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FloodNet
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NSERC Canadian Strategic Network for

Enhancing Flood Forecasting and Management Capacity

in Canada

Image Credit: Ryan Quan

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Université McGill
Trent University
Université de Moncton
University of Guelph
University of Manitoba
UNB Est. 1785
University of Saskatchewan
Western
University of Waterloo
University of Alberta

Dear Reader,

On behalf of the FloodNet Team, I warmly welcome your interest in learning more about this concerted nation-wide effort to enhance flood forecasting and management capacity in Canada. FloodNet is a NSERC Strategic Network with a multidisciplinary and collaborative perspective on floods and mitigation. By bringing together all levels of government, industry, and academia, FloodNet provides a unique opportunity to harness the experience, knowledge and specialized facilities and resources across Canada. This collection of expertise/skills and resources is beyond the capabilities of a single group or team within any private or public sector organization. In addition, FloodNet relies on a team of about 70 highly qualified personnel (PhD, MASc, and Postdoctal fellows). All working to achieving one vision: "Developing advanced knowledge, tools, and technologies that will allow Canada to better face the reality of floods."

This booklet will give you an overview of the FloodNet team, the Network objectives and Research program, and the 30 Partners currently involved, but the Network is still growing. Information on how to joint FloodNet is available on our website (www.nsercfloodnet.ca).

Enjoy the reading!

Professor Paulin Coulibaly, P.Eng.
FloodNet Scientific Director
McMaster University

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Introduction

In Canada, floods are recognized as the most common, largely distributed, natural hazard to life, property, the economy, community/industry water systems, and the environment. The 1996 Saguenay flood was Canada's first natural disaster with damages in excess of one billion dollars. In 1997, the Red River watershed was hit by "the flood of the century", the worst flooding event in Manitoba since 1852. In 2011, the province of Manitoba was again subject to very extensive flooding with costs estimated to be about $1.2 billion (MFRTF, 2013). In June 2013, the unprecedented floods of the Bow and Elbow Rivers in southern Alberta became Alberta's worst ever natural disaster with estimated costs of $6 billion (Wood, 2013).

A key point is that all these flooding events are related to river floods – which can be better forecasted than other flood events (e.g., urban flash floods).

While floods cannot be eliminated, mitigation measures can be put in place to reduce their impact on people and society. Effective mitigation requires a solid understanding of the frequency of floods for the design of flood protection infrastructure as well as the ability to forecast flood events with high accuracy and sufficient lead time to implement temporary protection such as evacuations and sandbag dikes.

In the aftermath of previous catastrophic flood events in Canada, recommendations for enhancing flood forecasting and early warning systems (FFEWS) have been made but without concerted follow-up actions. For example, a report released in April 2013 concluded that a major issue during the 2011 flood on the Assiniboine River in Manitoba, which caused damages of $1.2B, was that the "flood forecasting model was unable to provide accurate and reliable forecasts" (MFRTF, 2013).

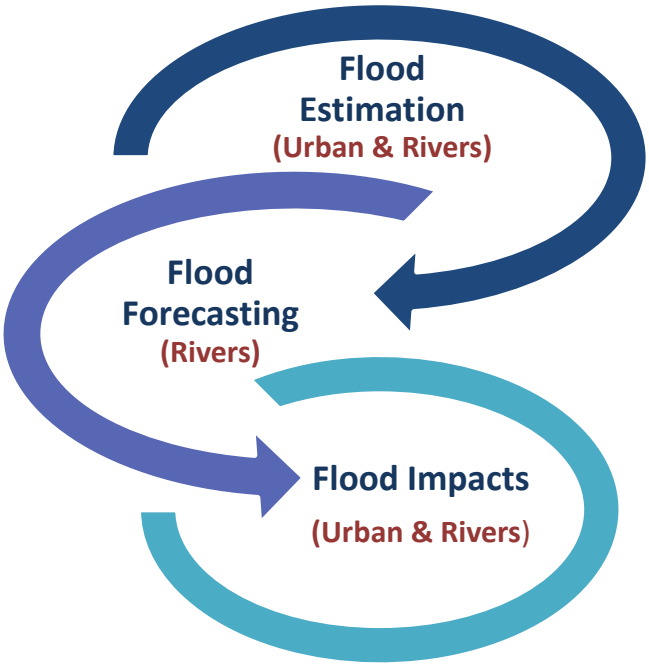
The need for enhanced flood forecasting tools and management capacity in Canada cannot be overstated. An effective solution for Canada requires a concerted national effort, similar to the initiatives in the United States and Europe, to enhance the knowledge of flood processes and their impacts, and to develop an advanced and adaptive FFEWS appropriate for Canadian conditions, which is at the heart of the FloodNet research program.

Effective flood forecasts represent the primary information needed for successful flood mitigation, including protecting source water, community/industry water systems, and aquatic ecosystems services, which provide benefits for the well-being and economic prosperity of Canada. At present, there is not a unified approach to flood forecasting in Canada, with each provincial Hydrologic Forecasting Centre (HFC) following its own procedures. While the procedures used by each HFC are tailored to the unique characteristics of the local hydrologic regime, there is a need for the implementation of a more advanced forecasting system, such as is in place in several other countries, to ensure that forecasts of flood events are as accurate and timely as possible.

What is FloodNet?

FloodNet is a multi-disciplinary research network, with active end-user involvement. The collaboration between academic experts, government scientists, and end-users (e.g., operational flood forecasters) is a key strength of FloodNet and will ensure that the new knowledge and technology developed will meet the user needs. FloodNet will allow the coordination and optimization of resources and expertise to address the important issue of river floods in Canada. The benefits of enhanced flood forecasts and management are tremendous and include the reduced cost of damages, the protection of people and livestock, the reduction of socio-economic impacts and human distress, and the protection of community water systems and the environment. In addition, students and post-doctoral fellows (PDFs) trained as part of the FloodNet research program will be uniquely and highly qualified to work in an area that is in high demand in Canada.

Funded by the Natural Sciences and Engineering Research Council (NSERC), with contributions from our partners in government agencies, industry and Canadian universities FloodNet provides one of the most advanced organizations in the world, in terms of human and technical capital, to deal with issues related to floods and will place Canada at the forefront of flood management. The knowledge and tools developed by the NSERC Canadian FloodNet will be disseminated on the world stage through our partnership with the United Nations University Institute of Water, Environment and Health (UNU-INWEH).



FloodNet Focus

The goal of the FloodNet Research Program is to achieve the following strategic objectives:

Objective 1: Advance Knowledge on Flood Regimes (Past and Future) and Provide Guidelines for Infrastructure Design

An important research challenge is the complexity of the space-time dynamics of the extreme events (floods and storms) driven by the large diversity of geographic, meteorological, and hydro-climatic conditions. Targeted research projects described in Theme 1 will enhance our understanding of these complex processes, which is essential to the development of:

1) formalized methodologies for frequency analysis of extreme events;
2) enhanced flood analysis tools;
3) risk and vulnerability indicators for populated regions; and
4) national guidelines for flood and storm frequency analysis.

Objective 2: Advance Knowledge on Flood Forecasting Systems and Enhance Flood Forecasting in Canada

"Flood forecasting has evolved from purely hydraulic and hydrologic science into a cross-cutting multidisciplinary research field, ranging from meteorology, via statistics, hydrology and hydraulics all the way to communication science." Arduino et al. (2005)

The research projects of Themes 2 and 3 will provide a collaborative environment to address the complex issue of producing and disseminating accurate and timely flood forecasts. The individual projects in these themes will:

1) facilitate ensemble hydrological predictions and data assimilation;
2) provide a framework for the quantification of predictive uncertainty;
3) increase forecast lead time while maintaining accuracy; and
4) harness advanced information technology systems to feed forecasting system and distribute flood warnings.

Objective 3: Assess Impacts of Floods on People, Society, and Environment

Enhanced understanding of the direct and indirect flood impacts at local and regional scales is essential for flood risk management, planning future development, informed engineering design and for sound science-based policy decision making. Accomplishing this research objective will increase our understanding of processes (linkages and feedbacks) and the holistic effects of floods on urban and rural environments, including socio-economic aspects. Objective 3 will be accomplished by research activities in Theme 4 which include:

1) quantitative analysis of flood effects on agricultural lands and aquatic ecosystems'
2) assessing the integrated effects of floods on surface water quality;
3) extending flood vulnerability assessment to include socio-economic aspects; and
4) development of evidence-based flood vulnerability indicators.

The FloodNet Team

FloodNet Principal Investigator (PI)

The Principal Investigator is Professor Paulin Coulibaly of McMaster University, who is a well-established and highly respected researcher in the international hydrology community. He has been engaged for more than two decades in cutting-edge research in hydrologic modelling and forecasting using physically-based, statistical, and machine learning techniques. His strengths and leadership record are outstanding at the national and international levels. He is the recipient of the prestigious Ontario Ministry of Research and Innovation Early Researcher Award (2007). This award was used to investigate the feasibility of using *Sequential Data Assimilation for Developing Adaptive Flood Forecasting System*, which is especially relevant to the proposed FloodNet research program.

Theme Leaders and Co-Leaders

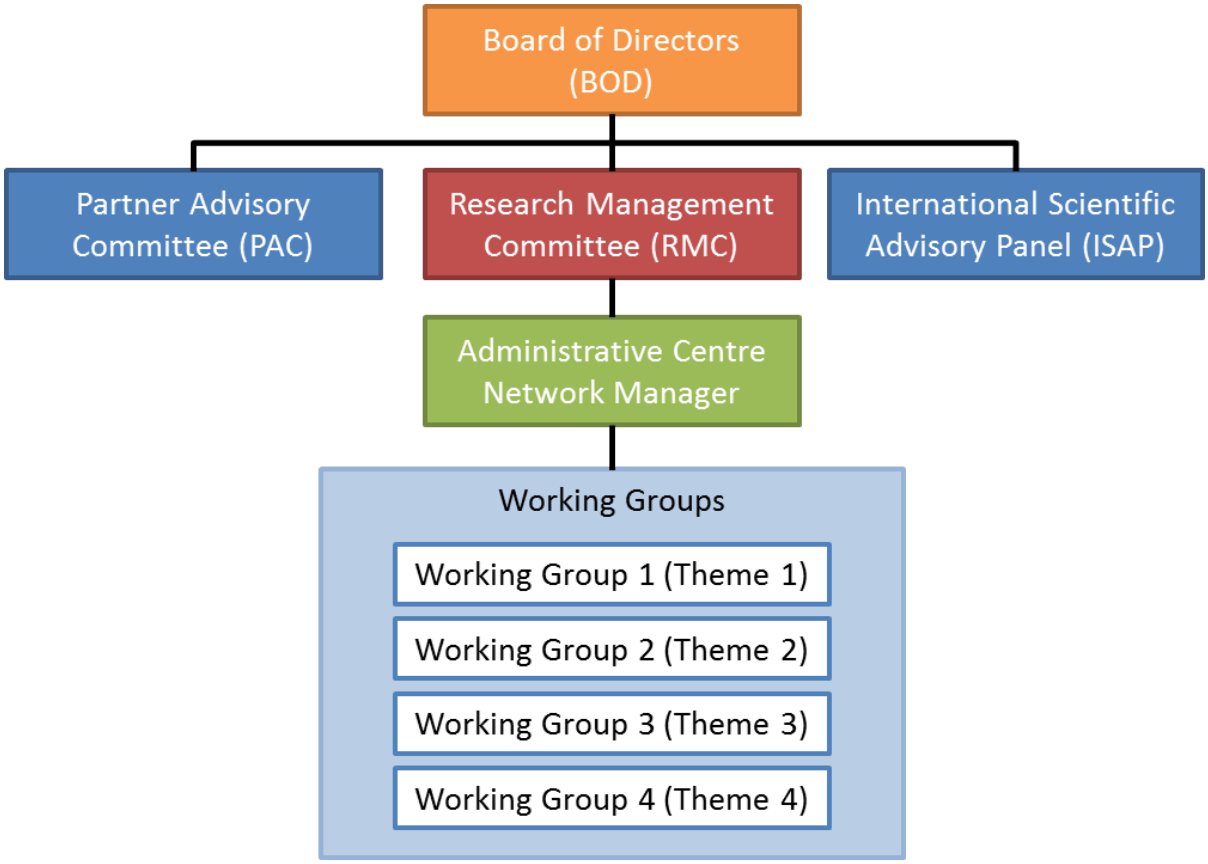
All the theme leaders/co-leaders are well established researchers with strong track records in research and research management. Leading Theme 1 (Flood Regimes in Canada: Learning from the Past and Preparing for the Future) are Professors Donald Burn and Van Nguyen, two internationally known experts in engineering/statistical hydrology. The leaders of Theme 2 (Quantifying and Reducing the Predictive Uncertainty of Floods) are Professors François Anctil and Peter Rasmussen, two well-established researchers with extensive experience in uncertainty analysis in hydrology. Theme 3 (Development of Canadian Adaptive Flood Forecasting and Early Warning System (CAFFEWS)) is led by the PI and Professor Weihua Zhuang, an internationally renowned expert in wireless communication technology. She holds a Tier-1 Canada Research Chair in Wireless Communication Networks. Leaders for Theme 4 (Risk Analysis of Physical, Socio-Economic, and Environmental Impacts of Floods) are Professors Marguerite Xenopoulos and Amin Elshorbagy, two well-known experts in their disciplines, aquatic ecosystem ecology and water resources engineering and decision analysis, respectively.

Network Investigators

Twenty one professors from 12 Canadian universities are co-applicants in FloodNet. All of them are recognized as leading researchers in their disciplines. FloodNet investigators also include 30 government/industrial scientists/engineers. This team will be joined by graduate students and post-doctoral fellows.

Network Governance

The management structure of FloodNET involves a Board of Directors (BOD), a Research Management Committee (RMC), an International Scientific Advisory Panel (ISAP), a Partners Advisory Committee (PAC), and an Administrative Centre led by a Network Manager. For each of the four themes, a Working Group is formed consisting of researchers involved in the theme.



Board of Directors

The Network's Board of Directors (BOD) holds the highest decisional level and governs the Network. The Board is composed of 9 voting members and 2 non-voting members (NSERC Program Officer and FloodNet Manager). The 9 voting members include representation from the Investigators, Host University, the public and private sectors in Canada, and appropriate others if necessary. The Network Scientific Director is a voting member of the Board.

The Board provides oversight of all Network activities and is responsible for the management, direction and financial accountability of FloodNet in compliance with NSERC's regulations and conflict-of-interest rules. The Board meets annually to set and review the Network policies, monitor progress and decision-making, and approve the annual budget recommended by the Research Management Committee. The Board sets policies and approves the admission and withdrawal of partner organizations.

Research Management Committee

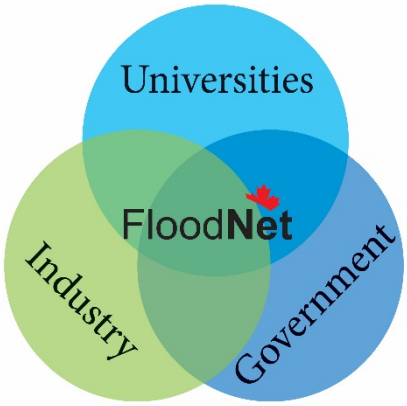
The Research Management Committee (RMC) is responsible for the general management and execution of the research plan. The RMC is composed of six theme leaders and is chaired by the Network PI. The RMC will meet twice a year. Through the PI, the RMC reports to the BOD, providing updates on progress, and making recommendations about new research projects, allocation of annual funds and resources, and new partners and network members. The RMC receives and reviews biannual progress reports for each sub-project and makes decisions on the termination of projects that do not meet satisfactory performance requirements. The RMC receives and considers input from the Partner Advisory Committee and communicates regularly with partners through an annual report, highlighting research accomplishments over the previous year. The RMC organizes a Network Annual Workshop for all network members (researchers, partners, students) where presentations and discussions will take place. The Network Manager will attend all meetings of the RMC.

International Scientific Advisory Panel

The International Scientific Advisory Panel (ISAP) was formed from leading international scientists in the areas of flood forecasting and flood mitigation. The role of the ISAP is to provide recommendations on the research directions of FloodNet and independent review of network scientific results. Feedback from the ISAP will be used to refine ongoing research and improve performance.

Partners Advisory Committee

A Partners Advisory Committee (PAC) was formed from representatives from all industry and government partners. The principal mandate of the PAC is to ensure the industrial relevance of the research activities in FloodNet. The PAC meets once a year to discuss the needs of partners, and the implementation and use of research results. The meeting is in connection with the Network Annual Workshop. The PAC makes recommendations to the Research Management Committee for new directions that will address the research needs of industry and government.



Benefits

The benefits of new knowledge and technologies for enhanced flood forecasting and management are manifold. Examples of specific outcomes of FloodNet research include:

1) Manual, guidelines and statistical tools for flood frequency analysis and updating Intensity, Duration and Frequency (IDF) curves in Canada. There is a need for formalized procedures for flood frequency analysis in Canada. Changes in the intensity and frequency of extreme events require an update for engineering design. This outcome is highly needed by municipal engineers. (Theme 1)

2) New frameworks for optimization of multi-reservoirs operation and ensemble forecasts in flood forecasting. Optimal operation of multiple reservoirs to reduce flooding downstream requires robust optimization techniques. Similarly, ensemble forecast techniques will enhance the reliability of water resource management. These tools are needed for the operation of water supply, hydropower reservoirs and hydrological forecasting. (Theme 2)

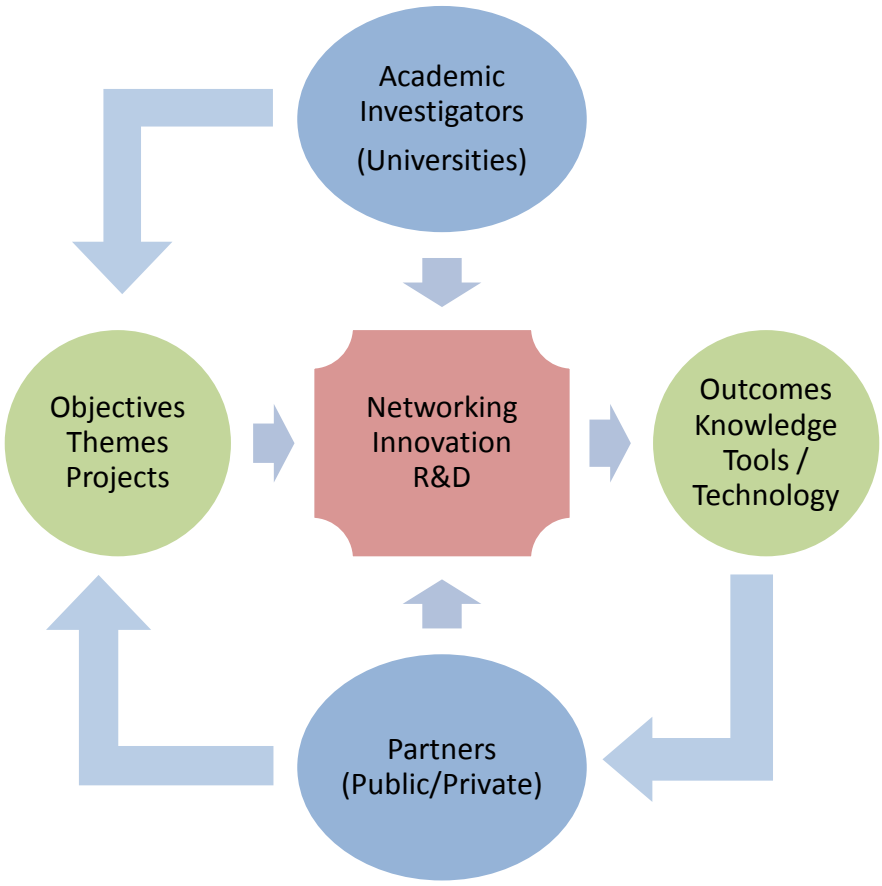
3) Canadian adaptive flood forecasting and early warning system (CAFFEWS). This advanced flood alert system will enhance flood forecasting capacity in Canada with significant benefits for flood mitigation. Embedded technologies, such as the P2P communication system and the real-time spatial information processing algorithms, have potential for spin-off activities, thus leading to high-skill job creation in Canada. (Theme 3)

4) Integrated flood vulnerability indicators for planning and decision making. Holistic flood vulnerability indicators will include the socio-economic impacts of floods, impacts on agricultural lands and the potential impacts on urban drainage systems. This knowledge will help municipal officials to better plan resilient infrastructure, identify flood risk level for a given area and estimate the cost-benefits of living in a flood prone area. (Theme 4)

The FloodNet Research Program

The FloodNet research program is carried out primarily at the collaborating universities, while working closely with the FloodNet partners. Representatives from partner organizations are associated with each research project with which they have a special interest and can interact with researchers by helping research planning as well as participating in the research itself.

A central component of the FloodNet collaboration will be the use of one or more common case study areas for development and testing of the research methodologies. In general, the case study locations have been selected in consultation with our partner organizations to ensure relevance for the partners' interests and to facilitate the assembly of the data and information required for some of the projects. In many cases, the data and information will be provided by our partners as an in-kind contribution to the research. Sites of primary interest to our partners have been supplemented with sites selected to better explore the capabilities of the techniques developed, particularly where there is an interest in evaluating a technique for the diversity of conditions expected to occur across Canada.



OBJECTIVES	PROJECTS	INVESTIGATORS	INSTITUTION
Advance Knowledge of Flood Regimes (Past and Future) and Provide Guidelines for Infrastructure Design	**Theme 1: Flood Regimes in Canada: Learning from the Past and Preparing for the Future**		
	1-1 Update of current flood and storm quantiles	**Burn**/Ashkar/Rasmussen	Waterloo/Moncton/ Manitoba
	1-2 Examination of current flood and storm quantiles	**Ashkar**/Burn/Gan	Moncton/Manitoba/Alberta
	1-3 Analysis and applicability of future extreme events in regional and local context	**Arain**/Gan/Coulibaly	McMaster/Alberta
	1-4 Development of new methods for updating IDF curves in Canada	**Nguyen**/Guo/Gan/Elshorbagy	McGill/McMaster/Alberta/ Saskatchewan
	1-5 Spatial changes to flood prone areas in urban environments	**Binns**/Guo/Tilmant	Western/McMaster/Laval
	1-6 Development of new flood estimation manual for Canada	**Rasmussen**/Burn/Ashkar	Manitoba/Waterloo/ Moncton
Advance Knowledge on Flood Forecasting Systems and Enhance Flood Forecasting in Canada	**Theme 2: Quantifying and Reducing the Predictive Uncertainty of Floods**		
	2-1 Comparison of ensemble forecast methods for operational streamflow forecasting based on a single model	**Tolson**/Anctil/Berg	Waterloo/Laval/Guelph
	2-2 Comparison of ensemble forecast methods for operational streamflow forecasting based on multiple models	**Anctil**/Tolson/Tilmant	Laval/Waterloo
	2-4 Evaluation of flood warning based on hydraulic model with assimilation and \ hydrological ensemble forecasts	**Anctil**/Tolson/Berg	Laval/Waterloo/Guelph
	2-5 Real-time reservoir operation based on a combination of long-term and short-term optimization and hydrological ensemble forecasts	**Tilmant**/Anctil/Tolson	Laval/Waterloo
	Theme 3: Development of Canadian Adaptive Flood Forecasting and Early Warning System (CAFFEWS)		
	3-1 Evaluation of flood forecasting and warning systems across Canada	**Rasmussen**/Gan/Coulibaly	Manitoba/Alberta/ McMaster
	3-2 Real-time spatial information evaluation and processing	**Berg**/Coulibaly/Gan	Guelph/McMaster/Alberta
	3-3 Enhanced information communication systems	**Zhuang**/Song/Coulibaly	Waterloo/NewBrunswick/ McMaster
	3-4 Development of Canadian Adaptive Flood Forecasting and Early Warning System (CAFFEWS)	**Coulibaly**/Elshorbagy/Berg/ Tolson/Anctil/Rasmussen	McMaster/Saskatchewan/ Guelph/Waterloo/Laval/ Manitoba
	3-5 Application and testing of CAFFEWS in selected regions across Canada	**Burn**/Elshorbagy/Coulibaly	Waterloo/Saskatchewan/ McMaster
Assess Impacts of Floods on People, Society, and Environment	**Theme 4: Risk Analysis of Physical, Socio-Economic, and Environmental Impacts of Floods**		
	4-1 Role of floods on aquatic ecosystem condition	**Xenopoulos**/Emery/Bennett/ Arain	Trent/McGill/McMaster
	4-3 Modeling-based integrated assessment of flood impacts on urban and rural water resources systems	**Elshorbagy**/Xenopoulos/Guo	Saskatchewan/Trent/ McMaster
	4-4 Flood risk analysis and its utility for management decisions	**Elshorbagy**/Coulibaly/Eyles/ Yiannakoulias	Saskatchewan/McMaster
	4-5 Assessing and planning for the socio-economic effects of floods	**Eyles**/Yiannakoulias/ Xenopoulos/ Elshorbay	McMaster/Trent/ Saskatchewan

Theme 1 - Flood Regimes in Canada: Learning from the Past and Preparing for the Future

Theme 1 will advance our knowledge of flood regimes in Canada (present and future) and provide guidelines for infrastructure design. This work is important to FloodNet since improved understanding of extreme events in Canada, both present and future, is required to design flood control infrastructure, plan for flood mitigation systems, and appropriately implement land use planning to minimize the economic and social impacts of flood events. The increased understanding of extreme events to be obtained in this theme will contribute to the design of the flood forecasting system to be developed in Theme 3 and help with the analysis of flood impacts in Theme 4.

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Dr. Paulin Coulibaly
Dr. Amaury Tilmant
Dr. Amin Elshorbagy
Dr. Yiping Guo

Theme 1 Partners Organizations

Credit Valley Conservation Authority
City of Hamilton
Toronto Region Conservation Authority
Manitoba Hydro
Ontario Ministry of Natural Resources
SNC Lavalin
Essex Region Conservation Authority
City of Edmonton
Saskatchewan Water Security Agency
BC-Hydrologic Forecast Centre
Ontario Climate Consortium
Environment Canada
Corrugated Steel Pipe Institute
Institute for Catastrophic Loss Reduction

Project 1-1 Update of current flood and storm quantiles

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Objective
Characterize flood and extreme precipitation regimes for selected locations across Canada and provide updated estimates for extreme event frequency curves.

Significance
Extreme events cause considerable damage to Canadian infrastructure and result in property damages as well as loss of life. It is hence essential that we are able to accurately estimate the probability of exceedance of extreme events to design appropriate infrastructure to protect humans and property from the impacts of extreme events.

Outcomes
The outcomes from this project will include updated estimates for flood and extreme rainfall quantiles for many locations across Canada as well as a unified procedure for applying frequency analysis that reflects the diversity of hydrologic and meteorological conditions in Canada.

Networking
This project will link closely to other projects in Theme 1, including Projects 1-2, 1-4 and 1-6. Information from Project 1-2 will inform the frequency analysis at the locations selected for analysis. The analysis procedures developed in this project will be used in Project 1-4 as part of the process of developing IDF curves for future conditions and form the basis for the new flood estimation manual for Canada, to be developed in Project 1-6. This project will provide the frequency analysis data required for Projects 4-1, 4-3, and 4-4.

Project 1-2 Examination of spatial and temporal variation of extreme events

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Objectives
Describing the spatial distribution of extreme rainfall and floods with specified return periods and assessing how changes in extreme events occur over time. Identifying regions where seasonal variations in floods need to be incorporated into the flood modelling due to the presence of distinct flood sub-populations.

Significance
Increases in storm intensity over time have substantial implications on water resources infrastructure. Assessing the spatial distribution of extreme rainfall and floods allows the identification of regions with significantly heavier rainfall or regions prone to flooding. Accounting for the seasonal variations in floods will improve estimates of low-frequency/large-magnitude extreme events.

Outcomes
Outcomes from this project include: i) the identification of geographic regions in Canada where infrastructure are prone to high risk of severe rainfall or flooding; ii) the identification of regions with distinct seasonal flood patterns; and iii) a simplified method to apply the POT approach for the purpose of extreme flood and rainfall event estimation by practitioners.

Networking
Project 1-1 will provide significant input to this project. The procedures jointly developed in this project and in Project 1-6 will be incorporated into the new flood estimation manual for Canada.

Project 1-3 Analysis and applicability of future extreme events in regional and local context

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Objectives
Assess the spatial variability of observed and simulated extreme precipitation events across Canada and investigate the limitations and applicability of various indices used to describe extreme precipitation events at local scales for both current and future climate.

Significance
This project will determine whether spatial trends in extreme precipitation have been adequately simulated by the Intergovernmental Panel on Climate Change (IPCC) Fifth Assessment Report (AR5) participating climate models for future climate scenarios and how these simulations may be applied at a local scale.

Outcomes
This project will estimate extreme precipitation indices for current and future conditions for a variety of locations across Canada and provide an indication of the expected changes for future conditions. The project will also develop and evaluate new extreme precipitation indices.

Networking
This project has close ties to Project 1-2 for spatial and temporal variation of extreme events and Project 1-4, through the downscaling of precipitation. The outcome of this project will also help in the work under Projects 1-5 and 4-3.

Project 1-4 Development of new methods for updated IDF curves in Canada

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Objectives
Evaluate climate change impact on Intensity-Duration-Frequency (IDF) curves of selected Canadian cities and develop new regional IDF curves for selected cities of Canada.

Significance
Climate change could modify the extreme events that form the basis for existing IDF curves of Canadian cities, meaning municipal infrastructure could suffer from under-design problems resulting in compromised public safety.

Outcomes
Outcomes will include new regional and at-site IDF curves for selected Canadian sites developed from statistical and dynamical downscaling of climate change scenarios and guidelines for updating IDF curves in Canada. There is an urgent need to update IDF curves in Canada as the IDF curves for most locations in Canada do not reflect the most recently available data and do not account for the impacts of climate change. The proposed guidelines will provide direction to municipalities, conservation authorities and other users of IDF curves to enable the updating of IDF curves in a timely manner using appropriate procedures.

Networking
This project will use techniques developed in Project 1-1 for regional frequency analysis and has close ties with Project 1-3.

Project 1-5 Spatial changes to flood prone areas in urban environments

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Objectives
To predict spatial changes to flood prone areas in urban environments as a result of changing environmental and hydrological factors.

Significance
This project will lead to a greater understanding of the relationship between flooding and land-use in urban environments. Results will provide improved guidance for future urban development and assist in planning for flood mitigation and storm-water management with the goal of protecting existing infrastructure and reducing the economic loss associated with flooding.

Outcomes
The outcomes from this project will include updated urban development guidelines to minimize risk of flooding; an evaluation of the effectiveness of various stormwater management features and recommendations for their retrofit in Canadian cities; and hydraulic engineering guidelines for more flood resilient waterway modification in urban environments.

Networking
The project will link with Projects 1-2, 1-3 and 1-6 and will also provide input for Project 4-3.

Project 1-6 Development of new flood estimation manual for Canada

Leader
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Objective
Produce a manual and statistical tools for flood frequency analysis in Canada.

Significance
Guidelines for flood frequency analysis will be an asset for practitioners, but must be based on a rigorous evaluation of candidate methods. The present research will consider the entire range of elements that must be considered in practice and will be tailored to Canadian conditions.

Outcomes
A manual with suggested best practices for flood frequency analysis and statistical tools that implement key procedures from the methodology will be developed and made available to practitioners.

Networking
This project will be coordinated with other subprojects under Theme 1. Projects 1-1 and 1-2 in particular will provide input to the development of guidelines for flood estimation in Canada.

Theme 2 - Quantifying and Reducing the Predictive Uncertainty of Floods

Prediction and decision-making in aquatic environments requires a diversified approach to monitoring, modelling, and risk assessment. Theme 2 addresses the challenges associated with the reduction and quantification of predictive uncertainty in the management of water resources. To achieve this, the research will process uncertainty through a complete vertical chain of models and techniques exploiting operational meteorological ensemble forecasts, a sound hydrological ensemble prediction system, including a probabilistic streamflow assimilation scheme, and water resources management tools. This theme will contribute to the design of the Canadian flood forecasting system to be developed in Theme 3.

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Theme 2 Investigators

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Dr. Bryan Tolson
Dr. Aaron Berg
Dr. Peter Rasmussen
Dr. Paulin Coulibaly
Dr. Amaury Tilmant

Theme 2 Partners Organizations

Environment Canada
Ontario Power Generation
Toronto Region Conservation Authority
Ontario Ministry of Natural Resources
Hydro-Québec
Centre d'Expertise Hydrique du Québec
Manitoba Ministry of Infrastructure and Transportation
BC-Hydrologic Forecast Centre
SNC Lavalin

Project 2-1 Comparison of ensemble forecast methods for operational streamflow forecasting based on a single model

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Objective
Compare the performance and reliability of many probabilistic implementations of operational ensemble streamflow forecasting based on a single hydrological model.

Significance
Many Canadian agencies interested in flood forecasting have devoted substantial resources into developing one reasonably accurate, often distributed, hydrologic simulation model of their system for use in a formal hydrological ensemble prediction system. Agencies are often hesitant to consider multi-model ensemble prediction systems and as such this project aims to identify the most robust single model based forecast method. In particular, the work will focus on calibrating the model to multiple realizations of input forcing data (precipitation and temperature) to identify multiple parameter sets (rather than multiple models) to use in the ensemble forecast.

Outcomes
This project will compare multiple approaches for making ensemble forecasts with a single model. We will also develop a forecast system evaluation framework customized for how each partner organization will make decisions using an ensemble forecast.

Networking
Work in this project will be undertaken collaboratively with Project 2-2 and case studies will be selected and data managed in a way to allow direct comparison of ensemble forecast systems built with differing levels of complexity. HQP will be expected to spend time with both Dr. Tolson and Dr. Anctil and to interface with 1or 2 additional research partners with existing hydrologic models to build a single-model ensemble forecasting system.

Project 2-2 Comparison of ensemble forecast methods for operational streamflow forecasting based on multiple models

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Objective
Compare the performance and reliability of many probabilistic implementations of operational ensemble streamflow forecasting based on multiple hydrological models.

Significance
Because models are abstractions of real systems, it cannot be anticipated which specific model offers the greatest accuracy and predictive capability for specific catchments and hydrologic conditions. Multi-model prediction aims to extract as much information as possible from existing models. A multi-model approach emerged as a top priority for a large group of recently interviewed professional flood forecasters (Wetterhall et al., 2013).

Outcomes
We will identify the advantages and disadvantages of ensemble prediction systems of various complexities. This outcome will guide Canadian agencies responsible for flood warning in identifying an ensemble prediction system suitable for their needs.

Networking
Work in this project will be undertaken collaboratively with Project 2-1, providing a comparison performance for its single-model operational set-up. It will also provide inputs to Projects 2-4 and 2-5 exploring water-level forecasts and reservoir operation, respectively. This project will also serve as a performance reference for Theme 3, as well as for identifying a suitable ensemble prediction methodology for Project 3-4 (CAFFEWS).

Project 2-4 Evaluation of flood warning based on a hydraulic model with assimilation and hydrological ensemble forecasts

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Objective
Explore flood warning based on a hydraulic model with assimilation and hydrological ensemble forecasts, extending the hydrological ensemble prediction system tested in Project 2-2, with an additional vertical component.

Significance
Flood warning relies on threshold-based decision rules that prescribe actions when streamflow exceeds a predefined value. In a deterministic world, the decision to act on forecast information is often guided by experience, especially when water levels are close to a threshold. It is then strictly up to decision makers to interpret the situation based on a qualitative appreciation of the uncertainty (experience). In a probabilistic world, access to a predictive distribution allows a better appreciation of the risks since the probability of exceeding a threshold may be estimated to be, for example, 20% or 70%.

Outcomes
Project 2-3 will extend hydrological ensemble forecasts by issuing a distribution of water level forecasts at each time step.

Networking
This project is linked to several other projects in FloodNet. We will use the same case studies as in other projects and the results from this project will provide input to Projects 3-1 and 3-4.

Project 2-5 Real-time reservoir operation based on a combination of long-term and short-term optimization and hydrological ensemble forecasts

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Objective
Incorporation of hydrological ensemble forecasts into a large-scale, stochastic, optimization algorithm.

Significance
Traditional optimization techniques are not feasible for solving large-scale reservoir operation problems subject to hydrological ensemble forecasts due to system complexity. Recent advances in stochastic programming offer opportunities in terms of modelling details, particularly with respect to system size and uncertainty (Tilmant et al., 2008; Marques and Tilmant, 2013). We propose a solution based on a locally accurate approximation of the objective function instead of an exhaustive representation over the entire state-space. This approximate solution strategy is particularly attractive because using frequently updated H-EPS implies there is no need to explore the entire state-space but only the most relevant subset considering the initial system status and the forecasts (Meier et al., 2012).

Outcomes
We propose an optimization framework to solve the multi-reservoir operation problem by integrating H-EPS in a stochastic optimization model. This will help Canadian agencies responsible for operating large-scale water resource systems to improve their management tools by deriving dynamic, risk-based, reservoir operation policies.

Networking
Work in this project will be undertaken collaboratively with Projects 2-1 and 2-2, which will provide the ensemble streamflow forecasts for this research. Reservoir operation for preventing flood events, but also for other considerations, will help with the analysis of flood impacts in Theme 4. For instance, Hydro-Québec has already used reservoir optimization as a means to evaluate the value of ensemble forecasting; this project will thus provide valuable feedback to Projects 2-1 and 2-2.

Theme 3 - Development of Canadian Adaptive Flood Forecasting and Early Warning System (CAFFEWS) – Projects

This theme aims to advance our knowledge on flood forecasting systems and enhance flood forecasting capacity in Canada, which is a key target of FloodNet. The benefits of timely and accurate flood warning could be on the order of multiple millions per year arising mainly from reduced property damages and loss of life but also from reductions in social disruption and distress, environmental damages, and interruption of economic activity in affected areas. The Canadian Adaptive Flood Forecasting and Early Warning System (CAFFEWS) will improve upon the current state of the art in advanced flood forecasting systems.

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Theme 3 Partners Organizations

Hydrological Forecasting Centres of Ontario, Quebec, British Columbia, Manitoba, Alberta, Saskatchewan, Newfoundland and Labrador and New Brunswick
Municipal Authorities of Hamilton, Mississauga, Toronto, Windsor, and Edmonton
Environment Canada
Ontario Power Generation
DHI
Deltares USA/Netherlands
Hydro-Québec
National Research Council
Manitoba-Hydro
AeroScribe Consulting
SNC Lavalin
United Nation University Institute of Water Environment and Health

Project 3-1 Evaluation of Flood Forecasting and Warning Systems across Canada

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Objective
Review flood forecasting systems currently implemented by Canadian provinces and evaluate their performance in meeting their intended purpose.

Significance
In order to propose better methods for flood forecasting in Canada, it is imperative to start with a thorough evaluation and comparison of existing methods. In this project, we will evaluate adopted and alternative methods.

Outcomes
The proposed research will result in recommendations for the type of tools and data that are most suitable for flood forecasting under particular circumstances. This information will provide input to other projects and guide some of the research efforts in FloodNet, specifically Project 3-4.

Networking
The information generated from this project will provide important input to other projects, in particular the development of CAFFEWS, described in Project 3-4. This project will also share case studies, and associated information, with Project 3-5.

Project 3-2 Real-time Spatial Information Evaluation and Processing

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Objective
First, assess if a monitoring network and available data can meet enhanced flood forecasting requirements and use other sources of information (e.g., remote sensing, radar, reanalysis datasets) with regionalization techniques to address data limitations. Second, use available satellite derived soil moisture products to assess near real time, spatially distributed, estimates of the status of soil water and snow water equivalence. Investigate bias correction techniques for estimating rainfall from the next generation of radar (NEXRAD) data.

Significance
This project will address the issue of the paucity of monitoring data. A general framework is needed to consistently address data limitation. The importance of the initial soil moisture and snow water equivalent state for improving the simulation of streamflow is well established. In recent years satellite derived hydrological products have emerged that are of interest for the improvement of initial state estimation for hydrologic models used in flood forecasting. Similarly, merging radar rainfall with rain gauge data allows the generation of distributed rainfall fields needed for improved flood forecasting.

Outcomes
A robust tool for data estimation will be developed to address the common problem of data limitation due to inadequate monitoring networks. This project will also generate practical tools for deriving distributed products (rainfall, soil moisture, snow water equivalent) from radar and satellite data for inclusion in flood forecasting systems.

Networking
The outcome of Project 3-2 will be useful to all projects dealing with ungauged (or poorly gauged) sites. All the selected study areas for Projects 3-4 and 3-5 will be evaluated using the data estimation tool developed in this project. The benefits of the distributed datasets (rainfall, soil moisture, snow water equivalent) derived from radar, satellite, and in-situ observation networks will be further evaluated in Project 2-2 and in Projects 3-4 and 3-5 using CAFFEWS.

Project 3-3 Enhanced Information Communication Systems

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Objective
Investigate and develop efficient wireless networking strategies to transmit sensor data to the information processing center and disseminate flood warning messages to the general public in a timely manner.

Significance
Due to potentially devastating damages from floods to lives and properties, enhanced information collection and communication is essential to the flood early warning system. This will help to better mitigate flood impacts on the economy and prevent casualties caused by such disasters.

Outcomes
We will develop new approaches for reliable transmission of spatially distributed data collected from various sources to an information processing center and information dissemination strategies to deliver timely alerts from CAFFEWS to the general public.

Networking
This project will be closely linked to other projects in Theme 3. To achieve reliable transmission of the sensing data, this project needs to consider the data characteristics of the wide-range data sources in terms of data volume, update frequencies, arrival patterns, and so on, which will be provided by Project 3-2. Project 3-4 will generate flood alert messages, which can be disseminated to the general public using the effective wireless network strategies that will be developed in this project.

Project 3-4 Development of Canadian Adaptive Flood Forecasting and Early Warning System (CAFFEWS)

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Objective
Develop a forward-looking flood forecasting tool (i.e., CAFFEWS) that includes adaptive structures for assimilating new technology and new data/information as they become available, and which can be adapted to different regions of Canada for enhanced flood forecasting.

Significance
Accurate and reliable flood forecasts are fundamental to enhanced flood mitigation and can be obtained by developing an advanced flood forecasting system. The development of CAFFEWS will contribute significantly to enhancing the national capacity for flood forecasting, which is one of the key targets of FloodNet.

Outcomes
To deliver an adaptive flood forecasting and early warning system for Canada.

Networking
This project will be informed by outcomes from Themes 1 and 2 and will use research results from Projects 3-1, 3-2 and 3-3 in the development of CAFFEWS. Project 3-5 depends entirely on the results of this project. In addition, outcomes of this project will be used in Project 4-3. Dynamic networking between investigators, HQP, and various partners of Themes 2 and 3 is inherently part of the research approach given the strong linkages among the projects.

Project 3-5 Application and Testing of CAFFEWS in Selected Regions across Canada

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Objective
To provide an impartial and thorough evaluation of CAFFEWS in a variety of forecast settings for conditions typical of Canadian forecast situations.

Significance
The efficacy of CAFFEWS for forecasting in a Canadian environment needs to be evaluated to determine which conditions the new system can provide improved forecasts and to quantify the range of expected improvements in forecasting capability.

Outcomes
The outcomes of this project will include a rigorous evaluation of CAFFEWS for a variety of differing data availability conditions and forecasting environments; a summary of the conditions for which CAFFEWS is anticipated to result in improved forecasts; and an estimate of the expected magnitude of improvement in the various forecast performance metrics.

Networking
This project relies directly on results obtained from Project 3-4. The evaluation of the forecasting method, and especially the selection of case study sites, will be informed by the examination of hydrologic regimes in Canada, conducted in Theme 1, specifically Projects 1-1 and 1-2. The project will also benefit from the uncertainty analysis conducted in Theme 2.

Theme 4 - Risk Analysis of Physical, Socio-Economic, and Environmental Impacts of Floods

The physical, environmental, and socio-economic effects of floods are complex and vary greatly depending on their location, duration, depth and speed, as well as the vulnerability of the affected area. As our understanding of the cost/benefits of flooding improves, there is a need for more information on the environmental consequences of floods, and the balance between mitigating floods and preserving the water flows required to conserve natural ecosystems and enhance environmental and human well-being (Poff et al. 2003). In general, the physical impacts of floods and risk levels have been documented to a greater extent than the environmental and socio-economic aspects. This may explain why the environmental and socio-economic consequences of flooding are usually not incorporated in management policies or in flood impact estimation models.

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Theme 4 Partners Organizations

Environment Canada
Ontario Power Generation
Toronto Region Conservation Authority
Ontario Ministry of Natural Resources
Hydro-Québec
Centre d'Expertise Hydrique du Québec
Manitoba Ministry of Infrastructure and Transportation
BC-Hydrologic Forecast Centre
SNC Lavalin

Project 4-1 Role of floods on aquatic ecosystem condition

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Objectives
The objectives of this project are to: i) examine the effects of high water levels on surface water quality of forested, urban and agriculture catchments; ii) quantify nutrient budgets of flooded forested and agriculture catchments; iii) analyze the frequency of flood events in regulated and non-regulated rivers and their relation to ecosystem condition; and iv) link flooding to ecosystem structure (e.g., biodiversity) and function (e.g., primary production) and aquatic ecosystem services.

Significance
Floods play an important role in maintaining key ecosystem functions and biodiversity (Bunn and Arthington, 2002; Poff et al., 2003). Large floods are often tightly coupled to ecological life history cycles (e.g., breeding, feeding and migration) and link the river with the land by distributing water, nutrients and sediments, recharging groundwater and filling wetlands. But floods also increase loading of nutrients into aquatic ecosystems increasing the risk of eutrophication (Hrdinka et al., 2012; Schindler et al., 2012).

Outcomes
We will provide much needed scientific information, data analysis, and links between flooding and aquatic ecosystem condition to facilitate the development of management and conservation plans.

Networking
This project will share case studies and overlay in datasets and modelling with several partner organizations and Themes 1 and 3.

Project 4-3 Modelling-based integrated assessment of flood impacts on urban and rural water resources systems

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Objectives
This project will investigate and predict the hydrologic connectivity in a watershed under high flow conditions; build a suitable systems modelling approach to simulate a flood and its spatial extent in a watershed and its effect on the various watershed components (e.g., agricultural lands, lakes and wetlands, rural development, and water supply); predict nutrient loadings into surface waters due to floods; and iv) simulate the effect of extreme rainfall on urban drainage infrastructure and storm water detention facilities.

Significance
It is important to develop an approach that allows for quantifying and predicting the impacts of floods on the physical environment in rural and urban areas in an integrated and comprehensive way. Based on the integrated assessment of the flood impacts, watershed authorities can evaluate and prioritize planning and action measures.

Outcomes
This project will produce a physical system modelling approach for assessing the integrated impacts of floods in rural, urban, and semi-urban watersheds. This tool can be used by conservation authorities and municipalities for land use development planning.

Networking
Field experiments will be coupled with past flooding events and archived data using empirical statistical methods (Project 4-1) and system modelling (Project 4-3). Data collected will be made available to other projects through the FloodNet data server.

Project 4-4 Flood Risk analysis and its utility for management decisions

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Objectives
This project will: i) develop a systematic approach for analyzing and quantifying flood risk, along with its uncertainty; and ii) assess the utility of flood risk quantification for management and planning decisions.

Significance
Various flood risk indicators have been developed without indication of the associated level of uncertainty. This project will fill that gap by proposing a systematic approach for quantifying flood risk along with the associated uncertainty. This is particularly important for decision making based on flood risk indicators.

Outcomes
The research will produce a systematic approach for developing risk indicators with uncertainty estimates that water resources and disaster managers can use for decision making. The indices will allow for quantifying the value of improving and investing in various aspects of modelling, monitoring, and damage mitigation measures.

Networking
There is a strong link with Project 4-2 as experimental data of Project 4-2 will be used for the water quality modelling component of this project. This project will also work with projects of Theme 1 to use the regional frequency analysis results and the climate change-induced storms as forcing variables for the rural and urban watershed models developed in this project. Project results will be used in Project 4-4 to estimate the flood risk levels.

Project 4-5 Assessing and planning for the socio-economic effects of floods

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Objectives
This project will develop a framework for generating holistic flood vulnerability indicators that account for socio-economic effects of floods.

Significance
Existing flood vulnerability indices in Canada do not account for the socio-economic impact of floods. This project will fill that gap by introducing a framework for estimating flood vulnerability indices that account for the socio-economic impacts of floods.

Outcomes
We will determine the costs and benefits of flooding and living in flood-prone areas to develop flood vulnerability indicators and a scale of severity. This information will be useful to decision makers, private home owners and insurance companies.

Networking
This project will use information (e.g., physical risk indicators) from Project 4-4 and will need input from government scientists (e.g., Environment Canada, provincial/municipal agencies), and data from insurance companies through our partner, the Institute for Catastrophic Loss Reduction (ICLR).

Training Opportunities

The training of highly qualified personnel (HQP) is central to FloodNet with over 72% of its budget allocated to HQP. The Network's aims of increasing Canada's knowledge and experience on flood impacts and management through carefully designed projects will not only produce much needed scientific and technical outcomes but also boost the number of HQP in hydrology and water resources. In that sense, the excellence of the training proposed by FloodNet resides in the pertinence of the projects, in their innovative qualities, in the leadership of internationally respected researchers that collaborate toward a common goal, and in many and diverse partner organisations that bring to the Network their expertise and a large dose of realism. Numerous hand-picked students and PDFs will thus have the opportunity to learn, grow, and gain valuable experience within a unique framework, unprecedented in Canada.

A multidisciplinary perspective on floods

A fundamental strength of the proposed FloodNet is the broad participation in the research of key scientists/experts from academia, federal and provincial agencies, and many private sector organizations. This offers a unique opportunity for enhancing highly qualified personnel (HQP) training by taking advantage of the multidisciplinary and multisectoral environment. The future generation of flood forecasters and flood managers must be well-educated and highly qualified to confront the complexities of future flood events in an increasingly changing environment. The FloodNet research program will use cutting-edge information processing technology, advanced system modelling techniques, and emerging wireless network communication technology to develop a new generation of flood forecasting system. Therefore, HQP will be at the forefront of research in the field. HQP involved in those integrative studies will benefit from working with a team of experts and experienced operational hydrologists, which is the ideal research environment for such complex topics.

Research exchanges between university laboratories

The research within FloodNet is interdisciplinary with much collaboration embedded in the highly qualified personnel (HQP) training plan. Collaboration between the many researchers involved in FloodNet will help HQP attain their individual goals. HQP will be able to visit and work with partner university laboratories, enhancing scientific outcomes and the quality of their training. Each university and organisation possesses specific skills and tools (models, databases, analysis methods, computer facilities, and more) that will thus be shared to the benefit of the whole Network. For example, McMaster has a vast understanding of hydro-informatics that will be shared with others, while the environmental experience of Trent University will influence the whole team. We thus anticipate that the majority of HQP will directly benefit from multidisciplinary training through exchanges between different academic laboratories.

Partners have committed to participate in HQP training and to co-supervise HQP where applicable. The HQP will thus gain hands-on/practical experience through the opportunities to work directly with public and/or private partners of FloodNet. For example, a student with interest in the management of water resources will typically have a greater management and policy-oriented emphasis to their work and be coupled with a collaborator from a government agency. Where applicable, HQP will also be coupled with private sector partners to allow them to gain industrial research experience. As a result, they will not only have a better understanding of the needs and issues facing flood forecasters, water resources managers, and policy/decision makers in Canada, but will also have practical skills in real-world problem solving (e.g., hydropower companies) that are highly needed in the job market.

Relevant Experience

There is an urgent demand for highly skilled graduates trained in water resources with expertise in hydrometeorological modelling, water management, valuation of ecosystem services, and decision-making under uncertainty. In addition to being trained by leading scientists in these fields, highly qualified personnel (HQPs) will be given the opportunity to work on practical water resources problems alongside specialists from the main agencies responsible for hydropower management, policy making, environmental prediction, and weather forecasting. HQP will also have the opportunity to present their results to these specialists and to the scientific community at large.

Partners

Government Partners

Saskatchewan Water Security Agency
Environment Canada, Weather and Environment
Agricultural and Agri-Food Canada
Ontario Ministry of Natural Resources
Ontario Ministry of the Environment
BC Ministry of Forests, Lands, and Natural Resources
Manitoba Ministry of Infrastructure and Transporation
Ministere du Developpement durable, de l'Environnement, de la Faune, et des Parcs
Water Survey of Canada
City of Hamilton
New Brunswick Ministry of Environment
Newfoundland and Labrador Ministry of Environment
National Research Council of Canada
Toronto and Region Conservation Authority
Town of Midland
City of Edmonton, System Management, Drainage Services
Government of Ontario
Credit Valley Conservation Authority
Essex Region Conservation Authority
Alberta Environment and Sustainable Development, Operations Infrastructure Branch
Natural Science and Engineering Research Council

University Partners

United Nation University Institute of Water, Environment and Health
University of Waterloo
University of Alberta
University of Manitoba
Trent University
Laval University
McGill University
University of Saskatchewan
University of Moncton
University of New Brunswick
Western University
University of Guelph
McMaster University

Industry Partners

Aeroscribe Consulting
Corrugated Steel Pipe Institute
Deltares USA
DHI Canada
Hydro-Quebec
Manitoba-Hydro
Ontario Power Generation
SNC Lavalin Inc. Environment and Water

Non-Profit Partners

Severn Sound Environmental Association
Institute for Catastrophic Loss Reduction
Ontario Climate Consortium
Manitoba Conservation and Water Stewardship

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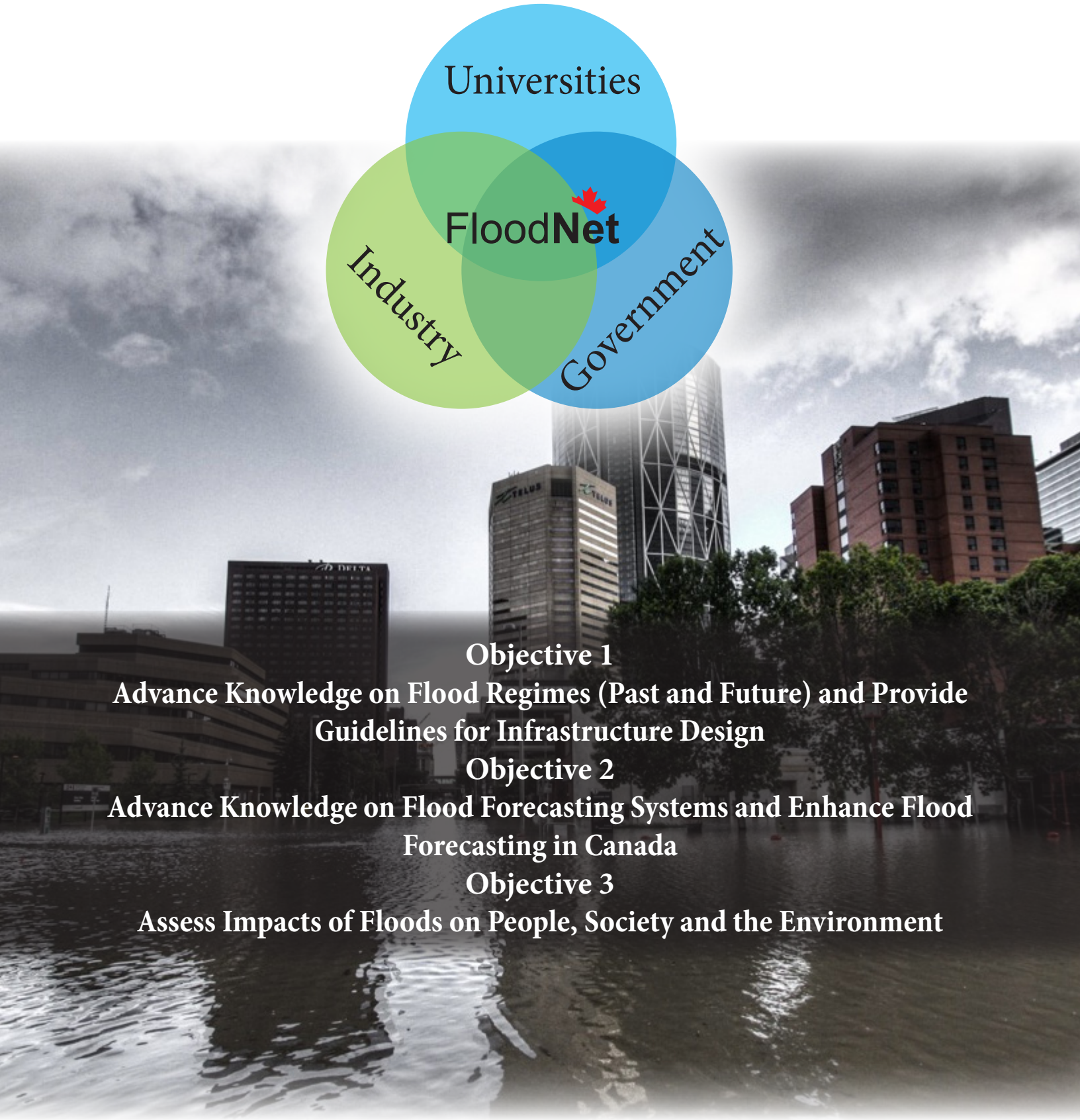

Objective 1
Advance Knowledge on Flood Regimes (Past and Future) and Provide Guidelines for Infrastructure Design
Objective 2
Advance Knowledge on Flood Forecasting Systems and Enhance Flood Forecasting in Canada
Objective 3
Assess Impacts of Floods on People, Society and the Environment

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