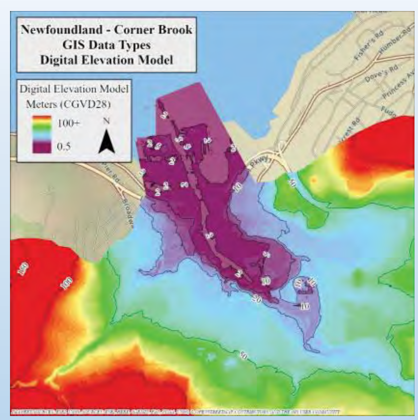
GIS Datasets



Polyline shapefile – river cross sections



Polygon shapefile – mean recurrence interval (MRI) flood extents (floodway & flood fringe)



Raster or LAS – elevation data

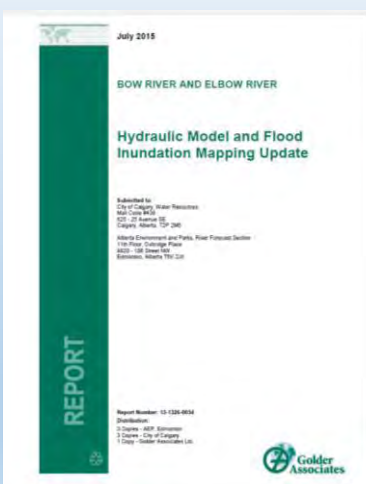
Technical Report No. 1 – Execution Plan: Requirements for Flood-Resistant Buildings

Test of Dataset Availability

Newfoundland | Corner Brook					
Type	**Info**	**Status**	**Data Format**	**Public Data**	**Source**
Topography	1-m DEM	Data Received	GIS Raster	No	Contact with Department of Municipal Affairs and Environment
River Transects	-	Data Received	GIS Shapefile	Yes	Newfoundland Municipal Affairs and Environment Website (https://www.mae.gov.nl.ca)
Flood MRI Extent	20yr/ 100yr +Climate change (2050/2080)	Data Received	GIS Shapefile	Yes	Newfoundland Municipal Affairs and Environment Website (https://www.mae.gov.nl.ca)
Flood MRI Elevations	Displayed 20 yr/100yr	-	-	Yes	Newfoundland Municipal Affairs and Environment Website (https://www.mae.gov.nl.ca)
Flood MRI Assocatied Discharge	Not Found	-	-	-	-

Technical Report No. 1 – Execution Plan: Requirements for Flood-Resistant Buildings

Development of **future conditions** including depth and velocity for long term return periods



Hydraulic Studies:

- Model to simulate flood events (2-, 5-, 8-, 10-. 20-, 35-, 50-, 75-, 100-, 200-, 350-, 500-, 1,000-yr)
- Flood inundation maps (integrated DEM and flood water levels to show flood boundaries)
- Data include shapefiles for: cross sections with simulated water levels, contour lines (from DEM), channel transect location, elevation along transect, and MRI flood extent

Technical Report No. 1 – Execution Plan: Requirements for Flood-Resistant Buildings

Questions?

bill@coulbourneconsulting.com
kimberly.mckenna@stockton.edu

Test of Dataset Availability

Alberta | Calgary					
Type	Info	Status	Data Format	Public Data	Source
Topography	DEM	Data Requested	-	No	City of Calgary
River Transects	-	Data Received	GIS Shapefile	No	Obtained from Alberta Enviroment and Parks division on 09/05/2019
Flood MRI Extent	5, 10, 20, 50, 100, 200 + select flooding events	Data Received	GIS Shapefile	Yes	City of Calgary Open Data (https://data.calgary.ca/browse)
Flood MRI Elevations	Not Found	-	-	-	-
Flood MRI Assocatied Discharge	Displayed	-	-	Yes	Calgary's River Flood Story (https://maps.calgary.ca/RiverFlooding/)
Flood Fringe and Floodway	Both	Data Received	GIS Shapefile	No	Obtained from Alberta Enviroment and Parks division on 09/05/2019

British Columbia | City of Surrey					
Type	*Info*	*Status*	*Data Format*	*Public Data*	*Source*
Topography	1-m DEM and Lidar	Data Received	GIS Raster, LAS	Yes	City of Surrey Open (https://data.surrey.ca/)
River Transects	Displayed	-	-	Yes	BC Environmental Protection & Sustainability - Flood Maps
Flood MRI Extent	200 Year	Data Received	GIS Shapefile	Yes	City of Surrey Open (https://data.surrey.ca/) - GIS Files
Flood MRI Elevations	20/200yr Displayed	-	GIS Shapefile	Yes	BC Environmental Protection & Sustainability - Flood Maps
Flood MRI Assocatied Discharge	Not Found	-	-	-	-

Test of Dataset Availability

Ontario | Ottawa					
Type	**Info**	**Status**	**Data Format**	**Public Data**	**Source**
Topography	0.5m DEM (2006-2015)	Requires Request	GIS Raster	No	University of Ottawa (requires login)
River Transects	Displayed	–	–	Yes	Mississippi Valley Conservation Authority - Flood Risk Maps
Flood MRI Extent	100 yr.	Requires Request	GIS Shapefile	No	City of Ottawa (Flood Plain Mapping)
Flood MRI Elevations	Displayed - Regultory flood	–	–	–	Mississippi Valley Conservation Authority - Flood Risk Maps
Flood MRI Assocatied Discharge	Not Found	–	–	–	–
Flood Fringe and Floodway	Dispalyed Floodway, Floodplain Regulatory Limit	–	–	–	Mississippi Valley Conservation Authority - Flood Risk Maps

Quebec | Quebec City					
Type	**Info**	**Status**	**Data Format**	**Public Data**	**Source**
Topography	1- m DTM (Viewable)	–	–	Yes	Quebec Open data hub (https://www.donneesquebec.ca/)
River Transects	Not Found	–	–	–	–
Flood MRI Extent	Displayed 2, 20, 100yr	–	–	Yes	Quebec Ministry of Sustainable Development\Natural Resources and Wildlife - Flood Maps
Flood MRI Elevations	Displayed 2, 20, 100yr Select flood events	–	–	Yes	Quebec Ministry of Sustainable Development\Natural Resources and Wildlife - Flood Maps
Flood MRI Assocatied Discharge	Displayed 20/100yr Large current area	–	–	Yes	Quebec Ministry of Sustainable Development\Natural Resources and Wildlife - Flood Maps

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Design Flood Conditions and Considerations

BILL COULBOURNE and DAVID KRIEBEL
Coulbourne Consulting, MD, USA

Abstract

This presentation will review recommended guidance for defining flood conditions and considerations across all Canadian provinces. The flood conditions discussed include depth, velocity, duration, debris, scour and erosion, and ice jams. The elements of the design flood will be discussed, including flood frequency considerations, freeboard, and considerations for future conditions. Also included are the results of research into how to approach developing flood frequency information and how to infer riverine flow velocity based on mapped flood hazard zones and flood elevations.

As background, flood loads on buildings in riverine flood plains require an estimate of both flood depth and flow velocity. Most flood hazard maps, however, only provide information on flood elevation and do not include information on flow velocity. While flood flow velocity may be obtained from application of a detailed numerical model, code provisions and commentary in the National Building Code of Canada should include a prescriptive method that allows a user to develop a fairly simple and robust estimate of velocity without using a complex numerical model. A method has therefore been developed to allow a user to approximate flow velocity from information contained on a flood hazard map.

Biographies

Mr. Bill Coulbourne has nearly 50 years of experience as an engineer and manager. For more information, see "Developing Requirements for Flood-Resistant Buildings" above.

Dr. David Kriebel has nearly 40 years of experience in coastal and ocean engineering, with an emphasis on ocean waves, wave forces, wave-structure interaction, sediment transport and erosion processes, marine soil mechanics and foundations, and coastal flooding and natural hazards. In addition, he has experience in naval architecture, including ship-generated waves, the effects of passing vessels, vessel berthing and mooring, and the response of floating structures. He is leading the report development for flood load formulas and provisions.

Dr. Kriebel teaches at the US Naval Academy in the areas of: coastal engineering, ocean wave mechanics, random wave analysis, wave loading, offshore structural analysis, marine soil mechanics and foundations, marine environmental engineering, naval architecture, and ocean engineering design. In addition, he has had a consulting practice for nearly 40 years and participates as a member of the ASCE 7 Main Committee on Minimum Design Loads for Buildings and Other Structures, the Flood Load Task committee, and the committee on Tsunami Loads and Effects.

Design Flood Conditions and Considerations

Bill Coulbourne, PE

Dave Kriebel, PhD, PE

National Research Council Canada | Conseil national de recherches Canada

Committee on Flood Resilience of Buildings &
Technical Committee for Flood-Resistant Buildings
Ottawa, ON February 26-27, 2020

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Outline

- Background & Objectives
- Flood Parameters Important for Flood-Resistant Design
- Design Flood and Flood Frequency Considerations
- Regulatory Mechanisms
- Consideration for Future Conditions
- Recommendations
- Important study topics – MRI and velocity

Background & Objectives

- Intent is to offer a process for developing flood design standard for any province or jurisdiction
- Objectives are to:
  - Identify and characterize flood parameters important to flood-resistant design
  - Discuss design flood and flood frequency consideration for flood hazard mapping and design
  - Discuss regulatory mechanisms to address flood
  - Use actionable science to incorporate climate change into future conditions
- Major challenge:
  - How to develop standards that are consistent across Canada when each Province has different mapping methods?

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Technical Report No. 2 – Design Flood Conditions and Considerations

Flood Parameters Important for Flood-Resistant Design

- Flood damage mechanisms and flood forces
- Flood depth
- Flood velocity
- Flood duration
- Flood-borne debris
- Scour and erosion
- Effects of flood protection structures and ice jams

Cars are submerged by the flood waters in High River, Alberta on Thursday, June 20, 2013 after the Highwood River overflowed its banks. (AP Photo/The Canadian Press, Jordan Verlage)

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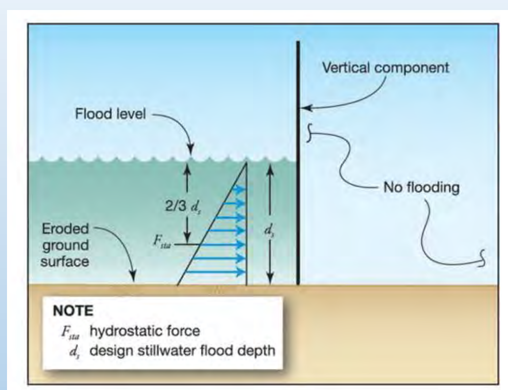
Technical Report No. 2 – Design Flood Conditions and Considerations

Flood Damage Mechanisms and Flood Forces

- Flood water surrounds building
  - Building could float, walls could collapse, or interior could flood
- Flood water moves with some velocity
  - Moving water could move building off foundation
- Flood water can rise rapidly causing a flash flood
- Flood water can cover large floodplain areas and recede slowly if small topographical relief or saturated soil
- Flood water can carry debris
  - Logs, cars, boats, ice
- Coastal flooding can cause damage to buildings from breaking waves and extensive building inundation

Flood Depth (1)

- Flood depth is required to find all types of flood loads
- Most current Canadian flood maps do not show depth
- Topo or digital elevation maps needed along with flood maps to find the depth at any particular location a
  - Both maps would need to be in some GIS format to do this simply
- Depth causes hydrostatic loading on a vertical surface (as shown) and/or buoyancy (uplift) on a horizontal surface



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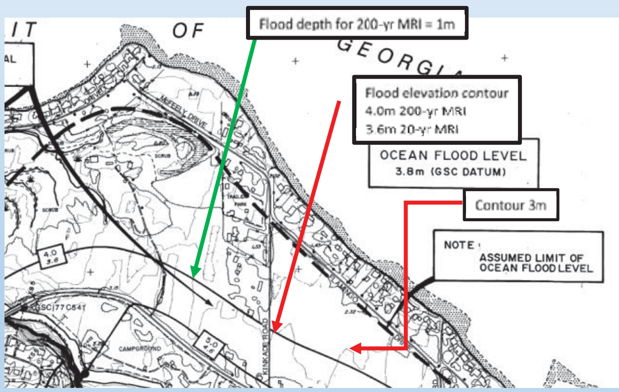
Flood Depth (2)

- Determination of accurate flood loads requires more depth precision than most current maps provide (< or > 1m which delineates flood way and flood fringe)
- Example of current map: Vancouver Island (Little Qualicum River)



Flood Depth (3)

- Coastal flood depths require storm surge + tide levels + additional height for waves
- Does not appear to have been done consistently (or even at all) in some Provinces
  - Ex: Toronto flood map shows flooding from river but not Lake
  - Usually done with detailed modeling in mapping studies
  - Some coastal flood studies used historical data for the 1:20 and 1:100 year and not flood modeling
- Flood depths for two coastal locations in BC used:
  - D_f = HHWLT + storm surge + waves above surge – ground Where HHWLT is the highest of tides and wave heights are 30-50% of storm surge depths
- Suggested guidance for coastal flood depths will require some work

Technical Report No. 2 – Design Flood Conditions and Considerations

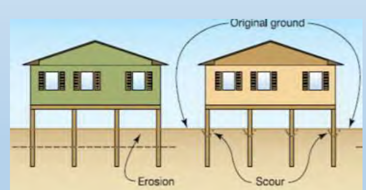
Flood Velocity

- Flow of moving water can cause significant damage to buildings in the flood plain
- Flood velocity is used in flood load equations for hydrodynamic loads and debris loads
- Flood velocity not generally part of most Provincial mapping programs
- Mapping in many provinces use velocity limits to define flood zone boundaries
  - > 1m/s defines the limit of the flood way
  - < 1m/s defines the edge of the flood fringe
- A range of < 1m/s or > 1m/s does not help define the loads, so a method must be developed to estimate riverine velocities that is sufficiently prescriptive that most practitioners can use the method

Technical Report No. 2 – Design Flood Conditions and Considerations

Flood Debris, Duration and Erosion/Scour

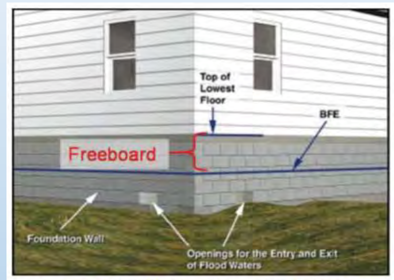
- Flood debris
  - Size, weight and velocity are important
  - Debris could be buildings or building components, boats, cars, logs, docks or piers, or ice
- Flood duration
  - Affects damage levels
  - Creates more mold especially in closed up buildings
  - Could affect resistance of materials below FCL to damage
- Erosion and scour
  - Loss of soil at building sites lowers ground surface thus increasing water depths, thus increasing flood loads
  - Need a way to predict this soil loss as a future condition



Technical Report No. 2 – Design Flood Conditions and Considerations

Freeboard

- Definition: A vertical height of water added to calculated flood elevations to provide additional protection, or to account for uncertainty from sources including climate change and data limitations.
- When FCL are developed from small return periods, freeboard is definitely a wise policy choice
- When FCL are developed from larger return periods (1:500 and larger perhaps), freeboard may not be as necessary
- A fixed number of meters of freeboard does not add an equal amount of additional protection everywhere given the varying return periods and flood conditions
- In U.S., increased freeboard results in lower flood insurance premiums



Courtesy of VTDEC River Management Program

Technical Report No. 2 – Design Flood Conditions and Considerations

Regulatory Mechanisms

- Regulatory mechanisms usually include locally (could be provincial) adopted ordinances and flood hazard information such as flood maps and studies
- This regulatory information MUST be publically available and be free
- Most common flood hazard information is shown on maps depicting the flood elevations for the floodway (1:20 MRI) and 1:100 (flood fringe – could be longer return period for fringe)
- A few examples of this for provinces will be illustrated in the report
- Plans and Guidelines must be developed to support any regulatory information (intended to be provided by this contract to some degree)
- Building regulations must follow the regulatory information as well

Technical Report No. 2 – Design Flood Conditions and Considerations

Consideration for Future Conditions (1)

- Possible future conditions include:
  - Sea level rise
  - Subsidence
  - Coastal erosion
  - Increased rainfall that overflows water conveyance channels
  - Increased density of built environment
- Inclusion of future conditions should be part of the design flood elevation or FCL
- Future conditions are most often dealt with as a scenario (projected flood levels at some time in the future)

Technical Report No. 2 – Design Flood Conditions and Considerations

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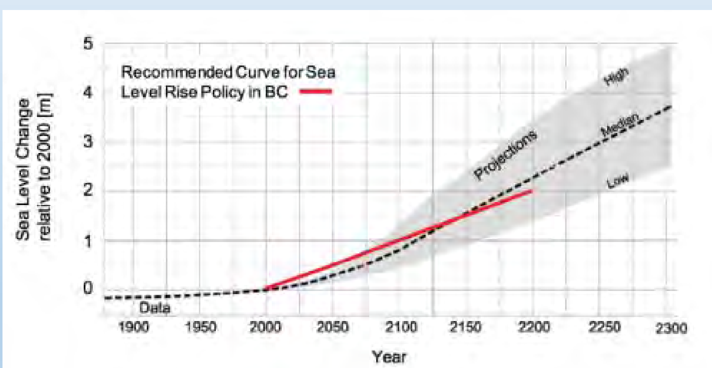
Consideration for Future Conditions (2)

- **An example from British Columbia**

  FCL = HHWLT + SLR + storm surge + wave effect + freeboard



Technical Report No. 2 – Design Flood Conditions and Considerations

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Recommendation for Determining the Design Flood or FCL

Flood Design Levels or Flood Construction Levels:

The D_f or FCL for riverine conditions should include:

Design flood depth for a specified MRI

+ FC (sea level rise, subsidence, increased development)

+ Freeboard (perhaps depending on the MRI

The D_f or FCL for coastal conditions should include:

Design flood depth for a specified MRI

+ Storm Surge for a coastal design flood event

+ Wave effects above Storm Surge

+ FC (sea level rise, subsidence, increased development)

+ Freeboard (perhaps depending on the MRI)

Current Canadian Practice on Return Periods

- For our reporting, we have chosen 5 provinces that appear to cover the range of return periods, consider future conditions, and cover both coastal and riverine locations.
- The flood hazard information available from those 5 provinces are:

Province	Design Flood (MRI)	What Data is Shown on Flood Maps	Climate change included in Maps
Alberta	100-year	Inundation	No
British Columbia	200-year	Inundation and depth	Yes, newer maps
Ontario	100-year	Inundation	No
Newfoundland	20- and 100-year	Inundation, depth on newer maps	Yes, newer maps
Quebec	20- and 100-year	Inundation	No

Design Flood Specification (1)

- The selection of the design flood should be based on human life safety and economic impact to community when a flood occurs
- Number of buildings likely damaged at various flood depths
- Number of people or businesses displaced during the design event
- Importance of a particular facility to community (importance category in NBC)
- Risk of flood damage commensurate with risks of damage by other hazards
- Should consider flood history

Design Flood Specification (2)

- Flood return periods are statements of annual probability of exceedance and lifetime risk
- Many Provinces now map 20 and 100 year floods.
  - 1:100 year MRI has 39% chance of being equaled or exceeded in 50 years
  - 1:20 year MRI has 92% chance of being equaled or exceeded in 50 years
  - Both give very high probability of flood during 50 year period
- A 1:500 year MRI has a much lower 9% chance of being equaled or exceeded in 50 years

	Time Periods			
Event MRI	10 yrs	30 yrs	50 yrs	100 yrs
10	0.65	0.96	0.99	0.999
20	0.4	0.78	0.92	0.99
50	0.18	0.45	0.64	0.87
100	0.09	0.26	0.39	0.63
200	0.05	0.14	0.22	0.39
500	0.02	0.06	0.09	0.18
1000	0.01	0.03	0.05	0.09
2000	0.005	0.01	0.02	0.05
3000	0.003	0.01	0.02	0.03

Design Flood Specification (3)

- Improving flood damage performance should create interest in designing for higher return periods (less frequent events with higher flood depths)
- Designing using PBD will likely create a need to design for longer return periods
- That is a problem when in most cases, flood studies only provide flood elevations for 2 return periods, mostly 1:20 and 1:100 year events
- NBC will eventually need information on load factors. The load factor is strongly influenced by the return period
- How is this information extrapolated to longer return period events?
- What follows is a prescriptive method for determining return periods (MRI) for flood elevations that are not mapped or included in a flood study
- Goal to enable consistency on a national level

Proposed Methods for Scaling MRI

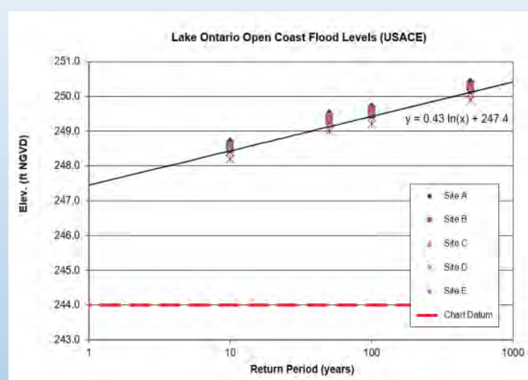
- Goal: Use information at known MRI to scale to another MRI
- Required: Two flood elevations established at the same datum
- Method: Common behavior that data often well-fit by Weibull distribution and plots as straight line on log graph of return period

$$S = a + b*\ln(MRI)$$

S = flood level above datum

a = intercept when MRI = 1

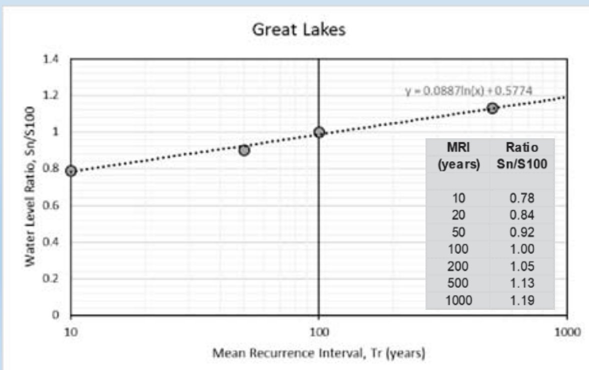
b = slope determined from any two points



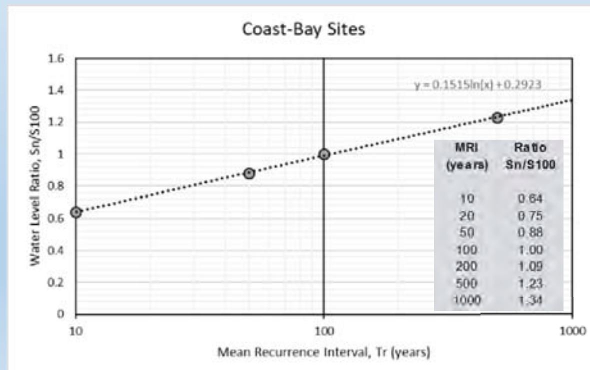
Scaling MRI Relative to 100-year Values

- Normalize by 100-year value (as most commonly mapped flood level)
- Coastal and Great Lakes sites well-behaved (at least in U.S.)

- Analysis of water levels from 53 sites around U.S. side of Great Lakes

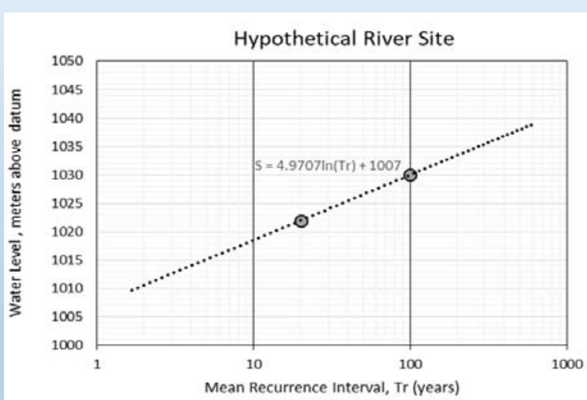


- Analysis of water levels from 85 sites around U.S. Atlantic and Pacific coasts



Scaling MRI for Riverine Floods

- Riverine sites more difficult because of large offset from datum to normal river level
- If flood level known at two MRI's, can still fit straight line (Weibull approximation)



S = a + b*ln(MRI)

S = flood level above datum
a = intercept when MRI = 1
b = slope determined from two points

Technical Report No. 2 – Design Flood Conditions and Considerations

Scaling MRI for Riverine Floods

- Eliminate intercept *a* and slope *b* using mapped flood levels at 20 and 100 years
- Develop generic scaling factors for river stage relative to 20 and 100 year values in chart
- Example from Hypothetical on previous slide
  - Know S_{20} = 1022m and S_{100} = 1030m
  - Find 500 year elevation S_{500}
  - From chart $(S_{500}-S_{20})/(S_{100}-S_{20}) = 2$
  - $(S_{500}-1022)/(1030-1022) = 2$
  - $S_{500} = 1022 + 2\,(1030-1022) = 1038$ m

MRI (years)	Ratio $(S_n-S_{20})/(S_{100}-S_{20})$
10	
20	0
50	0.57
100	1.00
200	1.43
500	2.00
1000	2.43

Proposed Method for Estimating Riverine Flow Velocity

The Problem:

- Velocity is needed to compute hydrodynamic loads in rivers
- Flood mapping programs generally do not show flow velocities
- A user cannot estimate velocity without running a detailed numerical model

The Goal

- Develop a simple prescriptive method for estimating velocity
- A "typical" civil engineer should be able to apply method

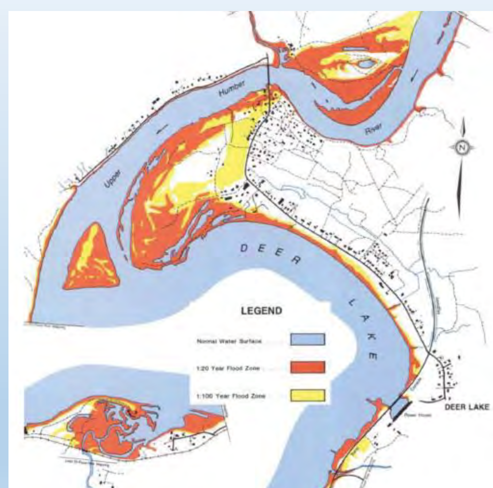


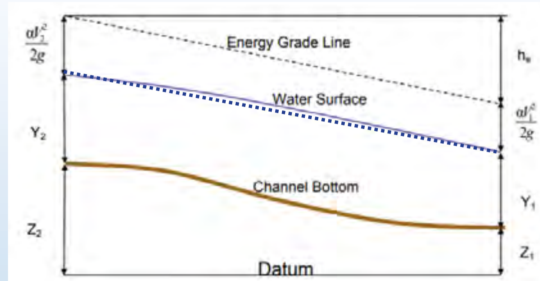
Figure 5.2: 1 in 20 year and 1 in 100 year FDRP Flood Map in Deer Lake

Background #1

- **Velocity from Manning Equation**

$$V = \frac{k}{n} R_h^{2/3} S^{1/2}$$

S = slope of water surface elevation (m/m or ft/ft)



- **Approximate slope of energy grade line with slope of water surface**
  - Should use slope of energy grade line – but cannot be obtained from flood maps
  - Slope of water surface, S, can be found from flood maps

- **Validity of Approximation**
  - Exact if flow uniform, good approx over short distances if flow gradually varying
  - Approximation not valid for rapidly-varying flow, flow constrictions and expansions

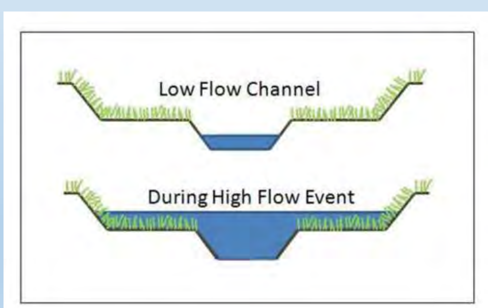
Technical Report No. 3 – Flood Load Formulas and Provisions

Background #2

- **Re-write Manning Equations with flow "conveyance"**

$$Q = K S^{1/2} \qquad K = A \frac{k}{n} R_h^{2/3} \qquad V = \left(\frac{K}{A}\right) S^{1/2}$$

K = conveyance or discharge capacity of cross section discharge (m^3/s or ft^3/s)



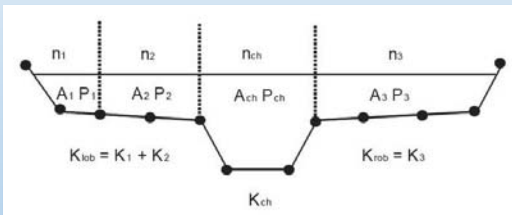
Conveyance K is a property of river cross-section at given flood level

Can be found from mapped flood elevation, ground elevations,and land roughness

Technical Report No. 3 – Flood Load Formulas and Provisions

Background #3

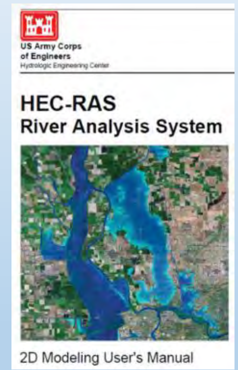
- **Define conveyance for sub-regions of river cross section**
- **Following HEC-RAS Methods:**



Floodway forms main channel and dominates conveyance

Flood fringe includes left and right over bank areas

Overbank regions may be subdivided based on differing depth or Mannings n to account for: ground roughness, vegetation, land use, development density, etc



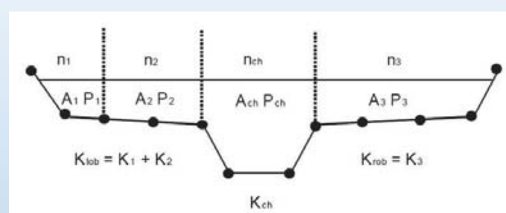
Background #4

- **Apply equations in each subregion**

$$K_i = A_i \frac{k}{n_i} R_{h_i}^{2/3}$$

$$Q_i = K_i S^{\frac{1}{2}}$$

$$V_i = \frac{K_i}{A_i} S^{1/2} = \frac{Q_i}{A_i}$$



- **Ensure all values sum to give total area, total conveyance, and total flow**

$$A = A_1 + A_2 + A_3 +_{...} = \sum A_i$$

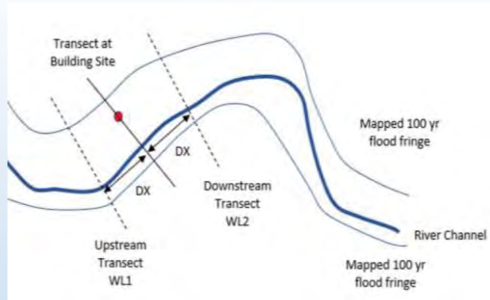
$$K = K_1 + K_2 + K_3 +_{...} = \sum K_i$$

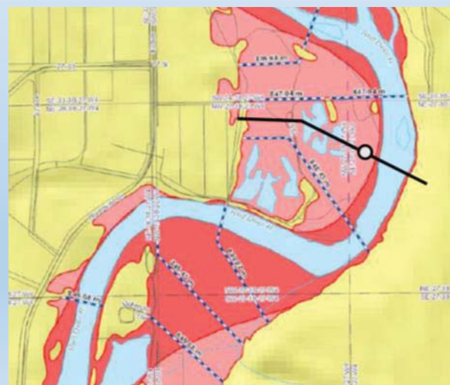
$$Q = Q_1 + Q_2 + Q_3 +_{...} = \sum Q_i$$

Allow solutions for mean velocity in each subregion

Easy to apply in a spreadsheet

Application Details #1





- **Establish transect across river at site**
  - Determine ground elevations from GIS, maps, or from local site survey
- **From flood map:**
  - Establish transects up and downstream
  - Define water surface elevations at all transects
  - Compute average water surface slope from up- and down-stream transects

$$S = (WL_1 - WL_2) / (2\Delta x)$$

Application Details #2

Figure 3-4 Example Cross Section Layout

Several cars left in a driveway are filled with water in Gatineau, Que., as rising river levels and heavy rains continue to cause flooding, on Saturday, May 6, 2017. THE CANADIAN PRESS/Justin Tang

- **Analyze regions that do not contribute to flood conveyance**
  - Some regions may serve as flood storage but not as part of flow conveyance
  - HEC-RAS calls these “ineffective” areas
  - Flow velocity would be zero in these areas
  - Probably would apply to large areas
  - Remaining analysis greatly simplified in those areas
    - Flood loads only hydrostatic

Application Details #3

- **Define sub-regions of design transect that convey flow**
  - Compute flooded depths, areas, wetted perimeters, hydraulic radius
  - Define conveyance in each subregion K_i
- **Determine Mannings n for each subregion**
  - Based on ground cover type, roughness, building density, etc
  - Can differentiate values for floodways vs flood fringe

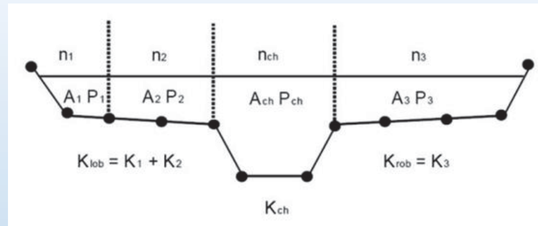


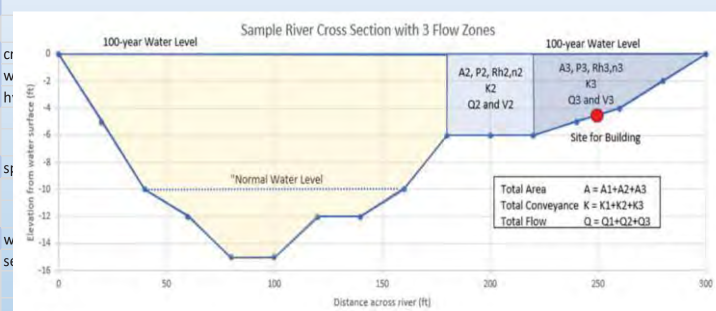
Table 3-1 Manning's 'n' Values

Type of Channel and Description	Minimum	Normal	Maximum
A. *Natural Streams*			
1. **Main Channels**			
a. Clean, straight, full, no rifts or deep pools	0.025	0.030	0.033
b. Same as above, but more stones and weeds	0.030	0.035	0.040
c. Clean, winding, some pools and shoals	0.033	0.040	0.045
d. Same as above, but some weeds and stones	0.035	0.045	0.050
e. Same as above, lower stages, more ineffective slopes and sections	0.040	0.048	0.055
f. Same as "d" but more stones	0.045	0.050	0.060
g. Sluggish reaches, weedy, deep pools	0.050	0.070	0.080
h. Very weedy reaches, deep pools, or floodways with heavy stands of timber and brush	0.070	0.100	0.150

Technical Report No. 3 – Flood Load Formulas and Provisions

Application of Method

	Total Transect	Floodway Channel Area	Flood Fringe 1 Area	Flood Fringe 2 Area	
Geometric Properties from Analysis of Cross Section					
A (ft^2)	2460	1940	240	280	cr
w ~ P (ft)	300.0	180.0	40.0	80.0	w
Rh (ft)	8.2	10.8	6.0	3.5	h
Specify Mannings n in each Section and Composite					
n	0.0471	0.03	0.04	0.08	sp
Water Surface Slope between Transects					
S =	0.007	0.007	0.007	0.007	w se
Computations Following HEC-RAS					
K	510299	468870	29440	11989	conveyance in each section (HEC-RAS Eqn 2-5), sum for total
%convey		92%	6%	2%	percent conveyance in each channel section
Q (cfs)	42695	39228	2463	1003	from from Manning equation (HES-RAS Eqn 2-4)
V (ft/sec)	17.4	20.2	10.3	3.6	



Solve in spreadsheet

Find mean velocity in each subregion

Technical Report No. 3 – Flood Load Formulas and Provisions

Summary

- Method follows standard open-channel flow methods
- Reverse engineering – know water surface and back solve for flow velocity
- Allows simple and rational way to estimate velocities in flood-fringe zones
- Suitable for majority of riverine flood conditions
- Would require more advanced methods (numerical models) in certain circumstances

A state of emergency remains in place in Bracebridge, Ont., as water levels in the Muskoka River continue to rise. (Jean-Francois Morissette/CBC)

Technical Report No. 3 – Flood Load Formulas and Provisions

Questions?

bill@coulbourneconsulting.com

dlkriebel@gmail.com

Flood Load Formulas and Provisions

DAVID KRIEBEL

Coulbourne Consulting, MD, USA

Abstract

This presentation will review existing provisions for computing flood loads based on international design guidance as summarized in the 50% draft report on Flood Load Formulas and Provisions. The goal is to consider a wide range of flood-induced loads on buildings for possible inclusion in the National Building Code of Canada, or its Commentary. Most of the cited sources and guidance comes from the US Federal Emergency Management Agency (FEMA) as well as the US Army Corps of Engineers, as these are the only international guidance documents that include the full range of flood effects on buildings.

Loads are considered for entire buildings and for primary structural elements, including vertical piles and columns, horizontal beams and bracing, floor systems, and vertical walls. Conditions reviewed include both riverine and coastal flooding scenarios.

Riverine flood loads occur mainly due to hydrostatic effects, hydrodynamic effects of moving flood waters, and the effects of debris carried in the river flow.

Coastal flood conditions include all of these, but also add in the effects of waves, which are split into effects of non-breaking oscillatory waves and more damaging impact loads of breaking waves.

The presentation will include some aspects that require discussion and decisions from the NRC, and will point out areas in need of further work. This presentation will also include the current revisions being prepared for the new edition of the ASCE 7 Flood Load standard.

Biography

Dr. David Kriebel has nearly 40 years of experience in coastal and ocean engineering. For more information, see "Design Flood Conditions and Considerations" above.

Flood Load Formulas and Provisions

David L. Kriebel, PhD, PE

National Research Council Canada | Conseil national de recherches Canada

Committee on Flood Resilience of Buildings &
Technical Committee for Flood-Resistant Buildings
Ottawa, ON February 26-27, 2020

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Goals of Study

- To provide standard methods of treating flood forces applicable across Canada
- To provide load formulas for inclusion in National Building Code of Canada


A view of Rigaud from above as floodwaters washed over the municipality in 2017. (Paul Chiasson/Canadian Press)

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Applicability

- Methods should apply to both riverine and coastal flood hazard zones
- Methods should use parameters obtained from flood hazard maps and studies
  - Design flood elevation, flood depth over ground, flow velocity, and on nearshore wave heights for coastal and lakefront regions
- Methods should apply to typical structural elements of buildings:
  - Vertical walls, vertical columns, horizontal beams, elevated floors, and floor slabs
- Methods not intended for design of:
  - Flood protection structures such as levees, dikes, or flood walls,
  - Shore protection structures such as bulkheads and seawalls,
  - Port and harbor structures such as piers, docks, or wharves,
  - Transportation structures such as roadways or bridges, or
  - Floating structures such as floating docks or floating buildings

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Partial List of Documents Reviewed

International Guidance

- ISO, 2016, *Actions from Waves and Currents on Coastal Structures*, Standard ISO 21650
- Australian Building Code, Information Handbook: Construction of Buildings in Flood Hazard Areas
- EUROCODE EN 1991-1-6 (2005): Actions on structures - Part 1-6: General actions
- BSI (2015) BS 85500:2015 Flood resistant and resilient construction – Guide to improving the flood performance of buildings. BSI Standards Limited, 2015

United States Guidance:

- ASCE7-16 *Minimum Design Loads for Buildings and Other Structures*, American Society of Civil Engineers, as well as draft revisions for upcoming ASCE7-22
- ASCE/SEI 24 Flood resistant design and construction, ASCE, 2014
- FEMA Coastal Construction Manual FEMA P-55 / Volume II / August 2011
- FEMA P-936, Floodproofing Non-Residential Buildings (2013)
- US Army Corps of Engineers, Coastal Engineering Manual, EM 1110-2-1100, 2002

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Types of Flood Loads

Load Category	Riverine	Coastal	Load Analysis
Hydrostatic loads Hydrostatic forces and buoyancy	Yes	Yes	Static
Hydrodynamic loads Fluid drag or velocity-dominated loads	Yes	Possible	Static
Wave loads Non-breaking wave loads or Breaking wave loads	No No	Yes Yes	Oscillatory Impulsive
Debris and Ice loads Loads due to debris & ice accumulations Loads due to debris & ice impacts	Yes Yes	Possible Yes	Static Impulsive

Input to Flood Forces

- **Design Flood Elevation**
  - For specified Mean Recurrence Interval
  - Required for all load calculations
- **Ground Elevation**
  - With erosion or scour
  - Required for all load calculations
- **Flood Depth over Ground**
  - Required for all load calculations
- **Flow velocity**
  - Required for hydrodynamic loads
- **Wave conditions**
  - Wave height (breaking or non breaking)
  - Wave Crest elevation or Wave Runup
  - Required in coastal and lake hazard areas

Flood Design Levels or Flood Construction Levels:

The D_f or FCL for riverine conditions should include:

Design flood depth for a specified MRI

+ FC (sea level rise, subsidence, increased development)

+ Freeboard (perhaps depending on the MRI

The D_f or FCL for coastal conditions should include:

Design flood depth for a specified MRI

+ Storm Surge for a coastal design flood event

+ Wave effects above Storm Surge

+ FC (sea level rise, subsidence, increased development)

+ Freeboard (perhaps depending on the MRI)

Hydrostatic Loads

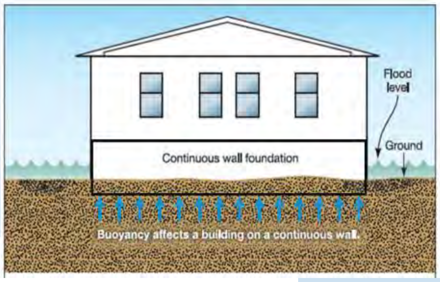
- **Hydrostatic Pressure**
  - Due to submergence in standing or moving water

$P = \rho g h = \gamma h$

h	= depth of submergence, from still water level down to point of interest based on Design Flood Level (DFL) or Flood Construction Level (FCL)
g	= acceleration due to gravity, 9.81 m/s2
ρ	= fluid density, 1,000 kg/m3 fresh water and 1,025 kg/m3 saltwater
γ	= water unit weight, 9,810 N/m3 fresh or 10,055 N/m3 salt

- **Discussion topics:**
  - Use standard values of density?
    - ASCE7 Tsunami chapter increase by 10% for sediment and debris
  - Add extra safety margin for uncertainties?
    - ASCE7 adds extra 0.3m (1 ft) safety margin to depth

- **Vertical Hydrostatic Loads - Buoyancy**
  - Apply to all submerged structural elements
  - Apply to entire building if watertight
  - Include trapped air pockets
  - Include areas below ground water level



$F_B = \rho g V\!\!\!\!- = \gamma V\!\!\!\!-$

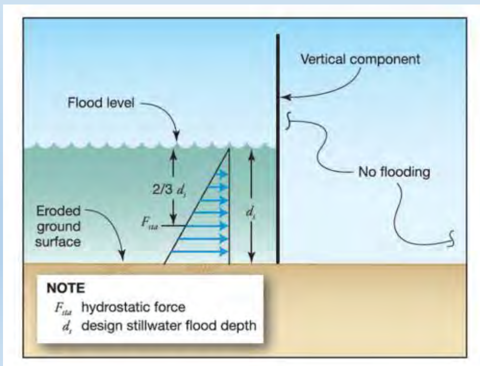
F_B	= vertical buoyant force due to hydrostatic pressures, in N
$V\!\!\!\!-$	= volume of water displaced by the structural element, in m^3

• Horizontal Hydrostatic Forces – on walls

$$f_H = \frac{1}{2} \rho g d_f^2$$

f_H = hydrostatic force per unit length along the wall, in N/m (or lb/ft)

d_f = design flood depth, based on design flood level minus ground elevation, including any added depth due to erosion or scour



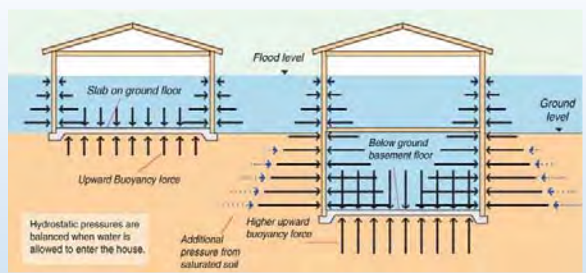
• **Include wall depth below grade**

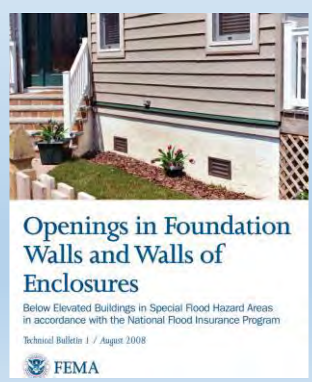
$$f_H = \frac{1}{2} \rho g (d_f + d_g)^2$$

d_g = submerged depth below grade

Reduction in Hydrostatic Forces

- Code should have provision for reduction in loads for entry/exit of floodwater
  - Australian code limits the differential in water levels to 1m to prevent or limit damages from hydrostatic loads
  - FEMA requires openings no more than 0.3m (1 ft) above grade for enclosed spaces below elevated first floor
  - FEMA requires breakaway walls if wave action considered
- Policy question for NRC:
  - Under what circumstances should code require rapid free flooding?





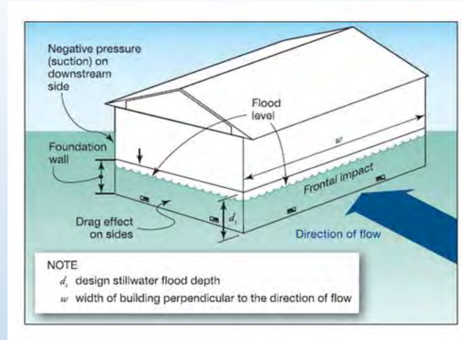
Hydrodynamic Loads

- **Drag-force due to moving water**
  - Applies to any structural element below design water level
  - May apply to entire building

$F_D = ½ \, C_D \, \rho \, V^2 \, A_p$

F_D	= hydrodynamic drag force, in N (or lbs)
C_D	= drag coefficient, function of structure shape and dimensions
V	= velocity of flood water, in m/s (or ft/s)
A_p	= the projected area in the flow direction exposed to the moving water, including any erosion or scour

  - Code would probably adopt standard values for C_D or allow use of best available science



Flooding in the north of Rock Creek in the Boundary region of the B.C. Interior. (Brady Strachan/CBC)

Drag Coefficients

- EUROCODE adopts C_D = 0.7 for circular members and C_D =1.44 for square or rectangular members
- ASCE7-16 values for structural elements or entire buildings:

Table 6.10-2 Drag Coefficients for Structural Components

Structural Element Section	Drag Coefficient C_d
Round column or equilateral polygon with six sides or more	1.2
Rectangular column of at least 2:1 aspect ratio with longer face oriented parallel to flow	1.6
Triangular pointing into flow	1.6
Freestanding wall submerged in flow	1.6
Square or rectangular column with longer face oriented perpendicular to flow	2.0
Triangular column pointing away from flow	2.0
Wall or flat plate, normal to flow	2.0
Diamond-shape column, pointed into the flow (based on face width, not projected width)	2.5
Rectangular beam, normal to flow	2.0
I, L, and channel shapes	2.0

Table 6.10-1 Drag Coefficients for Rectilinear Structures

Width to Inundation Depth[a] Ratio B/h_{sx}	Drag Coefficient C_d
<12	1.25
16	1.3
26	1.4
36	1.5
60	1.75
100	1.8
≥120	2.0

[a]Inundation depth for each of the three Load Cases of inundation specified in Section 6.8.3.1. Interpolation shall be used for intermediate values of width to inundation depth ratio B/h_{sx}.

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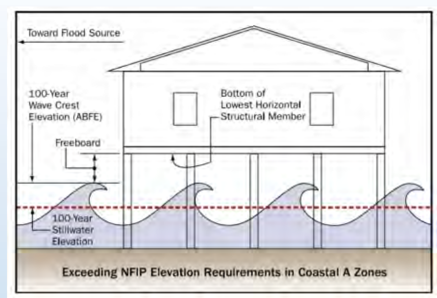
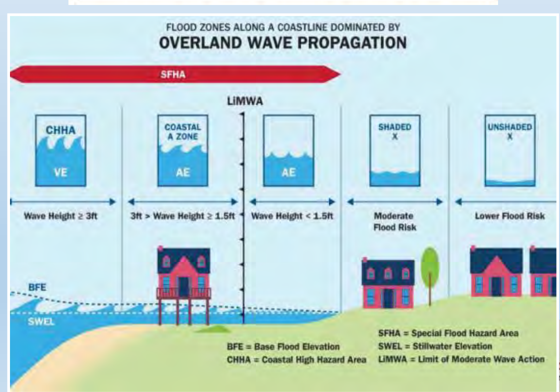
Wave Loads

- International design codes (EUROCODE, Australian code) mention wave loads but do not include formulas for computing wave loads
- U.S. guidance from FEMA and ASCE7 are the only building standards & codes that explicitly treat wave loads
- Methods would apply to any area in which wave conditions are included in flood hazard mapping
  - Atlantic coast
  - Pacific coast
  - Great Lakes
  - Other large lakes??
- Wave loads are complicated and will require numerous decisions from NRC on how to proceed

Wave Loads – FEMA Guidance

- Wave heights over 0.9m (3 ft) can cause extreme structural damage
  - Mapped as VE (High Velocity) flood zones or Coastal High Hazard Areas
  - FEMA mandates construction standards
    - Pile foundations
    - Elevate first floor above wave crest
    - Enclosed spaces below first floor must have breakaway walls
- Wave heights between over 0.45 and 0.9m (1.5 to 3 ft) can also cause structural damage
  - Mapped as Coastal AE zones with waves greater than 0.45m (1.5 ft)
  - FEMA encourages but does not mandate construction standards





Background on Waves

- Complete description of waves requires more information than is typically included in flood maps
- ASCE7 and FEMA adopt simplified approach assuming shallow water:
  - Maximum wave heights limited by breaking based on local water depth
  - May overestimate wav loads as waves might not be this large
- ASCE7 permits use of numerical or laboratory models to estimate the detailed wave conditions

Waves batter the Lake Ontario shoreline in Hamlin. *(Photo: Steve Orr/Rochester Democrat and Chronicle)*

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Statistical Wave Height Definition

- Waves are random, so a structure exposed to waves will encounter a range of wave heights and periods during a design storm event.
- Common to define the sea state using statistical properties
  - **Significant wave height, Hs**, in m (ft)
    - average of the highest one-third of the waves in a random sea
  - **Peak wave period, Tp,** in sec (s)
    - wave period corresponding to most energetic waves in the random sea.
- Per USACE, maximum value of significant wave height limited by breaking in shallow water

$H_{sb} <= 0.6\ d_f$

H_{sb} = significant wave height with active depth-limited wave breaking, in m (ft)

d_f = local still water depth in coastal location, m (ft)

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Individual Maximum Breaking Wave Height

- For structural loads, need to define largest individual wave height that can occur in any water depth, H_b
- FEMA and ASCE7-16 adopt breaking wave in shallow water

$$H_b = 0.78\, d_f$$

H_b = maximum breaking wave height in m (ft)

- ASCE7-22 considering use of Goda (1985) method for computing shallow water wave loads, which recommends

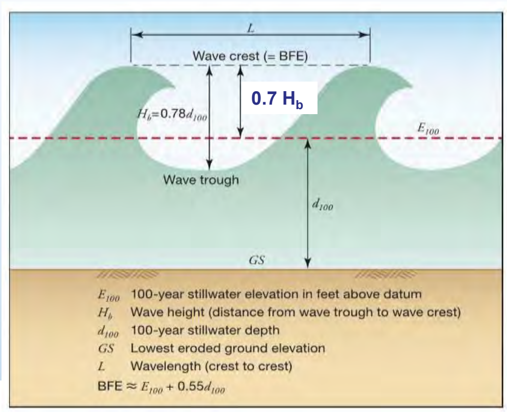
$$H_b = 1.8\, Hs$$

$$H_b = 1.08\, d_f$$

Maximum wave height based on significant wave height, which in turn is limited by water depth

Wave Crest Elevation

- FEMA requires bottom of first occupied floor to be above wave crests
- FEMA Base Flood Elevation (BFE) includes still water flood level plus wave crest elevation
- Wave crest elevation estimated as:



$$\eta_c = 0.7\, H_b$$

η_c = wave crest elevation, in m (ft), above the still water flood level

Wave Runup

- FEMA notes that wave runup is often the highest elevation reached by waves on steep slopes
- FEMA mapping considers wave runup when establishing the inland limit (and vertical limit) of wave action
- But…runup forces are not included in any of the FEMA, ASCE, or other international design guidance
- Not clear if runup included in any Provincial flood hazard maps
- NRC will have to decide if runup should be included

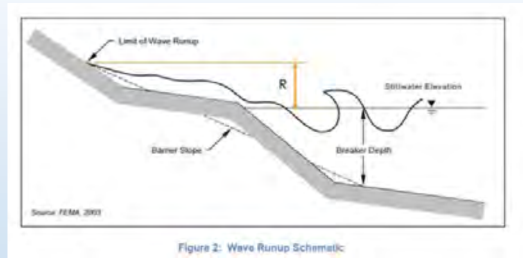
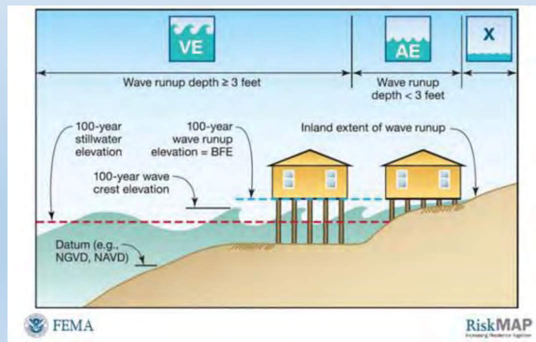
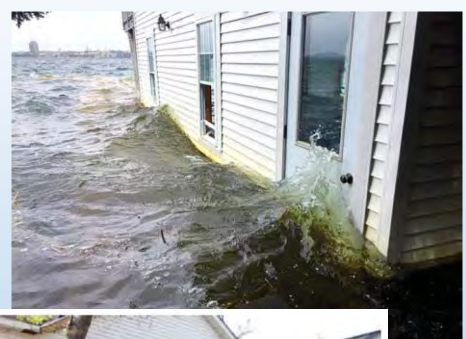


Figure 2: Wave Runup Schematic



Wave Forces

- FEMA and ASCE7-16 give formulas for wave forces for:
  - Waves on vertical piles and columns
  - Waves on vertical wall panels
- Neither FEMA nor ASCE7-16 give formulas for:
  - Wave uplift under elevated floors
- Several revision being considered for ASCE7-22



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Breaking Waves on Piles or Columns – in ASCE7-16

- Breaking wave forces based on fluid drag force related to wave-induced flow velocities:

$$F_b = \tfrac{1}{2} C_{Db} \rho g D H_b^2$$

F_b	= breaking wave force, in N (lbs)
C_{Db}	= breaking wave drag coefficient (1.75 for round piles, 2.25 for square piles)
D	= pile diameter for round pile, or 1.4 times width of pile for square, I mS (ft)
H_b	= breaking wave height, in m (ft)

- C_{Db} =1.75 for round piles and columns, 2.25 for square piles or columns
- FEMA and ASCE7 indicate that breaking wave force should be applied at still water level (large moment arm about ground level)

Non-Breaking Waves – not in ASCE7-16

- For nonbreaking waves, forces are lower but more complicated to compute
- Draft revisions to ASCE7-22 are considering methods outlined by USACE *Coastal Engineering Manual* (2002) where wave forces are given by

$$F_{nb} = \phi_m C_{Dnb} \rho g D H_b^2$$

F_{nb}	= non-breaking wave force, in N (lbs)
C_{Dnb}	= wave drag coefficient (0.7 to 1.2 based on Reynolds number)
ϕ_m	= force coefficient

- Drag coefficient for non-breaking waves are smaller than for breaking waves
- ϕ_m factor given in by 8 pages of figures in USACE *CEM* (2002) but max of 0.5

Breaking Wave Loads on Vertical Walls in ASCE7-16

- On Full-Depth Walls – loads related to wave reflection

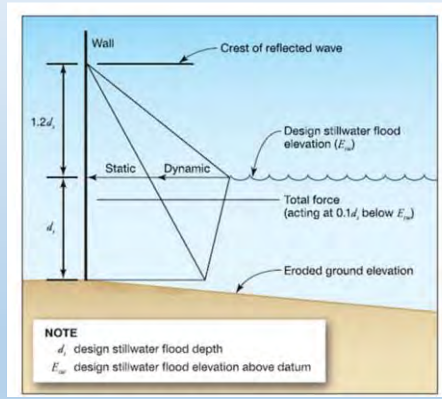
$f_{wb} = 1.1\, C_p\, \rho\, g\, d_f^2 + 2.4\, \rho\, g\, d_f^2$ *including hydrostatic forces*

f_{wb} = net breaking wave force per unit width of structure, in N/m
C_p = dynamic pressure coefficient (1.6 < Cp < 3.5)

$f_{wb} = 1.1\, C_p\, \rho\, g\, d_f^2 + 1.9\, \rho\, g\, d_f^2$ *excluding hydrostatic forces*

Table 8-1. Value of Dynamic Pressure Coefficient (C_p) as a Function of Probability of Exceedance

C_p	Building Type	Probability of Exceedance
1.6	Buildings and other structures that represent a low hazard to human life or property in the event of failure	0.5
2.8	Coastal residential building	0.01
3.2	Buildings and other structures, the failure of which could pose a substantial risk to human life	0.002
3.5	High-occupancy building or critical facility or those designated as essential facilities	0.001



Breaking Wave Loads - Draft ASCE7-22

- Wave-induced pressures based on Goda (1985) equations

$\eta^* = 1.5H$

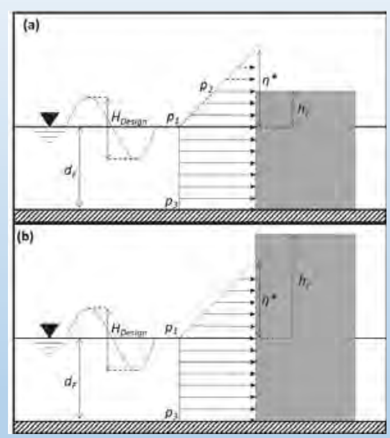
$p1 = (1.1 + \alpha^*)\, \rho g\, H$

$p2 = \begin{cases} \left(1 - \frac{h_c}{\eta^*}\right) p_1 & for\ \eta^* > h_c \\ 0 & for\ \eta^* \le h_c \end{cases}$

$p3 = p1$

- Wave force per unit length

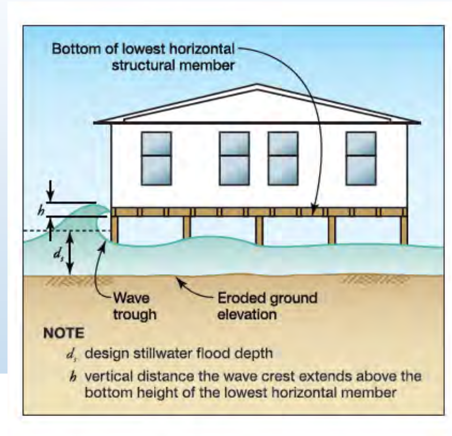
$ft = \begin{cases} \left(\frac{1}{2}(p_1 + p_2)h_c + p_1 d_F\right) & for\ \eta^* > h_c \\ p_1\left(\frac{\eta^*}{2} + d_F\right) & for\ \eta^* \le h_c \end{cases}$



- Forces more complicated but appear to be lower than current method in ASCE7-16

Wave Slam on Elevated Walls

- Another type of wave load – due to wave crest ‘clipping’ elevated structure
- Impulsive load
- Wave Slam from FEMA and ASCE7-16



$F_{ws} = w\, f_{wb} = w\, (0.5\, C_s\, \rho\, g\, d_f\, h)$

Fws	= Lateral wave slam force, in N (lbs)
Cs	= wave slam coefficient, with recommended value of 2.0
h	= vertical height of wall impacted from bottom of floor joist or beam to wave crest

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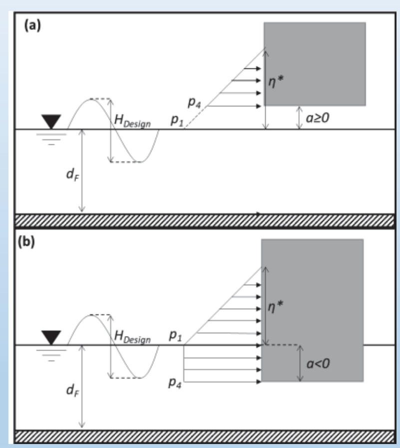
Wave Slam - Draft ASCE7-22

- Wave Slam from Goda equations
- Pressures at base of elevated wall

$$p_4 = \begin{cases} \left(1 - \frac{a}{\eta^*}\right) p_1, & a \geq 0 \\ p_1, & a < 0 \end{cases}$$

- Force per unit width

$$Ft = \begin{cases} \left(\frac{1}{2} p_4 (\eta^* - a)\right) & for\ a \geq 0 \\ \left(p_1 (\frac{\eta^*}{2} + |a|\right) & for\ a < 0 \end{cases}$$



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Debris Loads

- ASCE7-16 Commentary includes two types of debris loads
  - Accumulation of a mass of debris against a structure
  - Impact of an individual item of water-borne debris.
- Both types of debris may affect structures in riverine flood plains
- Debris impacts more likely in coastal regions as waves tend to disperse large accumulations of debris

Flooding along the Ottawa River (Photo by Ross Dunn / Flickr)

- Methods being revised in ASCE7-22

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Types of Debris

- Types of water-borne debris can vary with geographic area
  - Logs and woody debris, Floating ice floes, Man-made debris
- For very large debris, may be impractical to fully design a structure to resist the loads
  - Emphasis on structural performance to prevent progressive collapse
- ASCE7-16 recommends upper ranges of debris to be considered
  - Standard log with weight of 4.5 kN (1,000 lb) and length of 2.7m (30 ft).
  - In Pacific Northwest, larger tree and log sizes of 18.0 kN (4,000 lb) or more
  - In areas with ice, typical floes of 14.5 kN (1,000 lb) to 18.0 kN (4,000 lb) or more
- Debris impacts can be large
  - One lab test produced impact load of 37,000 N (8,300 lb) for a log weighing 3,250 N (730 lb), moving at 1.2 m/s (4 ft/sec)

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Debris Accumulations

- ASCE7-16 adopts drag force expression

$$F_{da} = 0.5\ C_D\ \rho\ A_a\ V^2$$

F_{da} = drag force due to debris accumulation, in N (lb)
V = flow velocity upstream of debris accumulation, in m/s (ft/s), assumed to equal the surface current speed
A_a = projected area of the debris accumulation into the flow, in m^2 (ft2)
C_D = drag coefficient, assumed to equal 1

- No guidance on how to estimate area of debris

- EUROCODE has additional guidance

$$F_{da} = k_{deb}\ A_a\ V^2$$

F_{da} = drag force due to debris accumulation, in N (lb)
V = flow velocity, in m/s (ft/s), averaged over depth
A_a = projected area of the debris accumulation into the flow, in m2 (ft2)
k_{deb} = debris density parameter, recommended as is 666 kg/m3.

Debris Impact Loads – ASCE7-16 Flood Load Commentary

- Guidance based on laboratory tests towing logs into targets

$$F_{di} = 1.57\ C_{de}\ C_{bl}\ C_{or}\ R_{max}\ W\ V\ /\ (g\ \Delta t)$$

F_{di} = impact force, in N (lbs)
W = weight of debris, in N (lbs)
V = Velocity of floodwater propelling debris, in m/s (ft/s)
Δt = Impact duration, time to reduce object velocity to zero, in sec, taken as 0.03 sec
C_{de} = Depth reduction coefficient
C_{bl} = Debris blockage coefficient
C_{or} = Debris orientation coefficient, recommended as 0.8
R_{max} = structural response coefficient

- Applied to most critical structural member only (not all simultaneously)
- Impact loads are impulsive in nature with very short durations of the most intense load of 0.03 sec suggested
- May require dynamic structural analysis

Debris Impact Loads from ASCE7-16 Tsunami Loads

- In ASCE7-16 Tsunami Loads provisions, debris loads are included in the main code, making them mandatory
- Being considered for ASCE7-22 Flood Loads
- Based on effective stiffness of debris or structure

$F_{di} = C_{or}\, V\, (k\, M)^{1/2}$

C_{or} = Orientation coefficient, equal to 0.65 for logs and poles;
V = Maximum flow velocity sufficient to float the debris;
k = Effective stiffness of the impacting debris or stiffness of the impacted structural element(s) deformed by the impact, whichever is less
M = Debris mass, also given as W/g

Table— Minimum Debris properties

Debris Type	Minimum Flood Depth (d_f) required to consider	Minimum debris weight (W_{debris})	Minimum elastic debris stiffness (k_e)
Wood Log/Pole	n/a	1,000 lbs (454 kg)	350 kip/in (61,300kN/m)
Passenger Vehicle	3ft (0.91m)	2,800 lbs (1,270 kg)	5.70 kip/in (998 kN/m)
Small Vessels	3ft (0.91m)	2,500 lbs (1,130 kg)	700kip/in (122,600 kN/m)
20ft Shipping Container	3ft (0.91m)	5,000lb (2,270 kg)	245kip/in (42,900 kN/m)
40ft Shipping container	3ft (0.91m)	8,400lb (3,810kg)	170kip/in (29,800 kN/m)
Ships/Barges	6ft (1.82m)[1]	n/a	n/a

[1]Grounding depth shall also be considered per 5.3.8.1.2

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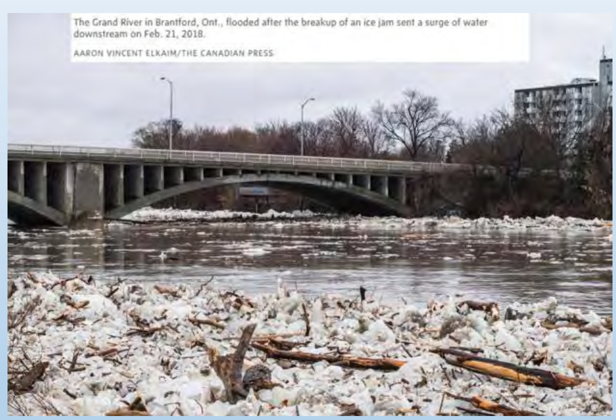
Ice Loads during Floods

- For the Canada Building Code, floating ice would form a common type of debris that should be included explicitly
- Of all debris types, ice is most thoroughly investigated, for bridge piers
- But much less is known about the interaction of ice with residential and commercial buildings



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Ice Loads during Floods

- Not considered in detail in 50% draft report, but three approaches for loads being considered:
  - **Limit Driving Force** – for large sheet of ice or ice jam lodged against a structure under the action of a steady current
    - Force would be given by expression similar to debris accumulation
  - **Limit-Momentum (or Energy)**– for ice floe impact loads based on incident momentum or kinetic energy of the moving ice floe
    - Force would be given by expressions similar to other debris impact loads
  - **Limit-Stress** - ice loads based on local crushing strength of ice leading to a condition of constant ice pressure on the structure
    - May provide an upper bound on ice loads

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Summary of Flood Load Scenarios

- **Riverine conditions:**
  - Hydrostatic only
  - Hydrostatic + Hydrodynamic drag + Debris
  - No waves
- **Coastal and Great Lakes conditions:**
  - Hydrostatic only
  - Hydrostatic + Hydrodynamic drag
  - Hydrostatic + Hydrodynamic drag + Waves + Debris loads
- **NRC policy decisions needed**
  - Wave mapping and wave loads
  - Debris and ice loads

HANDOUT | REUTERS
An aerial photo shows flooding in the City of Dawson Creek after heavy rain in this image posted on social media in British Columbia, Canada on June 16, 2016.

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Questions?

David L. Kriebel, PhD, PE
dlkriebel@gmail.com

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DAY 1
Session 1 – Part 2: Requirements for Flood-Resistant Buildings

Chair, Zoubir Lounis
National Research Council Canada

Performance-Based Design for Flood
Bill Coulbourne
Coulbourne Consulting, MD, USA

Improving Flood Resistance for Existing Buildings
Randall Behm
Coulbourne Consulting, MD, USA

Flood Standard Related Initiatives and Discussions in the USA
Bill Brown
Flood Science Center, WI, USA

Performance-Based Design for Flood

BILL COULBOURNE
Coulbourne Consulting, MD, USA

Abstract

This presentation will present the concepts of performance-based design (PBD) for flood as an alternative design method that could be adopted by the National Building Code of Canada. There is discussion about how this alternative could be used in practice, how performance objectives could be developed for the building types described in the National Building Code, what hazard levels to consider, and how to define damage levels. The connection between defining the parameters of PBD, defining a design flood frequency, and the associated flood conditions is made with the use of an example situation for Newfoundland. Additional case studies are expected to be added from other provinces. Possible recommendations for including PBD in the National Building Code are suggested.

Biography

Mr. Bill Coulbourne has nearly 50 years of experience as an engineer and manager. For more information, see "Developing Requirements for Flood-Resistant Buildings" above.

Performance-Based Design for Flood

Bill Coulbourne, PE

National Research Council Canada | Conseil national de recherches Canada

Committee on Flood Resilience of Buildings &
Technical Committee for Flood-Resistant Buildings
Ottawa, ON February 26-27, 2020

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Outline

- Background & Objectives
- Scope Limitations
- Development of Performance-Based Design
  - Performance objectives
  - Hazard levels
  - Damage levels
- Provincial Example
- Recommendations

Technical Report No. 4 – Performance-Based Design for Flood

Coulbourne Consulting

Background & Objectives

- Purpose of report is to offer an alternative approach to flood design
- Objective is to offer design approach that focuses on achieving performance objectives for the building or facility and not on prescriptive solutions required by code
- Offers a method to improve flood performance without necessarily elevating the entire facility to a code-minimum FCL

Technical Report No. 4 – Performance-Based Design for Flood

Coulbourne Consulting

Scope Limitations

- PBD method should be limited to those buildings that have labor support to install flood barriers or other flood fighting techniques as required to insure performance achievement
- Buildings most likely to have sufficient support include Normal high-rise or multi-family residential buildings, High use buildings such as schools, and post-disaster facilities such as hospitals

Technical Report No. 4 – Performance-Based Design for Flood

Coulbourne Consulting

Development of PBD (1)

- Develop performance objectives
  - Possible objectives were suggested in the report for schools, hospitals, emergency response facilities, fire and rescue facilities, vehicle storage, communication facilities and television, sewage treatment, public water treatment, transportation control centers, power generating stations, telephone exchanges, community centers

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Development of PBD (2)

- Hazard levels have been defined as:
  - Routine
    - Relates to serviceability
  - Design
    - Hazard level would likely affect building or operation
  - Extreme
    - Hazard level would likely affect the community

Technical Report No. 4 – Performance-Based Design for Flood

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PBD (3): Hazard Level Trigger - MRI

- Routine hazard level
  - Might be ≤ 100 years
- Design hazard level
  - Reasonable exceedance probability
- Extreme hazard level
  - Rare event

	Time Periods			
Event MRI	10 yrs	30 yrs	50 yrs	100 yrs
10	0.65	0.96	0.99	0.999
20	0.4	0.78	0.92	0.99
50	0.18	0.45	0.64	0.87
100	0.09	0.26	0.39	0.63
200	0.05	0.14	0.22	0.39
500	0.02	0.06	0.09	0.18
1000	0.01	0.03	0.05	0.09
2000	0.005	0.01	0.02	0.05
3000	0.003	0.01	0.02	0.03

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Development of PBD (4)

- Determine damage levels (follow ICC Performance Code)
  - Mild
    - Minimal damage from water
    - Occupancy overnight might be affected but daytime occupancy unaffected
  - Moderate
    - Some damage from water
    - Minimal mold easily remediated, downtime less than 1 week
    - Occupancy overnight might be affected for few weeks; daytime occupancy affected no more than few days

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Development of PBD (5)

- Severe
  - Extensive damage from water that causes partial or complete structural collapse
  - Mold requires remediation
  - Occupancy delayed until structure repaired. Downtime could be months
  - Operations are halted until structural and flood damage repairs are complete

Damage-Hazard Intensity Matrix for PBD

	Importance Categories for Buildings			
Event Magnitude	**Low**	**Normal.**	**High**	**Post-disaster**
Extreme (1:1000 years)	Severe	Severe	Moderate	Moderate
Design (1:500 years)	Severe	Moderate	Mild	Mild
Routine (1:100 years)	Moderate	Mild	Mild	Mild

PBD Design Example – Hospital* Newfoundland (1)

- Current flood mapping: 1:20 (floodway) and 1:100 (flood fringe)
- Current FCL (elevation) for 1:100 = 3.8 m

PBD Design Example – Hospital* Newfoundland (2)

- Design Condition determined to be 1:1000 event and design will include future conditions (climate change)
- Design FCL for 1:1000 event in 2100 = 4.9m

PBD Design Example – Hospital Newfoundland (3)

- Next steps in PBD design process include:
  - Determine flood loads and velocities for design conditions
  - Describe expected specific damage and expected performance under design conditions in 2100
  - Evaluate the extent to which the performance objectives will be attained under design conditions in 2100
  - Process requires considerable judgment
  - Process demands a peer review of the design
  - Requires acceptance by the AHJ
- Other examples with other building types for four other provinces will be in Appendix

Next slide illustrates a partial evaluation of the hospital performance objectives under the year 2100 design conditions

Specific damage	Performance level	Design Condition for 2100
No structural damage	Water does not damage the structure	Structural frame shall either resist flood loads for flood elevation of 4.9m or frame is above this elevation. The frame must be able to resist an increase of 4.86 N/m wherever the highest flood elevations are expected.
Minor damage to building envelope caused by flood-borne debris	Building envelope may be damaged but water will not inundate the interior and cause a loss of operation	Water leakage into interior shall be minimized to not cause a loss of operation. Interior will be protected with a water collection and disposal system for any interior leakage. Pumps shall be sized to pump out any leaking water and keep the water level on the interior to a maximum of 25 mm (an arbitrary limit established for this example)
No loss of power	Equipment must be elevated or floodproofed to XX m elevation	FCL = 4.9m
Upper floors used as shelter	Elevation of floor must be above XX m elevation	FCL = 4.9m

Probable Partial Recommendations

Recommended Minimum Hazard Levels to Use for PBD

Routine flood hazard: 100-year MRI

Design flood hazard: 500-year MRI

Extreme flood hazard: 1000-year MRI

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Questions?

bill@coulbourneconsulting.com

Improving Flood Resistance for Existing Buildings

RANDALL BEHM

Behm Hazard Mitigation LLC, NE, USA

Abstract

This presentation will summarize the 50% report submittal of the technical report on Improving Flood Resistance for Existing Buildings. The first part of the presentation will focus on a discussion of the common building stock, a description of the most common techniques for mitigating the flood risk to existing buildings, and the importance of reducing flood risk to critical facilities and public safety operations. The second part of the presentation will focus on a process for conducting a flood risk vulnerability assessment of existing buildings, determining the effective mitigation techniques for implementation, and will provide background information regarding flood barriers, flood resistant materials, and potential economic considerations.

Biography

Mr. Randall Behm has 35 years of experience in government service with the US Army Corps of Engineers (USACE) and with his own consulting practice, established after retirement from the USACE. He is a subject-matter expert in the effective use of physical and non-physical nonstructural mitigation techniques for establishing comprehensive flood risk management and reducing property damages due to flooding. He has comprehensive skills in flood risk management, planning processes, hydrologic engineering, and cultural resources. He is leading the report development for guidelines related to floodproofing existing buildings.

Mr. Behm has conducted detailed workshops on floodplain mitigation for the Ashokan Watershed Stream Management Program in the Catskill Mountains of New York for local, regional and state floodplain managers. He was instructor of nonstructural mitigation for USACE Planning Associates Program. He has led the nonstructural assessment and report development for studies in the St. Louis, Missouri metropolitan area, for the City of La Crosse, Wisconsin, and Fire Island in New York. He is the co-chair of the ASFPM Floodproofing Committee and was the Chair for the USACE National Nonstructural Committee.

Guidelines for Flood Resistance for Existing Buildings

Randall Behm P.E., CFM

National Research Council Canada | Conseil national de recherches Canada

Committee on Flood Resilience of Buildings &
Technical Committee for Flood-Resistant Buildings
Ottawa, ON February 26-27, 2020

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Outline

- Background & Objectives
- Applicability & Scope Limitations
- Available Information
- General Approach
- Recommendations

Technical Report No. 5 – Guidelines for Flood Resistance for Existing Buildings

Coulbourne Consulting

Background & Objectives

- The threat of coastal and riverine flooding is increasing globally
- Residential and nonresidential buildings are becoming more susceptible to flood damages.
- The purpose of this report is provide information on the techniques commonly used to mitigate flood risk to buildings.
- The objectives of this report are to:
    1. provide information on flood risk,
    2. discuss common building stock,
    3. describe the common techniques used for mitigating existing buildings and increasing flood resiliency,
    4. discuss the importance of reducing flood risk to critical facilities,
    5. provide the process for conducting a flood risk vulnerability assessment,
    6. discuss how to determine effective techniques for implementation, and
    7. provide information on barriers, flood resistant materials, and economic considerations.

Technical Report No. 5 – Guidelines for Flood Resistance for Existing Buildings

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Applicability & Scope Limitations

- The techniques illustrated in this report are applicable to mitigate future flood damages and increase resiliency to flooding for residential and nonresidential buildings.
- Any limitations in the scope of this technical report are currently being identified through the 50% draft report review and through the Committee on Flood Resilience of Buildings & Technical Committee for Flood-Resistant Buildings briefings.

Technical Report No. 5 – Guidelines for Flood Resistance for Existing Buildings

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Available Information

US Federal Emergency Management Agency

- TB 2 Flood Damage-Resistant Materials Requirements
- TB 3-93 Nonresidential Floodproofing – Requirements and Certifications
- TB 7-93 Wet Floodproofing Requirements
- P 259 Engineering Principles and Practices
- P-312 Homeowner's guide to Retrofitting
- P-936 Floodproofing Nonresidential Buildings
- P-986 Design Guidance for Dry Floodproofing Buildings

US Army Corps of Engineers

- Field Assessment Guide for Nonstructural Study
- Nonstructural Matrix User Guide
- Flood Proofing - How to Evaluate Your Options
- Flood Proofing Tests of Materials and Systems
- EP 1165-2-314 Flood Proofing Regulations

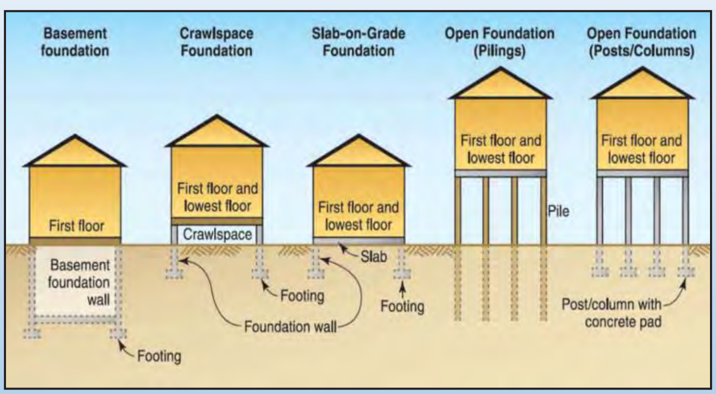
Additional Documents

- National Flood Barrier Testing and Certification Program
- American National Standards Institute (ANSI) FM 2510
- ASCE 24-14 Flood Resistant Design & Construction
- Floodwalls as a barrier (permanent or temporary) attached to or in the vicinity of an individual building

Technical Report No. 5 – Guidelines for Flood Resistance for Existing Buildings

General Approach

Typical Building Stock



- Enclosed Basement Foundation
- Crawlspace Foundation
- Slab-on-Grade Foundation
- Pilings (Open Foundation)
- Posts/Columns (Open Foundation)

Technical Report No. 5 – Guidelines for Flood Resistance for Existing Buildings

General Approach - continued

Flood Resistant Techniques

- Acquisition: Removal of the flood-prone structure and associated land.
- Relocation: Moving the flood-prone structure to a location outside of the floodplain.
- Elevation: Six techniques of lifting the habitable floors to above the flood elevation.
  - Extended Foundation Walls
  - Piers
  - Posts
  - Columns
  - Piles
  - Compacted Fill
- Basement Abandonment: Discontinue use of subgrade basements prone to flooding by filling.
- Wet Flood Proofing: Increasing resiliency to shallow flooding through water resistant materials.
- Dry Flood Proofing: Preventing floodwaters from entering building with water resistant materials.
- Utility Protection: Resiliency of utilities through elevation or component protection.

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General Approach - continued

Consideration of Critical Facilities

- Critical Facility Definition by US FEMA:
  - Hospitals, nursing homes and housing likely to have occupants who may not be sufficiently mobile to avoid injury or death during a flood.
  - Police stations, fire stations, vehicle and equipment storage facilities, and emergency operations centers that are needed for flood response activities before, during and after a flood.
  - Structures or facilities that produce, use or store highly volatile, flammable, explosive, toxic and/or water-reactive materials.
  - Public and private utility facilities that are vital to maintaining or restoring normal services to flooded areas before, during and after a flood.

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General Approach - continued

Consideration of Public Safety Operations

- Defining Public Safety Operations
  - Buildings can be categorized as to their importance based upon use. The National Building Code (NRC) of Canada 2015 provides categories of “Major Occupancy” classifications and “Post-disaster building” that includes hospitals and emergency response facilities. The NBC provides information regarding the importance categories for buildings.

Use and *Occupancy*	Importance Category
Buildings that represent a low direct or indirect hazard to human life in the event of failure, including: • low human-*occupancy buildings*, where it can be shown that collapse is not likely to cause injury or other serious consequences • minor storage *buildings*	Low[1]
All *buildings* except those listed in Importance Categories Low, High and Post-disaster	Normal
Buildings that are likely to be used as post-disaster shelters, including *buildings* whose primary use is: • as an elementary, middle or secondary school • as a community centre Manufacturing and storage facilities containing toxic, explosive or other hazardous substances in sufficient quantities to be dangerous to the public if released[1]	High

Post-disaster buildings are *buildings* that are essential to the provision of services in the event of a disaster, and include:
• hospitals, emergency treatment facilities and blood banks
• telephone exchanges
• power generating stations and electrical substations
• control centres for air, land and marine transportation
• public water treatment and storage facilities, and pumping stations
• sewage treatment facilities and *buildings* having critical national defence functions
• *buildings* of the following types, unless exempted from this designation by the *authority having jurisdiction*:[2]
  • emergency response facilities
  • fire, rescue and police stations, and housing for vehicles, aircraft or boats used for such purposes
  • communications facilities, including radio and television stations
	Post-disaster

General Approach - continued

Flood Risk Vulnerability Assessment

- Flood risk vulnerability assessments inform the selection of an appropriate nonstructural technique, inform cost estimates, and assist in the identification of a logical aggregation of structures for mitigation purposes. The data collected on individual structures can be illustrated as shown in the table below. This data can be used to determine the flood risk through simple comparison of building and flood elevations.

Structure Assessment/Data			
Structure Identifier Number			
Occupancy type			
Number of Structural Corners		**First Floor Elevation (FF)**	
Number of Stories		**Lowest Adjacent Grade (LAG)**	
Building Construction Material		**Basement/Crawlspace Elevation**	
Foundation Material		**Max 1% Flood Velocity**	
Slab/Crawlspace/Basement		**Base Flood Elevation (BFE)**	
Condition (Good/Fair/Poor)		**FF minus BFE**	
1st Floor Window Count		**FF minus LAG**	
1st Floor Pedestrian Door Count		**Flood Depth (BFE-LAG)**	
1st Floor Vehicle Door Count		**Perimeter Distance (meters)**	

Technical Report No. 5 – Guidelines for Flood Resistance for Existing Buildings

General Approach - continued

Determining an Effective Technique for Implementation

- Identifying Flood Characteristics
  - o Flood Depth; Flood Velocity; Flash Flooding; Debris / Ice Flow
- Identifying Site Characteristics
  - o Site Location; Soil Type
- Identifying Building Characteristics
  - o Building Foundation; Building Envelope/Exterior; Overall Building Condition
- Identifying Potential Community-Based Alternatives
  - o Community Goals such as Flood Risk Reduction or Maintaining Community Cohesiveness
- Considering Community Benefits
  - o Reduced Emergency Response Costs; Reduced Damages to Public Infrastructure; Recreation Benefits
- Determining a Technique for Implementation
  - o Flood Risk Management Matrix

Technical Report No. 5 – Guidelines for Flood Resistance for Existing Buildings

General Approach - continued

FLOOD RISK MANAGEMENT MATRIX		FLOOD RESISTANT MITIGATION MEASURES									
		Elevation						Relocation	Acquisition	Dry Flood Proofing	Wet Flood Proofing
		Extended Foundation	Piers	Posts	Columns	Piles	Fill (compacted)				
Flood Characteristics	**Flood Depth**										
	Shallow (< 1 meter)	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y
	Moderate (1 to 2 meters)	Y	Y	Y	Y	Y	Y	Y	Y	N	Y
	Deep (2 to 4 meters)	Y	Y	Y	Y	Y	Y	Y	Y	N	Y
	Very Deep (> 4 meters)	N	N	N	N	N	N	Y	Y	N	N
	Flood Velocity										
	Low (less than 1 meter per second)	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y
	Moderate (1 to 2 meters per second)	N	Y	Y	Y	Y	Y	Y	Y	N	N
	High (greater than 2 meters per second)	N	Y	N	N	Y	N	Y	Y	N	N
	Flash Flooding										
	Yes (less than 1 hour warning)	Y	Y	Y	Y	Y	Y	Y	Y	N	N
	No (more than 1 hour warning)	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y
	Debris /Ice Flow										
	Yes	N	Y	N	N	Y	Y	Y	Y	N	N
	No	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y
Site Characteristics	**Site Location**										
	Coastal Beach Front	N	N	N	N	Y	N	Y	Y	N	N
	Coastal Interior (Low Velocity)	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y
	Riverine Floodplain	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y
	Soil Type										
	Permeable	Y	Y	Y	Y	Y	Y	Y	Y	N	Y
	Impermeable	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y
Building Characteristics	**Building Foundation**										
	Slab on Grade (reinforced)	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y
	Crawlspace	N	N	N	N	N	Y	Y	Y	N	Y
	Basement	N	N	N	N	N	Y	Y	Y	N	Y
	Abandonment of Crawlspace Basement	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y
	Building Envelope/Exterior										
	Concrete, Stone, or Masonry	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y
	Metal	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y
	Wood	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y
	Overall Building Condition										
	Excellent to Fair	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y
	Fair to Poor	N	N	N	N	N	N	N	Y	N	N
Community Economics	**Community Benefits (project area)**										
	Avoids Adverse Impact on Adjacent Property	Y	Y	Y	Y	Y	N	Y	Y	Y	Y
	Reduction in Emergency Costs	N	N	N	N	N	N	Y	Y	N	N
	Public Infrastructure Damage Reduced	N	N	N	N	N	N	Y	Y	N	N
	Ecosystem Restoration Potential	N	N	N	N	N	N	Y	Y	N	N
	Recreation Potential	N	N	N	N	N	N	Y	Y	N	N
	Community (Project Area) Cohesion	Y	Y	Y	Y	Y	Y	N	N	Y	Y
	Flood Risk Eliminated to Building	N	N	N	N	N	N	Y	Y	N	N

Technical Report No. 5 – Guidelines for Flood Resistance for Existing Buildings

General Approach - continued

Flood Barriers

- Temporary Barriers
  - These products must be deployed and erected each time there is a threat of flooding.
  - Successful use of temporary barriers requires the determination of flood characteristics, site characteristics, and building characteristics.
  - Typical products are polyethylene sheeting, plywood closure panels, sealants and sandbags.
- Permanent Barriers
  - These barriers are typically affixed to, or erected in close proximity to the building.
  - Generally recommended as a passive device in order to reduce or eliminate human interaction in the implementation process.
- American National Standards Institute (ANSI) 2510 for Flood Abatement
  - Collaborative testing and certification program
    - Association of State Floodplain Managers (ASFPM)
    - FM Approvals (an insurance underwriting company)
    - USACE's National Nonstructural Committee
  - Program website: https://nationalfloodbarrier.org/

Technical Report No. 5 – Guidelines for Flood Resistance for Existing Buildings

General Approach - continued

Flood Resistant Materials

- Reference US FEMA Technical Bulletin 2

(Flood Damage-Resistant Materials Requirements)

- The United States National Flood Insurance Program regulations require the use of construction materials that are resistant to flood damage. The lowest floor of a residential building must be elevated to or above the design level (design level) flood elevation, while the lowest floor of a non-residential building must be elevated to or above the design level elevation or dry floodproofed to the design level elevation.

NFIP	Class	Class Description
ACCEPTABLE	5	Highly resistant to floodwater[1] damage, including damage caused by moving water.[2] These materials can survive wetting and drying and may be successfully cleaned after a flood to render them free of most harmful pollutants.[3] Materials in this class are permitted for partially enclosed or outside uses with essentially unmitigated flood exposure.
	4	Resistant to floodwater[1] damage from wetting and drying, but less durable when exposed to moving water.[2] These materials can survive wetting and drying and may be successfully cleaned after a flood to render them free of most harmful pollutants.[3] Materials in this class may be exposed to and/or submerged in floodwaters in interior spaces and do not require special waterproofing protection.
UNACCEPTABLE	3	Resistant to clean water[4] damage, but not floodwater damage. Materials in this class may be submerged in clean water during periods of flooding. These materials can survive wetting and drying, but may not be able to be successfully cleaned after floods to render them free of most[3] harmful pollutants.
	2	Not resistant to clean water[4] damage. Materials in this class are used in predominantly dry spaces that may be subject to occasional water vapor and/or slight seepage. These materials cannot survive the wetting and drying associated with floods.
	1	Not resistant to clean water[4] damage or moisture damage. Materials in this class are used in spaces with conditions of complete dryness. These materials cannot survive the wetting and drying associated with floods.

Technical Report No. 5 – Guidelines for Flood Resistance for Existing Buildings

General Approach - continued

Economic Considerations

- It is difficult to determine the exact cost for mitigating an individual building or group of buildings by implementing flood-resistant techniques without knowing specific information regarding the following characteristics:
  - o Flood depth, velocity, duration;
  - o site location, and soil type;
  - o structure style, foundation, and condition
- This table illustrates the relative increase in flood-resistance mitigation costs for different mitigation techniques.

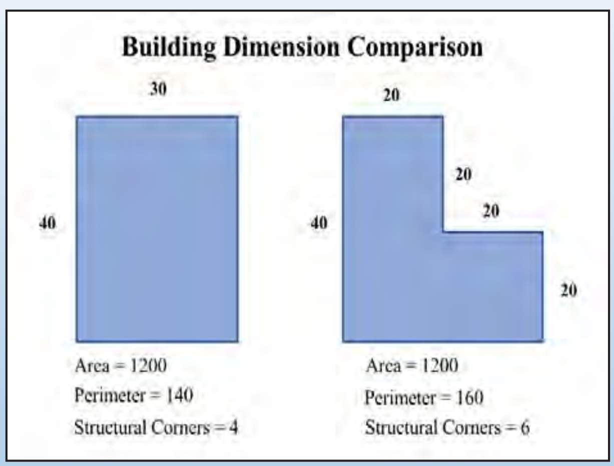
Construction Type	Existing Foundation	Measure	Retrofit	Relative Cost
Frame, Masonry Veneer, or Masonry	Crawlspace or Basement	Wet Floodproofing	Wet floodproof crawlspace to a height of 4 feet above lowest adjacent grade or wet floodproof unfinished basement to a height of 8 feet above basement floor	Lowest
Masonry Veneer or Masonry	Slab-on-Grade or Crawlspace	Dry Floodproofing	Dry floodproof to a maximum height of 3 feet above lowest adjacent grade	
Frame, Masonry Veneer, or Masonry	Basement, Crawlspace, or Open Foundation	Barrier Systems	Levee constructed to 6 feet above grade or floodwall constructed to 4 feet above grade	
Frame, Masonry Veneer, or Masonry	Basement, Crawlspace, or Open Foundation	Elevation	Elevate on continuous foundation walls or open foundation	
Frame, Masonry Veneer, or Masonry	Basement, Crawlspace, or Open Foundation	Relocation	Elevate on continuous foundation walls or open foundation	
Frame, Masonry Veneer, or Masonry	Slab-on-Grade	Elevation	Elevate on continuous foundation walls or open foundation	
Frame, Masonry Veneer, or Masonry	Slab-on-Grade	Relocation	Elevate on continuous foundation walls or open foundation	Highest
Frame, Masonry Veneer, or Masonry	Slab-on-Grade, Crawlspace, Basement, or Open Foundation	Demolition	Demolish existing building and buy or build a home elsewhere	Varies

Technical Report No. 5 – Guidelines for Flood Resistance for Existing Buildings

General Approach - continued

Economic Considerations

- When implementing mitigation to reduce flood risk it is important to identify all exterior dimensions of each building:
  - o Building Area
  - o Perimeter Distance
  - o Number of Structural Corners
- While the first floor area may be similar in size between two buildings, the difference in perimeter distance could affect the dry flood proofing costs and the difference in the number of structural corners could affect the elevation costs.



Technical Report No. 5 – Guidelines for Flood Resistance for Existing Buildings

Recommendations

As Flood Risk continues to increase, recommend

- continued development and implementation of primary flood resistant techniques:
  - Acquisition
  - Relocation
  - Elevation
  - Basement Abandonment
  - Wet Flood Proofing
  - Dry Flood Proofing
  - Utility Protection

- addressing flood risk to the following sectors:
  - Residential
  - Non-Residential (commercial)
  - Critical Facilities.

Technical Report No. 5 – Guidelines for Flood Resistance for Existing Buildings

Questions / Comments

Randall Behm P.E., CFM
floodfighter@q.com

Flood Standard Related Initiatives and Discussions in the USA

BILL BROWN

Flood Science Center, WI, USA

Abstract

Flood standards have been in place in much of the United States for the past 50 years. Participation in the National Flood Insurance Program requires a participating community to adopt minimum flood standards. The standards are generally based on a 1% chance flood risk standard. While these standards have been adopted and implemented in more than 22,000 communities, flood losses continue to rise in the US. As flood losses continue to rise, many people are reassessing the flood initiatives and practices. These efforts include questioning what is an appropriate risk standard, planning for resilience, the use of technology to improve risk estimates, and establishing standards for protecting structures from flooding. Also the issue of urban flooding (water overwhelming existing stormwater management systems) is coming to the forefront.

Many standards are based upon a 1% chance standard in the mapped Special Flood Hazard Area (SFHA). Unfortunately, SFHAs are only mapped for 1.2 million miles of streams, rivers and coastlines in the US, out of 3.5 million that exist. This standard tends to be the median probability based upon past observations. No consideration is made for a factor of safety, which is typical in virtually all other engineering designs, or consideration of future conditions (both watershed physical change and climate change). There are initiatives to move beyond the 1% chance standard and consider future conditions, statistical certainty and factors of safety. We are seeing a trend where communities are using the 2% chance standard (often as a proxy for future conditions), and many others are adding freeboard of up to 4 feet (Nashville, TN).

Recent publications by the American Planning Association, Planning for Infrastructure Resilience and Subdivision Design and Flood Hazard Areas provides users with tools they need to broker important discussions, inform decisions with the best available science, and consider future conditions when allocating present and future resources. The latter publication recommends over 60 standards that can be used to maximize flood-loss reduction when planning residential commercial subdivisions or commercial and industrial developments.

From a technology perspective, there are many new products that have evolved significantly beyond the sandbag that can be used to make existing development more resilient to flooding. There is growing interest in the National Flood Barrier Testing and Certification Program. Through a partnership with the Association of State Floodplain Managers (ASFPM), FM Approvals and the US Army Corps of Engineers,

there is a certification testing of many of these products, including temporary perimeter barriers, closure devices, backwater valves, mitigation pumps, sealants, and glazing (glass) based upon ANSI 2510 Standards. The certification requires water-based testing, component/material testing and manufacturing facility audits.

The general use of modelling techniques has rapidly evolved over the past 20 years. Many engineers and scientists are moving beyond the traditional steady state models to dynamic 1 or 2 dimensional models. Traditional tools and standards, such as the floodway concept, which are widely used for floodplain management, are not well-suited for these advanced modeling techniques.

Biography

Mr. Bill Brown is a Senior Project Manager and Past Director of the Association of State Floodplain Managers' Flood Science Center. He facilitates, develops and manages collaborative relationships with federal, academic, foundation, and NGO partners, with a mission of studying the technical, biologic, social, and economic aspects of flood science. Prior to his tenure with ASFPM, he was the inaugural Stormwater Executive Manager for the City of Arlington, Texas, where he directed the development of a comprehensive, integrated stormwater and floodplain management program. Over his 30-plus year career, Mr. Brown has worked in the private sector, municipal and county stormwater and floodplain management programs, academia, and not-for-profit organizations focused on integrating stormwater and floodplain management programs that reduce flood risks while improving the environment. He previously served as Chair of the Illinois Association for Floodplain and Stormwater Management; was past Co-Chair of ASFPM's Mapping and Engineering Standards Committee and ASFPM's Urban Stormwater Committee; was Adjunct Faculty member for the University of Texas at Arlington Department of Civil Engineering; served on a National Research Council for the National Academy of Science committee studying FEMA Flood Maps; served an appointment to the federal Advisory Committee on Water Information; and was a Subject Matter Expert for FEMA's Technical Map Advisory Committee. Mr. Brown holds Bachelor of Science degrees in Agriculture and Agricultural Engineering from the University of Illinois Urbana-Champaign and a Master of Science in Agricultural Engineering from Oklahoma State University.

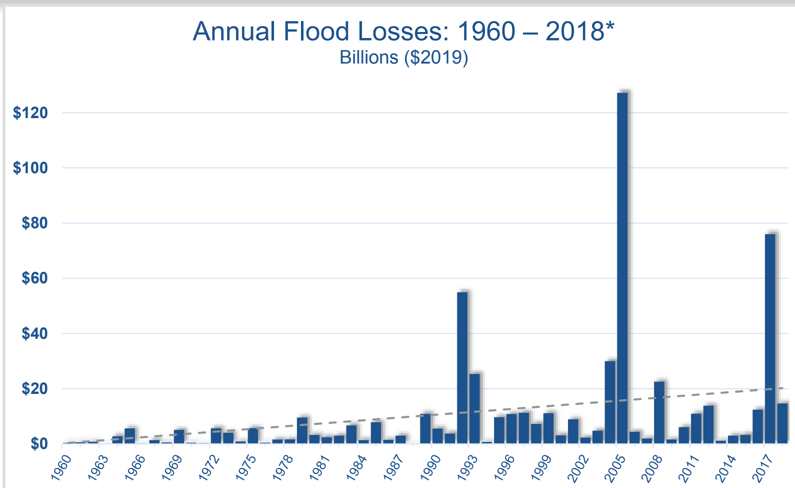
Flood Standard Related Initiatives and Discussions in the United States

J. William Brown, P.E.
Flood Science Center
February 26, 2020

Flood Standards in the US

- Flood Standards have been in place for more than 50 years in the US.
- Participation in the National Flood Insurance Program requires participating communities to adopt minimum flood standards.
- Standards are established in Title 44 Code of Federal Regulations.
- More than 22,000 communities have adopted the minimum standards.

Annual Flood Losses: 1960 - 2018

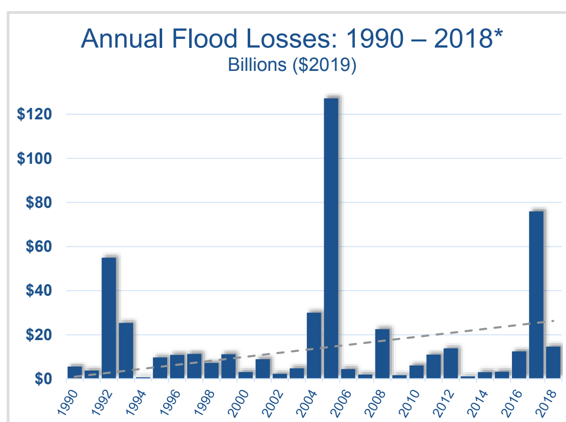


* CEMHS, 2019. Spatial Hazard Events and Losses Database for the United States, Version 18.0. [Online Database]. Phoenix, AZ: Center for Emergency Management and Homeland Security, Arizona State University.

Annual Flood Losses: 1990 - 2018

Since 1990…

- Losses have averaged nearly $17 billion per year
- Per person annual costs have increased by more than factor of 4



* CEMHS, 2019. Spatial Hazard Events and Losses Database for the United States, Version 18.0. [Online Database]. Phoenix, AZ: Center for Emergency Management and Homeland Security, Arizona State University.

Why do losses continue to increase?

- What is an appropriate risk standard?
- How do we plan for resilience?
- How can we better utilize technology to improve risk estimates and reduce risk?
- Need better standards for protection structures from flooding.
- Growing concern over the issue of urban flooding.

5

Why do losses continue to increase?

- Are we using technology to our advantage in identifying flood risks?
- What is the impact of Climate Change on increased flood risk?
- How do we account for Climate Change in our planning?
- How do we account for Climate Change in our design standards?

6

Current Flood Risk Identification

- Most standards in the U.S. are based upon the 1% Chance Event to establish the flood hazard risk.
- There are approximately 3.5 million miles *(~5.63 million Kilometers)* of rivers and coastlines in the US.
- The U.S. has mapped approximate 1.2 million miles *(~1.93 million Kilometers).*

7

Possible deficiencies in the Standard

- 1% chance standard in the mapped Special Flood Hazard Area
  - Median probability based upon past observations.
  - Typically no consideration for a factor of safety (which is typical in virtually all other engineering designs)
  - Typically no consideration of future conditions (both watershed physical change and climate change)

8

Possible Alternative Standards

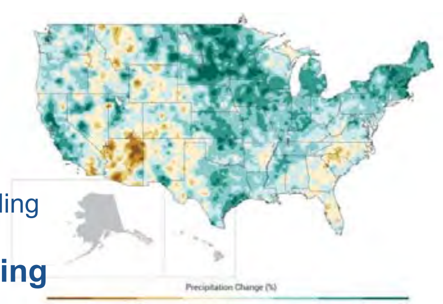
- Initiatives to consider future conditions
  - Future land conditions
  - Future climate conditions
- Incorporation of a Factor of Safety into flood related designs
- Initiatives to have risk based upon 0.2% chance risk
- Implementation of freeboard standards. (Some communities in the U.S. require up to 4 feet of freeboard)

9

Climate, Flooding, & Infrastructure

How does climate change increase flood risk?

- **Heavier and more frequent precipitation**
  Warm air has greater capacity for holding water
- **More frequent and slower moving hurricanes**
  Warm atmosphere is related to slower atmospheric currents
- **Increased sea level**
  Resultant increase in "nuisance", or sunny day flooding, and high tide flooding



Annual total precipitation changes for 1991-2012 compared to the 1901-1960 average, National Climate Assessment

10

PAS 584

- Subdivision Design and Flood Hazard Areas
  - Collaboration between APA and ASFPM
  - Companion to 1997 report with the same name
  - Recommends over 60 standards that can be used to maximize flood loss reduction
  - PAS report available for free on FEMA's website

https://www.fema.gov/media-library/assets/documents/126942

APA American Planning Association
Making Great Communities Happen

PAS 596

- Partnership the American Planning Association
- Best practices for future conditions, climate change, sea level rise considerations in Capital Improvement Program planning

https://www.floodsciencecenter.org/projects/building-coastal-resilience-capital-improvements-planning/

NFBTCP

The National Flood Barrier Testing and Certification Program tests and certifies cutting edge floodproofing technologies

Temporary (Perimeter) Barrier,

NFBTCP

National Flood Barrier Testing and Certification Program

- Currently tests/certifies:
  - Temporary (perimeter barriers),
  - Closure devices (opening barriers)
  - Backwater valves
  - Mitigation (flood abatement) pumps
  - Glazing (glass) systems
  - Sealants

Closure Device (Opening Barrier), Certified Platinum Level

NFBTCP

- National Flood Barrier Testing and Certification Program
  - Certification requires water based testing, component/material testing and manufacturing facility audits
  - Tests to ANSI/FM Approvals 2510 Standard

Temporary Barrier (Opening Barrier), Certified Platinum Level

ANSI 2510

- ANSI is an accredited standards development organization, using a consensus process
- The 2510 standard is intended to be used to evaluate the components and performance of flood abatement equipment
- Based on FM Approvals 2510 standard
- Is the REQUIRED standard for the Program

ANSI 2510

- ✓ Hydrostatic Strength
- ✓ System Leakage
- ✓ Component Durability – Cycling
- ✓ Vibration Resistance
- ✓ Impact and Wear Resistance
- ✓ Salt Spray Corrosion – Residue Build-Up
- ✓ Tensile Strength
- ✓ Ultimate Elongation
- ✓ Tensile Set
- ✓ Compression Set
- ✓ Accelerated Aging
- ✓ Ultraviolet Light Exposure
- ✓ Air Oven Aging
- ✓ Biological Degradation Resistance
- ✓ Environmental Corrosion Resistance
- ✓ Extreme Temperature Operation
- ✓ Reliability Study
- ✓ Abrasion Resistance
- ✓ Hail Resistance
- ✓ Tear and Puncture Resistance
- ✓ Performance (Water Tests)

Flood Risk Modeling Evolution

- Modeling techniques have rapidly evolved over the past 20 years.
- Engineers and scientists are moving beyond the traditional steady state models to watershed based, dynamic 1 or 2 dimensional models.
- Traditional tools and standards may not be well suited for these advanced modeling techniques.
- More practitioners are becoming involved.

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A vision for a more resilient Iowa

The Iowa Watershed Approach

Iowans working together to reduce flooding, improve water quality, and build resilient communities!

A vision for a more resilient Iowa

The Iowa Watershed Approach

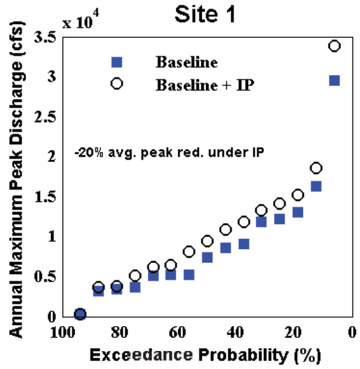
Hydrologic Assessment

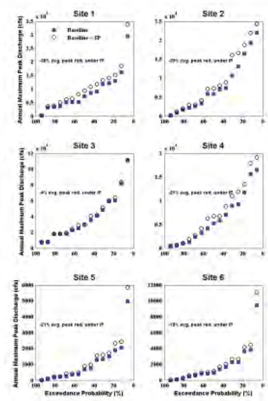
- Iowa's Flood Hydrology & Water Quality
- Conditions in each IWA Watershed
  - Hydrology
  - Geology & Soils
  - Topography
  - Land Use
  - Instrumentation/Data Records
- BMPs: Existing vs. Potential
- Hydrologic Model
- Watershed Scenarios
  - Ex. row crop to tall-grass prairie, row crop using cover crop, distributed ponds/wetlands

A vision for a more resilient Iowa

The Iowa Watershed Approach

Scenario Results/Historic Precipitation/Increased Precipitation

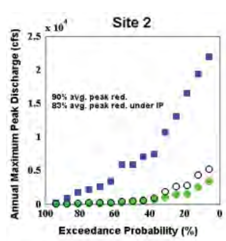




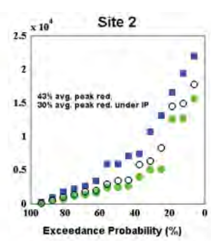
A vision for a more resilient Iowa

The Iowa Watershed Approach

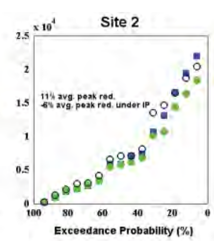
Scenario Results/Historic Precipitation/Increased Precipitation (IP)



Native Vegetation. 100% adoption.



Cover Crops/Soil Health/No-Till scenario. 100% adoption.



Distributed Storage. 684 ponds. 20 acre-ft. 12" outlet pipe.

22

The Nature Conservancy
Environmental Programs & Services IOWA SOYBEAN ASSOCIATION
CORALVILLE
IOWA CORN
USDA NRCS United States Department of Agriculture Natural Resources Conservation Service
IOWA FARM BUREAU
IAWA IOWA AGRICULTURE WATER ALLIANCE
CEDAR RAPIDS
ANTARES
DUBUQUE
University of Northern Iowa
IOWA
GOLDEN HILLS
IOWA STATE UNIVERSITY
ISAC Iowa State Association of Counties
IOWA DOT
IOWA WATER CENTER
DNR
NASA
NOAA
USGS
US Army Corps of Engineers
FEMA

THANK YOU

Questions?

Bill@floods.org

24

DAY 1
Session 2: Case Studies on Flood Data Generation

Chair, Peter Irwin
RWDI, ON, Canada

Analysis and Data Extraction for Flood Load Determination for Selected Case Studies from Alberta and British Columbia
Dan Healy
Northwest Hydraulic Consultants Ltd., AB, Canada

Analysis and Data Extraction for Flood Load Determination for Selected Case Studies from Manitoba and Saskatchewan
Raj Mannem
Hatch, MB, Canada

Analysis and Data Extraction for Flood Load Determination for Selected Case Studies from Great Lakes and Arctic coasts
Derek Williamson and Josh Wiebe
Baird & Associates, ON, Canada

Analysis and Data Extraction for Flood Load Determination for Selected Case Studies from Atlantic Provinces
Vincent Leys
CBCL, NS, Canada

Analysis and Data Extraction for Flood Load Determination for Selected Case Studies from Alberta and British Columbia

DAN HEALY

Northwest Hydraulic Consultants Ltd., AB, Canada

Abstract

Part of the work of the NRC's Climate-Resilient Buildings and Core Public Infrastructure Initiative (CRBCPI) is to: develop decision-support tools (including codes, guides and models) for the design and rehabilitation of resilient buildings and CPI in key sectors to ensure that climate change and extreme weather events are addressed. This project will support the development of guidelines for the provision of data arising from completed and new floodplain studies that will inform the NRC's role in supporting the development of the National Building Code.

The purpose of this study is to generate flood data from existing and new floodplain mapping studies to derive flood loads for the design of new buildings and rehabilitation of existing buildings. The methodology used to generate the flood data is presented, along with some of the initial findings.

Biography

Dr. Dan Healy is a Principal at Northwest Hydraulic Consultants Ltd. and works from the main office in Edmonton. He has some expertise in river ice hydraulics and most of his graduate research was based on ice jam physical model studies. Recently he has been spending a considerable portion of his time working on flood hazard studies for the Province of Alberta. Recent and ongoing projects Dan manages and/or assumes a lead technical role include:

- North Saskatchewan River Hazard Study (2017, ongoing) – Project Manager, Lead Project Engineer, Hydraulic Modelling Specialist
- Medicine Hat River Hazard Study (2017, ongoing) – Hydraulic Modelling Specialist
- Peace River Hazard Study (2015, ongoing) – Project Manager, River Ice Hydraulics
- North Saskatchewan River Dam Breach Inundation Study (2018) – Project Manager, Lead Engineer
- Floodway Criteria and Flow Change Impact Analysis Project (2017) – Hydraulic modelling
- Flood Hazard Identification Study of the Athabasca and McLeod Rivers, Woodlands County, Alberta (2015-2016) – Project Manager, Hydraulic Modelling, River Ice Hydraulics

Analysis & Data Extraction for Flood Load Determination for Selected Case Studies from Alberta and British Columbia

D. Healy[1]

Steering Committee on Flood Resilience of Buildings & the Technical Committee for Flood-Resistant Buildings
Ottawa, Ontario
26th – 27th February 2020

nhc
northwest hydraulic consultants

[1]Northwest Hydraulic Consultants Ltd. Edmonton, AB
dhealy@nhcweb.com

Abstract

Part of the work of the NRCC's Climate-Resilient Buildings and Core Public Infrastructure Initiative (CRBCPI) is to: develop decision support tools (including codes, guides and models) for the design and rehabilitation of resilient buildings and CPI in key sectors to ensure that climate change and extreme weather events are addressed. This project will support the development of guidelines for the provision of data arising from completed and new flood plain studies that will inform NRCC's role in supporting the development of the National Building Code.

The purpose of this study is to generate flood data from existing and new floodplain mapping studies to derive flood loads for the design of new buildings and rehabilitation of existing buildings for selected case studies from Alberta and British Columbia. The methodology used to generate the flood data is presented along with some of the initial findings.

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Outline

- Case Study Candidates
- Scope
- Methods
- Initial Findings
- (emphasis on 1D cross section data)

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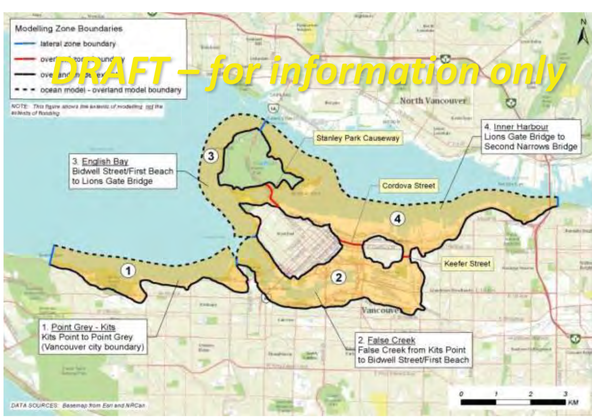
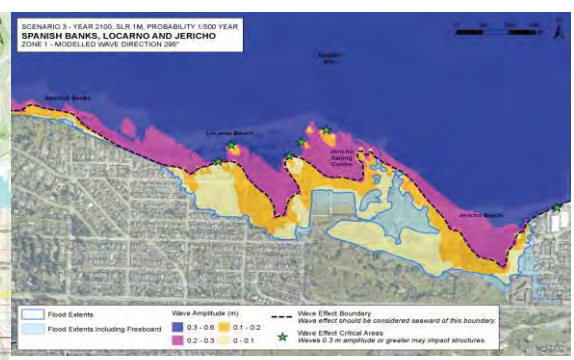
City of Vancouver

(coastal candidate study, Vancouver, AB)





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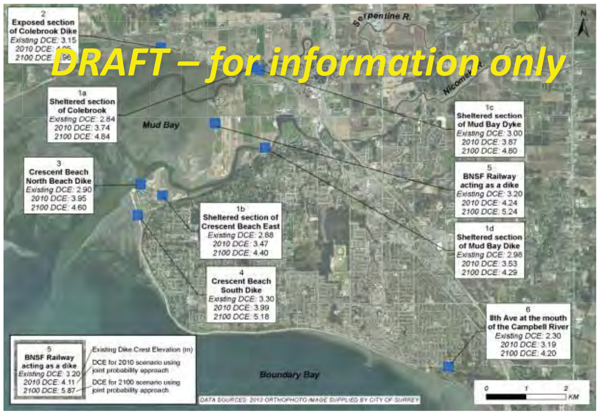
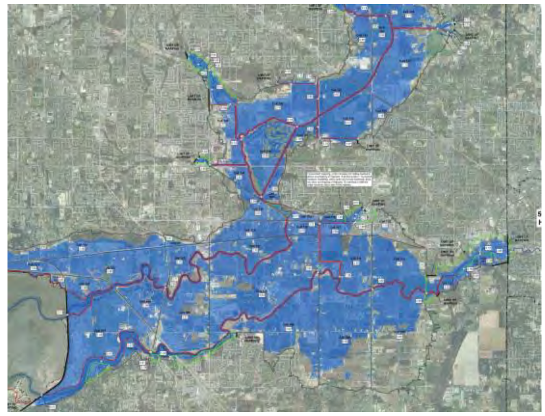
City of Surrey

(coastal candidate study, Surrey, AB)





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Peace River Hazard Study

(riverine candidate study, Peace River, AB)

reach length: 54 km
governing design flood: ice jam flood
crossings: 3 bridges
81 surveyed cross sections

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Medicine Hat River Hazard Study

(riverine candidate study, Medicine Hat, AB)

reach length: 103 km
basin area: 61,500 km^2
crossings: 61 bridges, 8 culverts, 1 weirs
667 surveyed cross sections

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North Saskatchewan River Hazard Study

(riverine candidate study, Edmonton, AB)

reach length: 111 km
basin area: 32,900 km^2
crossings: 29 major bridges
245 surveyed cross sections

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Scope (riverine studies)

- Consider a range of flood scenarios
  - 2-, 5-, 10-, 20-, 50-, 100-, 200-, 500-, and 1000-year return periods.
- For each flood scenario provide
  - floodplain maps
  - hydraulic characteristics at ten representative cross sections

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Scope – Cross Section Characteristics

- Location and geometry
- River discharge
- Cross-sectional area
- Water surface elevation
- Average depth
- Average velocity

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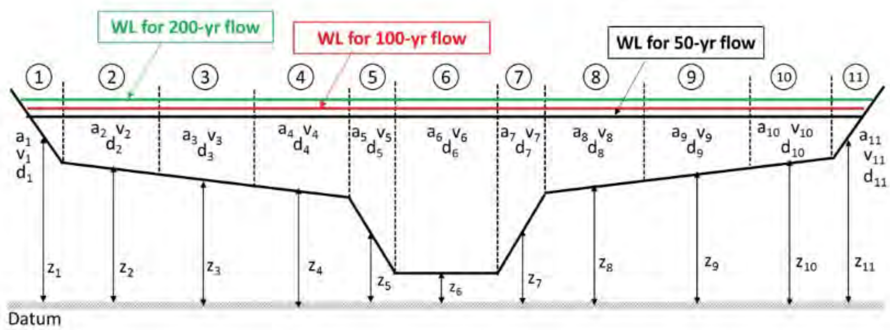
1D Hydraulic Characteristics



a: cross-sectional area
v: average local velocity
d: average local depth of water
a: average elevation from common datum

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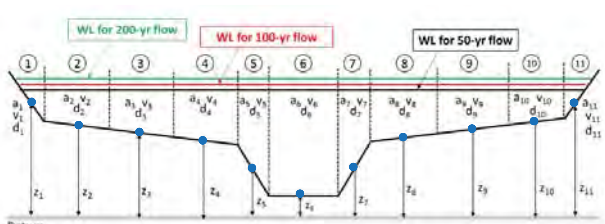
Methods

- Extract model output parameters from the hydraulic model.
- Assemble relevant information for each cross section save point.



- save points

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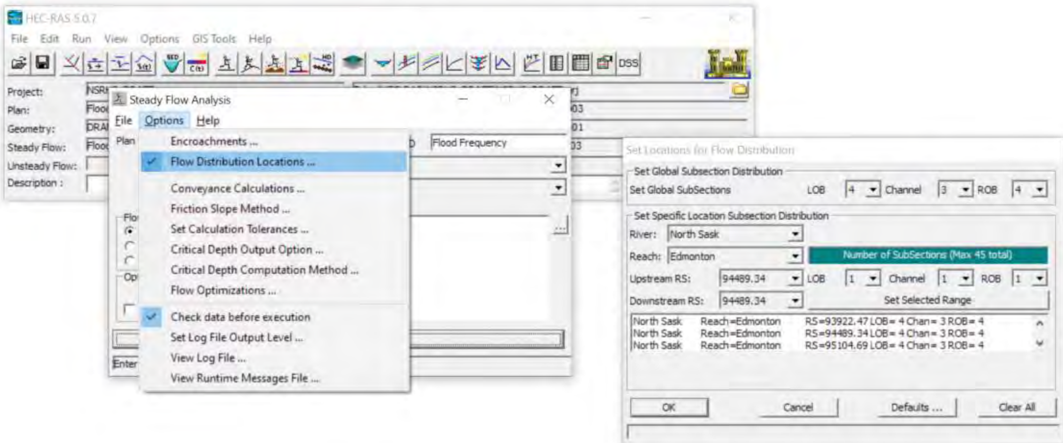
Methods



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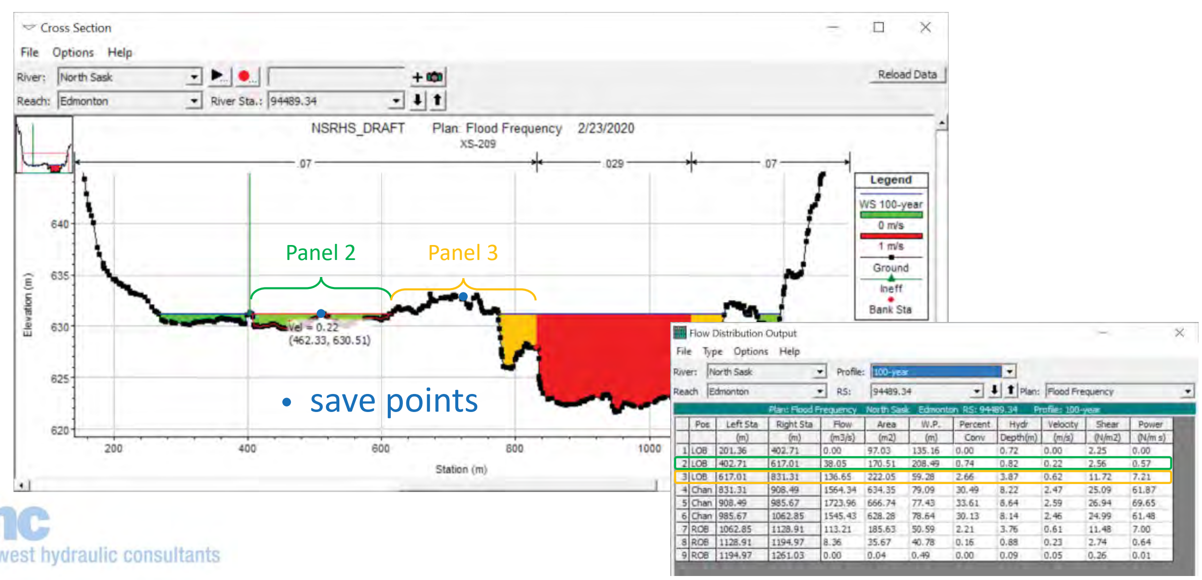
Methods



	Pos	Left Sta (m)	Right Sta (m)	Flow (m3/s)	Area (m2)	W.P. (m)	Percent Conv	Hydr Depth(m)	Velocity (m/s)	Shear (N/m2)	Power (N/m s)
1	LOB	201.36	402.71	0.00	97.03	135.16	0.00	0.72	0.00	2.25	0.00
2	LOB	402.71	617.01	38.05	170.51	208.49	0.74	0.82	0.22	2.56	0.57
3	LOB	617.01	831.31	136.65	222.05	59.28	2.66	3.87	0.62	11.72	7.21
4	Chan	831.31	908.49	1564.34	634.35	79.09	30.49	8.22	2.47	25.09	61.87
5	Chan	908.49	985.67	1723.96	666.74	77.43	33.61	8.64	2.59	26.94	69.65
6	Chan	985.67	1062.85	1545.43	628.28	78.64	30.13	8.14	2.46	24.99	61.48
7	ROB	1062.85	1128.91	113.21	185.63	50.59	2.21	3.76	0.61	11.48	7.00
8	ROB	1128.91	1194.97	8.36	35.67	40.78	0.16	0.88	0.23	2.74	0.64
9	ROB	1194.97	1261.03	0.00	0.04	0.49	0.00	0.09	0.05	0.26	0.01

- save points

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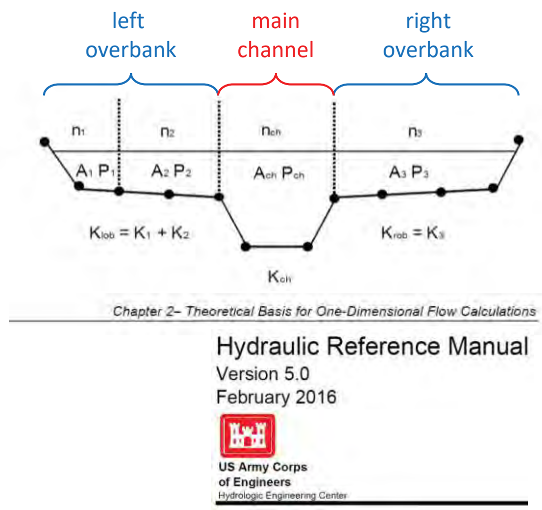
Cross Section Conveyance Subdivision

$$Q = KS_f^{1/2}$$

$$K = \frac{1}{n} AR^{2/3}$$

HEC-RAS "sums up all the incremental conveyances in the overbanks to obtain a conveyance for the left overbank and right overbank. The main channel conveyance is normally computed as a single conveyance element. The total conveyance for the cross section is obtained by summing the three subdivision conveyances (left, channel, and right)".



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Flow Distribution Subdivision

- A little different than normal cross section conveyance calculations
  - After the normal computational procedure (previous slide) the overbanks and main channel are sliced into the number of panels prescribed by the user.
  - Then, geometry based parameters are calculated for each panel (A, WP, HD).
  - Using panel A, WP, and S_f (energy slope computed in the "normal" manner) compute conveyance for each panel.
  - The sum of the computed panel conveyance values do NOT equal the originally computed conveyance. The panel values are then corrected by a ratio found between the originally computed conveyance and sum of the panel conveyances.
  - Then, panel velocities are calculated from the corrected conveyance and panel area.

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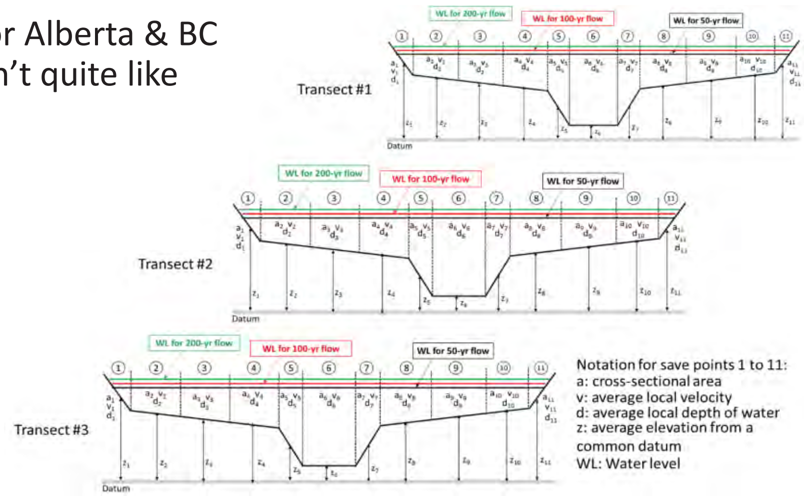
Initial Findings

- Cross sections for Alberta & BC case studies aren't quite like these…



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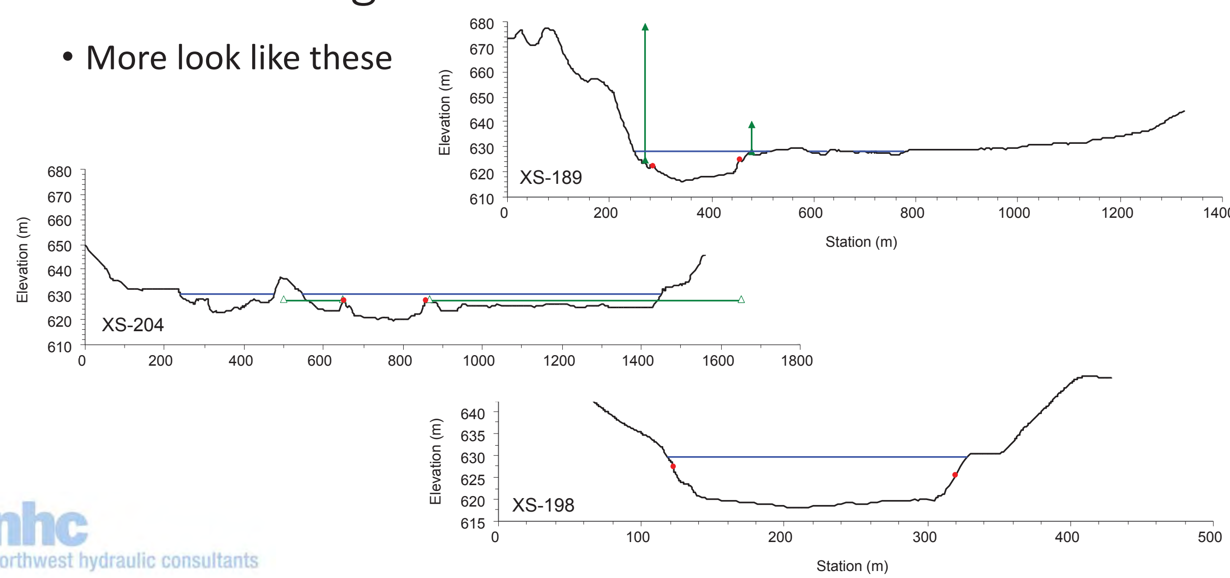
Initial Findings

- More look like these



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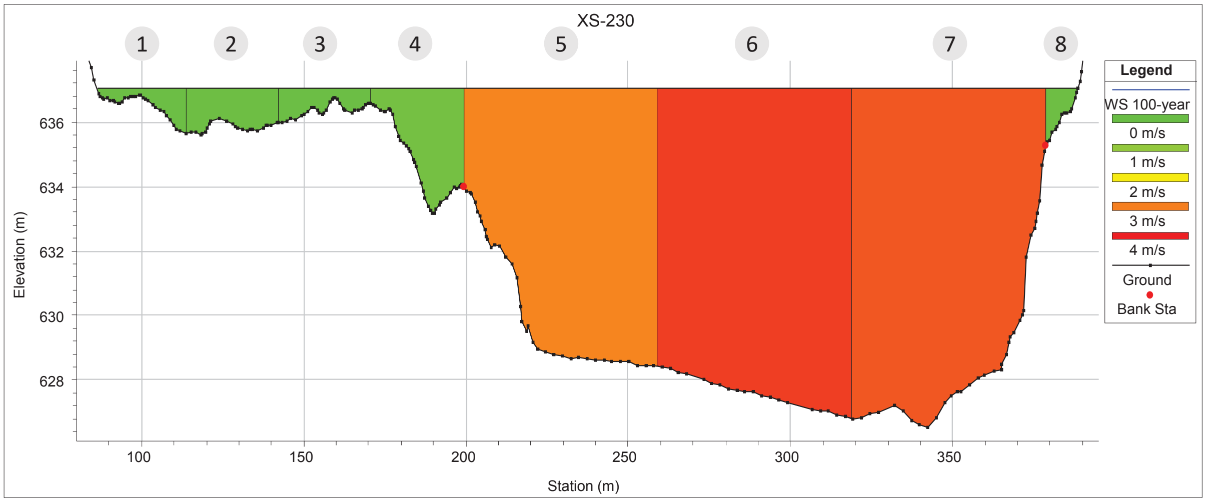
	LOB	LOB	LOB	LOB	Chan	Chan	Chan	ROB
Panel	1	2	3	4	5	6	7	8
Width	28.46	28.46	28.46	28.46	59.83	59.83	59.83	20.06
Velocity	0.2	0.32	0.23	0.49	2.95	3.58	3.34	0.32



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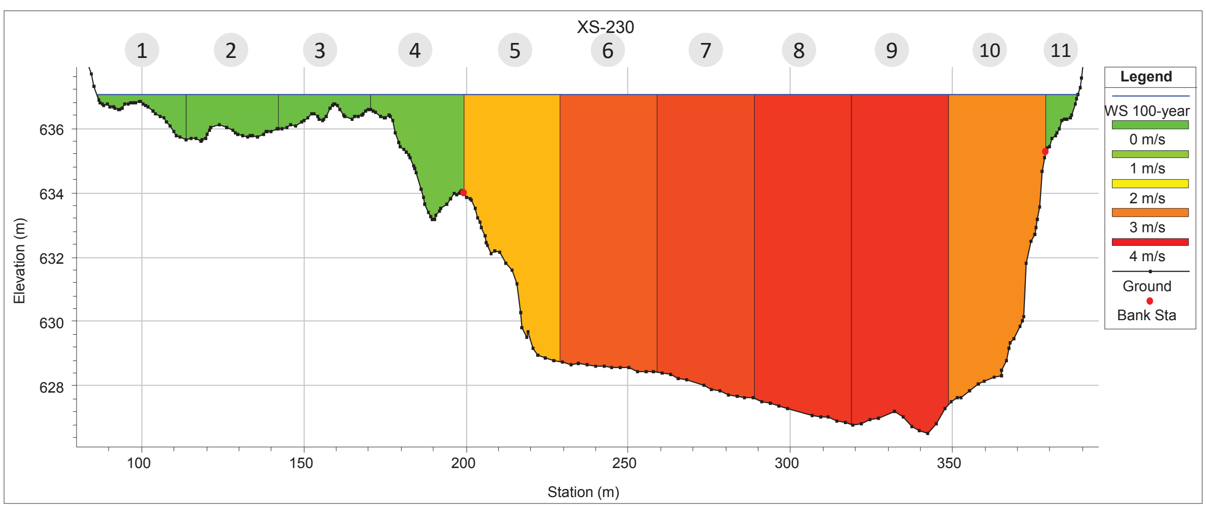
	LOB	LOB	LOB	LOB	Chan	Chan	Chan	Chan	Chan	Chan	ROB
Panel	1	2	3	4	5	6	7	8	9	10	11
Width	28.46	28.46	28.46	28.46	29.92	29.91	29.92	29.91	29.92	29.91	20.06
Velocity	0.2	0.32	0.23	0.49	2.55	3.28	3.43	3.64	3.69	2.91	0.32



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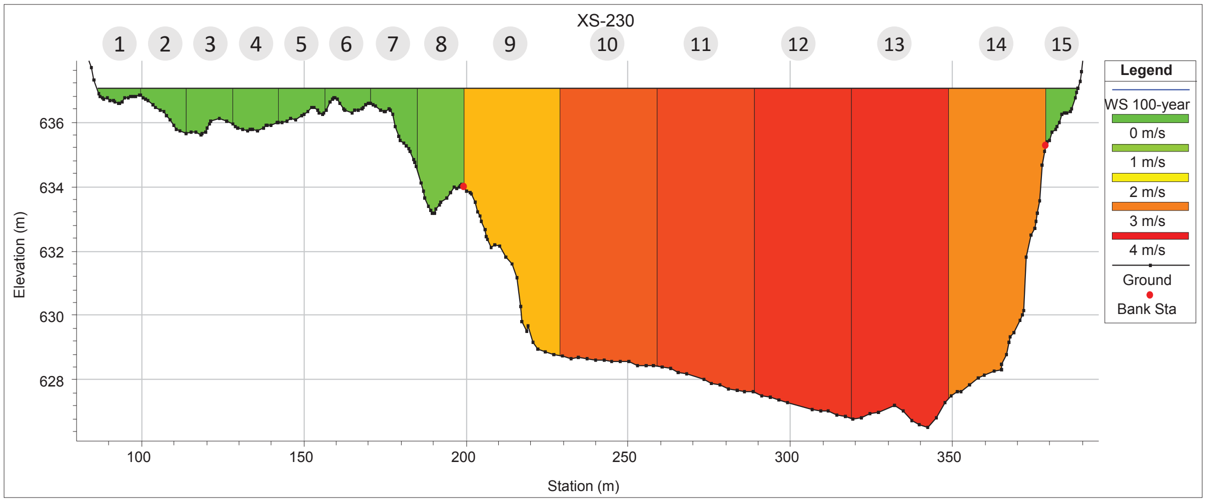
	LOB	LOB	LOB	LOB	LOB	LOB	LOB	LOB	Chan	Chan	Chan	Chan	Chan	Chan	ROB
Panel	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
Width	14.23	14.23	14.23	14.23	14.23	14.23	14.23	14.23	29.92	29.91	29.92	29.91	29.92	29.91	20.06
Velocity	0.12	0.23	0.29	0.3	0.23	0.18	0.3	0.58	2.55	3.28	3.43	3.64	3.69	2.91	0.32



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Initial Findings

- Considerations on spacing and density of save point data
  - When using HEC-RAS tools to define the number of flow distributions, the model determines the location of "slices" and resulting panel widths
  - Resulting panel widths vary across the section and from section to section
    - irregular save point spacing across a section
    - sometimes save points can land on dry areas
- Will statistics be sensitive to panel spacing and density?
  - comparing regional data sets
  - aggregating into a national data
- Will methods for calculating hydraulic properties vary?
  - Model/method to model/method, region to region, study to study

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Analysis and Data Extraction for Flood Load Determination for Selected Case Studies from Manitoba and Saskatchewan

RAJ MANNEM

Hatch, MB, Canada

Abstract

The National Building Code of Canada (NBC) provides loading criteria for wind, snow, ice, seismic and live loads for the design of buildings. The topic of flood loading is not addressed in the current version of the NBC. The National Research Council Canada (NRC) wants to cover the topic of flood loading for buildings in the floodplain area and requires information on flood loads and load combinations. Hatch has vast experience modelling flood inundation and performing dam break analyses. This data will be made available for use by the NRC for the design of flood-resistant buildings.

Biography

Mr. Raj Mannem is currently the Engineering Manager and Senior Civil-Structural Engineer for the Winnipeg Office of Hatch. He has been the Structural Discipline Lead and has more than 22 years of experience in engineering, construction and project management. Since completing his Master of Engineering at Memorial University of Newfoundland, Raj has worked on many industrial, offshore and hydraulic structures, including spillways, dams, control structures, powerhouses / generating stations and diversion structures, dealing with ice loads and developing specifications, design criteria, and structural designs. His Forrest Kerr Hydroelectric Station Project located in BC received both the Award of Excellence and Tree for Life Award from the Canadian Association of Consulting Engineers in 2015.

Floodplain Mapping Studies

Analysis & Data Extraction for Flood Load Determination for Selected Case Studies from Manitoba & Saskatchewan

HATCH

Global operations

+ Global Delivery Centers

150 countries
9,000 staff
$50+ billion in projects

HATCH

Project Overview

- National Building Code (NBC) update
- Flood loading on buildings in floodplain areas
- Statistical data from floodplain mapping studies

HATCH

Hatch Experience - Canada

- Rafferty & Alameda Flood and Dam Breach Study for Water Security Agency
- Souris River hydrodynamic study for Manitoba Infrastructure
- Seine River hydrodynamic study for Manitoba Infrastructure
- Assiniboine River hydrodynamic study for Manitoba Infrastructure
- Wuskwatim GS Dam Break & Inundation Mapping for Manitoba Hydro
- Dam Breach for Chain Lakes, Paddle & Belly River for Alberta Environment
- Elbow River 2D hydraulic model & inundation mapping study for Alberta Environment
- Hazard studies for Sheep River and Fort McMurry for Alberta Environment
- Dam breach analyses Barrier Dam for TransAlta
- Dam Breach for Mactaquac, Grand Falls, Tobique & Beechwood Dams for NB Power
- Dam Breach for 10 dam structures on the Exploits River, Newfoundland for Nalcor

HATCH

Hatch Experience - Canada

HATCH

Model Selection

Souris River Hydrodynamic Modeling Study - Manitoba Infrastructure

Rafferty and Alameda Inflow Design Flood and dam breach study - Water Security Agency

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Souris River Hydrodynamic Model

Total River Length of 700 km

River Length in MB 273 km

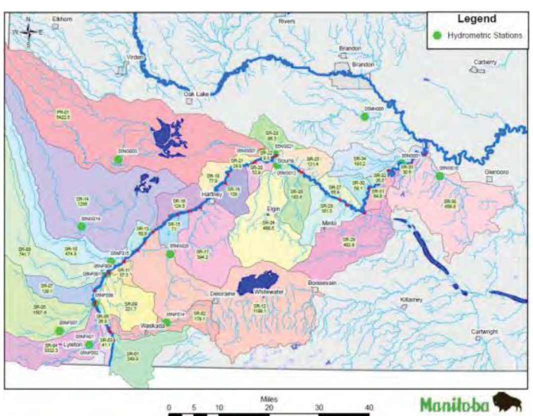
Floods – 2017, 2014, 2011

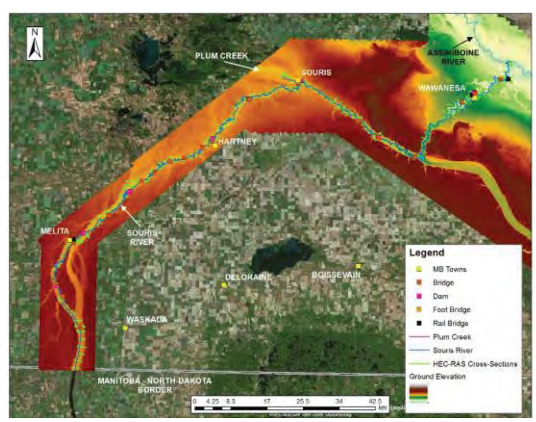
Client – Manitoba Infrastructure

Program – 2018 to 2019

HATCH

Souris River Hydrodynamic Model





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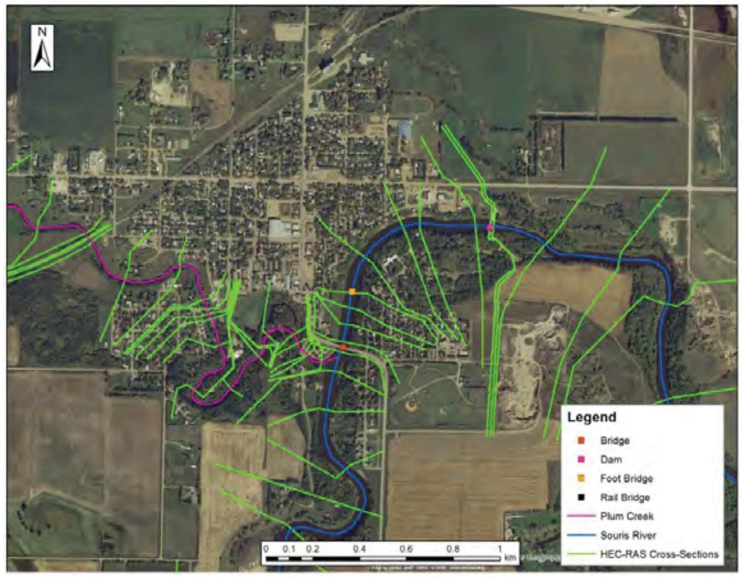
Souris River Hydrodynamic Model

Callibrated HEC-RAS Model

- Souris River
- Plum Creek

To Estimate

- Anticipate Water Levels
- Inundation limits
- Protection measures
- Public Safety



Model Area – Town of Souris.

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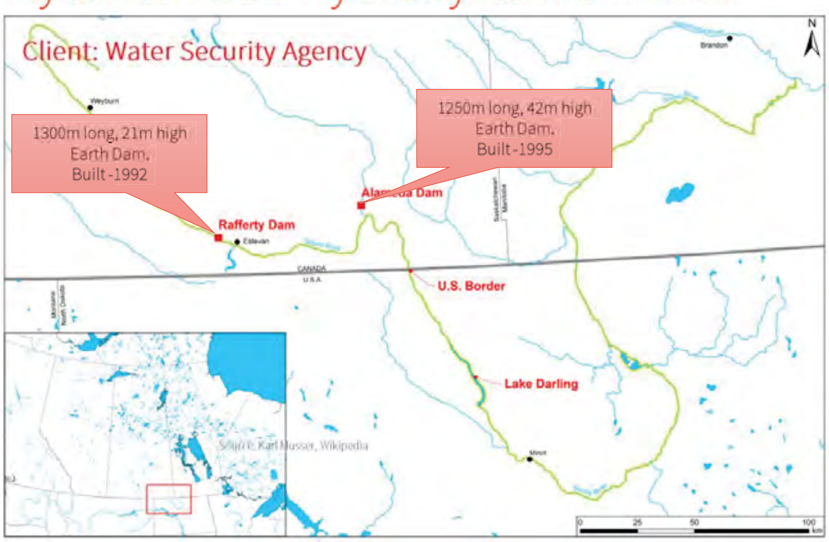
Rafferty & Alameda Hydrodynamic Model



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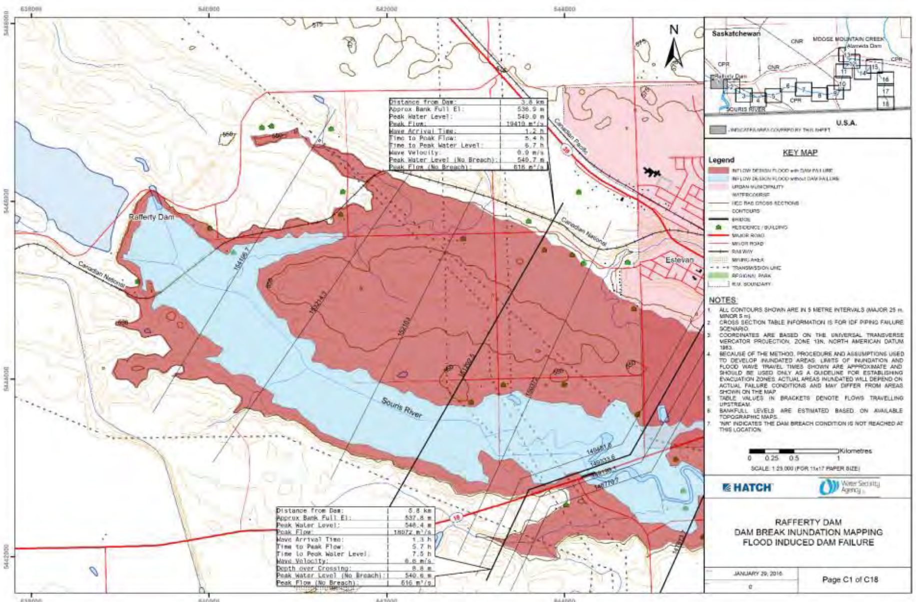
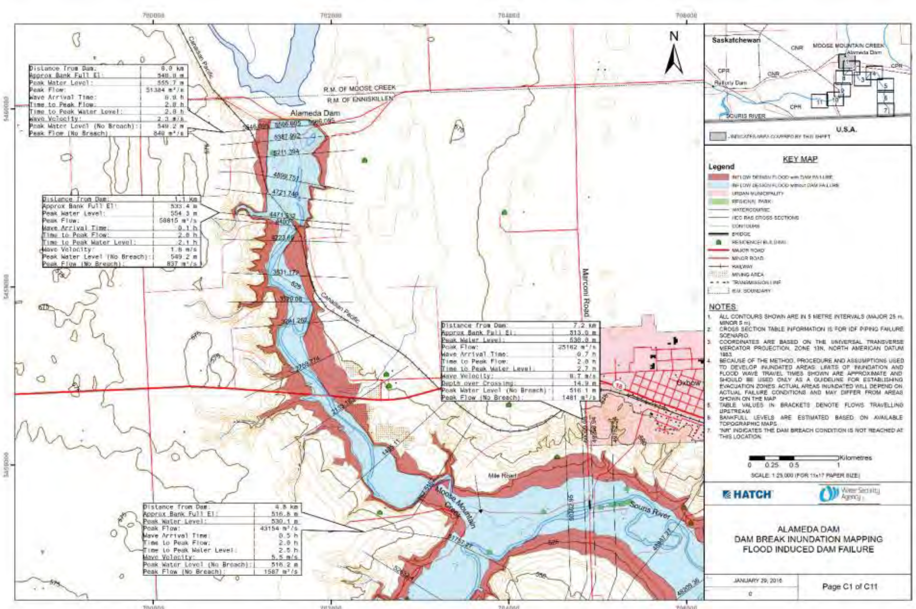
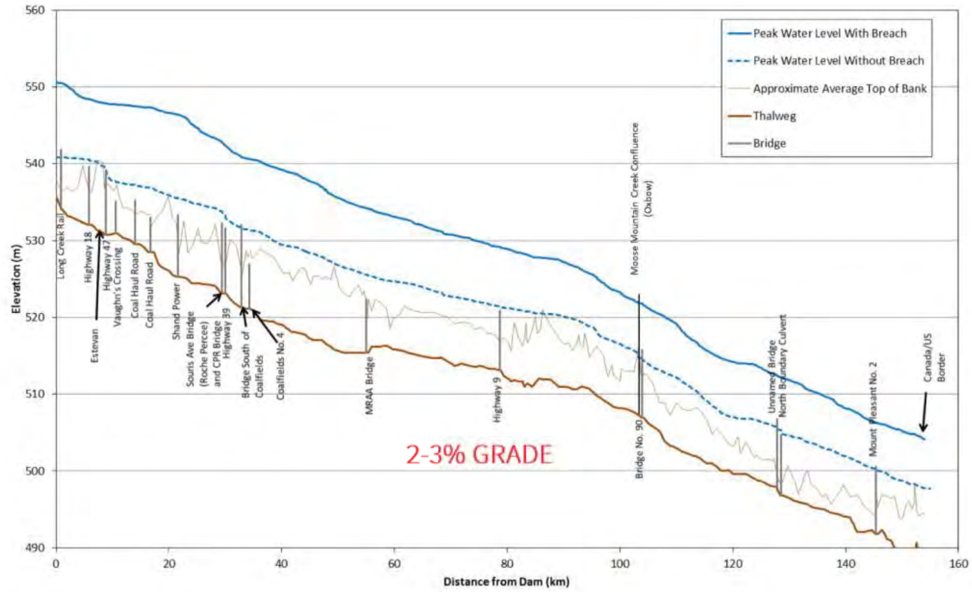

Distance from Dam: 3.8 km
Approx Bank Full El: 536.9 m
Peak Water Level: 549.0 m
Peak Flow: 19410 m³/s
Wave Arrival Time: 1.2 h
Time to Peak Flow: 5.4 h
Time to Peak Water Level: 6.7 h
Wave Velocity: 0.9 m/s
Peak Water Level (No Breach): 540.7 m
Peak Flow (No Breach): 618 m³/s
Distance from Dam: 5.8 km
Approx Bank Full El: 537.8 m
Peak Water Level: 548.4 m
Peak Flow: 18072 m³/s
Wave Arrival Time: 1.3 h
Time to Peak Flow: 5.7 h
Time to Peak Water Level: 7.5 h
Wave Velocity: 0.8 m/s
Depth over Crossing: 8.8 m
Peak Water Level (No Breach): 540.6 m
Peak Flow (No Breach): 616 m³/s
Rafferty Dam
Souris River
Estevan
Canadian National
Canadian Pacific
Saskatchewan
U.S.A.
KEY MAP
Legend
NOTES:
RAFFERTY DAM
DAM BREAK INUNDATION MAPPING
FLOOD INDUCED DAM FAILURE
JANUARY 29, 2016
Page C1 of C18


Distance from Dam: 0.0 km
Approx Bank Full El: 540.0 m
Peak Water Level: 555.7 m
Peak Flow: 51384 m³/s
Wave Arrival Time: 0.0 h
Time to Peak Flow: 2.0 h
Time to Peak Water Level: 2.0 h
Wave Velocity: 2.3 m/s
Peak Water Level (No Breach): 549.2 m
Peak Flow (No Breach): 840 m³/s
Distance from Dam: 1.1 km
Approx Bank Full El: 533.4 m
Peak Water Level: 554.3 m
Peak Flow: 58815 m³/s
Wave Arrival Time: 0.1 h
Time to Peak Flow: 2.0 h
Time to Peak Water Level: 2.1 h
Wave Velocity: 1.8 m/s
Peak Water Level (No Breach): 549.2 m
Peak Flow (No Breach): 837 m³/s
Distance from Dam: 7.2 km
Approx Bank Full El: 513.0 m
Peak Water Level: 530.8 m
Peak Flow: 25162 m³/s
Wave Arrival Time: 0.7 h
Time to Peak Flow: 2.0 h
Time to Peak Water Level: 2.7 h
Wave Velocity: 0.7 m/s
Depth over Crossing: 14.9 m
Peak Water Level (No Breach): 516.1 m
Peak Flow (No Breach): 1481 m³/s
Distance from Dam: 4.8 km
Approx Bank Full El: 516.8 m
Peak Water Level: 530.1 m
Peak Flow: 43154 m³/s
Wave Arrival Time: 0.5 h
Time to Peak Flow: 2.0 h
Time to Peak Water Level: 2.5 h
Wave Velocity: 5.5 m/s
Peak Water Level (No Breach): 518.2 m
Peak Flow (No Breach): 1587 m³/s
R.M. OF MOOSE CREEK
R.M. OF ENNISKILLEN
Alameda Dam
Canadian Pacific
Marconi Road
Moose Mountain Creek
Souris River
Saskatchewan
U.S.A.
KEY MAP
Legend
NOTES:
ALAMEDA DAM
DAM BREAK INUNDATION MAPPING
FLOOD INDUCED DAM FAILURE
JANUARY 29, 2016
Page C1 of C11



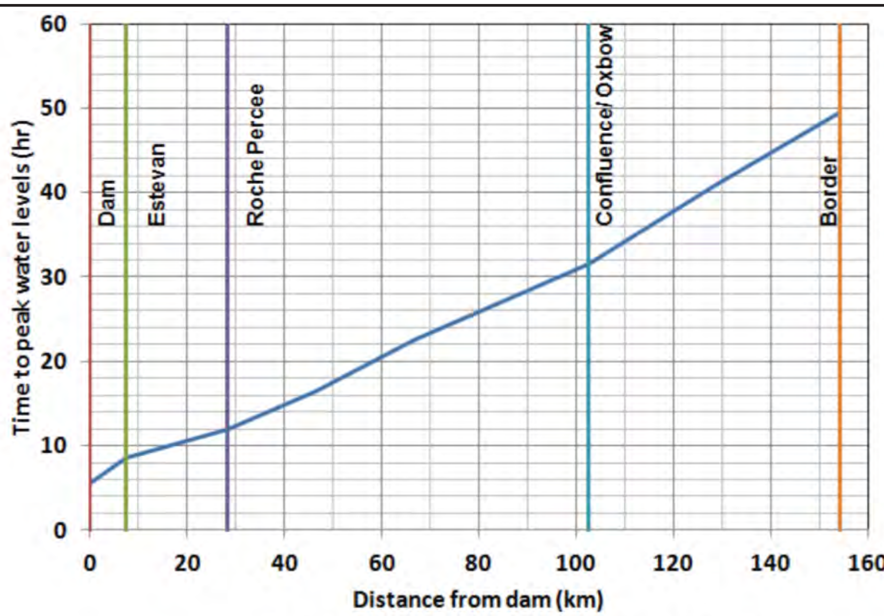


Figure 4-7 - Time to Peak Water Level During IDF Failure

HATCH

Table 4-2 - Sample Model Results for Key Locations: IDF Failure

River	Reach	HECRAS Cross-section	Description	Distance from Dam (km)	Crossing El. (m)	Peak Water Level (m)	Depth Over Crossing (m)	Peak Flow (m^3/s)	Time to Peak Water Level (hr)	Time to Peak Flow (hr)	Wave Arrival Time (hr)	Flood-plain Velocity (m/s)	Peak Water Level (No Breach) (m)	Peak Flow (No Breach) (m^3/s)
Souris River	Upper	154196.7	Just downstream of Rafferty Dam	0.9	541.8	550.5	8.7	21393	5.5	5.0	1.0	0.8	540.8	622
Souris River	Upper	146811.0	Estevan	8.3	-	547.9	-	16350	8.5	6.0	1.5	0.4	539.6	832
Souris River	Upper	125824.9	Roche Percee	29.3	-	542.9	-	8793	12.0	10.0	4.0	0.6	533.8	831
Souris River	Upper	87493.5	Halfway between Roche Percee and Oxbow	67.6	-	531.3	-	6235	22.5	18.5	9.0	0.6	523.3	825
Souris River	Lower	49752.5	Oxbow	105.4	-	521.6	-	5095	32.0	30.0	14.5	0.4	514.3	842
Souris River	Lower	25295.0	Halfway between Oxbow and the border	129.8	-	512.1	-	4622	41.0	38.0	20.5	0.3	504.9	840
Souris River	Lower	0	At Canada/ U.S. border	155.1	-	504.0	-	4218	49.5	48.5	27.5	0.4	497.7	836
Moose Mountain Creek	-	757.5	Last section in Alameda reach	104.2	-	521.8	-	89	31.5	22.0	14.5	0.0	514.7	128

Note: Peak flows include tributary inflows.

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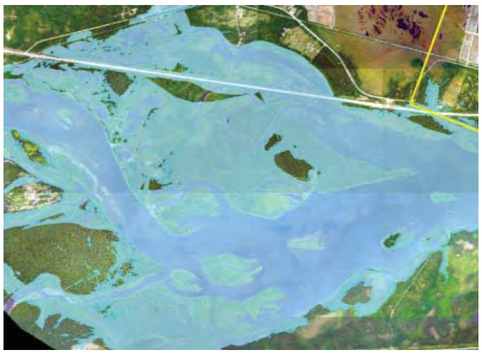
Floods in the Prairie Regions

- Riverine flooding - Surface Runoff causing the Water to Breach Banks.
- Snow Melt (spring flood) coupled with a Wet Fall.
- Can be large flood extent (wide and flat floodplain), with relatively low velocities.
- Long duration (Days to months) due to small Geographic Gradient.
- Large warning time (weeks or months) before flood's peak.
- Local effects: Ice Jams during Spring Freshnet.

HATCH

Work Plan

Floodplain mapping



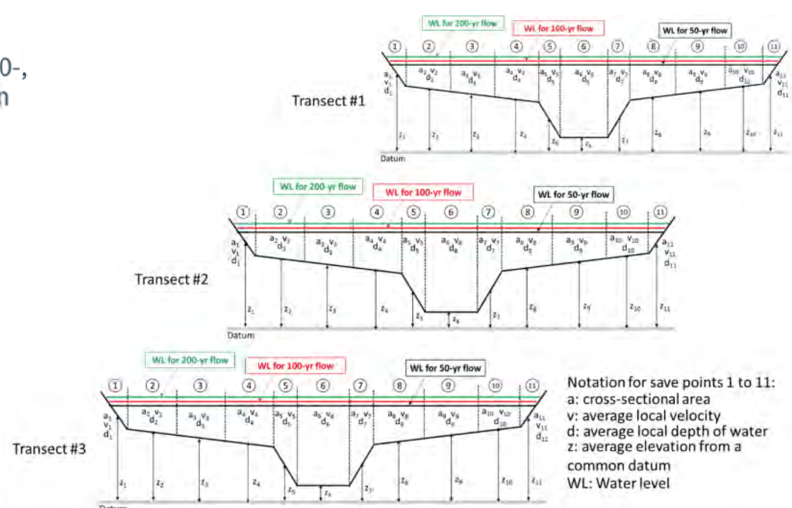
Statistical data extraction

http://www.clker.com/cliparts

HATCH

Work Plan

- 10-, 20-, 50-, 100-, 200-, 500-, 1000- and 2500-year return period peak flood flow review
- Cross section selection



Notation for save points 1 to 11:
a: cross-sectional area
v: average local velocity
d: average local depth of water
z: average elevation from a common datum
WL: Water level

HATCH

HATCH

Analysis and Data Extraction for Flood Load Determination for Selected Case Studies from Great Lakes and Arctic Coasts

DEREK WILLIAMSON and JOSH WIEBE

Baird & Associates, ON, Canada

Abstract

The National Research Council (NRC) is in the process of developing national guidelines for the design of flood-resistant buildings. W.F. Baird & Associates (Baird) is supporting the NRC in the development of the guidelines and design procedures by undertaking case studies that are developing new datasets of water depths, velocities, and wave conditions for select flood-vulnerable communities on Canada's Great Lakes and Arctic coasts. These case studies are expansions of coastal flood hazard studies that Baird undertook for Ontario Conservation Authorities and the Government of Northwest Territories in 2019 and 2020. The case study locations are affected by relatively large storm surges (greater than 2 m) and waves (greater than 5 m). The case studies focus on select neighbourhoods that have experienced building damage in the past or are known to be at high risk.

Biographies

Mr. Derek Williamson has been a coastal engineer with Baird & Associates since 1991, and is a principal and director at Baird & Associates. He has worked extensively in the field of numerical modelling and risk analyses for riverine and coastal processes. He has also led field studies, undertaken design work, and developed software systems for analysing and mapping hazards and risk. Mr. Williamson combines a strong technical background with a practical approach to projects.

Mr. Josh Wiebe has over 11 years of consulting experience in coastal engineering and has been the project manager for several coastal flood hazard and risk assessment studies. His recent project experience includes coastal hazard and risk assessment studies for Toronto Islands, Haldimand and Norfolk Counties (Lake Erie), Tuktoyaktuk, and Barbados. Mr. Wiebe is also a member of the Technical Advisory Committee for the National Research Council's guidelines document on Coastal Flood Risk Assessment for Climate-Resilient Buildings and Core Public Infrastructure.

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B.
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81

Coastal Flood Case Studies to Support the Design of Flood Resistant Buildings

NRC Workshop on Flood Resilience of Buildings

Derek Williamson, P.Eng.

February 26, 2020

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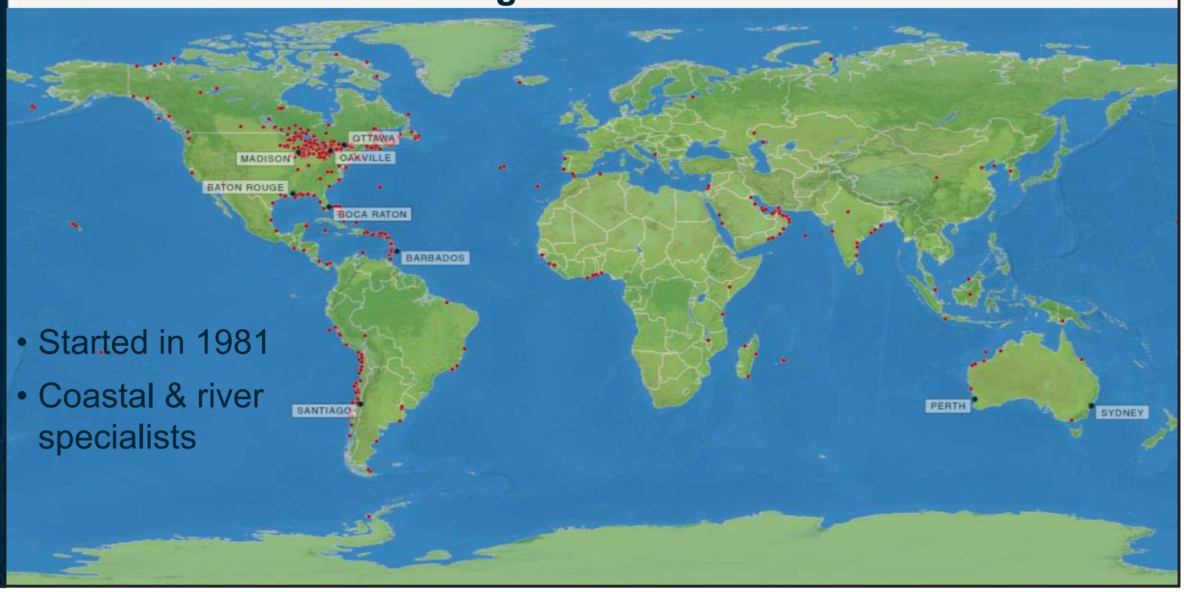
baird.com

Baird & Associates – Background



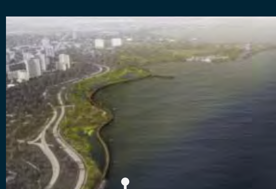
- Started in 1981
- Coastal & river specialists

METEOROLOGY & OCEANOGRAPHY

COASTAL & RIVER ENVIRONMENTAL

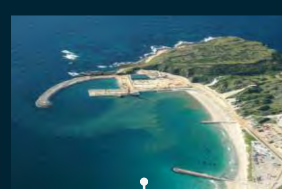
HAZARDS / RISKS

COASTAL & MARINE STRUCTURES



SHORELINE & COASTAL RESTORATION

WATERFRONTS & MARINAS



PORTS, TERMINALS & VESSEL OPERATIONS

...what we do.

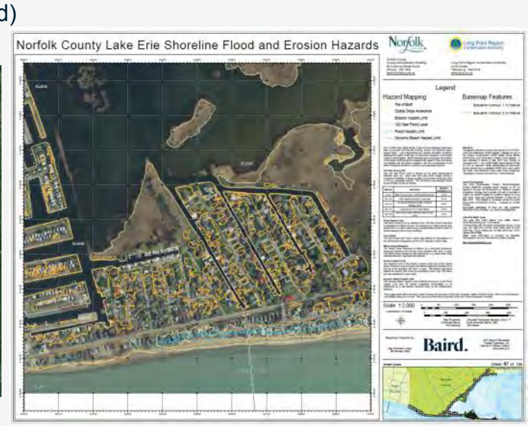
Project Overview / Our Role

- NRC developing national guidance for flood-resistant buildings
- Baird's role is to provide flood data for three coastal flood case studies
  - Two on Lake Erie, one on Beaufort Sea
  - Outputs will include water depth, water velocity, wave height and period
  - Data will be used by NRC to develop design procedures to estimate flood loads on buildings
- Case studies expand on recently completed coastal flood studies by Baird
  - More extreme scenarios up to 2,500-year event
  - New analyses and data products

Lake Erie Haldimand and Norfolk County Case Studies

Recently updated coastal hazard mapping for over 200 km of Lake Erie shoreline

- Flood, erosion, and dynamic beach hazards
- Includes wave uprush and overtopping analyses
- Analyses for regulatory event (100-year return period)



Lake Erie Haldimand and Norfolk County Case Studies

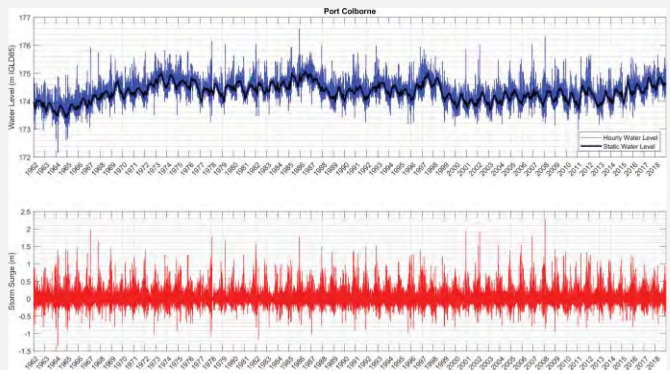
- Completed a coastal flood risk assessment for buildings
- 2,400 dwellings, 260 commercial institutional buildings within 100-year floodplain
- Impacts for 2-year to 200-year event
- Findings for 100-year event:
  - $160M building and contents damages
  - $70M lost productivity
  - $18M temporary accommodation

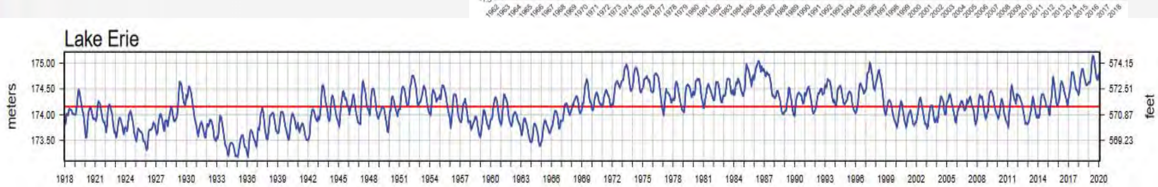
Lake Erie Haldimand and Norfolk County Case Studies

- Focus on select high-risk neighborhoods
- Joint probability analysis of static lake levels, storm surge, waves up to 2,500-year event
- Extend existing model grids for 2,500-year event using LiDAR
- Simulate extreme events using coupled storm surge-wave model
- 1D profile model to simulate wave runup, overtopping, and overland wave propagation
- Extract water levels/depths, water velocities, and waves at predefined locations
- NRC to use dataset to develop/validate procedures to estimate flood loads on buildings

Lake Erie Water Levels

- Multi-decadal fluctuations of approx. 2 m
- Seasonal variation of 0.5 m
- Large storm surges due to shallow bathymetry and orientation of lake
  - 100-year surge up to 2.6 m
  - Highest storm surges of the Canadian Great Lakes



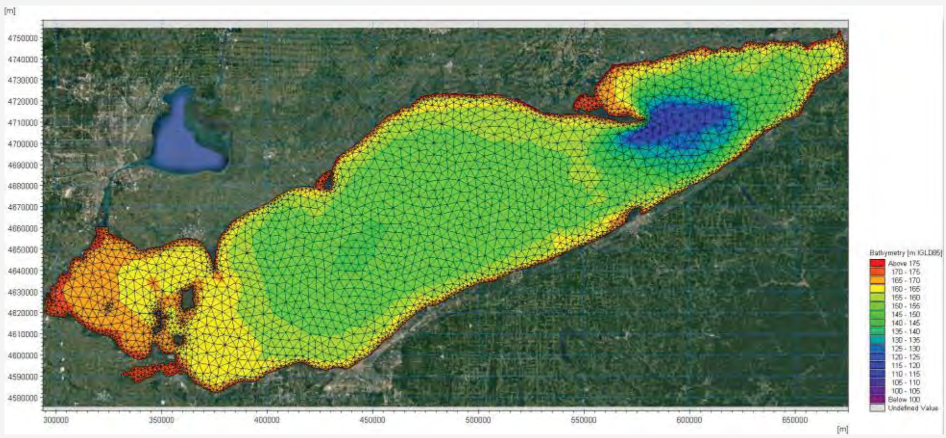


Lake Erie Waves

- Lake is 400 km by 80 km
- Fetch at Long Point = 230 km
- 100-year wave conditions
  - 6 m significant wave height, 10 second period

Lake Erie Wave and Surge Modelling

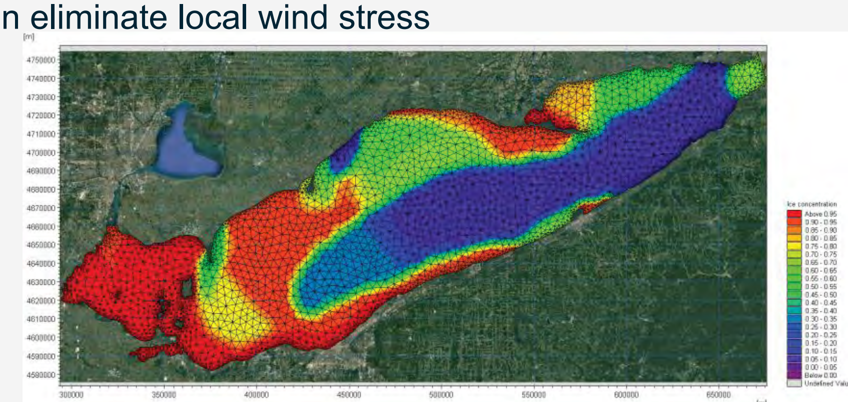
- Using MIKE21 Flexible Mesh & Spectral Wave models



B. 19 81

Ice Cover in Lake Erie Model

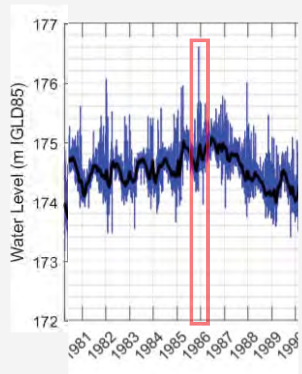
- Required for some simulations
- Partial ice can increase surface friction
- Shore-fast ice can eliminate local wind stress
- Blocks waves
  - 30% threshold

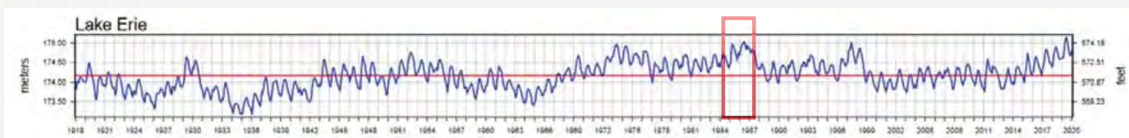


B. 19 81

Lake Erie December 1985 Storm

- High static lake levels
- 1.7 m storm surge at Port Colborne
- 5.5 m, 9 s offshore waves
- 1,415 property owners responded to damage survey in Haldimand and Norfolk Counties
- Excess of $10M damage (1985 dollars)





Lake Erie December 1985 Storm

Long Point, Norfolk County

- Extensive wave damage to building walls and foundations

Lake Erie December 1985 Storm

Long Point, Norfolk County

- Wave, current, and possible debris loads
  - Broken and bent piles
  - Lateral movement

Lake Erie December 1985 Storm

Long Point, Norfolk County

- Complete building collapse
- Movement and transport by water
- Shoreline erosion

Tuktoyaktuk Case Study

Tuktoyaktuk Case Study

Completed erosion mitigation study in 2019

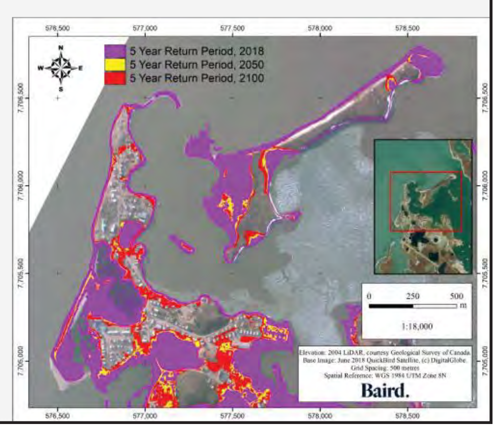
- Develop design criteria for shore protection
- Waves, tides, storm surge, sediment transport, ice, permafrost/ground ice
- Climate change impacts
  - Longer ice-free season
  - Increased wave exposure, wave energy due to increased fetches and longer ice-free season
  - Increased exposure to surge
  - Sea level rise and land subsidence
  - Permafrost degradation

Tuktoyaktuk Case Study

- Population ~ 900
- Largest community on Canadian Beaufort Sea
- Erosion ~ 0.8 m/yr
- Houses have been moved due to erosion
- Community vulnerable to storm surge flooding

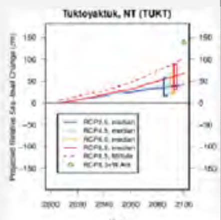
Tuktoyaktuk Case Study

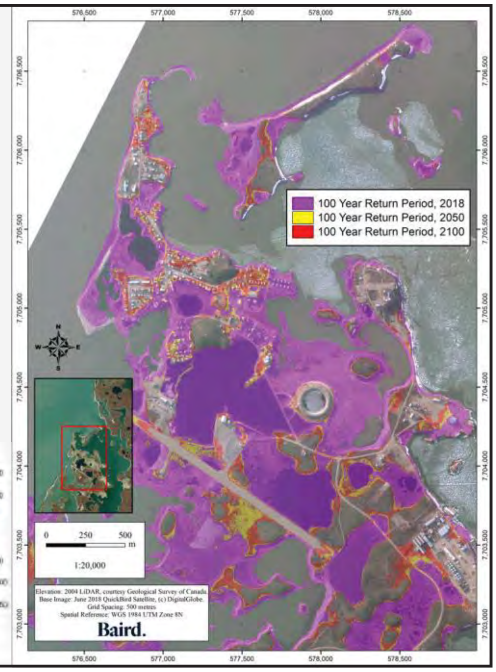
- Micro-tidal with spring tide range of only 0.3 m
- Shallow offshore shelf and low topography
- Sea ice limits open-water fetch distances
- Storm surges of up to 2.5 m under open-water conditions
- Surges accompanied by erosion due to waves
- Depth-limited wave conditions



Tuktoyaktuk Case Study

- Large areas of the community experience flooding, even during low return period events
- Surge occurs suddenly, cutting off ingress/egress to community
- Flooding risks are almost certain to increase with climate change



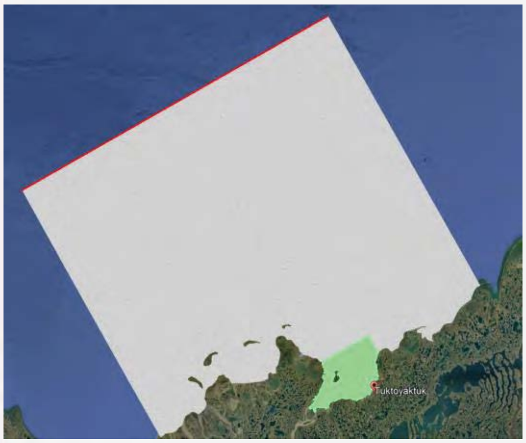


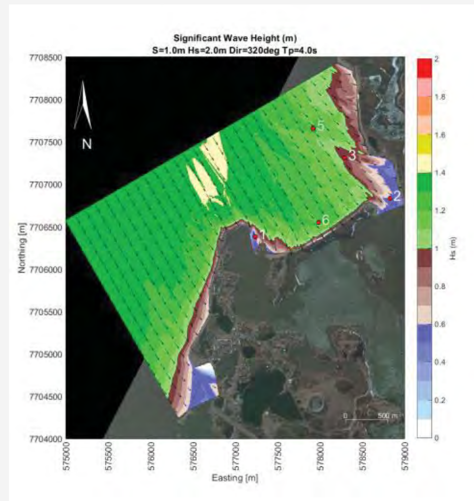
Tuktoyaktuk Case Study

- Analyses of CIS ice charts

Tuktoyaktuk Case Study

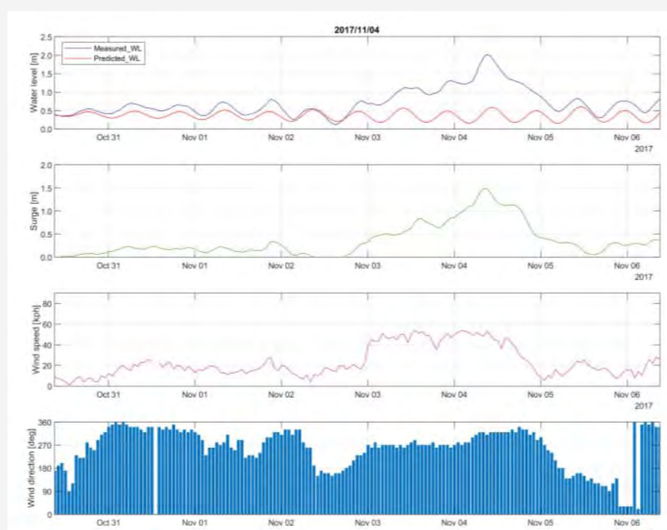
- Delft3D wave and surge model grid





Tuktoyaktuk Case Study

- Example of surge event, sustained 50 kph winds from W to WNW



Baird.
Innovation Engineered.

Analysis and Data Extraction for Flood Load Determination for Selected Case Studies from Atlantic Provinces

VINCENT LEYS

CBCL, NS, Canada

Abstract

An overview of CBCL's work will be presented to the NRC to support the Development of Requirements for the Design of Flood Resilient Buildings. The project includes four case studies with 2D riverine modeling and 2D coastal flood modeling in urban settings. For each flooding scenario, floodplain maps will be produced and representative model transects will be extracted for key parameters such as discharge, depth, flow velocity and bed resistance. Flood loads will be developed for various return periods, based on mean and standard deviation of model outputs. It is intended that each case study be used to determine data requirements and identify potential challenges with the development of flood loads based on hydrodynamic model outputs.

Biography

Mr. Vincent Leys is a Senior Coastal Engineer with the Halifax-based engineering firm CBCL. He leads coastal infrastructure and environmental projects related to harbours, waterfronts, and adaptation to climate change and sea level rise. His work focuses on mitigating coastal impacts from extreme events on people and infrastructure, while accommodating natural processes such as sediment transport and flooding. Over the last 20 years, he has provided scientific and engineering inputs to a wide variety of projects across Atlantic Canada and in the Caribbean.

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International Workshop on

FLOOD-RESISTANT BUILDINGS

Analysis and Data Extraction for Flood Load Determination for Selected Case Studies from Atlantic Provinces

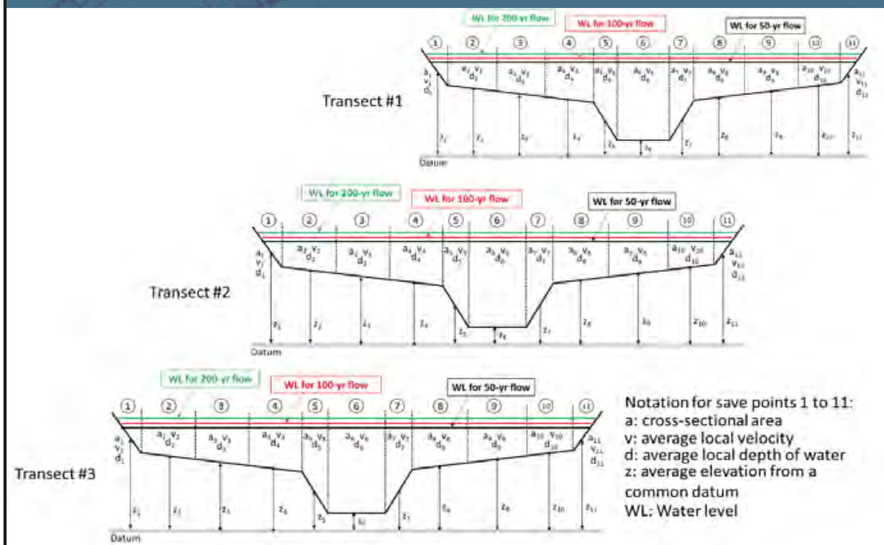
Preliminary considerations

CBCL

Vincent Leys
Coastal Engineer
CBCL
vincentl@cbcl.ca

Flood Study sites

CBCL Idealized outputs



Select 10 transect model data with flood loads of RP:

- 10 years,
- 20
- 50
- 100
- 200
- 500
- 1,000
- 2,500

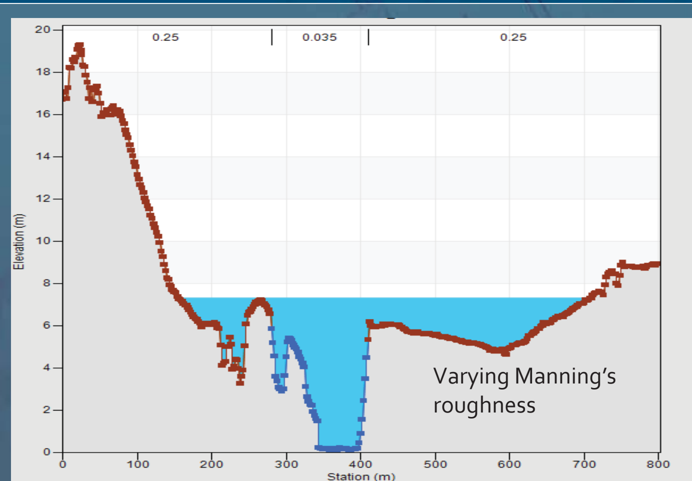
CBCL Main challenges

- **Modeling** - Limitations in model resolution, output type
- **Processes**
  - o Interaction between river/coastal processes and joint probabilities
  - o Limited long-term observations in some areas
  - o Return periods required far exceed length of observations (tide gauges, rainfall, river gauges)

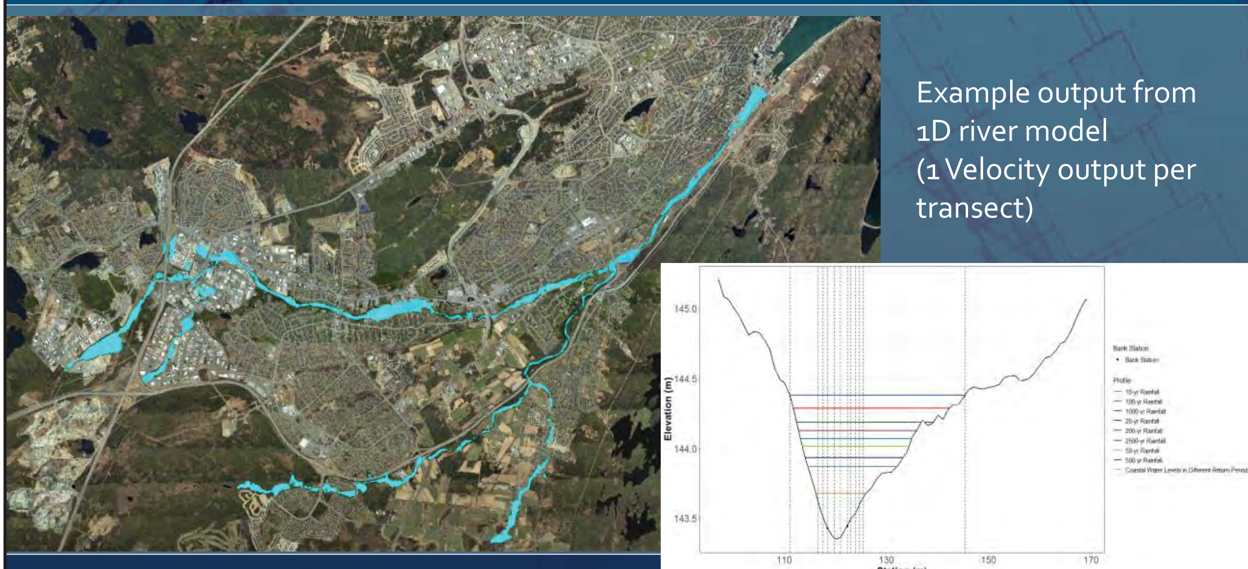
Models Used – 1D River hydraulics

SWMM
- Unsteady flow analysis
- Includes effect of storage, backwater, momentum on flows
- 1 Velocity output per transect

HEC RAS
- Steady flow analysis
- 1 Velocity output per transect



Waterford River, St John's NL



Example output from 1D river model (1 Velocity output per transect)

Waterford River – Extracted data

Transect

Profile ID	Rainfall	Coastal Water Level	Total Flow (m3/s)	Total Flow Area (m2)	Water Surface Elevation (m)	Average Velocity (m/s)	Alpha
1	10yr	2yr	4.100	4.432	143.868	0.925	2.340
2	20yr	2yr	5.700	5.643	143.934	1.010	2.473
3	50yr	2yr	8.200	7.282	144.015	1.126	2.551
4	100yr	2yr	10.200	8.399	144.067	1.214	2.567
5	200yr	2yr	12.400	9.699	144.125	1.278	2.603
6	500yr	2yr	15.500	11.152	144.185	1.390	2.642
7	1000yr	2yr	18.000	14.024	144.285	1.284	2.932
8	2500yr	2yr	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
9	2yr	10yr					
10	2yr	20yr					
11	2yr	50yr					
12	2yr	100yr					
13	2yr	200yr					
14	2yr	500yr					
15	2yr	1000yr					
16	2yr	2500yr					

Save point

Profile ID	Save Point	Station: Left	Station: Right	Location: Area	Elevation: Average Ground Elevation (m)	Elevation: Elevation at the Center of the Channel (m)	Water Level (CGVD28)	Local Flood Depth: Section Averaged Depth (m)	Local Flood Depth: Maximum Depth (m)	Local Flow Velocity (m/s)	Local Flow Area (m2)	Manning's n
1	1	110.947	116.500	LOB	143.983	143.965	143.868	0.124	0.252	0.601411	0.2511	0.058
	2	116.500	117.500	LOB	143.557	143.553	143.868	0.312	0.364	0.601411	0.3117	0.058
	3	117.500	118.393	LOB	143.464	143.461	143.868	0.405	0.439	0.601411	0.3614	0.058
	4	118.393	119.677	Channel	143.390	143.387	143.868	0.478	0.508	1.598201	0.6141	0.035
	5	119.677	120.962	Channel	143.354	143.352	143.868	0.515	0.521	1.680344	0.6612	0.035
	6	120.962	122.246	Channel	143.401	143.402	143.868	0.467	0.508	1.573071	0.5998	0.035
	7	122.246	123.000	ROB	143.468	143.468	143.868	0.401	0.424	0.311237	0.3023	0.089

Profile ID	Save Point	Station: Left	Station: Right	Location: Area	Elevation: Average Ground Elevation (m)	Elevation: Elevation at the Center of the Channel (m)	Water Level (CGVD28)	Local Flood Depth: Section Averaged Depth (m)	Local Flood Depth: Maximum Depth (m)	Local Flow Velocity (m/s)	Local Flow Area (m2)	Manning's n
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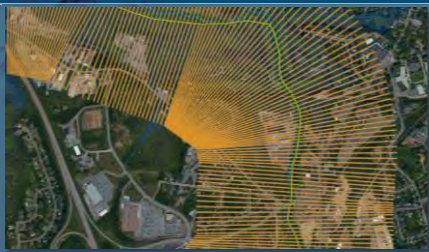
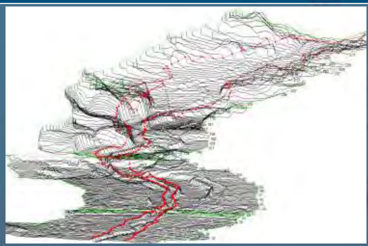
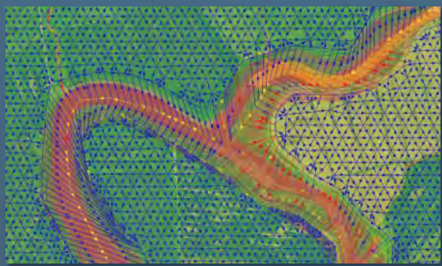
	7	122.246	123.000	ROB	143.468	143.468	143.868	0.401	0.424	0.311237	0.3023	0.089

Models Used – 2D floodplain





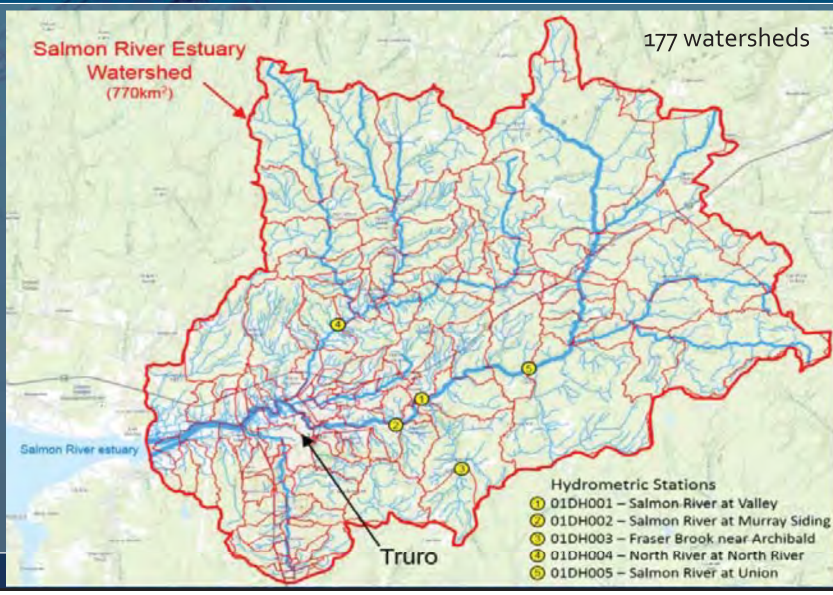


PCSWMM 2D
Uses water levels from 1D river model as input (quasi 2D model)

Truro, NS

- Partly built on floodplain
- Extreme rainfall
- Bay of Fundy tides (17 m range), storm surge, sea level rise
- Channel sedimentation
- Ice jams

Truro models



hydrology

↓

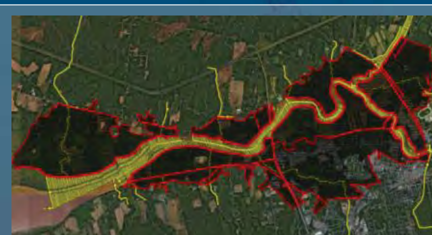
1D river

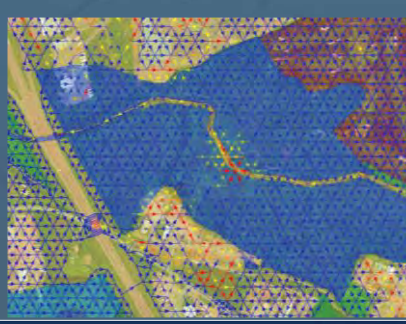
↓

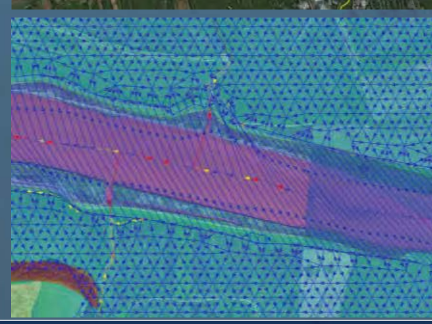
2D floodplain

Truro 2D floodplain model

- 2D Modelling of Floodplain
- Mesh resolution:
- 40m hexagonal mesh in the floodplain
- 20m rectangular mesh along major roads, railways and dykes

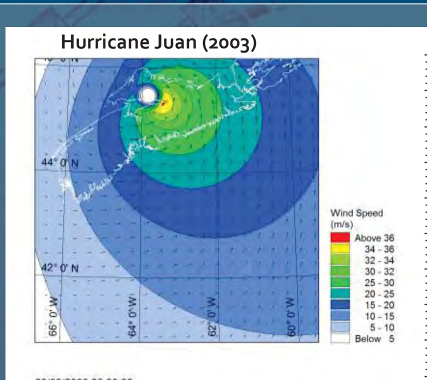


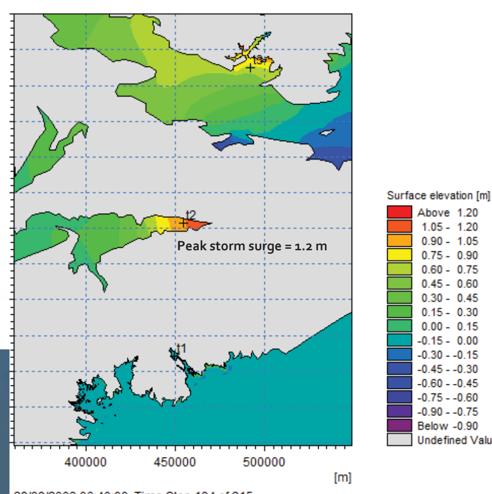




Truro Flood event example (2012)

Truro storm surge



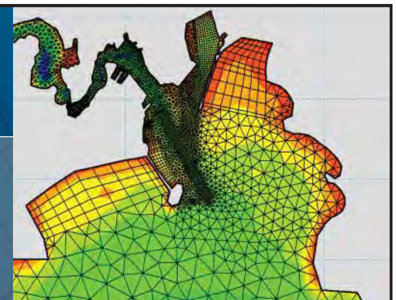


No tide gauge record in Minas Basin

Relies on modeling

Storm surge must occur at high tide (+9 m above mean sea level) to cause any flooding

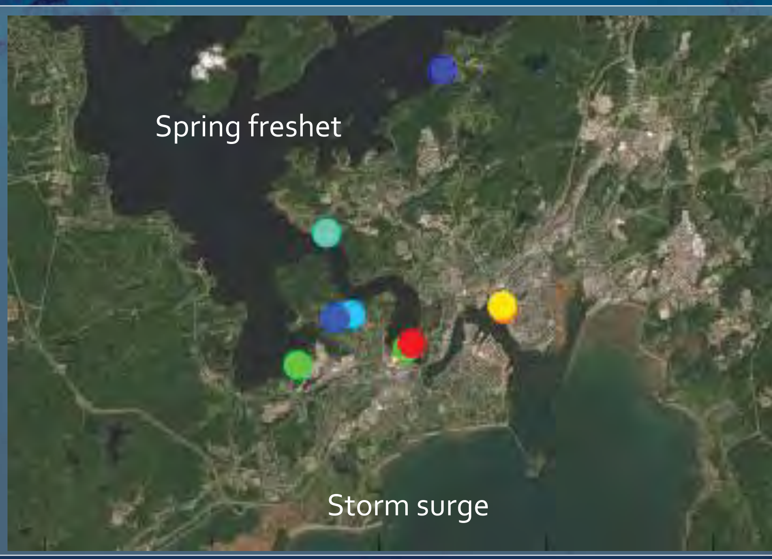
Models Used – 2/3D coastal



DHI MIKE3
Saint John Harbour NB

- Flexible mesh hydrodynamic model
- Open boundaries with storm surge / river levels
- Incl. density, salinity
- Gridded map for bottom roughness
- Velocity, water level output for each element of model

Saint John NB flood areas

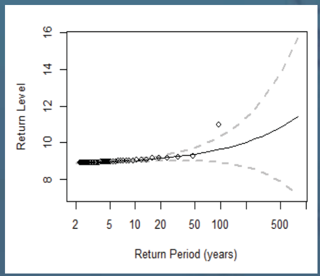


Saint John NB extreme storm surge levels

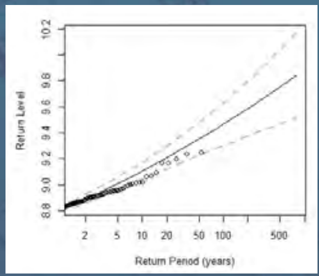
Data record is ~100 years
(+1869 Saxby Gale record estimate)

Estimating extreme coastal water level beyond 200 years is deemed unreliable

Peak over threshold



Annual maxima



Conclusions

- Data extraction is underway
- Some areas require model refinement
- Limitations must be addressed, notably:
  - o Interaction between river/coastal processes and joint probabilities
  - o Limited long-term observations in some areas
  - o Return periods required far exceed length of observations (tide gauges, rainfall, river gauges)

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FLOOD-RESISTANT BUILDINGS

Thank you
Questions / discussion

Vincent Leys
Coastal Engineer
CBCL
vincentl@cbcl.ca

DAY 2
Session 3 – Part 1: Federal, Provincial, Territorial and Municipal Initiatives on Flood-Related Issues

Chair, Annick Maletto
Centre de sécurité civile - Ville de Montréal, QC, Canada

Standards Used by Conservation Authorities in Ontario for Great Lakes and Riverine Flood Plain and Erosion Management, and How Climate Change May Challenge this Approach
Mark Peacock
Lower Thames Conservation Authority, ON, Canada

Building Flood Resilience in Calgary
Sandy Davis and Marco Civitarese
City of Calgary, AB, Canada

Flood Hazard Management Initiatives in BC
Jesal Shah
Ministry of Forests, Lands, Natural Resource Operations, and Rural Development, BC, Canada

Standards Used by Conservation Authorities in Ontario for Great Lakes and Riverine Flood Plain and Erosion Management, and How Climate Change May Challenge this Approach

MARK PEACOCK

Lower Thames Conservation Authority, ON, Canada

Abstract

This presentation will review the existing standards used for floodplain management by Conservation Authorities in Ontario. This will include flood and erosion elements that might be affected in both riverine and Great Lakes hazard areas. The review will include considering the three riverine flood zones of Ontario, and how these standards may need to change. Additionally, flood elevation and erosion setback standards used in management of Great Lakes hazard areas will be reviewed. Results of recent floods and erosion events will be used to comment on how a new approach may be needed.

Biography

Mr. Mark Peacock graduated from the University of Guelph in 1988 with a bachelor degree in Water Resources Engineering. Prior to this, he graduated from the University of Toronto with an Honours Bachelor of Arts Degree with a Specialist Certificate in English Literature. He is currently a registered Professional Engineer.

In December of 2017 Mark moved to Southwestern Ontario to become the CAO / Secretary Treasurer of the Lower Thames Valley Conservation Authority. In the past, Mark provided watershed engineering direction and services to the Ganaraska Region, Central Lake Ontario, Kawartha Region, Otonabee Region and Nottawasaga Valley Conservation Authorities. Mark has produced a number of technical studies looking at elements of floodplain mapping and policy. In 2015, Mark coauthored a review of floodplain mapping in Ontario entitled “Metadata Inventory of Existing Conservation Authority Flood Mapping”.

Before working with Conservation Authorities, Mark was a Water Resources Engineer at Long Associates Consulting Limited, in Orangeville, Ontario.

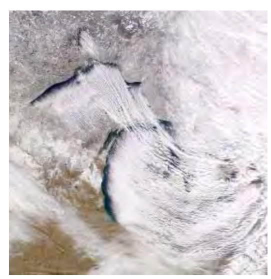
Standards used by Conservation Authorities in Ontario for Great Lakes and Riverine Flood Plain and Erosion Management and How Climate Change May Challenge this Approach

Presentation to:
International Workshop on
FLOOD-RESISTANT BUILDINGS

Mark Peacock, P. Eng.
Lower Thames Valley Conservation Authority
February 27, 2020

Lower Thames Conservation

Presentation Topics



1. General Context – Conservation Authorities implementing with Province setting standards
2. Provincially defined program
   I. Flood Plain Criteria Zones
   II. Three Development Approaches – One Zone, Two Zone and Special Policy Areas
3. Climate Change Challenges – Riverine Hazards
4. Climate Change Challenges - Shoreline Hazards

Lower Thames Conservation

Ontario's Conservation Authorities(CAs)

Conservation Authorities, created in 1946 by an Act of the Provincial Legislature, are mandated to ensure the conservation, restoration and responsible management of Ontario's water, land and natural habitats through programs that balance human, environmental and economic needs.

Objective – Natural Hazards

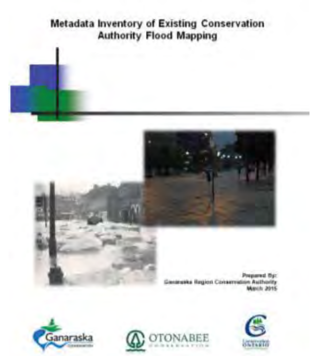
develop and maintain programs that will protect life and property from natural hazards such as flooding and erosion

Lower Thames Conservation

Ontario's Flood Plains
CA General Numbers as of 2015

- Approx. 35,000 km of flood plains - CA defined
- Approx.1/3 1990s or older
- Approx. 75% need updates
- Approx. 135,000 buildings identified in flood plain
- Very limited Climate Change considerations

Recent updates through National Disaster Mitigation Program



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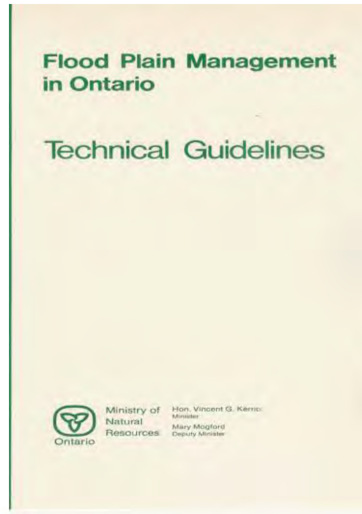
Flood Plains – how they are defined in Ontario – Province lead

- In 1988 the Province published
  " Flood Plain Management in Ontario -Technical Guidelines"
- Provincial Planning Policy Statements –past, present and future
- Provincial standards to regulate and define flood plains



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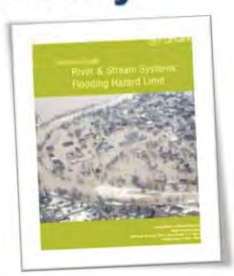
Provincial Documents over time defines basis of the regulatory approach



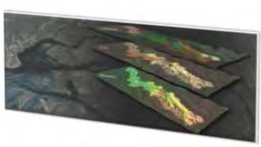
- Regulatory and Planning approach to flood plain management in Ontario through CA Panning Services and Conservation Authorities Act Section 28 regulations, therefore changes to regulations **and standards** are required to include climate change in approach.
- Needs to address Transparency and Accountability

Lower Thames Conservation

Flood Plain Criteria – and how this relates to Climate Change

- Regulatory Flood defined within Ontario
- Based on evaluation of relevant events in zones
- 3 Flood Hazard Criteria zones created across Ontario
- By length of floodplain, 65% of the floodplains delineated by CAs are found in Zone 1, 25% in Zone 2, and 10% in Zone 3 (Approx.)
- As of 2015 – no climate change considerations in 35,000 km of flood plain mapping in Ontario

Lower Thames Conservation



Regulatory Flood Zone 1 Definition

In Zone 1, the flooding hazard limit is defined as the greater of:

i. the flood resulting from a rainfall actually experienced by the Hurricane Hazel storm (1954) transposed over a specific watershed and combined with the local conditions.

ii. ii. the one hundred year flood; or

iii. a flood which is greater than i) or ii) which was actually experienced on a particular watershed or portion thereof as approved by the Ministry of Natural Resources and Forestry. An example is a portion of Southwestern Ontario where a critical event that occurred in 1937 is considered the flood hazard standard

Lower Thames Conservation

Climate Change impacts to Zone 1

- Hurricane Hazel – big storm over longer period create huge response in larger watersheds
- 100 yr – use of duration and distributions can create critical responses for small and short response watersheds
- Hurricane Hazel – probably big enough – but should be tested
- 100yr event – needs significant consideration

Lower Thames Conservation

Flood Hazard Criteria Zone 2

In Zone 2 the flooding hazard limit is defined as:

i. the one hundred year flood; or

ii. a flood which is greater than i) which was actually experienced on a particular watershed or portion thereof as approved by the Ministry of Natural Resources and Forestry.

Lower Thames Conservation

Climate Change impacts to Zone 2

- On larger watersheds the 100 yr flow is determined by frequency analysis and not models
- Frequency analysis has issues with collection of data for very large events (e.g. above the rating curve)
- For smaller watersheds need to determine if 100 years of response is large enough to properly protect watershed residents
- Need to update mapping and analysis with climate change projections

Lower Thames Conservation

Flood Hazard Criteria Zone 3

In Zone 3, the flooding hazard limit is defined as the greater of:

i. the flood resulting from a rainfall actually experienced during the Timmins storm (1961) transposed over a specific watershed and combined with the local conditions

ii. the one hundred year flood; or

iii. a flood which is greater than i) or ii) which was actually experienced on a particular watershed or portion thereof as approved by the Ministry of Natural Resources.

Lower Thames Conservation

Climate Change impacts to Zone 3

- On larger watersheds the Timmins Storm may not be big enough to match the type of protection needed
- For smaller watersheds need to determine if 100 years of response is large enough to properly protect watershed residents
- Need to update mapping and analysis with climate change projections

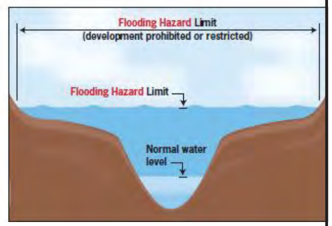
Lower Thames Conservation

The Three Development Approaches in Ontario Flood Plains

- One Zone – Hazard Approach
- Two Zone – Risk Approach
- Special Policy Areas – Risk Approach

Lower Thames Conservation

One Zone - A Hazards Approach



Generally, the flood plain will consist of one zone, defined by the selected flood standard

New development in the flood plain is to be prohibited or restricted.

Where the one zone concept is applied:

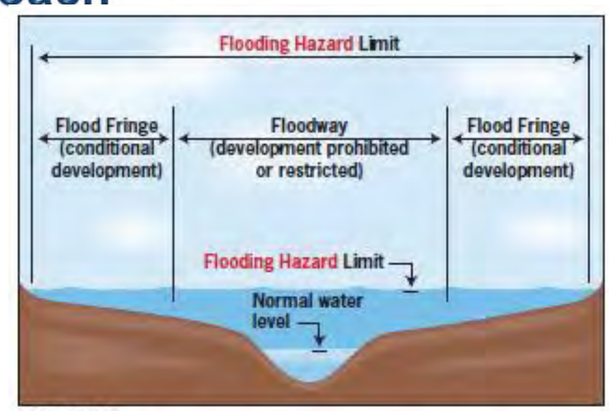
i) Municipalities and planning boards include policies in their official plans that explain the intent of the one zone concept;

ii) The flood plain appropriately zoned in conformity with the official plan designation to reflect its prohibitive or restrictive use; and

iii) The entire flood plain is treated as the floodway.

Lower Thames Conservation

Two Zone – a Managed Risk Approach



(NOT TO SCALE)

Figure B-3 - Two Zone Floodway - Floodfringe concept

Lower Thames Conservation

Two Zone

In 1988 replaced the rigid 100 year flood fringe criterion with a more flexible approach based on managing upstream and downstream impacts and risk.

Encroachment only if addressing:

- increases in upstream/downstream flood levels
- increases in downstream flows
- increases in downstream velocities
- change in the timing of flows.
- safe depths, velocities and depth/velocity products
- safe ingress/egress

Lower Thames Conservation

Two Zone Technical Requirements

- Must meet requirements of Ministry of Natural Resources and Forestry - Technical Guide River & Stream Systems: Flooding Hazard Limit, MNRF, 2002, Appendix 4
- Many across Ontario dating into the 1980s which do not include Climate Change
- Significant cost to update technical and policy documents in these areas

Lower Thames Conservation

Special Policy Area –
A Second Managed Risk Approach

Special Policy area means an area within a community that has historically existed in the flood plain where site specific policies apply, **approved by the Ministers of Natural Resources and Forestry (MNRF) and Municipal Affairs and Housing (MMAH)**, which are intended to address the significant social and economic hardships to the community that would result from strict adherence to provincial policies concerning development.

Lower Thames Conservation

Special Policy Areas – e.g. Town of Cobourg Components
Planning , Technical, Approvals

3.11.3 **Land Use Policies**

The policies for the lands in the Environmental Constraint Area designation shall be in accordance with the policies of Section 4.2.

3.11.4 **Special Provisions**

3.11.4.1 **North-east Corner Elgin and Ontario Streets**

Notwithstanding any other policies of this Plan, the uses permitted on those lands located adjacent to the north-east corner of the intersection of Elgin Street and Ontario Street, which are designated as an Environmental Constraint Area, shall be in accordance with the policies in Table 1 of this Plan for convenience commercial uses. Regard shall be had for the policies set forth under Section 4.2 hereof prior to the erection of any new buildings or structures, inclusive of additions to existing structures.

3.11.4.2 **North Side of Hamilton Avenue**

Notwithstanding any other policies of this Plan, the hardwood forest on the lands designated Environmental Constraint Area located on the north side of Hamilton Avenue shall be preserved and enhanced.

3.12 SPECIAL POLICY AREA

3.12.1 **Purpose**

The delineation of this area, as originally set forth in the Town of Cobourg Official Plan, approved by Ministry of Municipal Affairs and Housing on August 19, 1986, was subject to the approval of the Ministers of Municipal Affairs and Housing and Natural Resources.

The Special Policy Area designation on Schedule "A" is an overlay designation. The designation applies to areas within the Town that have historically existed in the flood plain and where site specific policies apply which are intended to address the significant social and economic hardships to the community which would result from strict adherence to provincial policies concerning development in the flood plain.

3.12.2 **Permitted Uses, Buildings and Structures**

Town of Cobourg Official Plan
Office Consolidation 3 - 57 Revised May 2010

APPENDIX 5 : SPECIAL POLICY AREAS -

Lower Thames Conservation

Special Policy Areas

- Most currently do not address climate change
- Would require significant cost and time to update across the province with many SPAs dating to the 1980s
- Due to older criteria some SPAs may be challenging to update

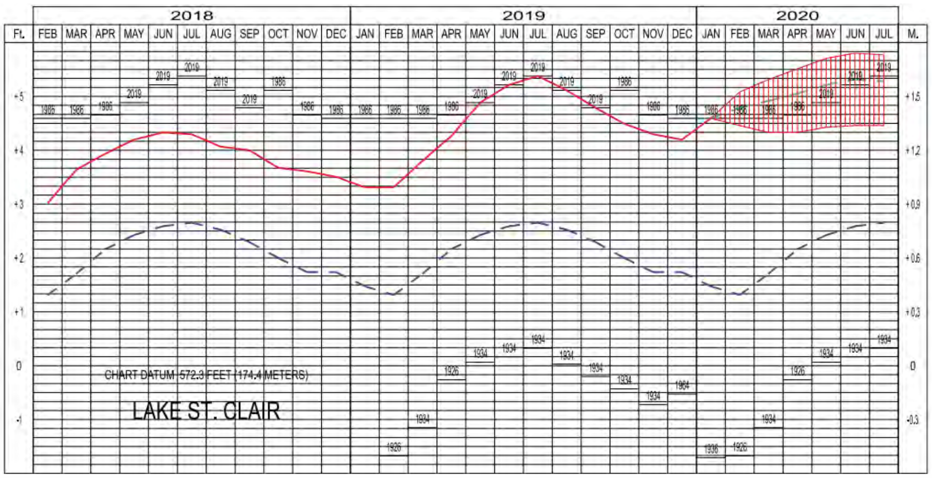
Lower Thames Conservation

Ice Jam Feb 2019
Specific Factors Affecting Ice Jam

- Needs enough cold days to generate enough ice thickness
- After development, the ice can't be degraded by too many warm and/or sunny days
- Needs a fairly significant rain/snowmelt event from the Upper Thames watershed to lift the ice and break it up
- Restrictions in the river or the exit into Lake St. Clair causes the ice to jam up on itself

Lower Thames Conservation

Lake St. Clair Water Levels



Ice Thickness Measurements

- What we check:
  - Theoretical ice thickness calculations based on degree days of freezing temperatures are performed
  - When ice thicknesses are predicted to be around 20 cm, staff will take ice cores at Lighthouse Cove and in the City of Chatham.
- What we had:
  - Calculations suggested 20 cm of ice had formed
  - It was reported to us that there was 12.5 cm of ice in the city on Sunday the 2nd
  - Measurement at Lighthouse Cove measured 10 cm and 5 cm of ice on the 7th
  - Visual observation of the ice jam showed very little over 20 cm.

What happened this year?

- Did not have the ice thickness typically associated with ice jams. (20cm max.)
- Did not have flows typically associated with ice jams. (350 cms)
- Ice jamming for a 2 week period, significant flooding and dyke failures

Lower Thames Conservation

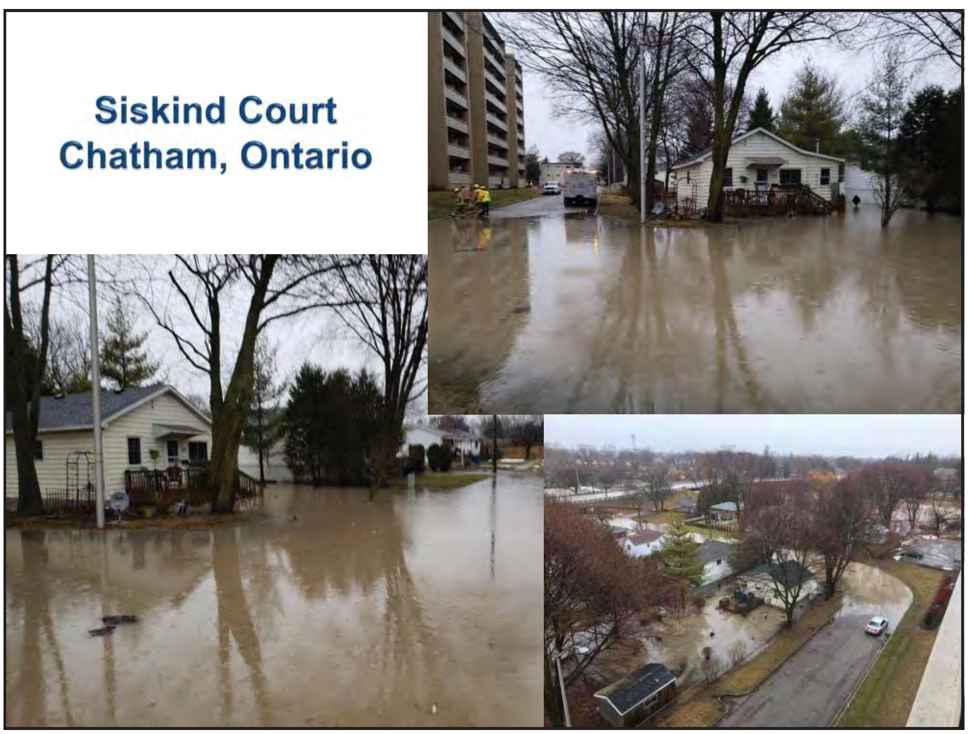
Historical Ice Jams

Year	Ice (mm)	Snow (mm)	Rain (mm)	Melt ˚C-days	Byron Peak (cms)	Result
1968	300		46	4	805	Jam at Prairie Siding
1979	500	109	15	12	710	Jam at Prairie Siding
1985	350	104	64	13	770	Jam at Prairie Siding
1981	450	93	18	20	510	Jam at mouth
1984	425	121	39	17	735	Jam at mouth
2001	300	258	35	5	680	Jam at mouth
2011	150	200	15	7	580	Jam at mouth

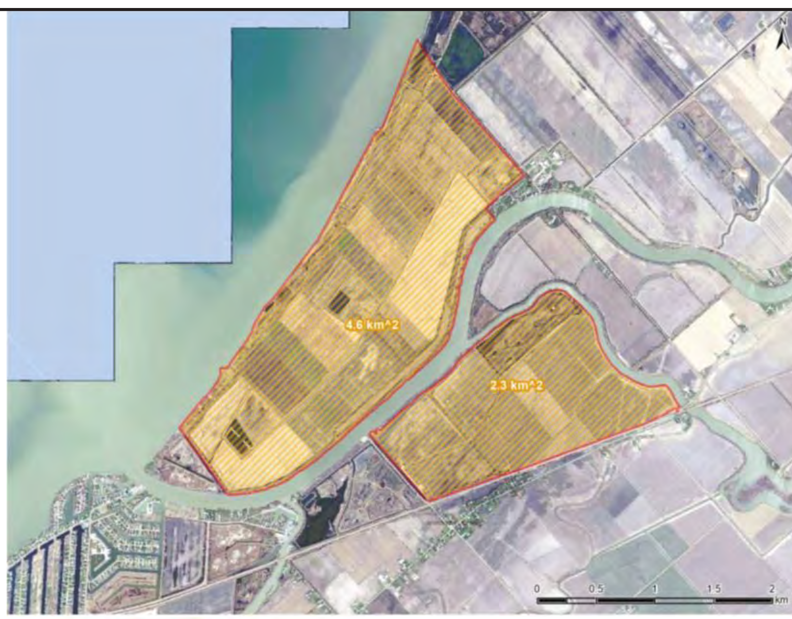
- Note 2011 jam due to woody debris in the river

Lower Thames Conservation


Ice Jam @ the Prairie Siding Bridge


Siskind Court
Chatham, Ontario

Salter St & Thames St
Chatham, Ontario



Lower Thames Conservation

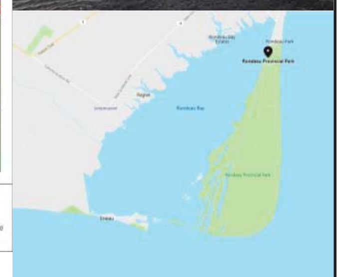
Lower Thames Conservation

- Flooding – and Erosion 2019
Lake Erie and Lake St. Clair Water levels

Monthly Mean Lake levels in Lake Erie and Lake St. Clair Lake levels reached record-breaking all time highs in July, exceeding highs recorded in 1986:

- Lake Erie was approximately 84 cm (33") above long-term monthly average lake levels. This is 13 cm (5") above previous highs in 1986, and 35 cm (14") higher than last year.
- Lake St. Clair was approximately 86 cm (34") above long-term monthly average lake levels. This is 10 cm (4") above previous 1986 highs, and 35 cm (14") higher than 2018.

The Protection is Gone



Lower Thames Conservation

Erie Shore Drive

- State of Emergency declared August 27/19 due to significant flooding caused by high winds and rain
- 123 homes at risk along Erie Shore Drive; 35% are permanent residents
- Significant damage occurred to 12 homes, the roadway, supporting slope, drain and 3 breakwalls
- A voluntary evacuation took place in a localized area of Erie Shore Drive comprising 50 homes
  - Hydro and Natural Gas services were shut off where there as a safety risk
- Thankfully, there were no injuries

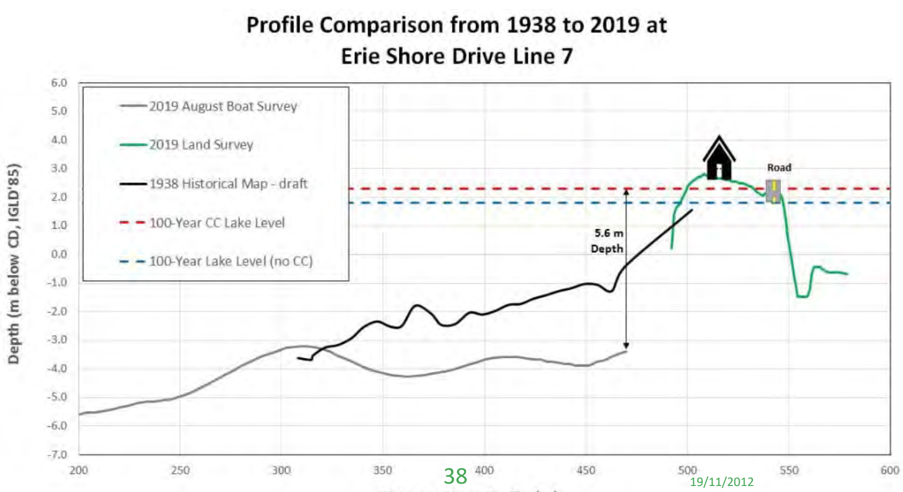
Lower Thames Conservation 36

Immediate Actions Taken

- $300k invested to shore up roadway structure and enhance water flow management over the road
  - Clay packing to restore the slope
  - Concrete blocks to aid and direct water flow
  - Addition of rock shutes and reinforcement
  - Drainage clean out
  - Road crack sealing, milling / paving of roadway
- Future Work:
  - Municipality will be converting the road to a one-way direction only (west to east)
  - Additional reinforcement of the road planned
  - $200k incremental investment anticipated
  - Even more $$$ in 2020

Engineering Challenges

the shoreline is eroding and dropping at a rapid rate which leads to increased wave energy along the shoreline.

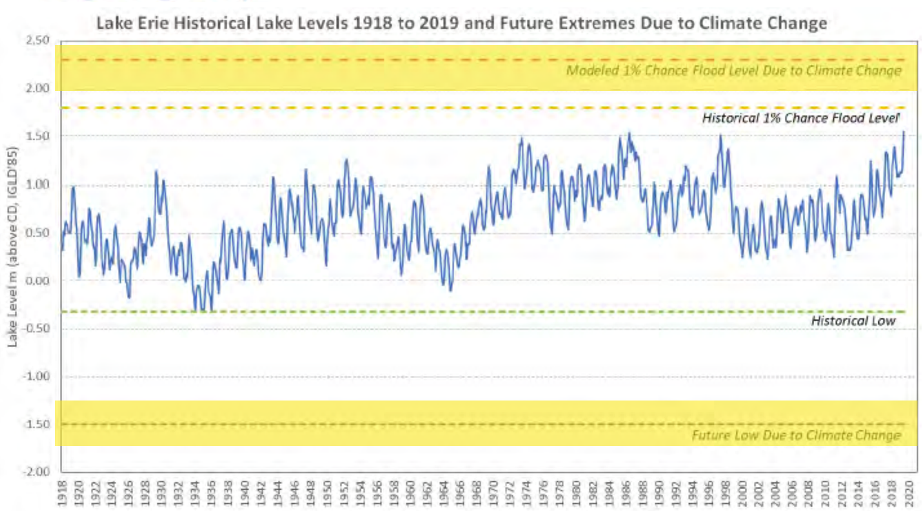


Engineering Challenges

- Mother Nature and Climate Change
  - Long term temperatures in are expected to rise which leads to –
    - Higher frequency and intensity of storms
    - Reduced ice coverage which leads to year round erosion
    - Increased wave energy
  - Winds that exceed 30 kph from the south will result in flooding
  - Design criteria for investment must include long term climate change modeling and forecasts

  - Note: The conditions experienced on August 27, 2019 were the worst that any long term residents or Municipal staff can remember.

Designing for the Future (yellow highlights)



Long Term Plans for Lake Erie Shoreline Issues

- Recommendations will be forthcoming in March 2020 from the Lake Erie Shoreline Study –
  - This paper will also serve as a template for other flood /erosion prone areas and in addressing climate change
- Recommendations will fall under four primary categories –
  1. Avoid – no development in flood prone areas – hazard approach
  2. Accommodate – eg. Raise the building foundation
  3. Protect – harden shorelines to protect investments
  4. Retreat – withdraw or relocate assets in harms way – when should a dwelling be allowed to be rebuilt?

Lower Thames Conservation

Sep. 9, 2019

41

Thank-you

Lower Thames Conservation

Building Flood Resilience in Calgary

SANDY DAVIS and MARCO CIVITARESE

City of Calgary, AB, Canada

Abstract

The presentation will summarize Calgary's current flood-related building regulations, current challenges in regulating for flood resiliency and where codes could help, and a tool for post-disaster building assessments.

Biographies

Ms. Sandy Davis is the River Engineering Team Lead at the City of Calgary. Sandy and her team focus on river-flow monitoring and forecasting, modelling, mapping, development application reviews and policy development, and public education and communication for river flooding.

Mr. Marco Civitarese is the Manager and Chief Building Official for Calgary Building Services, and has worked in different departments and varied capacities at the City of Calgary for 33+ years. He has participated in numerous initiatives, industry partnerships, investigations and educational forums over his career. He currently is the Service Owner for Building Safety and a member of the Advisory Committee on Accessibility at the City of Calgary. At the provincial level, Marco sits on the Board of Directors for the Alberta Safety Codes Council, and at a national level he serves on the Canadian Commission on Construction Materials Evaluation and most recently was a member on the Standing Committee for Housing and Small Buildings.


Calgary
Flood Resilience in Calgary, Alberta
National Research Council
International Workshop on Flood Resistant Buildings
Ottawa, ON
Feb 26-27, 2020
Feb 2020
1


Calgary
City of Calgary Flood Mitigation Plan (2017)
Enhanced TransAlta reservoir operations
Future Bow River reservoir
Floodplain policy and resilient development
Glenmore Dam gate upgrades (Elbow River)
Future Springbank Off-stream Reservoir (Elbow River)
Community flood barriers on the Bow River
Emergency response
Property-level flood protection and preparedness
V05

Calgary

Building Flood Resilience

The City's intentions include guiding development in flood-prone areas to be able to:

- respond effectively,
- protect life safety,
- minimize damages, and
- recover more quickly.

Flood-resilient development must be appropriate with respect to:

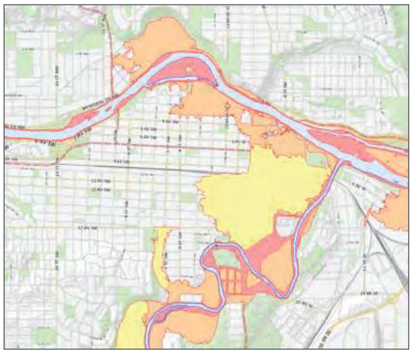
- Current, up to date flood mapping and flood elevations,
- Structural mitigation currently in place to reduce flood risk,
- Future flood risk due to our changing climate,
- Proposed land use and potential exposure/vulnerability,
- Return on investment - cost of resilience measures and avoided costs from reduced future damages.

V05 3

Calgary

Land Use Bylaw – Flood Hazard Area (FHA) Zones

- Floodway - Area of river where velocities and depths will equal or exceed 1 m/s and/or 1m depth during the *designated flood event*.
- Flood fringe - where the flood waters are below 1m depth and 1m/s velocity during the *designated flood event*.
- Overland flow zones are areas which become inundated by shallow overland floodwater during the *designated flood event*.
- The *designated flood event* is the 1:100 flood event as calculated in 1983. This is currently being updated by the Government of Alberta.

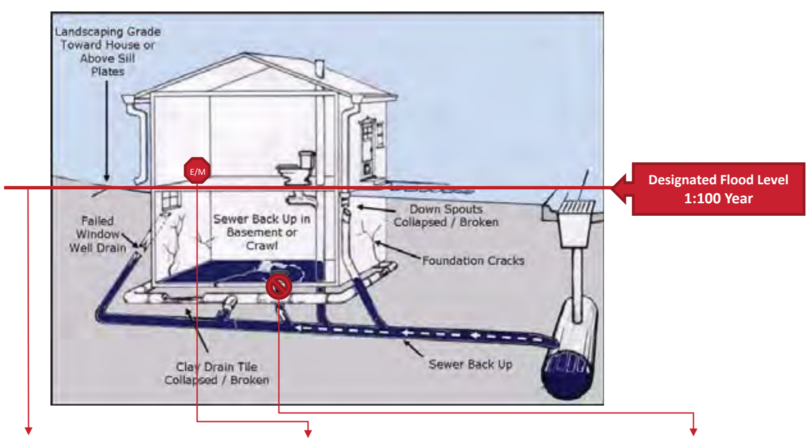


V05 4

Land Use Bylaw – Floodway

- Floodway - Area of river where velocities and depths will equal or exceed 1 m/s and/or 1m depth during the designated flood event.
- Land Use Bylaw
  - No new structures or buildings within the floodway or within the 6m setback from floodway
  - Definition of structures includes berms, decks, docks, fences, gates, patios, rip-rap and retaining walls
  - Can replace buildings on same footprint

Land Use Bylaw, Flood Fringe



60(1)(b) the first floor of all *buildings* must be constructed at or above the *designated flood level*

60(1)(c) all electrical and mechanical equipment within a *building* shall be located at or above the *designated flood level*

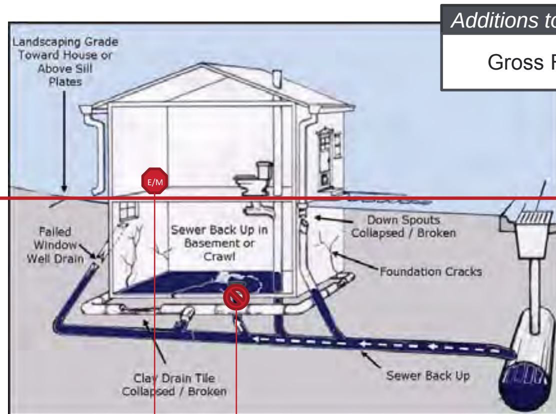
60(1)(d) a sewer back-up valve must be installed in the *building*

Calgary

Land Use Bylaw, Flood Fringe

Additions to buildings 60(2)

Gross Floor Area < 10%



Designated Flood Level 1:100 Year

60(1)(b) the first floor of all *buildings* must be constructed at or above the *designated flood level*

60(1)(c) all electrical and mechanical equipment within a *building* shall be located at or above the *designated flood level*

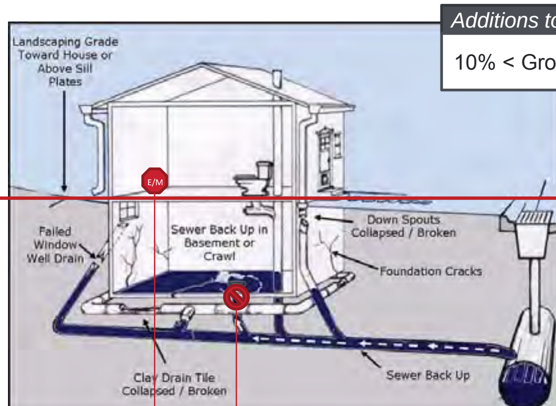
60(1)(d) a sewer back-up valve must be installed in the *building*

Calgary

Land Use Bylaw, Flood Fringe

Additions to buildings 60(3)

10% < Gross Floor Area < 75%



Designated Flood Level 1:100 Year

60(1)(b) the first floor of all *buildings* must be constructed at or above the *designated flood level*

60(1)(c) all electrical and mechanical equipment within a *building* shall be located at or above the *designated flood level*

60(1)(d) a sewer back-up valve must be installed in the *building*

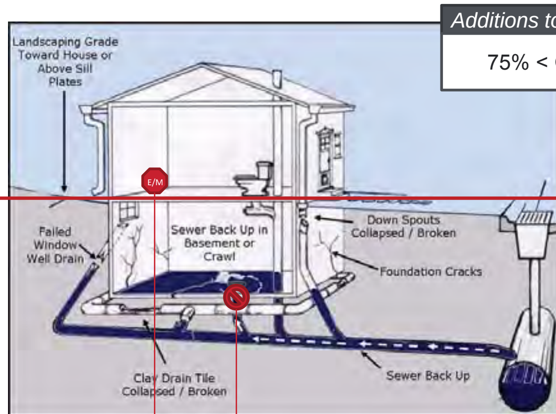
Electrical isolation for entire *building* above *designated flood level*

Calgary

Land Use Bylaw, Flood Fringe

Additions to buildings 60(4)

75% < Gross Floor Area



Designated Flood Level 1:100 Year

60(1)(b) the first floor of all *buildings* must be constructed at or above the *designated flood level*

60(1)(c) all electrical and mechanical equipment within a *building* shall be located at or above the *designated flood level*

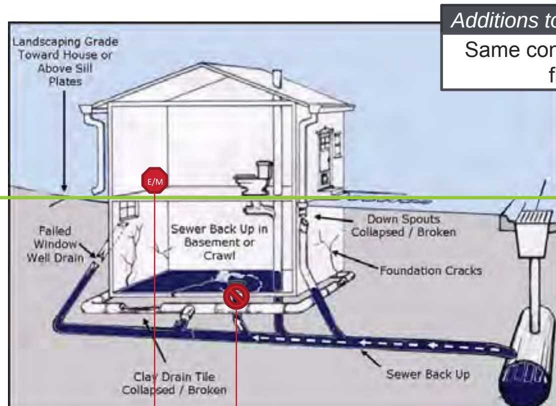
60(1)(d) a sewer back-up valve must be installed in the *building*

Calgary

Land Use Bylaw, Overland Flow

Additions to buildings 61(2,3,4)

Same conditions apply as for flood fringe



Minimum 0.3 m above highest grade on abutting street

61(1)(b) the first floor of all *buildings* must be constructed at a minimum of 0.3 meters above the highest grade existing on the street abutting the parcel

61(1)(c) all electrical and mechanical equipment within a *building* shall be located at or above the *first floor* as reference in 61(1)(b)

61(1)(d) a sewer back-up valve must be installed in the *building*

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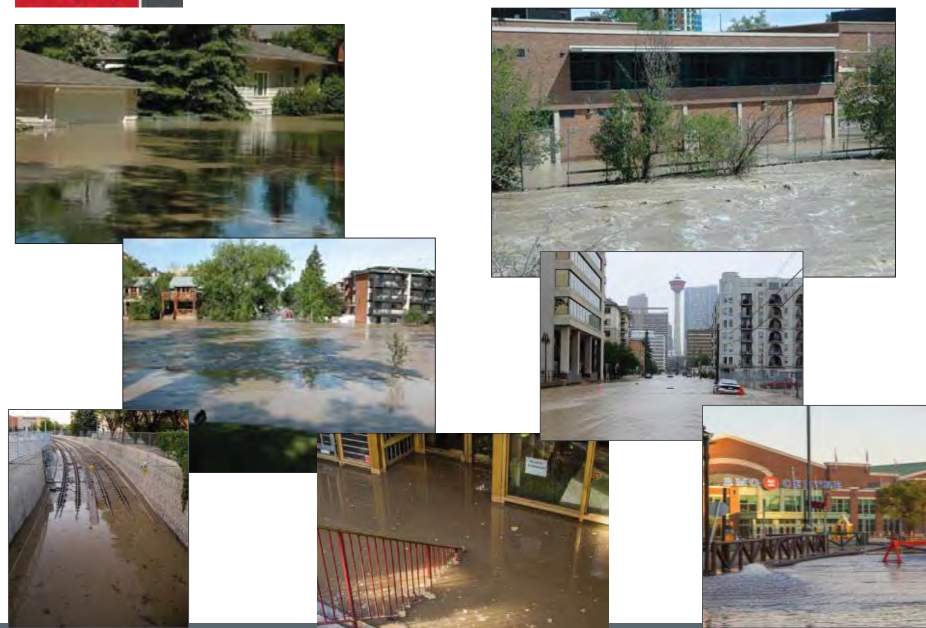
Challenges to address



V05 11

Calgary

Challenges to address

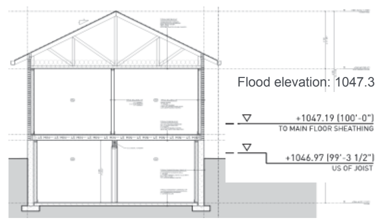
- Where to apply regulations (which areas)
- Where to apply relaxations (protected areas?)
- Design flood – now and in future climate
- Regulating basements – elevation, use (living areas, bedrooms, suites)
- Quantifying groundwater impacts and area
- Clarity in bylaw – e.g., flood proofing, mechanical/electrical, main floor
- Densification – requirements for safe evacuation, emergency response/planning
- “Critical” Infrastructure, utilities – all development is not equal?
- Other risks: erosion, channel avulsion, ice jam flooding
- Process – inspections, requirement for engineering report, capacity to review

V05 12

Calgary

Challenges to address: Groundwater

- Groundwater risk or mitigation not currently regulated in LUB.
    - Sump pumps and backflow valves are advised or required
- Groundwater risk due to high river levels is flagged in development applications
- Potential regulation:
    - minimum / basement elevation
    - below-grade habitable space
    - suites
    - building openings
    - parkades



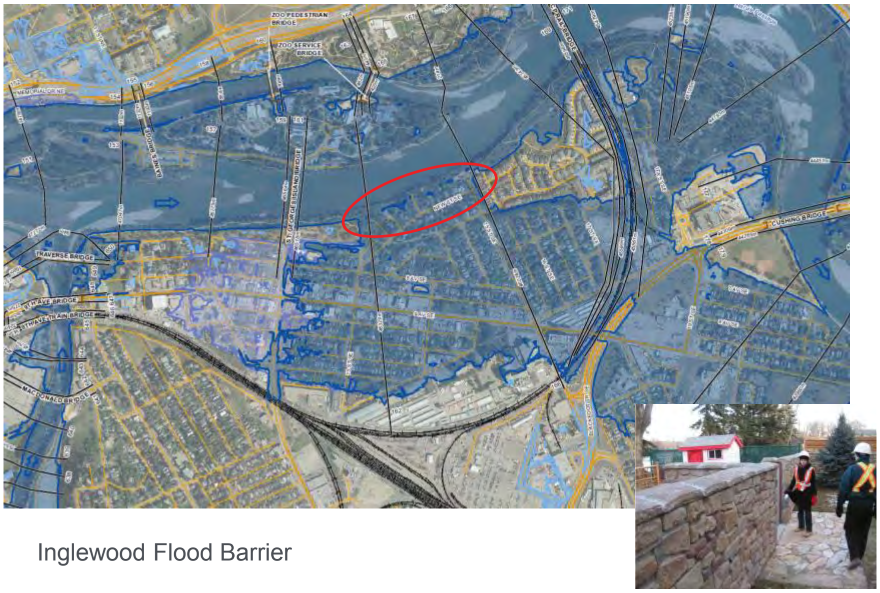
Calgary

Challenges to address: Regulation in areas protected by flood mitigation infrastructure

- Could show “protected flood fringe” on maps, for areas with reduced risk due to flood mitigation infrastructure (e.g., barriers, reservoirs)
- Dedicated flood mitigation infrastructure reduces flood risk – in some areas, to below 1:100 – this lower risk should be reflected in development restrictions in these areas
- High groundwater still a risk, unless full groundwater mitigation is included

Calgary

Example: area with a flood barrier



Inglewood Flood Barrier

V05

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Example: area with upstream mitigation

Elbow River 1:20 flood – mitigated to a 1:5 flood (or less), post improvements to Glenmore Dam

V05

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Disaster Recovery Program

- Basement Materials Acceptable
- Basement penetrations Sealed
- Disconnect or Panel above grade
- Basement Circuits Isolated
- Back Water Protection

Flood Mitigation Permit Form
Disaster Recovery Program
1-866-825-4455
PLEASE PRINT

Project Location
Project address | Municipality

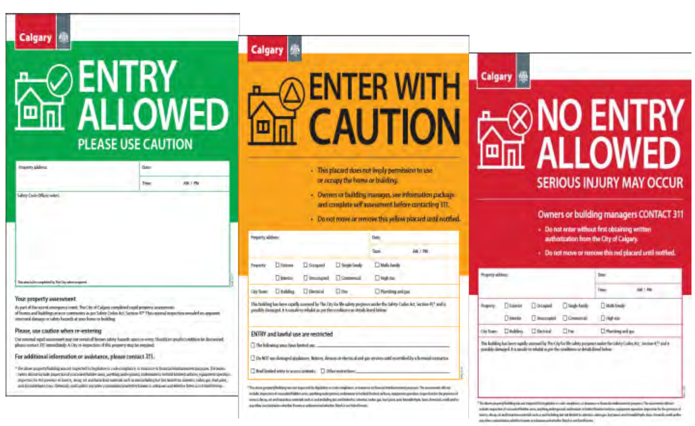
Applicant/Owner Information
Owner Name | Contact Person | Phone
Address (if different than Project Address) | Fax
DRP Reference Number

Permit Information
Building | Contractor Name | Building Permit Number
Issuer signature (or attach permit copy)
Basement Penetrations Sealed | ☐ Yes ☐ No ☐ NA (if NA explain)
Basement materials Acceptable | ☐ Yes ☐ No ☐ NA (if NA explain)
Building Certified Compliant | SCO Signature | Date
Electrical | Contractor Name | Electrical Permit Number
Issuer signature (or attach permit copy)
Disconnect or panel above grade | ☐ Yes ☐ No ☐ NA (if NA explain)
Basement circuits isolated | ☐ Yes ☐ No ☐ NA (if NA explain)
Electrical Certified Compliant | SCO Signature | Date
Plumbing | Contractor Name | Plumbing Permit Number
Issuer signature (or attach permit copy)
Back Water protection in place | ☐ Yes ☐ No ☐ NA (if NA explain)
Plumbing Certified Compliant | SCO Signature | Date

Project Information
Applicant's Declaration, I certify that information provided above and/or submitted with this application is true and correct.
Please Print Name | Signature
Address | Phone Number | Date

Calgary

Rapid Damage Assessment



2017
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SAIT

Southern Alberta Institute of Technology

The time is **now**.

INTEGRATED WATER MANAGEMENT

This initiative is the first integrated water management diploma in Canada. Graduates will have transferable skills for working in a multitude of industries such as energy, government, non-profit, agriculture, education, manufacturing, engineering and construction.

Climate Change and Water Management Course

Climate change fundamentally changes how and when we receive water and directly affects water management decisions. This course will prepared graduates to take action on climate change throughout their careers.

- **Psychological Element of Climate Change**
- **Climate Change Fundamentals and Impacts**
- **Indigenous Knowledge and Climate Impacts**
- **Emergency Preparedness, Response and Recovery**
- **Adaptive Planning**

sait.ca




Land-Based Learning • Industry Collaboration • Applied Skills Development

WATR 300 CLIMATE CHANGE AND WATER MANAGEMENT Course Outcomes

Psychological Element of Climate Change
Develop appropriate water-related climate change communication materials reflecting the values and perceptions of various stakeholders.

Climate Change Fundamentals and Impacts
Explain the current context to changes in our climate and the impacts on water management.

Indigenous Knowledge and Climate Impacts
Explain how Indigenous knowledge can inform adaptation to climate change and water.

Emergency Preparedness, Response and Recovery
Prepare for emergency responses and recovery in water-related disasters by developing technical elements of preparedness plans and practicing response actions.

Adaptive Planning
Develop a strategic adaptation plan to reduce water-related impacts of climate change.

V05

Flood Hazard Management Initiatives in BC

JESAL SHAH

Ministry of Forests, Lands, Natural Resource Operations and Rural Development, BC, Canada

Abstract

Since 2016, the Province of BC has spent approximately $200M to respond to and recover from flooding. To help reduce these costs in the future, the province is investing over $10M in several important flood hazard management initiatives such as risk assessments of BC dikes, flood risk strategies, Emergency Program Act modernization, and the BC Extreme Flood project. This presentation will provide an overview of these projects and describe how they will help improve BC's resilience to flooding.

Biography

Mr. Jesal Shah holds a B.S. and M.S. in civil and environmental engineering from the University of Southern California, and in 2015 he completed his MBA from the University of Victoria.

Jesal has been a part of BC Public Service for the last 11 years, working as a Flood Safety Engineer in the Water Management Branch, the Director of the Disaster Mitigation Unit at Emergency Management BC, and currently as the Manager of Dam Safety and Water Utilities. In his career in BC, he has managed several hazard mitigation funding programs and flood hazard management projects with total value worth over $150 million. Prior to moving to BC, Jesal worked as a civil engineer in both the public and private sectors in California.

BC Flood Resiliency Projects

Jesal Shah, P.E., P.Eng., MBA

Manager – Dam Safety and Water Utilities

Ministry of Forests, Lands, Natural Resource Operations & Rural Development

February 27, 2020

Provincial Orphan Dike Assessment

- Objectives:
  - Document the condition of the works
  - Inform local government of benefits and risks
  - Inform the public living near these structures of the benefits and risks
  - Provide information and aid to local governments in making an informed decision to become the diking authority for these works

Seismic Assessment and Geotechnical Investigation of Lower Mainland Dikes

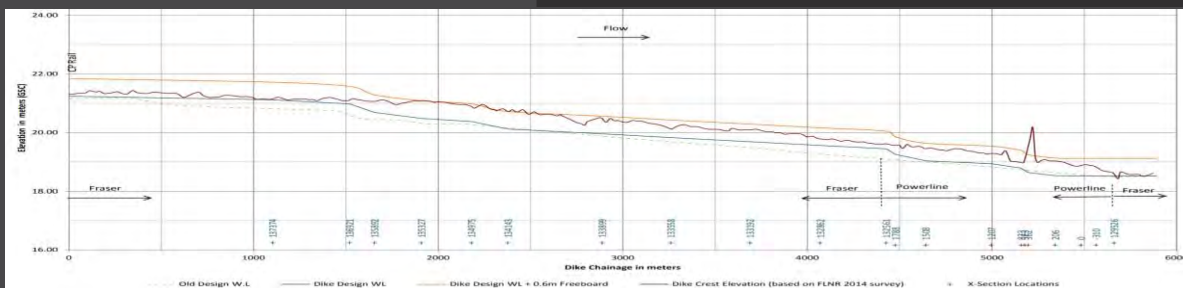
- The goal is to develop seismic resiliency for the dikes in the lower mainland
- The program will begin with:
  - Geotechnical investigations of the soil structures along the Lower Fraser
  - Analysis the risk of dike failure during earthquakes of various magnitudes
  - Review seismic guidelines and develop options for resilience
  - Create professional practice guidelines for seismic design of dikes

Provincial Dike Crest Survey

- GPS survey regarding approximately 900 kms of regulated dikes in the province
- The goal is to determine the existing dike crest heights
- These will then be compared to design flood stage heights
- This allows for the determination of flood level protection offered by these dikes and identify areas of concern
- Profile drawings will be created for informational purposes by local governments and diking authorities.

Fraser River 2D Hydraulic Model

- This project will create a new, more accurate model of the Lower Fraser River (from Hope to the Salish Sea)
- Establish a new Fraser River design flood profile for the communities in the Lower Fraser
- Utilize new inputs developed for the Province from the Climate Change Scenario Modeling for the Fraser Basin project recently completed by PCIC



Dike Consequence Classification

- Develop in-depth dike consequence classification system (low → extreme)
- This would provide expanded information on the economic, social, and environmental losses associated with failure of the regulated dikes in the province
- The results will also inform which dikes are required to meet the seismic design guidelines and assist in prioritizing mitigation funding and emergency response.

BC Flood Portal

Creation of a single access portal for public and enhanced access for government bodies

- oFloodplain maps & reports
- oDike consequence classification
- oDike information
- oDike survey & elevation profiles

The site will also be the portal for the BC Flood Risk Strategy where information will be held for public viewing/input

BC Flood Risk Strategy

This high-level commitment document will articulate visions, principles, and key outcomes for integrated flood management in BC.

It is the first step to develop and implement measures to increase public confidence that the Province is taking actions to understand, prepare, and respond to risks related to flooding and climate change.

Risk strategy is necessary to help province focus on risk identification and mitigation, which are key to managing hazards and reducing the impact of events.

Strategy will complement Provincial Flood Emergency Plan that guides and coordinates response actions.

Probable Maximum Precipitation Guidelines for British Columbia

- Objectives:
  - Develop a database of historical extreme storms to be used in PMP studies across the province of BC
  - Develop comprehensive PMP estimation guidelines for the entire province considering different geographic and climatic regions
  - Improve design of structures that must manage extreme flood events.

British Columbia Regional Precipitation Frequency Analysis

- Objectives:
  - Complete single station precipitation frequency analysis and regional precipitation frequency analysis
  - Prepare guidelines for completing precipitation frequency analysis studies in BC

British Columbia Regional Flood Frequency Analysis

- Objectives:
  - Complete single station flood frequency analysis and regional flood frequency analysis
  - Prepare guidelines for completing flood frequency analysis studies in BC
  - Improve baseline information for predicting the magnitude of typical flood events as well as extreme flood events across all of BC

Questions?

Contact Info:

T: (236) 478 - 0608

E: Jesal.Shah@gov.bc.ca

DAY 2
Session 3 – Part 2: Federal, Provincial, Territorial and Municipal Initiatives on Flood-Related Issues

Chair, Marco Civitarese
City of Calgary, AB, Canada

An Emergency Response Perspective to What Renders Homes Uninhabitable During Floods
Annick Maletto
Centre de Sécurité Civile, QC, Canada

Newfoundland and Labrador - Provincial Flood Risk Mapping Initiatives
Amir Ali Khan
Municipal Affairs and Environment, NL, Canada

Flood Mapping Activities, Natural Resources Canada
Paula McLeod
Natural Resources Canada

An Emergency Response Perspective to What Renders Homes Uninhabitable During Floods

ANNICK MALETTO

Centre de Sécurité Civile - Ville de Montréal, QC, Canada

Abstract

A flood event in an urban setting significantly impacts the built environment as well as the safety of citizens. As such, authorities may choose to evacuate citizens living in flood-prone areas in an effort to ensure their safety for the duration of the event. A residential building is generally considered unsafe if much or all of its living space is flooded or if the flood is affecting the structural integrity of that building. For this reason, mitigating measures tend to focus on protecting structural integrity or stopping water infiltration within the living space. Such mitigating measures do much to protect a home but they do not always ensure the safety of its residents. This presentation looks at home safety during flood events from a public safety perspective.

Biography

Ms. Annick Maletto is Section Chief at the Montréal Fire Department and heads the Montréal Civil Protection Centre. As such, she manages and oversees emergency planning and preparedness for Montréal, and assists the Emergency Management Coordinator in his duties when emergency measures are implemented. She has worked for the City of Montréal for 13 years and contributed to both climate change adaptation and disaster response. She holds an Honours Bachelor of Environmental Science from Concordia University and a Master of Atmospheric Science from the University of British Columbia.

Sécurité civile Montréal

An emergency Response Perspective of What Renders Homes Uninhabitable During Floods

Annick Maletto, Section Chief, Civil Protection Centre, Montreal
International Workshop on Flood Resistant Buildings
Ottawa, February 26-27, 2020

Sécurité civile Montréal

PRESENTATION PLAN

Cause for Evacuation

Temporary Mitigation Measures

Real-time monitoring and Response

Sécurité civile Montréal

CAUSE FOR EVACUATION

Sécurité civile Montréal

CAUSE FOR EVACUATION

STRUCTURAL INTEGRITY

- Fast flow submersion
- Previously weakened structure

CAUSE FOR EVACUATION

ELECTRICAL HAZARDS

CAUSE FOR EVACUATION

MOLD

- Even minor infiltration can be hazardous with long duration
- Hidden inflitration

CAUSE FOR EVACUATION

DRINKING WATER CONTAMINATION

- Submerged wells – No consumption advisory

CAUSE FOR EVACUATION

ACCES FOR EMERGENCY SERVICES

Sécurité civile Montréal

CAUSE FOR EVACUATION

CITIZEN ISOLATION

Sécurité civile Montréal

TEMPORARY MITIGATION MEASURES

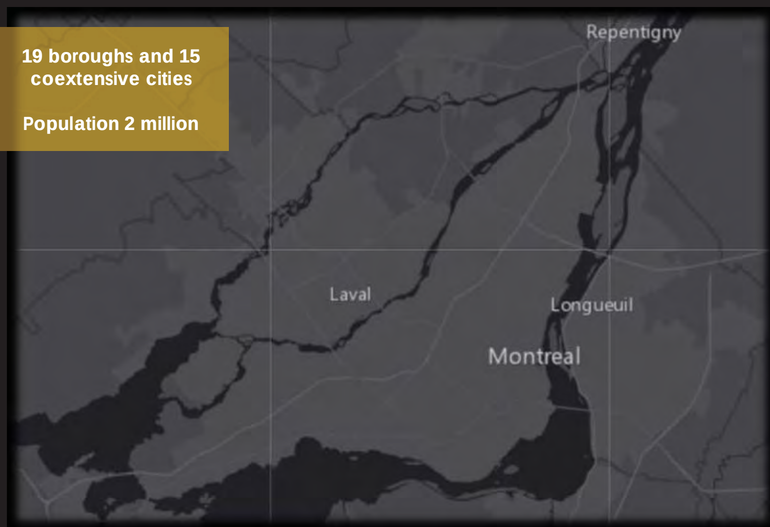
Sécurité civile Montréal

TEMPORARY MITIGATION MEASURES

Montreal Agglomeration

19 boroughs and 15 coextensive cities

Population 2 million



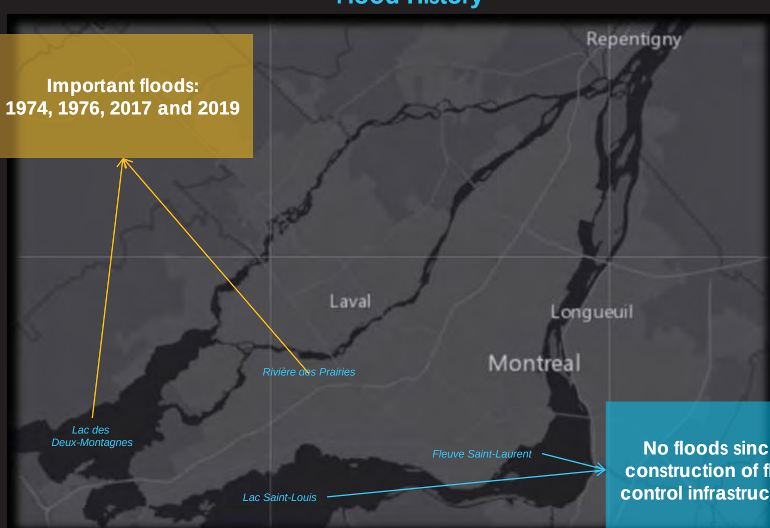
Sécurité civile Montréal

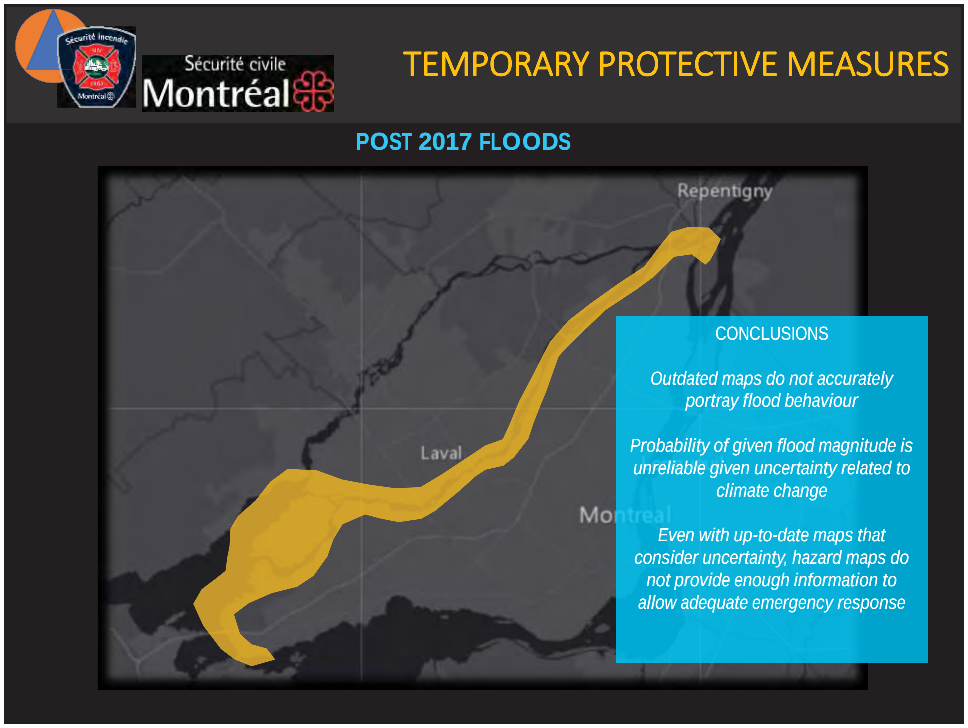
TEMPORARY MITIGATION MEASURES

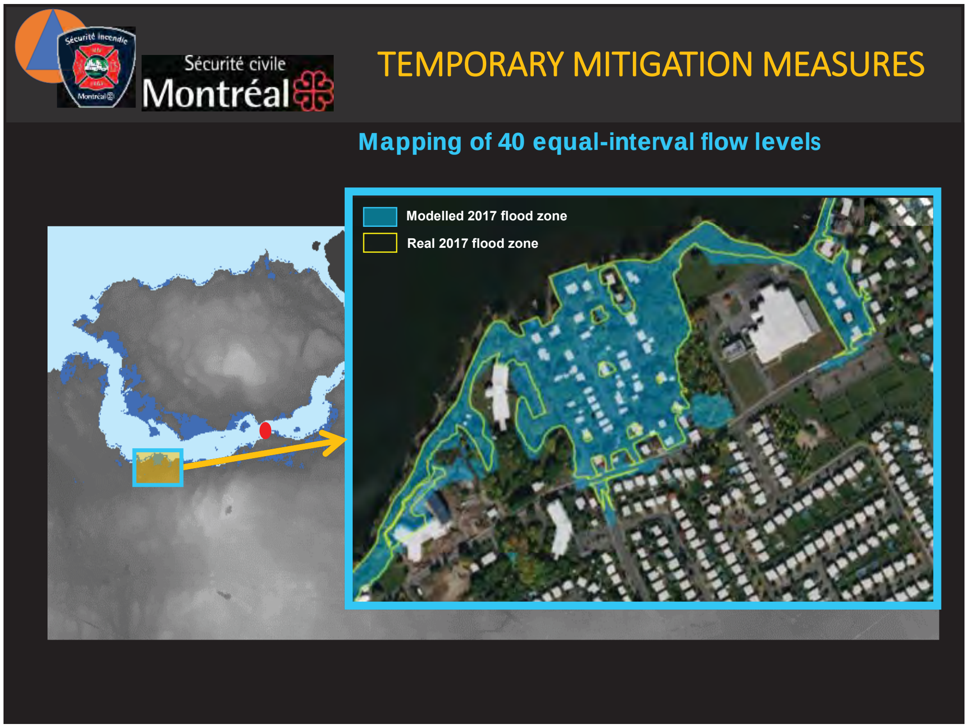
Flood History

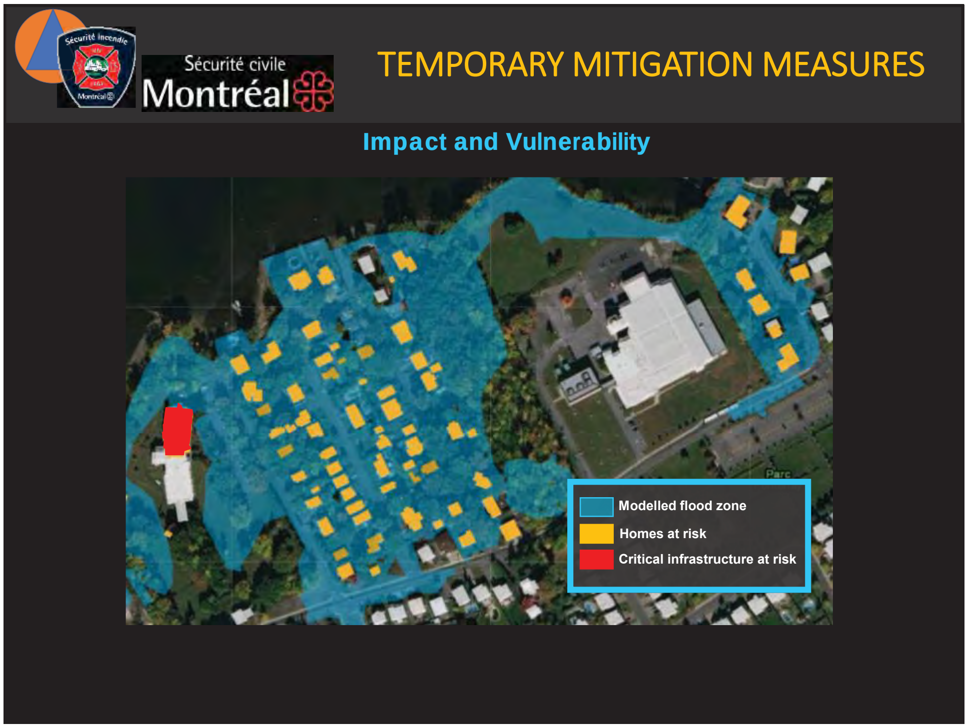
Important floods: 1974, 1976, 2017 and 2019

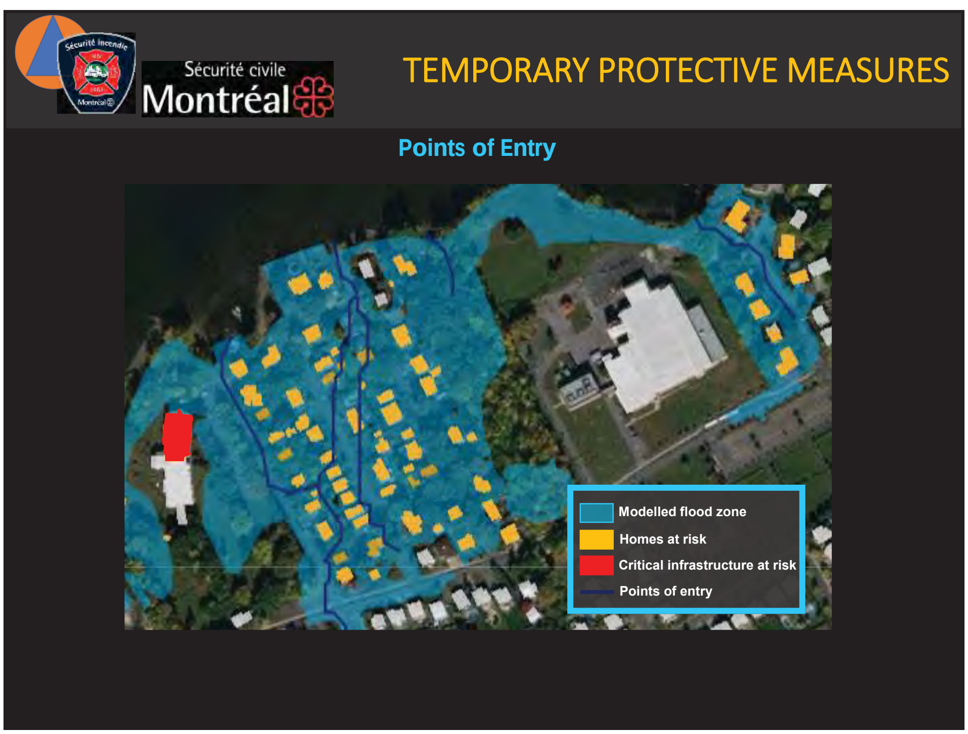
No floods since construction of flow control infrastructure

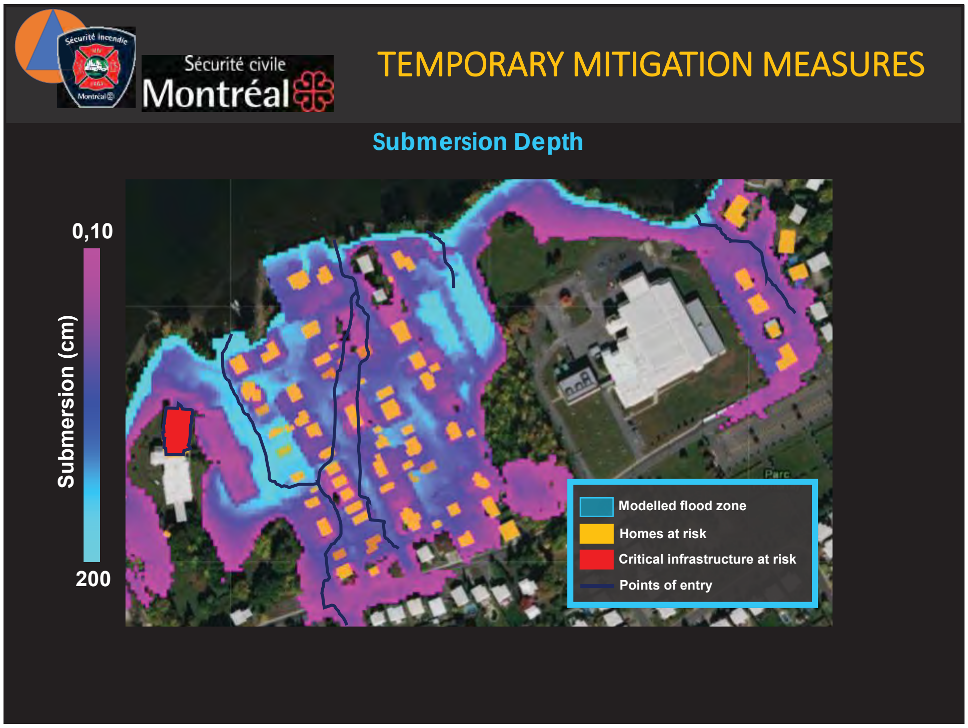


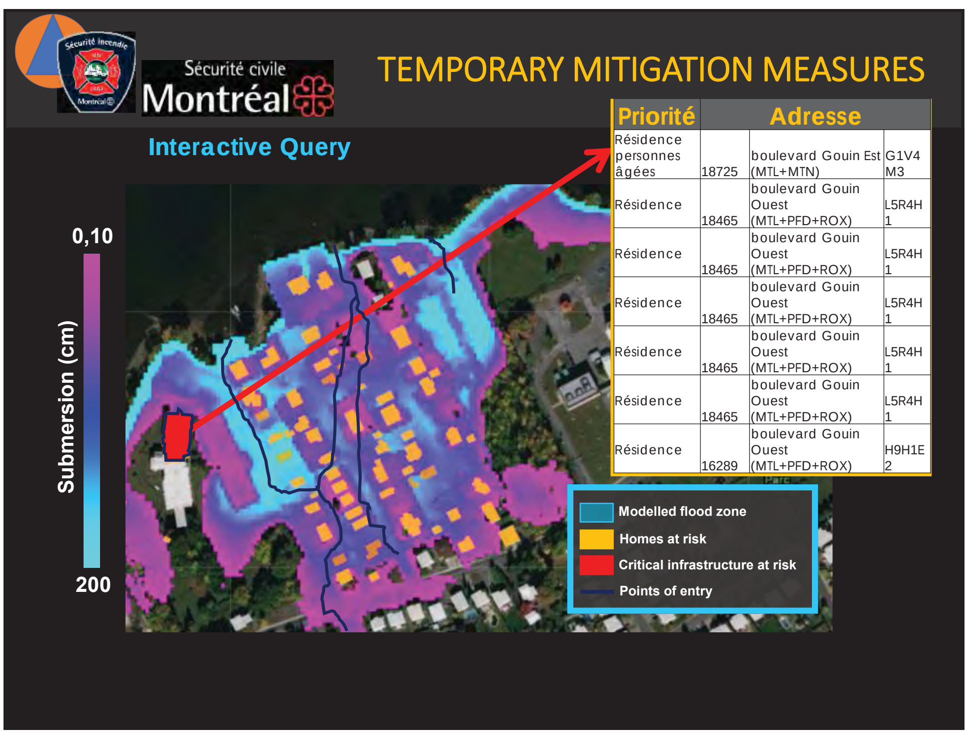

Sécurité civile
Montréal
TEMPORARY PROTECTIVE MEASURES
POST 2017 FLOODS
Repentigny
Laval
Montreal
CONCLUSIONS
Outdated maps do not accurately portray flood behaviour
Probability of given flood magnitude is unreliable given uncertainty related to climate change
Even with up-to-date maps that consider uncertainty, hazard maps do not provide enough information to allow adequate emergency response


Sécurité civile
Montréal
TEMPORARY MITIGATION MEASURES
Mapping of 40 equal-interval flow levels
Modelled 2017 flood zone
Real 2017 flood zone

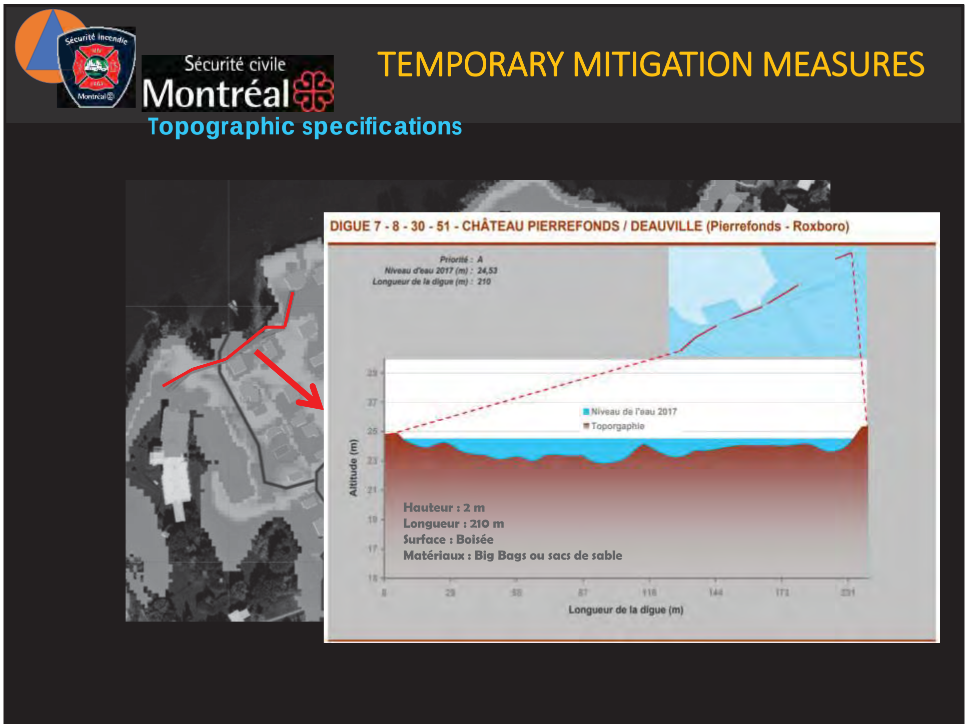

Sécurité incendie
Sécurité civile
Montréal
TEMPORARY MITIGATION MEASURES
Impact and Vulnerability
Modelled flood zone
Homes at risk
Critical infrastructure at risk


Sécurité incendie
Sécurité civile
Montréal
TEMPORARY PROTECTIVE MEASURES
Points of Entry
Modelled flood zone
Homes at risk
Critical infrastructure at risk
Points of entry

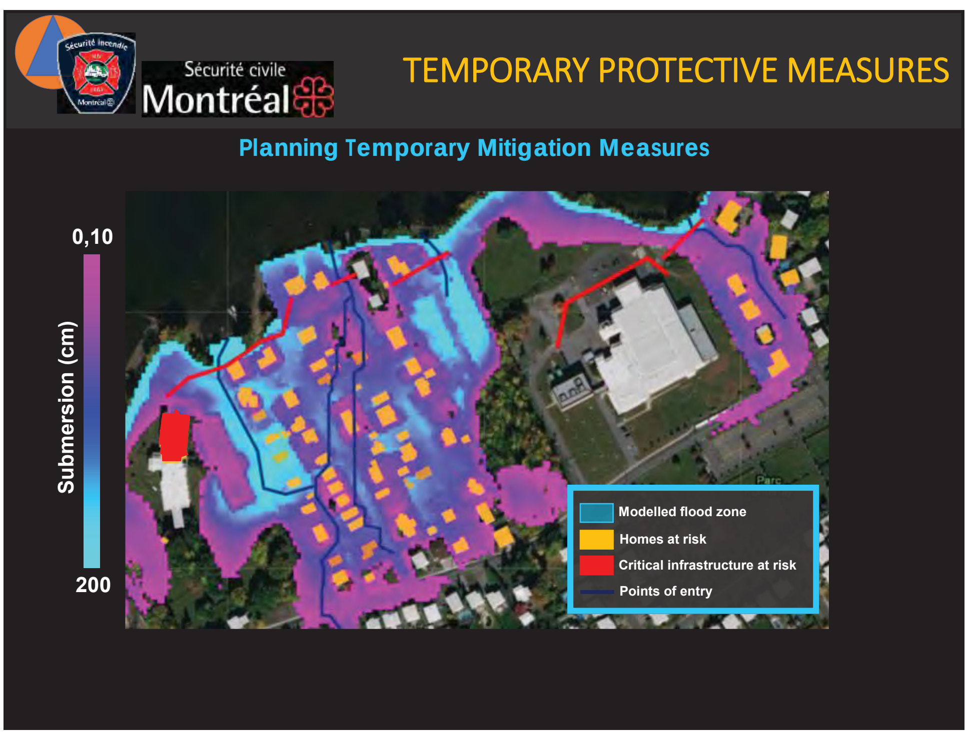




Priorité	Adresse		
Résidence personnes âgées	18725	boulevard Gouin Est (MTL+MTN)	G1V4 M3
Résidence	18465	boulevard Gouin Ouest (MTL+PFD+ROX)	L5R4H 1
Résidence	18465	boulevard Gouin Ouest (MTL+PFD+ROX)	L5R4H 1
Résidence	18465	boulevard Gouin Ouest (MTL+PFD+ROX)	L5R4H 1
Résidence	18465	boulevard Gouin Ouest (MTL+PFD+ROX)	L5R4H 1
Résidence	18465	boulevard Gouin Ouest (MTL+PFD+ROX)	L5R4H 1
Résidence	16289	boulevard Gouin Ouest (MTL+PFD+ROX)	H9H1E 2



Sécurité civile
Montréal
TEMPORARY MITIGATION MEASURES
Topographic specifications
DIGUE 7 - 8 - 30 - 51 - CHÂTEAU PIERREFONDS / DEAUVILLE (Pierrefonds - Roxboro)
Priorité : A
Niveau d'eau 2017 (m) : 24,53
Longueur de la digue (m) : 210
Niveau de l'eau 2017
Toporgaphie
Altitude (m)
Hauteur : 2 m
Longueur : 210 m
Surface : Boisée
Matériaux : Big Bags ou sacs de sable
Longueur de la digue (m)



Sécurité civile
Montréal
TEMPORARY PROTECTIVE MEASURES
Planning Temporary Mitigation Measures
0,10
Submersion (cm)
200
Modelled flood zone
Homes at risk
Critical infrastructure at risk
Points of entry

TEMPORARY MITIGATION MEASURES

2019: Efficiency of Temporary Protective Measures

Sécurité civile Montréal

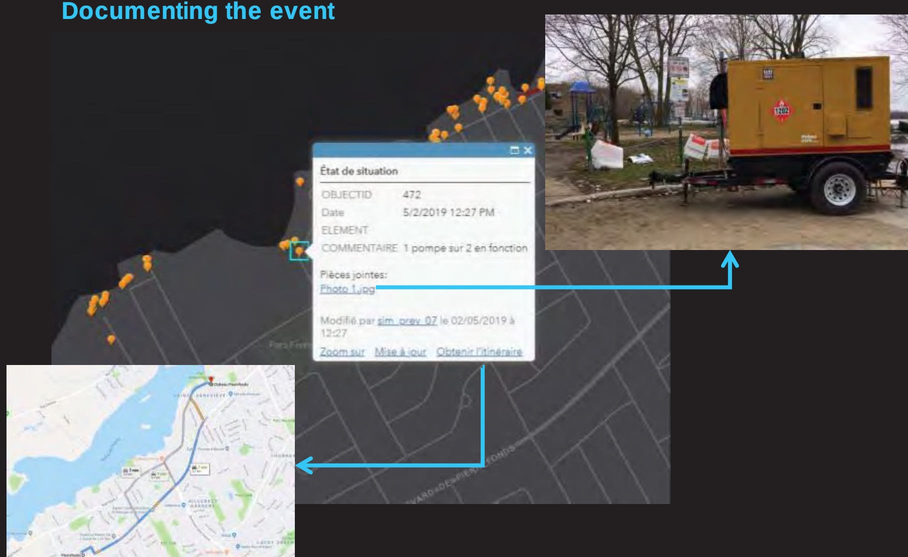
REAL-TIME MONITORING

Sécurité civile Montréal

REAL-TIME MONITORING

REAL-TIME MONITORING

Documenting the event



Sécurité civile Montréal

REAL-TIME MONITORING

Real-time Dashboard

Sécurité civile Montréal

THANK YOU!

annick.maletto@montreal.ca

Newfoundland and Labrador - Provincial Flood Risk Mapping Initiatives

AMIR ALI KHAN

Department of Municipal Affairs and Environment, NL, Canada

Abstract

The Province of Newfoundland and Labrador, in conjunction with the federal government, has worked to reduce the human hardship and economic loss of floods through the Canada-Newfoundland Flood Damage Reduction Program (CNFDRP), the Atlantic Climate Adaptation Solutions (ACASA) Project, and more recently the National Disaster Mitigation Program (NDMP). A new template for flood risk mapping was developed in 2009 and has been enhanced over the years to include climate change flood-risk mapping, inundation mapping, velocity mapping and hazard mapping.

The presentation describes this work, including the templates and tools developed by the Province.

Biography

Dr. Amir Ali Khan, Ph.D, P.Eng, is the Manager of the Water Rights, Investigations and Modelling Section with Newfoundland and Labrador's Department of Municipal Affairs and Environment. His responsibilities include water rights, flood-risk mapping, flood forecasting, flood alerts and climate change adaptation. He developed the climate change flood-risk mapping template used in Newfoundland and Labrador.

His Ph.D. in Civil Engineering is from Memorial University of Newfoundland. He is also a sessional instructor at Memorial University of Newfoundland.

He and his work are the recipients of several awards and commendations, including the 2005 Government of Newfoundland and Labrador Individual Public Service Award for Excellence for Innovation and Service Delivery Excellence, the 2005 ESRI Canada Award of Excellence for Drinking Water Quality GIS Application, the 2018 PEGNL Environmental Award for the Badger River Ice Service, and a “Fellow of the School of Graduate Studies” title from Memorial University.

He has worked on several International Technology Innovation and International Water Resources Capacity and Technology Building Projects with international agencies such as the European Space Agency (ESA) and the North American Treaty Organization (NATO).

Newfoundland and Labrador - Provincial Flood Risk Mapping Initiatives

International Workshop on

FLOOD-RESISTANT BUILDINGS

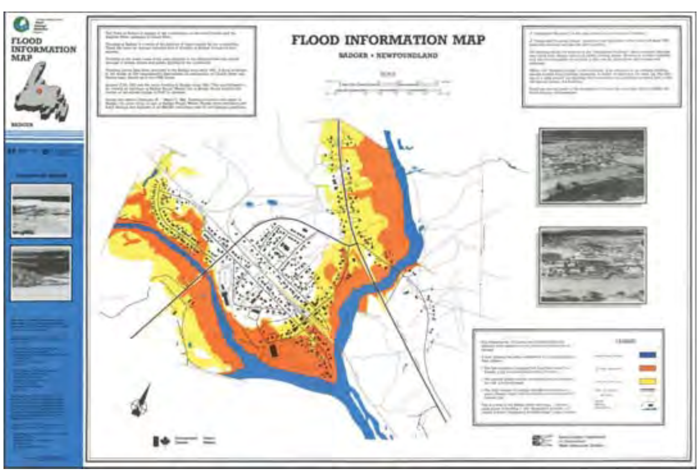
Amir Ali Khan, Ph.D., P.Eng

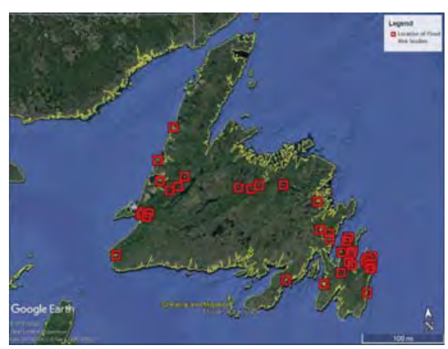
Water Resources Management Division

Government of Newfoundland and Labrador

February 27th, 2020

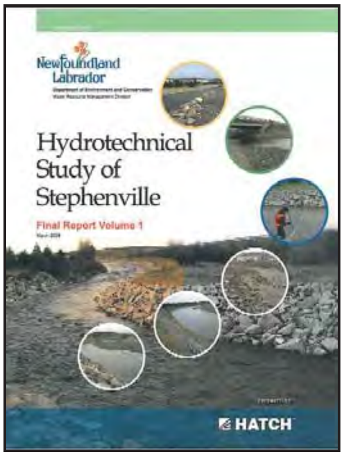
Canada-Newfoundland Flood Damage Reduction Program 1981-1996

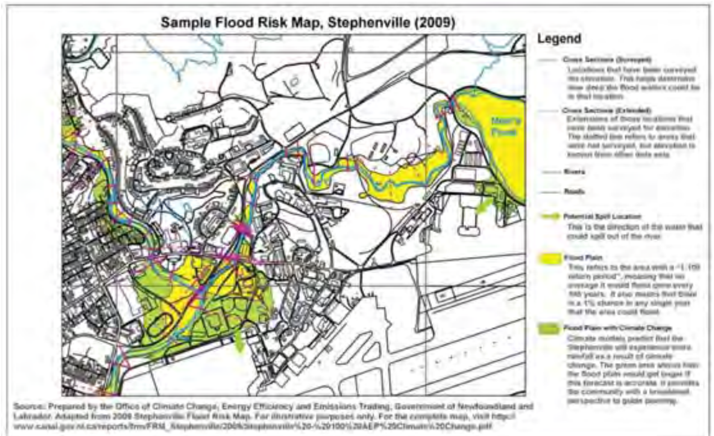




https://www.mae.gov.nl.ca/waterres/flooding/badger_flood_risk.pdf

Climate Change Floodplain Mapping - 2009





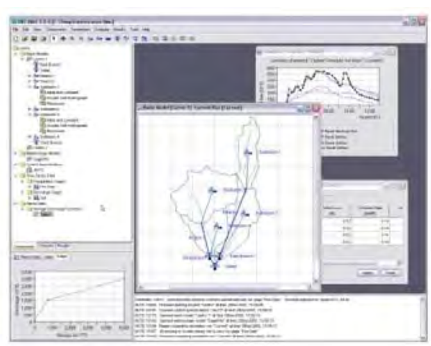
https://www.mae.gov.nl.ca/waterres/flooding/frm.html

Newfoundland Labrador

Set Up a Hydrologic Model- 2009

The consultant will be required to undertake both a stochastic (a flood frequency analysis and a regional flood frequency analysis) and deterministic (hydrologic modelling) approach in the estimation of the 1:20 and the 1:100 AEP

HEC-HMS



Newfoundland Labrador

Policy for Flood Plain Management - 2010

Provincial Policy for Flood Plain Management

Updated in 2010

Regulates development in CC flood zone

Category	All Flood Plains	Where Flood Plains are Designated		
		Floodway (1:20 year Zone)	Floodway Fringe (1:100 year Zone)	Climate Change Flood Zone
Temporary alterations	Permitted	Permitted	Permitted	Permitted
Non-structural uses	Permitted	Permitted	Permitted	Permitted
Structures related to use of water resources	Permitted	Permitted	Permitted	Permitted
Minor structural or other projects	Permitted	Permitted with conditions*	Permitted with conditions*	Permitted with conditions*
Other structures not used primarily for residential	Permitted with conditions*	Permitted with conditions*	Permitted with conditions*	Permitted with conditions*
Industrial Uses related to shipping (marine only)	Permitted with conditions*	Permitted with conditions*	Permitted with conditions*	Permitted with conditions*
Other industrial and commercial	Not Permitted	Not Permitted	Permitted with conditions*	Permitted with conditions*
Institutional	Not Permitted	Not Permitted	Not Permitted	Not Permitted
Residential and other institutional	Not Permitted	Not Permitted	Permitted with conditions*	Permitted with conditions*
Hydraulic Structures	Permitted	Permitted	Permitted	Permitted

Newfoundland Labrador

https://www.mae.gov.nl.ca/waterres/regulations/policies/flood_plain.html

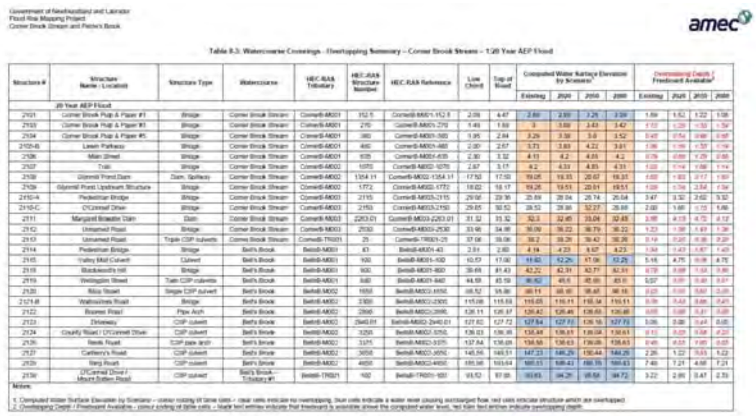
Policy for Flood Plain Management - 2010

1. the ground floor elevation of the structure is higher than the 1:100 year flood level and the climate change flood zone (where designated), and,
2. the structure will not interfere with the flow of water or displace water such that it creates a worse flooding situation for other properties, and,
3. the structure and the associated utilities must be designed and constructed in accordance with the approved flood proofing guidelines of the Department and entrances and exits from the building can be safely used without hindrance in the event of a flood, and,
4. the proposed use of the facility and site will not involve any storage of pollutants such as fuels, chemicals, pesticides etc., and,
5. additional conditions which may be appropriate for specific projects and included in a permit issued under Section 48 of the Act.

Newfoundland Labrador

https://www.mae.gov.nl.ca/waterres/regulations/policies/flood_plain.html

Infrastructure Assessment - 2010



https://www.mae.gov.nl.ca/waterres/flooding/frm.html

Newfoundland Labrador

Future Sea Level Rise/Land Use - 2013

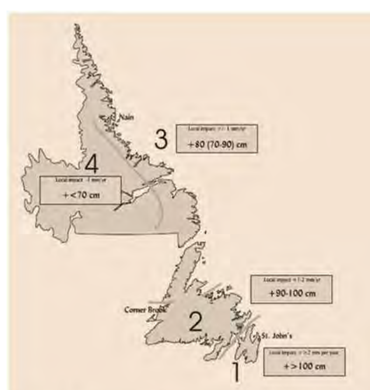


Figure 4. *Projections of potential relative sea-level rise in Newfoundland and Labrador by 2099.*

http://www.nr.gov.nl.ca/mines&en/geosurvey/publications/CR2010/2010_Batterson-Liverman.pdf

Newfoundland Labrador

LiDAR – Inundation Mapping – 2012/2013

Federal Airborne LiDAR Data Acquisition Guideline, Version 1.1, 2017

8.05 Projects Permitted Where Flood Plains Are Designated

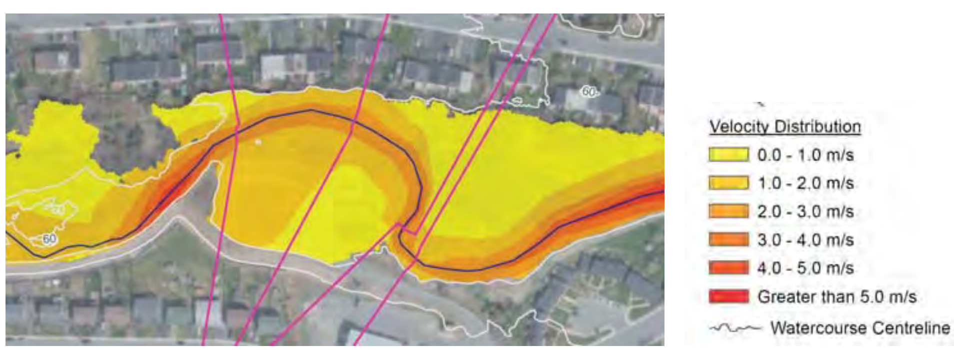
In Table 1 where projects may be permitted with conditions, the following conditions will apply:

i. the ground floor elevation of the structure is higher than the 1:100 year flood level and the climate change flood zone (where designated), and,

https://www.mae.gov.nl.ca/waterres/flooding/frm.html

Newfoundland Labrador

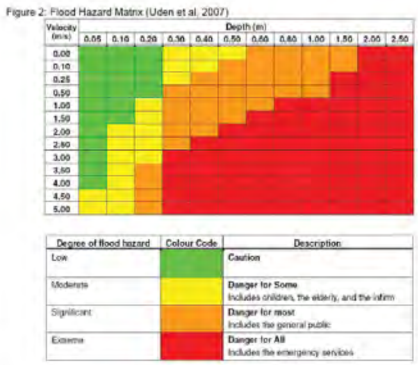
Velocity Mapping - 2013

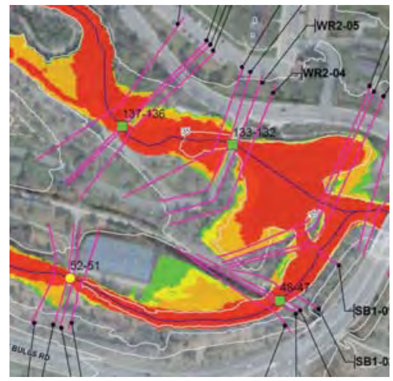


https://www.mae.gov.nl.ca/waterres/flooding/frm.html

Newfoundland Labrador

Flood Hazard Mapping - 2013





https://www.mae.gov.nl.ca/waterres/flooding/frm.html

Newfoundland Labrador

Hurricane Season Flood Alert System - 2014

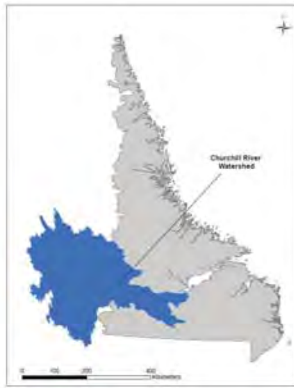
This system generated over 9630 flood forecasts for 45 communities/areas and issued 59 flood alerts in 2018.

https://www.mae.gov.nl.ca/waterres/flooding/hurricane.htm

Newfoundland Labrador

Real Time Flood Forecasting Systems - 2019

1. Churchill River Flood Forecast System (CRFFS) -2019
2. Humber River Flood Forecast System (HRFFS) -2020
3. Exploits River Flood Forecast System (ERFFS) -2020



Newfoundland Labrador

Churchill River Flood Forecasting System - 2019

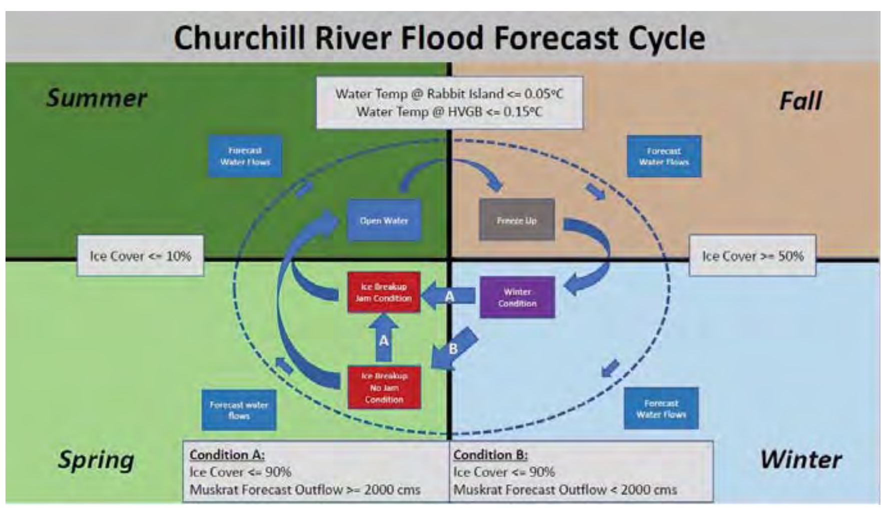
Lower Churchill River Flood Forecasting System

Simulates water levels through out the year

KGS GROUP CONSULTING ENGINEERS

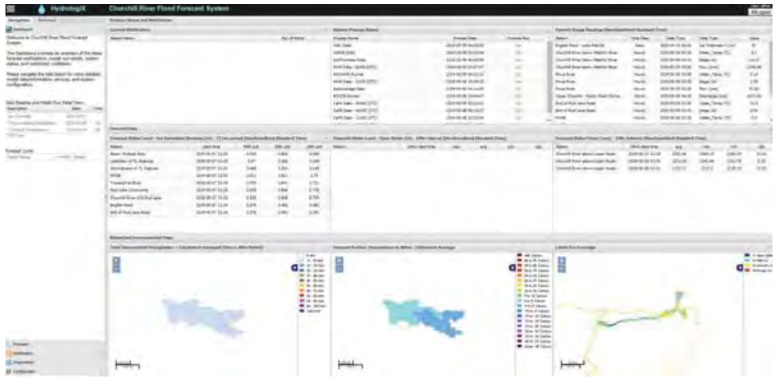
4DM Providing solutions through mapping technology

UNIVERSITY OF SASKATCHEWAN Global Institute for Water Security USASK.CA/WATER



Churchill River Flood Forecasting System - 2019

- Automated web based flood forecasting tool is the first system in the country to incorporate real time remote sensing data with real time water flows, ice thickness and weather data.



Dashboard for Current Conditions (water level, weather, ice etc) and Forecasted Conditions

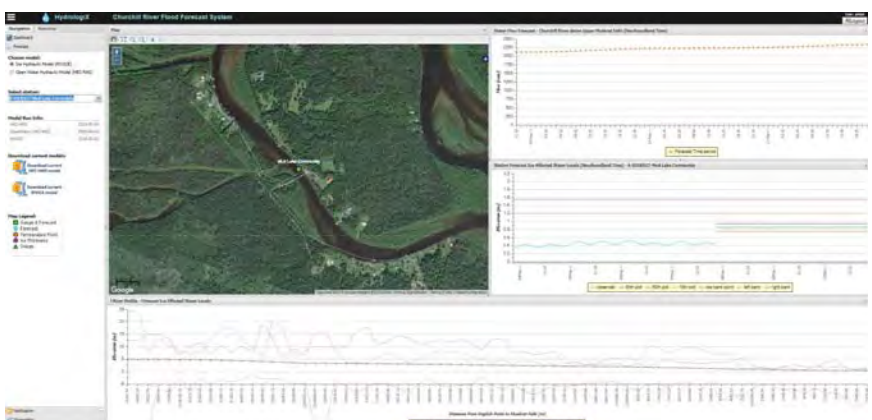
Newfoundland Labrador

Churchill River Flood Forecasting System - 2019

KGS GROUP CONSULTING ENGINEERS

4DM Providing solutions through mapping technology...

UNIVERSITY OF SASKATCHEWAN Global Institute for Water Security USASK.CA/WATER



Information Windows for each Forecast

Models can be downloaded

Newfoundland Labrador

Climate Change Floodplain Mapping Studies

Since 2009 the following FRM studies have been completed:

1. Hydrotechnical Study of Stephenville 2009
2. Hydrotechnical Study of Stephenville Crossing/Black Duck Siding 2012
3. Town of Logy Bay – Middle Cove – Outer Cove Flood Risk Mapping Study 2012
4. Flood Risk Mapping Project for Shearstown/Bay Roberts Area 2012
5. Flood Risk Mapping Project Goulds and Petty Harbour Area 2013
6. Flood Risk Mapping Project Corner Brook Stream and Petrie's Brook 2013
7. Town of Portugal Cove-St. Philip's Flood Risk Mapping Study 2015
8. Waterford River Flood Risk Mapping Study 2018
9. Lower Churchill River Flood Risk Mapping Study 2020
10. Exploits River Flood Risk Mapping Study 2020
11. Humber River Flood Risk Mapping Study 2020

https://www.mae.gov.nl.ca/waterres/flooding/frm.html

Newfoundland Labrador

Thank You!

Amir Ali Khan, Ph.D., P.Eng
Phone: (709) 729-2295
Email: akhan@gov.nl.ca
Web: https://www.mae.gov.nl.ca/waterres/flooding/index.html

Newfoundland Labrador

Flood Mapping Activities, Natural Resources Canada

PAULA MCLEOD

Natural Resources Canada

Abstract

In recognition of increasing disaster risks and costs, the Government of Canada is investing in flood mapping as part of its commitment to build safer and more resilient communities. Natural Resources Canada (NRCan) has been working in collaboration with federal, provincial, territorial, Indigenous and academic organizations to advance Flood Mapping to reduce the impacts of floods on Canadians. Flood maps inform communities about flood mitigation and land planning. Flood maps can be used to inform adaptation measures and raise awareness of risks of development in flood zones. During major flood events in Canada, Natural Resources Canada provides the Government Operations Centre near real-time delineations of inundation extents, derived from satellite imagery. Natural Resources Canada provides leadership, expertise, guidelines, and conducts engagement activities in support of flood mapping and data sharing. The availability of current flood maps and the sharing of flood-risk data in Canada are key to strengthening resiliency. NRCan is actively collecting information in an effort to fully understand and share knowledge about the state of flood mapping in Canada.

Biography

Paula McLeod graduated from the University of Toronto with a Bachelor of Science in Surveying and has obtained a Canada Lands Surveyor (CLS) Commission. She joined Natural Resources Canada in 1993 as a Geomatics Engineer working in areas of cadastral and geodetic surveying, remote sensing and mapping. She has experience in the areas of international collaboration, open geospatial data, policy analysis, representing Canada in various committees and technical fora, geospatial standards and policies, geographical names data management, and national scale datasets. Currently her focus is on managing an earth observation science and geospatial program for providing data about Canada's freshwater resources. She also leads programs and advises a federal initiative for national flood mapping in support of risk mitigation for community resilience. From 1998 to 2014, she worked on advancing the Canadian Geospatial Data Infrastructure by developing research and technical and policy projects in partnership with public, academic, private sector and international stakeholders.

Natural Resources Canada / Ressources naturelles Canada

Flood Mapping Activities

Paula McLeod

Canada Centre for Mapping and Earth Observation
Natural Resources Canada

Canada

Presentation

- Flood maps
- Natural Resources Canada and Flood Mapping
- Federal Flood Mapping Guidelines
- Collaborations

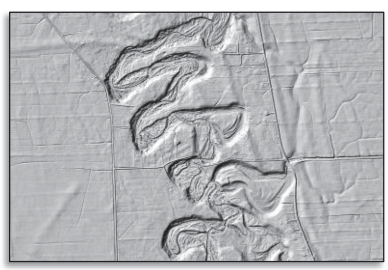
Natural Resources Canada / Ressources naturelles Canada

Flood Maps

- Flood maps are the first step to flood risk mitigation

Flood Maps

- Current and accurate geospatial data are essential to the development of flood maps
- These maps apply throughout the emergency management cycle
- Flood maps across Canada vary



Flood Mapping

Water management is the jurisdiction of provinces and territories in Canada, including flood mapping.

Successful flood mapping programs have been conducted as joint efforts between the federal and provincial governments.

- Flood Damage Reduction Program (FDRP) 1975-1996 mapped flood hazard across the country.
- First Nations Adapt program 2017-2022, flood mapping on reserve in partnership communities.
- National Disaster Mitigation Program (NDMP) 2015-2020 with 133 mapping projects across Canada.
- Emergency Management Strategy (EMS) for Canada: National Risk Profile (EMS) 2019-2024.

However, there is currently a critical flood mapping deficit in Canada.

Provinces and territories have progressed flood mapping within their jurisdictions, but significant gaps remain, and many flood maps are out of date.

NRCan and Flood Mapping

- **Strengthening partnerships** and developing mechanisms to share flood hazard maps and new foundational geospatial data
- **Active collaboration** with F/P/T, Indigenous organizations, municipalities, academia, private sector, insurance industry, and NGOs
- **Continued engagement** with Indigenous and P/T stakeholders on the development of the *Federal Flood Mapping Guidelines Series*
- **Leadership** of Federal Flood Mapping Committee
- **Established** the Indigenous Technical Working Group on Flood Mapping
- **Developing** a long-term vision and strategy for flood mapping in Canada
- **Providing** near-real time mapping services for major flood events, increased satellite capacity through Radarsat Constellation Mission
- **Creating** a National Flood Hazard Data Layer by compiling an inventory of existing flood maps from across Canada to build a more complete national picture of flood risk, and to better understand remaining gaps.

Natural Resources Canada is actively collecting information in an effort to fully understand and share knowledge about the state of flood mapping in Canada.

Stakeholder Engagement

- Workshops, consultation meetings, webinars, conferences, and contracts

Federal Flood Mapping Committee

- Natural Resources Canada
- Public Safety Canada
- Environment and Climate Change Canada
- Department of National Defence
- National Research Council
- Canadian Space Agency
- Crown-Indigenous Relations and Northern Affairs Canada
- Indigenous Services Canada and Infrastructure Canada

Technical Working Group

- 180 members across Canada
- All levels of government, academia, industry, NGO, and other stakeholders
- Working groups focusing on specific guideline topics
- Ongoing consultation

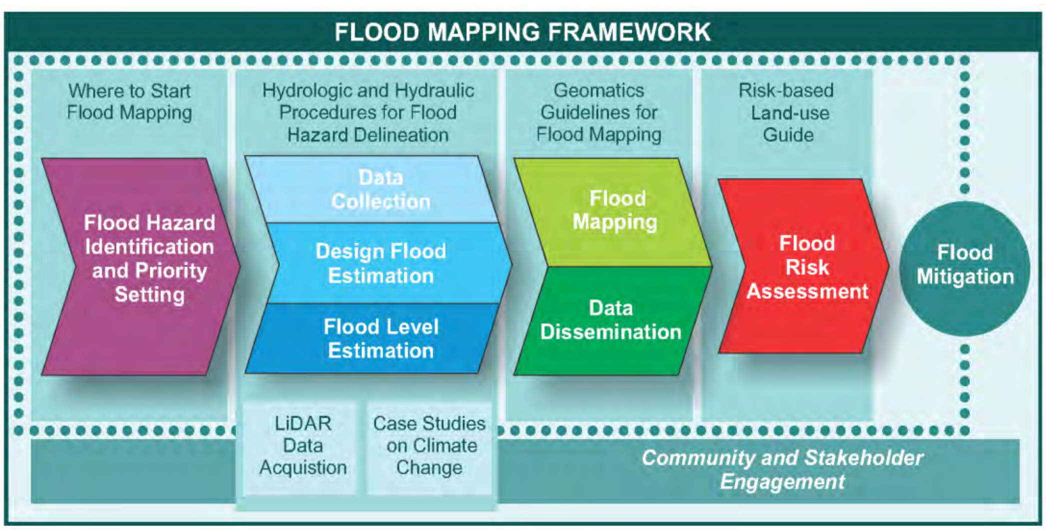
Indigenous Technical Working Group

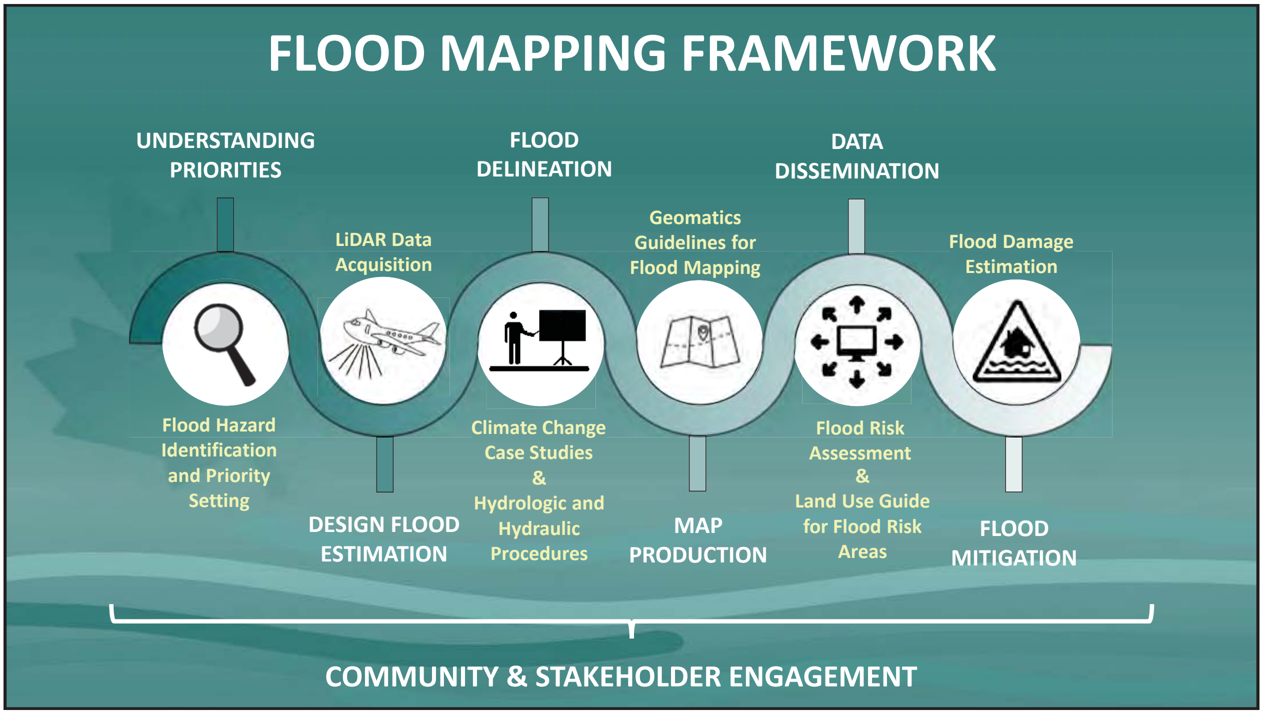
- Regional Organizations
- Tribal Councils

Studies and Reports

- Research and private consultants

Federal Flood Mapping Framework





Federal Flood Mapping Guidelines Series

Federal Flood Mapping Guidelines Series Document	Status
Federal Flood Mapping Framework v 1.0	Published
Flood Hazard Identification and Priority Setting v 1.0	In Progress
Federal Hydrologic and Hydraulic Procedures for Flood Hazard Delineation v 1.0	Published
Federal Airborne LiDAR Data Acquisition Guideline v 2.0	Published
Case Studies on Climate Change in Floodplain Mapping v 1.0	Published
Federal Geomatics Guidelines for Flood Mapping v 1.0	Published
Flood Risk Assessment v 1.0	In Progress
Federal Land Use Guide for Flood Risk Areas v 1.0	Final Review
Bibliography of Best Practices and References for Flood Mitigation v 2.0	Published
Federal Flood Damage Estimations Guidelines	In Progress

Natural Resources Canada Ressources naturelles Canada

Flood Mapping Guidelines Principles

The ***Federal Flood Mapping Guidelines Series*** intends to inform consistent practices for flood mapping in Canada.

Collaborative | Local | Adaptable | Interoperable

Evergreen | Accessible | Voluntary → Standards

National Flood Hazard Data Layer

National Flood Hazard Data Layer (NFHDL)

- We require Canada-wide understanding of flood hazards
- Flood hazard data is created using different methodologies and presented using different schemas
- Through RFP, we are seeking proposals for the development of:
  - an inventory of available flood hazard data
  - a common schema for the most up-to-date data
  - a mechanism for automatically linking to databases
- **Status:** Project to start by April 1st 2020

Supporting Initiatives and Collaborations

- Indigenous firm contracted to conduct engagement on inclusion of Indigenous Knowledge and considerations within the Federal Flood Mapping Guidelines Series
- Flood hazard data quality enhancement pilot project with Canadian Water Network / Insurance Bureau of Canada
- High-profile research projects with Global Water Futures and Natural Resources Canada
- First Nations Adapt Program
- Collaborative work across federal departments to evaluate existing flood hazard models
- Canadian Water Resources Association / Natural Resources Canada Flood Mapping Workshops: Mississauga 2016, Vaughan 2018, Montreal 2018 & 2019, Saint John 2020.
- Advisory Council on Flooding work on Flood Risk Awareness and Long-Term Vision
- Presentation to National Aboriginal Land Managers Association Executives and Assembly of First Nations EM Chiefs, 2019
- Emergency Management Strategy for Canada's National Risk Profile Initiative

Speech from the Throne

Fighting Climate Change

*"From forest fires and **floods**, to ocean pollution and coastal erosion, Canadians are living the impact of climate change every day. The science is clear, and it has been for decades."*

Mandate Letter

Office of the Prime Minister | Cabinet du Premier ministre

Ottawa, Canada K1A 0A2

"Work with the Minister of Public Safety and Emergency Preparedness and with the provinces and territories and Indigenous Peoples to complete all flood maps in Canada."

Natural Resources Canada | Ressources naturelles Canada

Natural Resources Canada | Ressources naturelles Canada

View our Guidelines at:
publicsafety.gc.ca/ndmp

THANK YOU!

Paula McLeod
Canada Centre for Mapping and Earth Observation
Natural Resources Canada

Canada

DAY 2
Session 4: Extreme Precipitation

Chair, Laxmi Sushama
McGill University, QC, Canada

Long Period Return Level Estimates of Extreme Precipitation

Francis Zwiers
Pacific Climate Impacts Consortium, BC, Canada

Long Period Return Level Estimates of Extreme Precipitation

FRANCIS ZWIERS

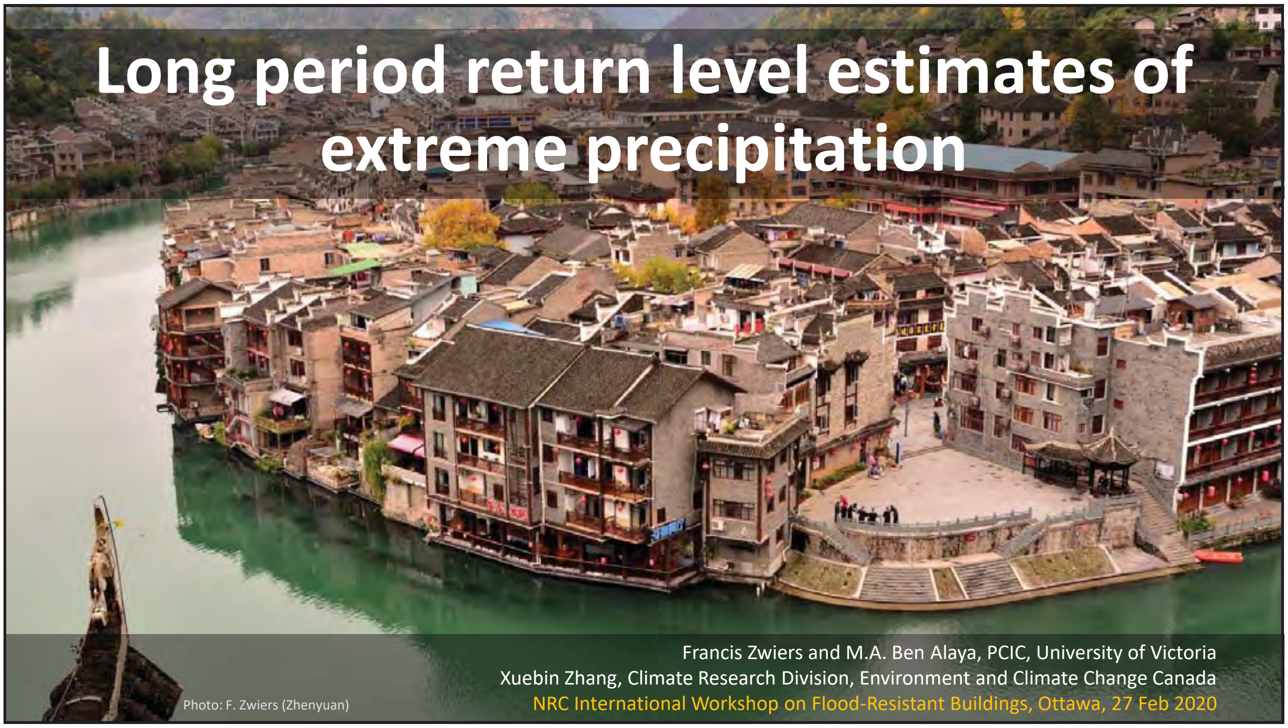
Pacific Climate Impacts Consortium, BC, Canada

Abstract

Statistical extreme value theory (EVT) is a fundamental tool for characterizing climate extremes and understanding whether they are changing over time. Most operational frequency and intensity estimates are obtained by using EVT to analyze time series of annual maxima; for example, of short duration precipitation accumulations or some aspect of wind speed. A key implicit assumption in the application of EVT is "max-stability"; i.e., that the statistical behaviour of annual maxima is predictive of maxima calculated over multi-decadal or longer intervals. This assumption cannot be tested using available observational records, and it is rarely discussed in studies of extremes. Here we use a recent large ensemble simulation to assess whether max-stability holds for annual maxima of extreme precipitation. We find that annual maxima tend not to be max-stable in the model-simulated climate. We explore the implications of the lack of max-stability on the estimation of very long period return levels, and discuss reasons why the annual maxima of precipitation extremes may not be max-stable. We also demonstrate a possible solution that is based on an alternative statistical approach and that incorporates additional process-based information into the analysis. While our study focuses on precipitation simulated by a regional climate model, our findings have serious implications for the estimation of high return levels of many climate and weather elements from models and observations that may potentially impact engineering practice.

Biography

Dr. Francis Zwiers is director of the Pacific Climate Impacts Consortium (PCIC) at the University of Victoria. His former roles include chief of the Canadian Centre for Climate Modelling and Analysis and director of the Climate Research Division, both at Environment and Climate Change Canada. As a research scientist, his expertise is in the application of statistical methods to the analysis of observed and simulated climate variability and change. Dr. Zwiers is a Fellow of the Royal Society of Canada, the American Geophysical Union and the American Meteorological Society. He is also a recipient of the Patterson Medal and President's Prize, and has served as an IPCC Coordinating Lead Author of the Fourth Assessment Report and as an elected member of the IPCC Bureau for the Fifth Assessment Report.



Outline

- Introduction
- Problem definition
- Possible solution
- Conclusions

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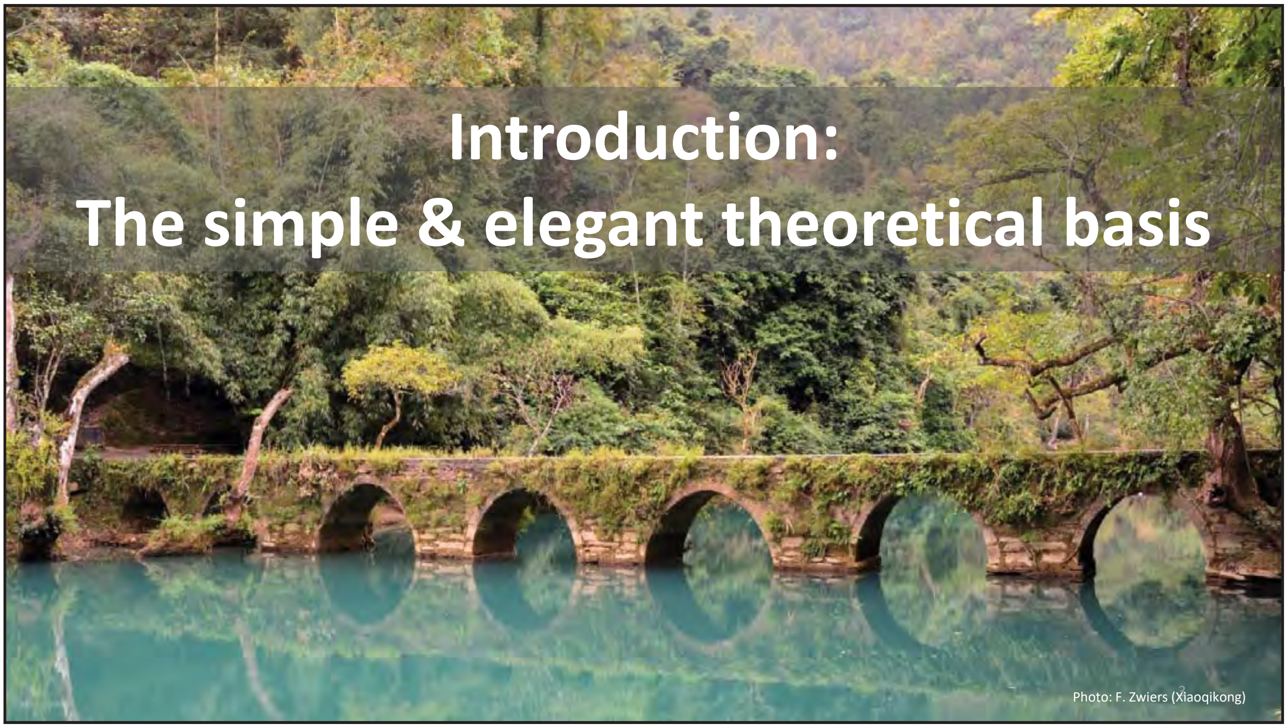

Introduction

- Extreme value theory provides two general approaches
  - Block maximum
    - Set a fixed ”block” length (typically a year)
    - Analyze a time series of block maxima
    - Leads to the Generalized Extreme Value (GEV) distribution
  - Peaks over threshold
    - Set a high threshold
    - Analyze exceedances above the threshold, usually after de-clustering
    - Leads to the Generalized Pareto distribution (GPD)

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Block maximum approach

- Approach most widely used in engineering design problems
- Natural block length is a year ➔ annual maxima
- Seeks to estimate a point in the upper tail of the distribution (e.g., an n-year "return level")
- Most work uses the Generalized Extreme Value (GEV) distribution

$$F(Y=y|\mu,\sigma,\xi)=\begin{cases}\exp\left\{-\left[1+\frac{\xi(y-\mu)}{\sigma}\right]^{-1/\xi}\right\}, \xi<0, y<\mu-\sigma/\xi & \text{Reversed Weibull, or Type III}\\ \exp\left\{-\left[1+\frac{\xi(y-\mu)}{\sigma}\right]^{-1/\xi}\right\}, \xi>0, y>\mu-\sigma/\xi & \text{Fréchet, or Type II}\\ \exp\left\{-\exp\left[-\frac{y-\mu}{\sigma}\right]\right\}, \xi=0 & \text{Gumbel, or Type I}\end{cases}$$

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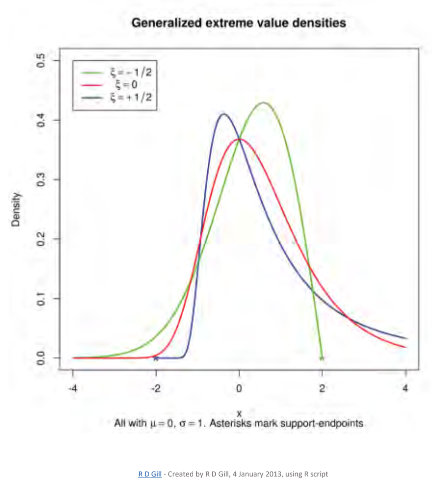
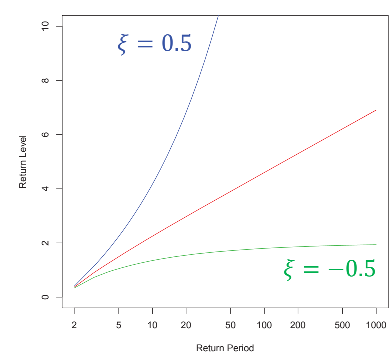
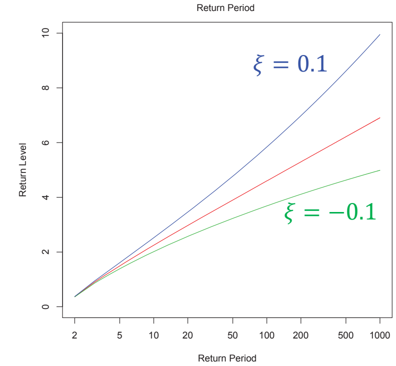
Reversed Weibull, or Type III

Fréchet, or Type II

Gumbel, or Type I







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Block maximum approach

- The ”Extremal Types Theorem” provides some justification

> Let $M_n = \max\{X_1, X_2, \dots, X_n\}$ where X_i are iid random variables.
> If for some constants $a_n > 0, b_n$,
> $$P\{a_n(M_n - b_n) \leq x\} \overset{w}{\rightarrow} G(x)$$
> for some nondegenerate G, then G is one of the three extreme value types that comprise the GEV distribution

- This theorem has been generalized to some types of stationary processes
- This is a *limit theorem*, like the *Central Limit Theorem*

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Real world applications

- This is a *limit* theorem, like the Central Limit Theorem
- Working assumption is that 1-year blocks are large enough
- But … observed processes are generally not iid or even stationary
- There can be strong serial dependence and a strong annual cycle (e.g., rainfall and streamflow) → effective block lengths << 1-year
- There might be “surprises” in the upper tail (e.g., hurricanes or atmospheric rivers) that are not consistently observed in each block

It is safe to use the GEV (or the GPD) for rainfall and wind?

- We study this question with a climate model

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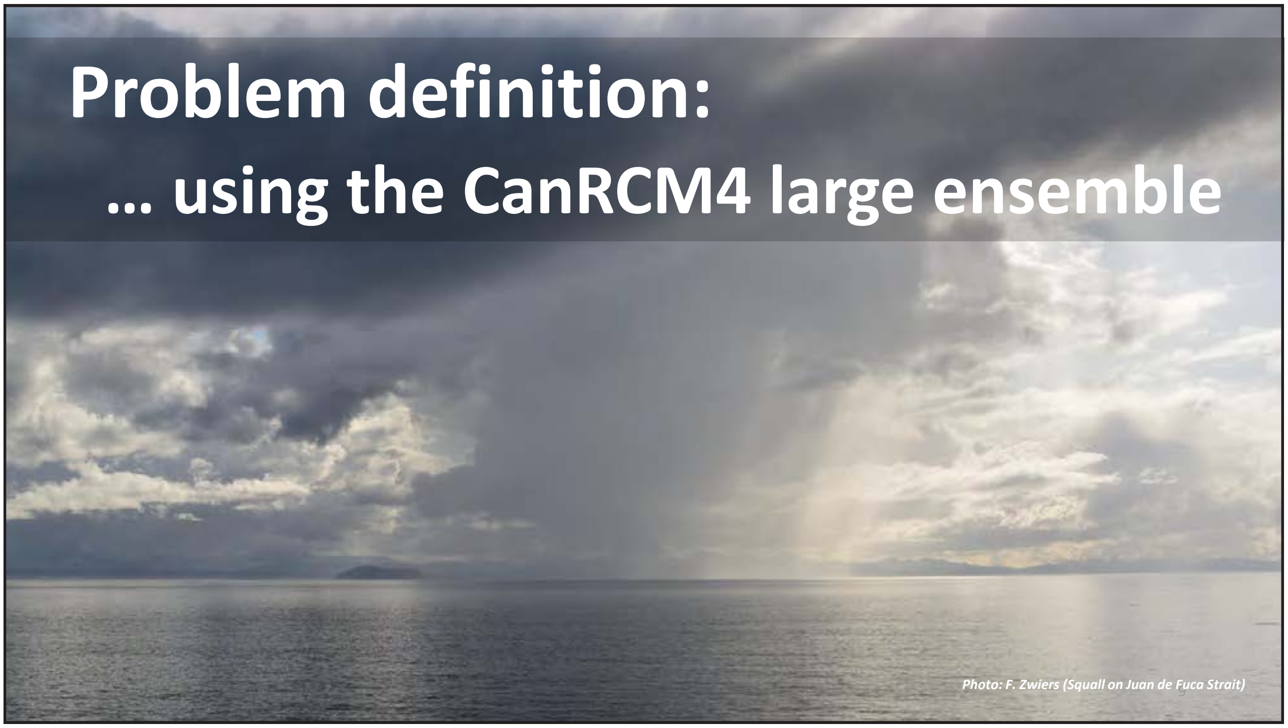


CanRCM4 large ensemble

- 50-members, 50 km resolution, driven by the CanESM2 large ensemble
- historical + RCP8.5 forcing
- hourly precipitation archived for 35-members
- considering 1951-2000 only, we have 35x50=1750 annual maxima

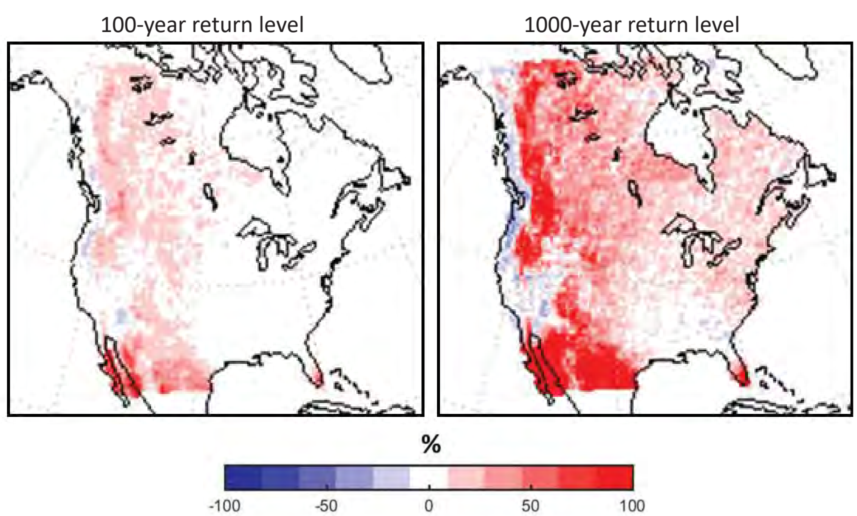
GEV fitting method

- assume stationarity over 1951-2000
- fit via maximum likelihood
- results are similar if using probability weighted moments

Bias in return level estimates

Relative bias of extreme quantile estimates

Relative bias in extreme quantiles of CanRCM4 simulated 1-hour precipitation accumulations for 1951-2000 based on fitting a GEV distribution to 1750 annual extremes for 1951-2000



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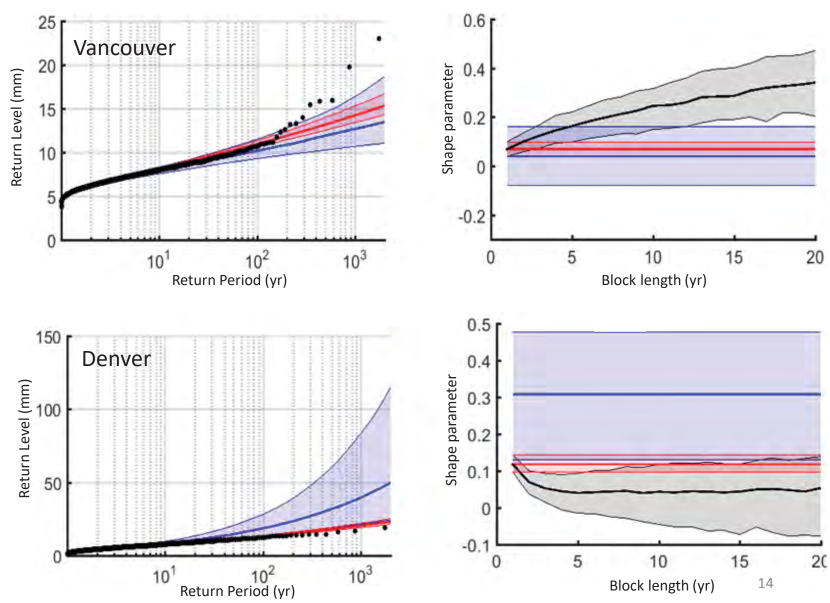
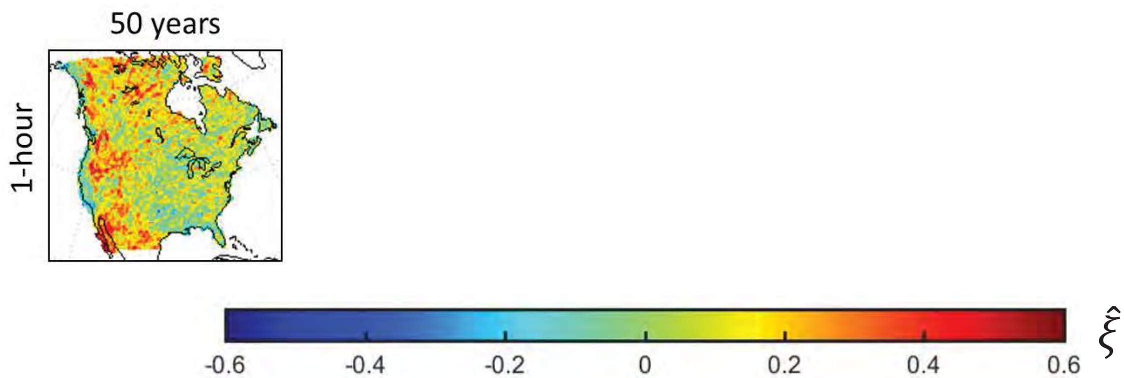
GEV fits to block maxima at 2 locations

Extreme quantiles based on 1750-years of CanRCM4 simulated 1-hour precipitation accumulations for 1951-2000

- Empirical distribution from 1750 annual maxima (dotted black)
- GEV from 50 annual maxima (blue)
- GEV from 1750 annual maxima (red)
- GEV from 1 to 20 year block maxima (black)

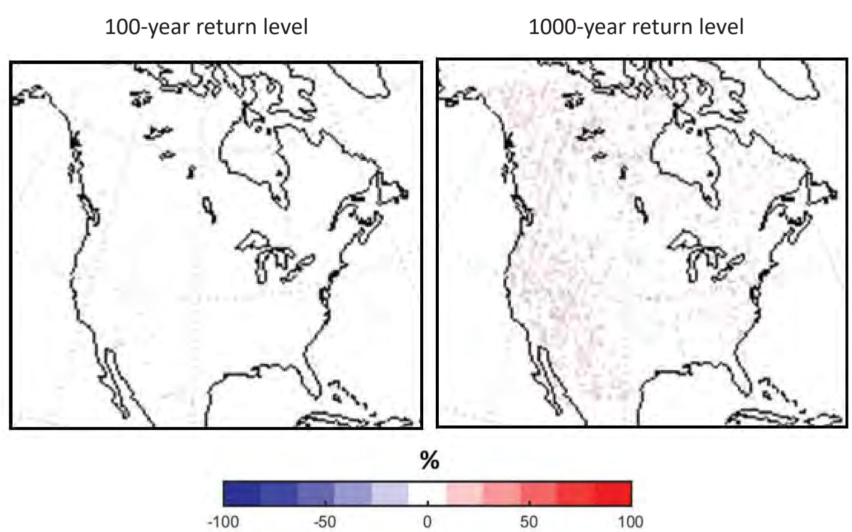


Shape parameters of extreme 1-hour precipitation



Relative bias of extreme quantile estimates

Relative bias in extreme quantiles of CanRCM4 simulated 1-hour precipitation accumulations for 1951-2000 based on fitting a GEV distribution to <u>175 decadal extremes</u> for 1951-2000



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Discussion

- We should worry about tail stability and where we sample
- Sampling the annual maximum may leave us ignorant (in relative terms) about surprises deeper in the upper tail
- Using a peaks-over-threshold approach does not solve the problem
- Extrapolation into the deep tail requires information from somewhere
- It is either constructed from basic postulates, assumed, or perhaps can be objectively derived from further information about the underlying physics

Can physical considerations help?

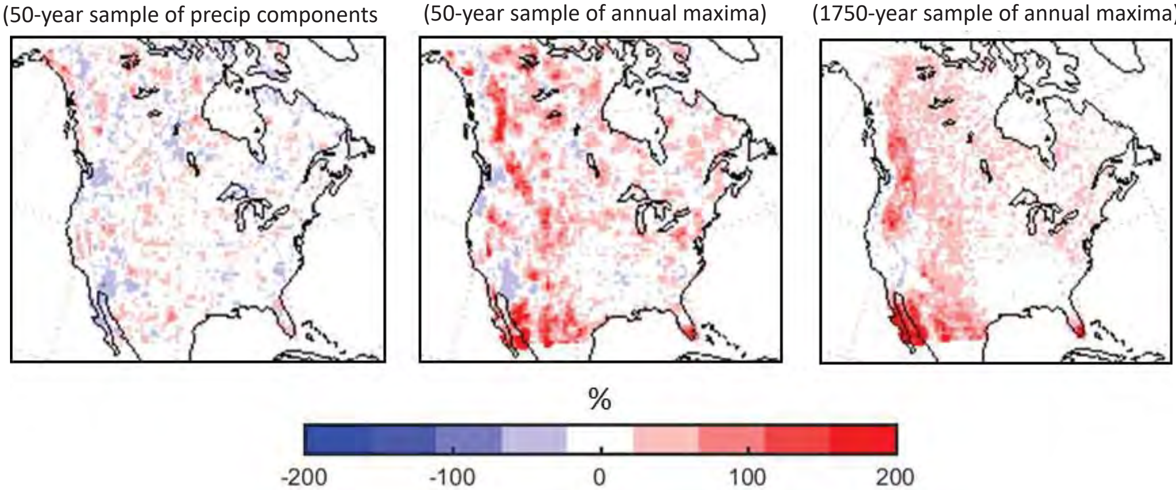
- Existing approaches include use of mixtures of distributions, in combination or not with storm classification, or empirical selection of distributions from amongst several heavy-tailed candidate
- We use a multivariate approach in which extreme precip is decomposed into two components as PCP=PW×PE, where
  - PW is the precipitable water in the atmospheric column
  - PE is the precipitation efficiency (the fraction of PW that is precipitated during the event)
- PW is generally bounded, whereas PE can be heavy tailed, with PE >> 1 possible.
- The two components represent two different aspects of the physics controlling precipitation

Proposal …

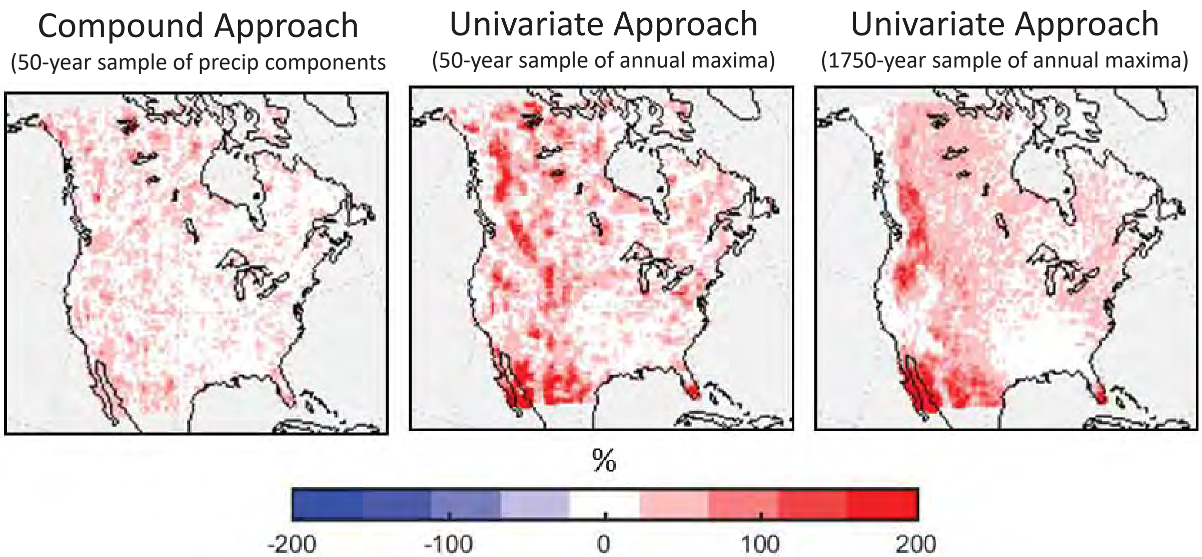
- Model the joint behaviour of extreme PW and PE and then use Monte Carlo methods to derive the distribution of PCP=PWxPE
- Options
  - Heffernan and Tawn (2004) conditional dependence model
  - Ben Alaya et al (2018) extreme value copula based model
- We opted for Heffernan and Tawn (2004) because the flexibility offered using copula's is quite limited

Relative bias in 1000-year return level estimates

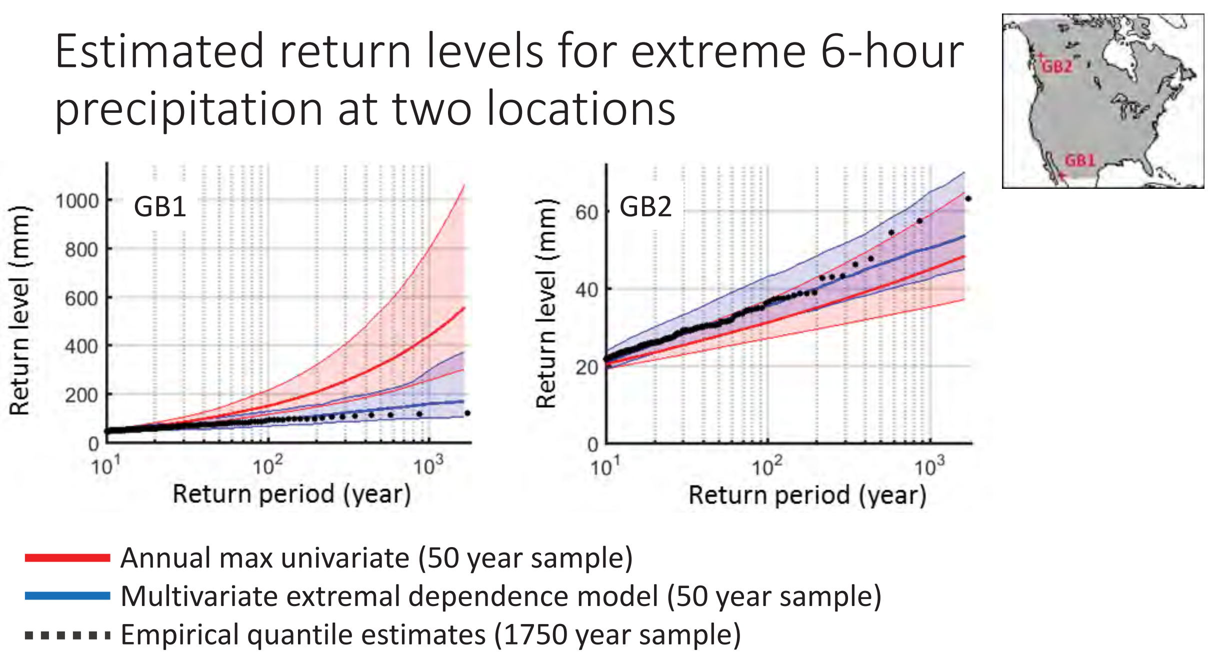
Compound Approach	Univariate Approach	Univariate Approach
(50-year sample of precip components	(50-year sample of annual maxima)	(1750-year sample of annual maxima)



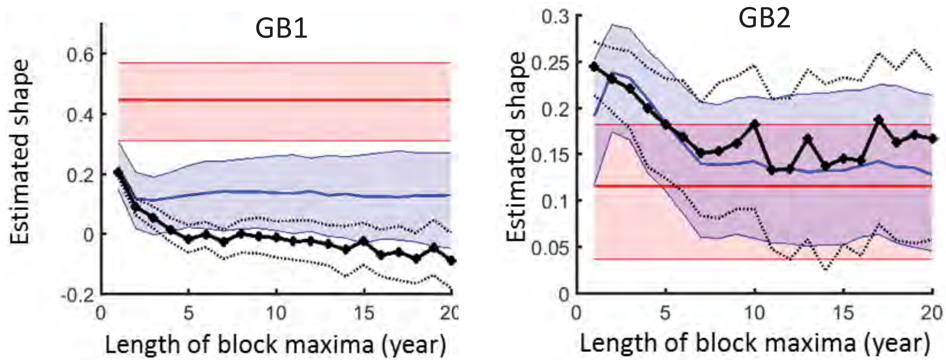
Relative RMSE in 1000-year return level estimates



Estimated return levels for extreme 6-hour precipitation at two locations



Estimated shape parameters for extreme 6-hour precipitation at two locations

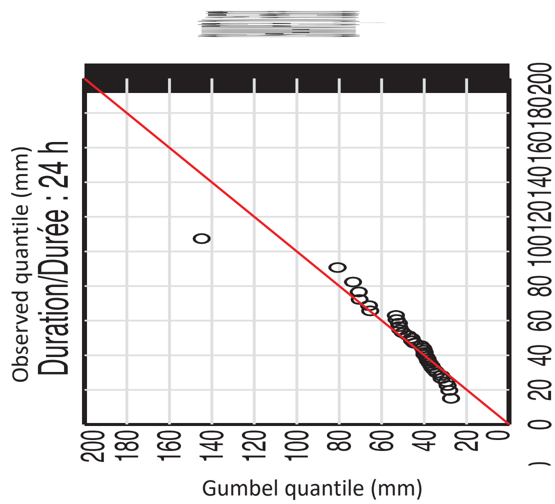


Predicted shape using annual max univariate (50 year sample)
Predicted shape using multivariate extremal dependence model (50 year sample)
Empirical estimates (1750 year sample)

Conclusions

Conclusions

- Traditional univariate analysis assumes a stable upper tail
- The underlying process generating extremes, may however, be very complex, implying that stability will only be attained once blocks are large enough to consistently sample extremes from the physical process responsible for the largest events
- Large multi-year blocks are infeasible with short historical records



Conclusions

- It is therefore necessary to better use information available in the historical record
- One option is to extract information from the constituent variables that produce univariate extremes
- We illustrated this approach by decomposing precipitation as the product of precipitable water and precipitation efficiency
- The ”compound events” extremal dependence model appears to be able to capture fluctuations in tail shape that result from physical relationships between the component variables.
- Bias is, consequently, considerably reduced, even when using a modestly short 50-year sample.
- Note that additional information that allows this to happen comes from PW

Problem is not limited to extreme precipitation

- We see similar issues with extreme wind speed
  - Fitting GEV distributions to annual maxima of model simulated "instantaneous" wind speed tends to find bounded distributions
  - Leads to negative bias in long-return period extreme wind speed (and thus extreme wind load) estimates

Summary of Key Issues

Bruce Ellingwood
Colorado State University, CO, USA

Summary

Canada's Buildings and Core Public Infrastructure (B&CPI) includes buildings, bridges and other transportation infrastructure, municipal water/wastewater systems, power delivery systems and telecommunications facilities. Climate change presents a serious challenge to Canada's B&CPI, as it could lead to an increased risk of damage and failure as a result of changing loads. This could, in turn, lead to a disruption or loss of public services, an increase in costs to infrastructure users and owners, and considerable negative socio-economic impacts. The National Research Council of Canada (NRC) is leading a project on Climate-Resilient Buildings and Core Public Infrastructure (CRBCPI). This project aims to enhance the resilience of B&CPI through code changes and best engineering practices for the design and rehabilitation of B&CPI against current and future weather and climate extremes. Over the past three years, the NRC has organized a series of workshops and panel meetings involving engineers, climate scientists, code development experts and infrastructure owners. These workshops identify the issues involved in designing civil infrastructure for climate change, determine the state-of-the art in climate science and its adaptability to infrastructure design, and identify gaps in knowledge necessary to advance the science and engineering needed to enhance the resilience of B&CPI under a changing climate.

The first workshop was held in January 2017 in Ottawa, Canada, where participants discussed the state of the art in climate change modelling and provided recommendations for new approaches to streamline and implement climate change effects in codes and standards. It was noted that, unlike the provisions for wind and snow, there are no flood design criteria that have been developed for buildings at a national scale across Canada. Rather, flood criteria are developed by provincial and municipal governments, and due to a lack of consistency between these flood criteria, the identification and treatment of flood risks are not uniform across Canada. Therefore, a Technical Committee on Flood-Resistant Buildings was formed to address the problem of riverine and coastal flooding. To this end, the NRC has retained the professional services of an independent consultant, Coulbourne Consulting, to draft technical guidance and flood-resistant design provisions for consideration by the Technical Committee. Coulbourne Consulting has organized its guide development into the following six tasks:

1. Execution plan
2. Design flood conditions and considerations
3. Flood load formulas and provisions
4. Performance-based design for floods

5. Guidelines for improving flood resistance of existing buildings
6. Recommendations for the inclusion of flood-design requirements in Canadian guides, standards or codes.

The International Workshop on Flood-Resistant Buildings—held on February 26-27, 2020 in Ottawa, Canada—was a continuation of the above efforts, and was focused on work that the NRC is undertaking to develop requirements and guidelines for flood-resistant buildings. The workshop was organized into four sessions of technical presentations, each of which had a dedicated period of time allotted for questions and discussion. These discussions were used to review the progress of developing technical support for flood-resistant building design in Canada and to identify future needs and directions for riverine, coastal, and urban flooding from a building-design perspective. Session 1 "Requirements for Flood-Resistant Buildings" was aimed at reviewing the progress made by Coulbourne Consulting. Session 2 "Case Studies on Flood Data Generation" summarized the development of databases by the Western, Interior and Atlantic Provinces to support general flood-resistant design procedures. Session 3 "Federal, Provincial, Territorial and Municipal Initiatives on Flood-Related Issues" described various initiatives underway at the federal, provincial, territorial and municipal levels, including current flood mapping activities. Finally, Session 4 "Extreme Precipitation" presented recent developments in statistical estimation of long period return levels estimates of extreme precipitation relevant to flood mapping and flood-resistant design. The proceedings that follow summarize the presentations and discussions held at this workshop.

A number of significant accomplishments and overarching issues were identified in the technical presentations and the discussions that followed. These can be broken down into three categories: 1) Data analysis and additional data needs; 2) Standardization of flood mapping and flood protection measures; and 3) Standardization of flood-resistant design development across Canada. These categories are summarized in the following paragraphs.

Data analysis and additional data needs

Environment and Climate Change Canada (ECCC) has prepared an exhaustive report summarizing the impact of climate change on code parameters in the National Building Code (NBC) of Canada, including analysis and projections of future climatic data up to the year 2100. In addition to considering insights from several completed studies aimed at flood risk reduction in different parts of Canada, over a dozen case studies, involving a mix of riverine and coastal communities (for example, the Great Lakes and Maritime Provinces), are planned. Lessons learned from these case studies will be integrated into the flood-resistant design guidelines being developed by Coulbourne Consulting.

Despite this extensive data collection and analysis, additional data on flooding from individual riverine and coastal sites is still needed, including data on flood depth and velocity and, for coastal sites, wave heights and surge. Currently, flood maps are developed by each province, and the associated procedures have not been standardized across Canada. It is common to map a 20-year floodway and a 100-year floodplain. However, flood mapping is done for different purposes, including infrastructure design, flood mitigation, water resources management and insurance estimates. Therefore, the following examples should be considered to improve the standardization of flood mapping. Digital Elevation Maps (DEMs) would enable better information on flood depths. Wave loading is not well-defined, and may be a major source of structural damage in some areas. Relationships between breaking wave height and depth are empirical. Situating the building above the wave zone is the safest approach, but may not always be possible. The questions of what to include, such as wave loading, debris and ice, remain open.

Future conditions should be reflected in the design criteria for flood-resistant buildings, the selection of which should depend on tolerance or risk, life safety and economic losses. Analysis of flood data for the purposes of design standards and building regulation remains problematic. Estimates of flood levels for return periods of 500 years or higher obtained using the current techniques that structural engineering organizations commonly employ to develop the codes are associated with large uncertainties. This is because these estimates are based on the extrapolation of data from the tails of the distributions. Supplementary information is required to overcome this problem.

While the insurance industry has some coarse resolution data on flood depth and velocity, much of this information is proprietary in nature.

Standardization of flood mapping and flood protection measures

Flood hazard mapping is done for different purposes; however, on some level, the basic physics of mapping must be the same. A common method should be applied Canada-wide, even if performed by individual provinces. Uniform risk will not be achieved (or even predictable) without a standardized approach that can be used by provinces or municipalities. Since each province follows its own approach, a compilation of these procedures should be critically appraised, with the objective of identifying factors that challenge the achievement of uniform risk. The mapping procedure, in particular, has not been consistent. For example, some provincial maps include the projected impact of climate change, while others do not. Similarly, flood velocity is not part of mapping in most provinces, and although flood velocity can be backed out of inundation using the Manning's equation, the values obtained are highly uncertain and several case studies are required for validation. In addition, the extrapolation of annual extreme flood for longer return periods required for the design stage carries a good deal of uncertainty, as noted previously.

Standardization of flood-resistant design development across Canada

The draft guidelines on flood-resistant design of buildings developed to date by Coulbourne Consulting have focused on information that can be gleaned from existing flood maps or from readily-available information, such as ASCE Standard 24. This approach will facilitate the implementation of risk-informed flood-resistant design guidelines in professional practice. However, important issues must still be addressed in the development of the guidelines. Namely, what are the appropriate risk levels for flood-resistant design for different buildings, and how do these risk levels compare with the risks due to other natural hazards, such as snow, wind and earthquakes? How should one measure risk (based on hazard or consequences), and what should the risk levels be in existing versus new buildings? How does one deal with buildings and other structures that have a higher risk potential, such as auditoriums and stadiums, hospitals and healthcare facilities, fire and police stations, and critical communication facilities? The traditional way of dealing with buildings in different risk categories is to stipulate importance factors greater than 1.0 or longer return period design loads. These traditional methods focus on the hazard component of risk, but are of limited use if one is striving for a uniform risk instead of a traditional uniform hazard approach. A Performance-Based Engineering (PBE) approach provides a potential solution. A PBE approach requires consideration of several hazard levels at increasing return periods: routine (100-year), severe (500-year) and extreme (1,000-year); and damage levels: mild, moderate, severe, and extreme. The resulting hazard/damage matrix is a useful risk communication tool for engineers, building regulators and public officials to answer such questions such as: 1) How do we plan for urban resilience under severe or extreme flooding? 2) What is the risk downstream, not just in the floodway or the floodplain? 3) How should future land use conditions be taken into account in the codes? 4) What time frame should be considered in future code development and in code revisions? 5) How can uniform flood risk be achieved throughout Canada if a provincial approach cannot be addressed adequately? There is no clear resolution of this final question, but it should be considered at the present time because of its impact on flood-resistant design provisions in the coming years.

Finally, aside from the technical issues summarized above, professional implementation of risk-informed flood-resistant design guidelines will impose new and unanticipated demands on the structural engineering profession. A series of trial designs must be conducted to determine the economic impact of flood-resistant design on building construction. Such trial designs will go a long way in promoting the adoption of the new approach, creating a demand for more rational approaches to flood-resistant design, and making an economic case for the new guidelines. It is important that new provisions developed from the current project be simple enough in their application to minimize the chance that they will be applied incorrectly. Along these lines, a task should be initiated to develop professional education programs to familiarize engineers and building regulators with the concepts of flood-resistant design and risk mitigation developed from this project.

Appendix:
Workshop Program

International Workshop on
FLOOD-RESISTANT BUILDINGS

COURTYARD BY MARRIOTT OTTAWA DOWNTOWN

350 Dalhousie Street

Ottawa, ON K1N 7E9

February 26 to 27, 2020

Workshop Program

Day 1: February 26, 2020

8:45–9:00 AM	**Introduction and Opening Remarks** *Ahmed Attar* *National Research Council Canada*
9:00–9:10 AM	**Welcome and Workshop Objectives** *Marianne Armstrong and Zoubir Lounis* *National Research Council Canada*
9:10–9:30 AM	**NRC's Flood-Resistant Buildings Initiative** *Naveed Khaliq and Ahmed Attar* *National Research Council Canada*
9:30–9:45 AM	**Break**
	SESSION 1 - Part 1: Requirements for Flood-Resistant Buildings *Chair, Bruce Ellingwood* *Colorado State University, CO, USA*
9:45–10:15 AM	**Developing Requirements for Flood-Resistant Buildings including Execution Plan and Discussion of Data Needs** *Bill Coulbourne and Kimberly McKenna* *Coulbourne Consulting, MD, USA*

10:15–10:30 AM	**Q&A and Discussion**
10:30–11:00 AM	**Design Flood Conditions and Considerations** *Bill Coulbourne and David Kriebel* *Coulbourne Consulting, MD, USA*
11:00–11:15 AM	**Q&A and Discussion**
11:15–11:45 AM	**Flood Load Formulas and Provisions** *David Kriebel* *Coulbourne Consulting, MD, USA*
11:45–12:00 PM	**Q&A and Discussion**
12:00–1:00 PM	**Lunch**
	SESSION 1 - Part 2: Requirements for Flood-Resistant Buildings *Chair, Zoubir Lounis* *National Research Council Canada*
1:00–1:30 PM	**Performance-Based Design for Flood** *Bill Coulbourne* *Coulbourne Consulting, MD, USA*
1:30–1:45 PM	**Q&A and Discussion**
1:45–2:15 PM	**Improving Flood Resistance for Existing Buildings** *Randall Behm* *Coulbourne Consulting, MD, USA*
2:15–2:30 PM	**Q&A and Discussion**
2:30–3:00 PM	**Flood Standard Related Initiatives and Discussions in the USA** *Bill Brown* *Flood Science Center, WI, USA*
3:00–3:15 PM	**Q&A and Discussion**
3:15–3:30 PM	**Break**
	SESSION 2: Case Studies on Flood Data Generation *Chair, Peter Irwin* *RWDI, ON, Canada*
3:30–3:45 PM	**Analysis and Data Extraction for Flood Load Determination for Selected Case Studies from Alberta and British Columbia** *Dan Healy* *Northwest Hydraulic Consultants Ltd., AB, Canada*

3:45–4:00PM	**Analysis and Data Extraction for Flood Load Determination for Selected Case Studies from Manitoba and Saskatchewan** *Raj Mannem* *Hatch, MB, Canada*
4:00–4:15 PM	**Analysis and Data Extraction for Flood Load Determination for Selected Case Studies from Great Lakes and Arctic Coasts** *Derek Williamson and Josh Wiebe* *Baird & Associates, ON, Canada*
4:15–4:30 PM	**Analysis and Data Extraction for Flood Load Determination for Selected Case Studies from Atlantic Provinces** *Vincent Leys* *CBCL, NS, Canada*
4:30–5:00 PM	**Open Discussion**
5:00–5:10 PM	**Closing Remarks and Adjournment** *Zoubir Lounis* *National Research Council Canada*

Day 2: February 27, 2020

	SESSION 3 - Part 1: Federal, Provincial, Territorial and Municipal Initiatives on Flood-Related Issues *Chair, Annick Maletto* *Centre de sécurité civile - Ville de Montréal, QC, Canada*
9:00–9:20 AM	**Standards Used by Conservation Authorities in Ontario for Great Lakes and Riverine Flood Plain and Erosion Management, and How Climate Change May Challenge this Approach** *Mark Peacock* *Lower Thames Conservation Authority, ON, Canada*
9:20–9:40 AM	**Building Flood Resilience in Calgary** *Sandy Davis and Marco Civitarese* *City of Calgary, AB, Canada*
9:40–10:00 AM	**Flood Hazard Management Initiatives in BC** *Jesal Shah* *Ministry of Forests, Lands, Natural Resource Operations, and Rural Development, BC, Canada*
10:00–10:15 AM	**Q&A and Discussion**
10:15–10:30 AM	**Break**
	SESSION 3 - Part 2: Federal, Provincial, Territorial and Municipal Initiatives on Flood-Related Issues *Chair, Marco Civitarese* *City of Calgary, AB, Canada*
10:30–10:50 AM	**An Emergency Response Perspective to What Renders Homes Uninhabitable During Floods** *Annick Maletto* *Centre de Sécurité Civile, QC, Canada*
10:50–11:10 AM	**Newfoundland and Labrador - Provincial Flood Risk Mapping Initiatives** *Amir Ali Khan* *Municipal Affairs and Environment, NL, Canada*

11:10 –11:30 AM	**Flood Mapping Activities, Natural Resources Canada** *Paula McLeod* *Natural Resources Canada*
11:30–12:00 PM	**Q&A and Discussion**
12:00–1:00 PM	**Lunch**
	SESSION 4: Extreme Precipitation *Chair, Laxmi Sushama* *McGill University, QC, Canada*
1:00–1:30 PM	**Long Period Return Level Estimates of Extreme Precipitation** *Francis Zwiers* *Pacific Climate Impacts Consortium, BC, Canada*
1:30–1:45 PM	**Q&A and Discussion**
1:45–2:30 PM	**Summary of Key Issues and Path Forward** *Bruce Ellingwood* *Colorado State University, CO, USA*
2:30–2:45 PM	**Closing Remarks and Adjournment** *Ahmed Attar* *National Research Council Canada*