FLOODNET AGM – JUNE 18-20, 2019

MCMASTER UNIVERSITY STUDENT CENTER (MUSC)

DAY ONE - JUNE 18, 2019	
8:00 - 8:30	**Breakfast & Registration – MUSC CIBC Hall**
Opening Session 8:30 – 8:45	**Welcome Message** *Dr. Mossman, McMaster University, Acting Vice-President, Research* *Dr. Pietroniro, Chair of FloodNet Board of Directors*
8:45 – 9:00	**Network Update** *Dr. Coulibaly, Scientific Director of FloodNet*
SESSION 1: THEME 2 - QUANTIFYING AND REDUCING THE PREDICTIVE UNCERTAINTY OF FLOODS *CHAIRS: Dr. Anctil & Dr. Tolson*	
Project 2-1 9:00 - 9:15	Project 2-1 Update: Comparison of ensemble forecast methods for operational streamflow forecasting based on a single model *B. Tolson*
Project 2-2 9:15 - 9:30	Project 2-2 Update: Comparison of ensemble forecast methods for operational streamflow forecasting based on multiple models *F. Anctil*
Project 2-2 9:30 - 9:40	Hydrological post-processing of streamflow forecasts issued from single-model/multimodel ensemble prediction systems *J. Xu*
Project 2-2 9:40 - 9:50	What have we learned comparing in the loop and out of the loop hydrologic prediction systems? *P. Richard*
Project 2-2 9:50 - 10:00	When it is worth applying meteorological post-processing to improve the hydrological forecast? *E. Valdez*
Project 2-4 10:00 - 10:15	Project 2-4 Update : Evaluation of flood warning based on a hydraulic model with assimilation and hydrological ensemble forecasts *F. Anctil*
Project 2-4 10:15 - 10:25	Short-Term Ensemble Water Level Forecasting *M. Bessar*
10:25 - 10:45	**COFFEE BREAK**
Project 2-5 10:45 - 11:00	Project 2-5 Update: Real-time reservoir operation based on a combination of long-term and short-term optimization and hydrological ensemble forecasts *A. Tilmant*
Project 2-5 11:00 - 11:10	Analyzing the relationship between statistical scores and the economic performance of probabilistic hydrologic forecasts *M. Osina*
SESSION 2: THEME 1 - FLOOD REGIMES IN CANADA: LEARNING FROM THE PAST AND PREPARING FOR THE FUTURE *CHAIRS: Dr. Burn & Dr. Nguyen*	
Project 1-1 11:10 - 11:25	Project 1-1 Update: Update of current flood and storm quantiles *D. Burn*

FLOODNET AGM – JUNE 18-20, 2019

MCMASTER UNIVERSITY STUDENT CENTER (MUSC)

Project 1-1 11:25 - 11:35	Exploring and Improving the Pooled Flood Frequency Analysis Framework for Canada *T. Zhou*
Project 1-1 11:35 - 11:45	An adaptive system for the regional frequency analysis of extreme rainfall events in a nonstationary environment *Z. Yang*
Project 1-2 11:45 - 12:00	Project 1-2 Update: Examination of spatial and temporal variation of extreme events *F. Ashkar*
Project 1-3 12:00 - 12:15	Project 1-3 Update: Analysis and applicability of future extreme events in regional and local context *A. Arain*
Project 1-3 12:15 - 12:25	Past and future shift in winter streamflow modulated by internal variability of climate in southern Ontario *O. Champagne*
12:25 - 1:30	**LUNCH**
Project 1-3 1:30 - 1:40	Spatiotemporal changes in precipitation extremes over Canada and their teleconnections to large-scale climate patterns *Y. Yang*
Project 1-4 1:40 - 1:55	Project 1-4 Update: Development of new methods for updating IDF curves in Canada *V-T-V. Nguyen*
Project 1-4 1:55 - 2:05	A Scale-Invariance Approach to Statistical Modeling of Extreme Rainfall Processes in a Changing Climate *T-H. Nguyen & V-T-V. Nguyen*
Project 1-4 2:05 - 2:15	Stochastic Modeling of Daily Rainfall Process in the Context of Climate *S. El Outayek*
Project 1-5 2:15 - 2:30	Project 1-5 Update: Spatial change in flood prone areas in urban environments *A. Binns*
Project 1-5 2:30 - 2:40	Assessing the impacts of Low Impact Developments (LIDs) on large storm events using real world and synthetic sub-catchments *P. De Boer*
2:40 - 3:15	**COFFEE BREAK**
Project 1-6 3:15 - 3:30	Project 1-6 Update: Development of new flood estimation manual for Canada *D. Burn*
Project 1-6 3:30 – 3:40	Estimation of Design Levels in Nonstationary Context Using Regression Techniques *M. Durocher*
Project 1-6 3:40 – 3:50	Gridded Relative Changes in 24-h Extreme Rainfall Intensity for Canada *A. Requena*
Keynote Address 4:00 - 5:00	The Pursuit of Extreme Events and State-of-the Art Hydrometeorological Forecasting, Time for Paradigm Shift? *Dr. Hamid Moradkhani, Member of FloodNet International Scientific Advisory Panel* *Director, Center for Complex Hydrosystems Research, University of Alabama*
5:30 - 7:00	**Networking Dinner - *Convocation Hall***

FLOODNET AGM – JUNE 18-20, 2019

MCMASTER UNIVERSITY STUDENT CENTER (MUSC)

DAY TWO - JUNE 19, 2018	
8:00 - 9:00	**Partner Advisory Committee & Partner Meeting – CIBC Hall**
8:30 - 9:00	**BREAKFAST**
SESSION 3: THEME 3 - DEVELOPMENT OF CANADIAN ADAPTIVE FLOOD FORECASTING AND EARLY WARNING SYSTEM (CAFFEWS) *CHAIRS: Dr. Coulibaly & Dr. Song*	
Project 3-4 9:00 - 9:15	Project 3-4 Update: Development of Canadian Adaptive Flood Forecasting and Early Warning System (CAFFEWS) *P. Coulibaly*
Project 3-4 9:15 - 9:30	Application of the Hydrologic Uncertainty Processor combined with ensemble weather forecasts *S. Han*
Project 3-4 9:30 - 9:45	Multi-model ensemble inflow forecasting for large watersheds *F. Awol*
Project 3-4 9:45 – 10:00	The limits of soil moisture assimilation in an urban sub-basin *J. Leach*
Project 3-4 10:00 – 10:10	Evaluation of various Bayesian Model Averaging modifications in simulating streamflow *P. Darbandsari*
Project 3-4 10:10 – 10:30	Multi-watersheds and multi-models integration in Delft-FEWS platform towards CAFFEWS *J. Keum*
10:30 - 10:50	**COFFEE BREAK**
Project 3-1 10:50 - 11:10	Project 3-1 Update: Evaluation of flood forecasting and warning systems across Canada *P. Coulibaly & A. Muhammad* A modified Soil Water Assessment Tool (SWAT) for assessing the impact of future climate change on reservoir inflow in the Prairie Pothole Region *A. Muhammad*
Project 3-2 11:10 - 11:25	Project 3-2 Update: Real-time spatial information evaluation and processing *A. Berg*
Project 3-2 11:25 - 11:40	In-situ soil F/T state validation using monitoring networks *R. Pardo*
Project 3-2 11:40 - 11:55	Evaluation of radar quantitative precipitation estimates as additional precipitation forcing for enhanced calibration of flood forecasting models *D. Wijayarathne*
Project 3-2 11:55 - 12:05	Design of Hydrometric Networks for Flood Forecasting Applications using Entropy and Multi-objective Optimization based Methods *J. Ursulak*
Project 3-5 12:05 - 12:20	Project 3-5 Update: Application and testing of CAFFEWS in selected regions across Canada *D. Burn*

FLOODNET AGM – JUNE 18-20, 2019

MCMASTER UNIVERSITY STUDENT CENTER (MUSC)

Project 3-5 12:20 - 12:30	Objective Evaluation of CAFFEWS in Operational Context *M. Durocher*
12:30 - 1:30	**LUNCH**
Project 3-3 1:30 - 1:45	Project 3-3 Update: Enhanced Information Communication Systems *W. Song*
Project 3-3 1:45 - 2:00	Truthful Location-Protected Mobile Crowdsensing Framework for Data Collection in Flood Affected Situations *X. Tao*
Project 3-3 2:00 - 2:15	Smart Flood Warning Systems via Massive Cellular IoT or M2M Communications *H. Moussa*
Project 3-3 2:15 - 2:30	Radio Resource Slicing for Time-Critical Information Dissemination for Flood Warning Systems *Q. Ye*
SESSION 4: THEME 4 - THEME 4 - RISK ANALYSIS OF PHYSICAL, SOCIO-ECONOMIC AND ENVIRONMENTAL IMPACTS OF FLOODS *CHAIRS: Dr. Xenopoulos & Dr. Elshorbagy*	
Project 4-1 2:30 - 2:45	Project 4-1 Update: Role of floods on aquatic ecosystem condition *M. Xenopoulos*
Project 4-3 2:45 - 3:00	Project 4-3 Update: Modeling-based integrated assessment of flood impacts on urban and rural water resources systems *A. Elshorbagy*
Project 4-4 3:00 - 3:15	Project 4-4 Update: Flood risk analysis and its utility for management decisions *M. Ahmed*
3:15 - 3:35	**COFFEE BREAK**
Project 4-5 3:35 – 3:55	Project 4-5 Update: Flood insurance purchase behaviour in an empirically informed agent-based model *C. Darlington*
Project 4-5 3:55 - 4:05	Measuring changes in accessibility of emergency services during flooding in Calgary, Alberta *M. Tsang*
SESSION 5: WORKING GROUP PANEL MEETING	
4:30 – 5:00	**Working Group 1 Panel Discussion** *Chairs: Burn, Ashkar, Nguyen, Kornelsen, Chekol*
5:00 - 5:30	**Working Group 2 & 3 Panel Discussion** *Chairs: Anctil, Craig, Coulibaly, Campbell, Hallborg*
5:30 – 6:00	**Working Group 4 & Panel Discussion** *Chairs: Xenopoulos, Elshorbagy, Arain, Perera, Pietroniro*
6:15 – 7:30	**NETWORKING DINNER – *University Club*** *HQP @ The Phoenix Pub*

FLOODNET AGM – JUNE 18-20, 2019

MCMASTER UNIVERSITY STUDENT CENTER (MUSC)

DAY THREE - JUNE 20, 2018	
8:30 - 9:00	**BREAKFAST**
8:30 – 10:00	Board of Directors Meeting (BOD) – BSB 337
SESSION 5: PARTNER & COLLABORATOR INVITED PRESENTATIONS *CHAIRS: Dr. Keum and Dr. Requena*	
Partner Presentation 9:00- 9:20	Recent evolution and application of the Raven Hydrologic Modelling Framework in Canada *James Craig*
Partner Presentation 9:20- 9:40	Flood Forecasting and Adaptive Management *Dilnesaw Chekol & Wilfred Ho*
Collaborator Presentation 9:40- 10:00	Flow Forecasting and Reservoir Operation Planning in Saskatchewan: Challenges, Current Work, and Our Vision for the Future *Curtis Hallborg*
10:00 - 10:15	**COFFEE BREAK**
10:15 – 10:30	**PAC Feedback**
10:30 - 11:00	**ISAP Feedback**
Wrap-Up 11:00 -11:30	**Closing Remarks** *Dr. Pietroniro & Dr. Coulibaly*
11:30 - 12:30	**LUNCH & END OF AGM**

FLOODNET AGM – JUNE 18-20, 2019

MCMASTER UNIVERSITY STUDENT CENTER (MUSC)

Abstracts

Theme 1

Project 1.1: Update of Current Flood and Storm Quantiles

Donald H. Burn

Flooding in Canada continues to be a concern with many locations impacted by flooding on a regular basis. This project seeks to provide improved estimates of flood and rainfall quantiles for Canadian conditions through the development of a unified procedure for applying frequency analysis that reflects the diversity of hydrologic and meteorological conditions in Canada. This presentation provides an overview of the techniques that have been developed for both flood and rainfall quantiles.

Project 1.1: Exploring and Improving the Pooled Flood Frequency Analysis Framework for Canada

Tianshuo Zhou

Two regional flood frequency analysis frameworks were developed in FloodNet Theme 1, annual maximum (AMAX) framework and Peaks-over-threshold (POT) frameworks. Both frameworks use three flood similarity measures when forming the pooling group, flood seasonality measure; mean annual precipitation; and drainage basin area. The performance of the developed frameworks was assessed by comparing the width of the confidence intervals for flood quantile estimates. The POT framework performs better than the AMAX framework for most sites with a record length greater than 50 years. Overall, both regional frameworks perform better than at-site flood frequency analysis for most of Canada, except for the Rocky Mountain region and the Prairies. An alternative POT pooled flood frequency analysis framework is developed for the Rocky Mountain region. In this framework, the pooling group is developed from 261 stations in the Rocky Mountain area. Four flood similarity measures are used to form pooling groups, modified flood seasonality measure; site elevation; mean annual precipitation; and geographic proximity. The POT framework for the Rocky Mountain region improves the performance of pooled flood frequency estimates for Rocky Mountain sites. The POT framework for the Rocky Mountain region can be used as an alternative framework for this area in the Flood Estimation Manual for Canada.

Project 1.1: An adaptive system for the regional frequency analysis of extreme rainfall events in a nonstationary environment

Zhe Yang

Under the impacts from climate change, the intensity and frequency of the extreme rainfall events over certain area can experience nonstationary changes. The alternations of the extreme atmospheric conditions can affect the intensity of extreme rainfall events and cause the changes in the spatial distribution of the stations that share similar extreme rainfall patterns. The adaptive system for the regional frequency analysis of extreme rainfall events in a nonstationary environment is design to achieve

three goals: 1) Form the current optimal homogenous group in the historical stationary environment. The improved version of three-layer searching algorithm is applied to select the optimal combination of the similarity indicators for the homogeneous group formation at each layer, during which the potential impacts from climate change and urbanization are considered through using relevant atmospheric features as similarity indicators. 2) Adjust the original homogenous group in the future nonstationary environment. Under the assumption that extreme rainfall conditions will be altered under climate change, certain number of stations included in the former optimal homogenous group may show inconsistent extreme rainfall patterns with the remaining stations. To remove the rainfall inconsistent stations in the future context, an adjustment procedure, which involves the stages of potential rainfall centres identification, similarity indicators selection, centre-similar stations gathering and inconsistent station trimming, is conducted in a testing loop to reach the final optimality in the adjusted group. 3) Estimate the changed extreme rainfall intensity in the adjusted homogenous group. To utilize the advantage that data points from multiple stations can be provided at each analysis period in regional frequency analysis, the unscented Kalman filter is applied for the estimation of potentially non-monotonic changing parameters. By considering the potential spatial and temporal changes of the original homogenous group under climate change, the proposed adaptive system for the regional frequency analysis of extreme rainfall system in a nonstationary environment can provide more accurate rainfall estimates of the extreme rainfall intensities for the sustainable planning of urban drainage systems.

Project 1.3: Future shift in winter streamflow modulated by internal variability of climate in southern Ontario

Olivier Champagne

Fluvial systems in southern Ontario are regularly affected by widespread early-spring flood events primarily caused by rain-on-snow events. Recent studies have shown an increase in winter floods in this region due to increasing winter temperature and precipitation. Streamflow simulations are associated with uncertainties tied to the internal variability of climate. These uncertainties can be assessed using hydrological models fed by downscaled Global Climate Model Large Ensemble (GCM-LE) data. The Canadian Regional Climate Model Large Ensemble (CRCM5-LE), a dynamically downscaled version of a GCM-LE, was developed to simulate climate variability over northeastern North America under different future climate scenarios. In this study, CRCM5-LE temperature and precipitation projections under RCP 8.5 scenario were used as input in the Precipitation Runoff Modelling System (PRMS) to simulate near future (2040s) streamflow for four watersheds in southern Ontario. Model simulations show that 14â€‰% of the ensemble project a high (low) increase of streamflow volume in January-February. Streamflow increases may be driven by rain and snowmelt modulation caused by the development of high (low) pressure anomalies in North Americaâ€™s East Coast. Additionally, the streamflow may be enhanced by high pressure circulation patterns directly over the Great Lakes creating warm conditions and increasing snowmelt and rainfall/snowfall ratio (16â€‰%). These results are important to assess the internal variability of the hydrological projections and to inform society of increased winter streamflow.

Project 1.3: Spatiotemporal changes in precipitation extremes over Canada and their teleconnections to large-scale climate patterns

Yang Yang

In the past few decades, there have been more extreme climate events occurring worldwide, including Canada, which has also suffered from many extreme precipitation events. In this paper, trend analysis, probability distribution functions, principal component analysis, and wavelet analysis were used to investigate the spatial and temporal patterns of extreme precipitation events of Canada. Ten extreme precipitation indices were calculated using long-term daily precipitation data (1950-2012) from 164 Canadian gauging stations. Several large-scale climate patterns such as El Nino Southern Oscillation (ENSO), Pacific decadal oscillation (PDO), Pacific North American (PNA), and North Atlantic Oscillation (NAO) were selected to analyze the relationships between extreme precipitation and climate indices. Convective available potential energy (CAPE), specific humidity, and surface temperature were employed to investigate potential causes of trends in extreme precipitation. The results reveal statistically significant positive trends for most extreme precipitation indices, which means that extreme precipitation of Canada has generally become more severe since the mid-twentieth century. The majority of indices display more increasing trends along the southern border of Canada while decreasing trends dominated the central Canadian Prairies. In addition, strong teleconnections are found between extreme precipitation and climate indices, but the effects of climate patterns differ from region to region. Furthermore, complex interactions of climate patterns with synoptic atmospheric circulations can also affect precipitation variability, and changes to the summer and winter extreme precipitation could be explained more by the thermodynamic impact and the combined thermodynamic and dynamic effects, respectively. The seasonal CAPE, specific humidity, and temperature are correlated to Canadian extreme precipitation, but the correlations are season dependent, which could be positive or negative.

Project 1.3: Weather Impacts on the Infrastructure Development Industries

Muhammad Rizwan

The objective of this study is to evaluate the impacts of extreme weather events on the infrastructure development or construction industries in Ontario. The purpose of this research work is to seek input from various stakeholders including owners, managers and engineers to explore how changes in extreme weather events are impacting operations, employees, costs and profitability of this important economic sector. What are major risks to their operations, workers and profits and what strategies they might have adopted to minimize these risks. This study will help to determine the nature and scale of these impacts and explore what strategies may be developed to alleviate these impacts and risks. There are only a handful studies in the literature focusing on extreme weather event impacts on this important economic sector which will be prone to damages and disruptions due to increase in the frequency, duration and intensity in extreme weather events due to future climate change, in particular heavy precipitation, flooding and heatwaves.

This research study based on survey design questionnaire. Questionnaire consists of 13 questions. The questionnaire will be asking about extreme weather impacts on the operations of construction company

and measures taken to deal with these impacts. It will also seek input about information or knowledge need to improve the operations and profitability of company. The approximate 30-50 numbers of participants required for this study. Participants will be recruited through E-mails IDs. The website of engineering firms and relevant organisations will be browsed to compile a contact list of names, positions and E-mails of potential participants. Lime survey will be utilized to conduct actual survey using a questionnaire. Participant filling the survey will click on the survey link in the recruitment email. After that they will be redirected to the Lime Survey page and they will be presented with a short version of the consent form which will include a link to the full Consent Form. After reading it, participants will clink the "accept or agree" button to register their consent to participate in the study. People filling out this survey may include manager, engineers, planners, supervisors associated with infrastructure development companies as well as employees of provincial, local or municipal government and conservation authorities associated with infrastructure development sector.

Construction companies are facing disruptions in their operations due to bad and extreme weather conditions, resulting in loss of productivity and financial losses. In some cases, changes in weather conditions may also be beneficial for their operations and work conditions. This survey would help to evaluate what sort of issues are faced by the construction companies or infrastructure development sector due to bad weather conditions and how increase in the frequency and severity of these condition in future due to climate change may impact this sector. Such a knowledge will help these companies to better plan and manage their operations and effectively utilize their human resources. It may result in savings in costs, increased profits and timely delivery of services of by these companies. Such a knowledge will also be a good addition to scientific literature in this area. (Poster)

Project 1.4: A Scale-Invariance Approach to Statistical Modeling of Extreme Rainfall Processes in a Changing Climate

Truong Huy Nguyen & Van-Thanh-Van Nguyen

Climate change has been recognized as having a profound impact on the extreme rainfall process affecting the design and management of urban storm drainage systems. Global and regional climate models have been hence commonly used in various studies for assessing this impact. However, outputs from these models are usually at coarse spatial and temporal scales and are not suitable for those impact studies for small urban catchments which require short-duration rainfalls of sub-daily time scales. Therefore, the present study proposes a novel statistical approach to modeling of extreme rainfall processes over a wide range of time scales (e.g., from several minutes to one day) in the context of climate change.

Project 1.4: Stochastic modeling of daily rainfall process in the context of climate change

Sarah El Outayek & Van-Thanh-Van Nguyen

Information on the variations of extreme rainfall events in space and time is essential for the design and management of different water resources systems. However, it is difficult in practice to obtain this information simply based on the available historical precipitation records due to the random behavior of

these phenomena, especially in the context of climate change. Hence, statistical and stochastic approaches have been commonly used for describing more accurately the spatio-temporal variability of the precipitation process. In particular, in the context of climate change the statistical approach such as the popular SDSM method has been often relied on the physically unrealistic assumption that the statistical model parameters remain the same for current and future climates. Consequently, the use of a stochastic approach should be considered as more suitable in order to overcome this limitation of statistical methods. The main objective of the present study is therefore to develop an original stochastic model to represent the daily precipitation process in the context of climate change. The proposed model (referred herein as MCME- Markov Chain Mixed Exponential) consists of two components: (i) the first component representing the occurrences of daily rainfalls based on the first-order Markov Chain; and (ii) the second component describing the daily rainfall intensities using the Mixed Exponential distribution. The MCME model can generate synthetic daily rainfall series having the same statistical properties of the observed data. A comparative study was then carried out to assess the performance of the MCME as compared to the popular LARS-WG stochastic model, using NCEP re-analysis data and observed daily precipitation data available in stations across the province of Quebec, Canada. Both models are calibrated and validated for the period between 1961 and 1990 in consideration of different climate change scenarios. Results of this assessment have indicated the feasibility, accuracy, and robustness of the proposed MCME model as compared to the LARS-WG model using a set of common graphical and numerical performance criteria.

Project 1.5: Spatial change in flood prone areas in urban environments

Andrew Binns

Project 1-5 is assessing the effect of intensifying urban development on spatial changes to flood prone lands and flood hazard in urban environments. Previous research has investigated the hydrological response of urbanizing watersheds in the Greater Toronto Area (Black Creek watershed) and Edmonton (East River storm basin), with hydrological modeling simulations and assessed the effectiveness of stormwater management measures to mitigate the adverse effects of urbanization. Present work is expanding on the results from these studies to consider the Humber River watershed (of which the Black Creek watershed is a subwatershed) and attempting to develop generalized results which may be applied outside of the studied locations. Results from this research will assist in updating urban development guidelines to minimize flood hazard and guide in future land use management and the design of storm water management infrastructure.

Project 1.5: Assessing the performance of low impact development measures during large rainfall events using real world and synthetic subwatersheds.

Philip De Boer, Yiping Guo & Andrew Binns

In previous FloodNet research, Kokas (2017) and Zhang (2018) concluded that low impact development (LID) measures designed to regulatory standards were unable to provide substantial peak flow reduction during large rainfall events. This research aims to verify that conclusion by simulating the effects of LID measures on real world and synthetic subwatersheds for the 2- to 100-year rainfall events. A semi-calibrated EPA SWMM model representative of the Humber River watershed (Ontario, Canada) was tested

as the real world watershed at a subwatershed scale. Subwatersheds for LID measure implementation were selected by grouping them into eight categories based on subwatershed properties such as area, percent imperviousness, width and slope. Each subwatershed category is tested with the LID measures created by Kokas (2017) and Zhang (2018) and LID measures specifically designed for the Humber River watershed. Design storm modeling was completed with the Chicago 4-hour and AES 12-hour storm events. Continuous simulations were also completed with simulated annual peak flows fitted to Gumbel distributions to obtain 2- to 100-year peak flows for comparison with the design storm modelling results. The design storm and continuous simulation modelling demonstrated that LID measures are able to capture some runoff from the rising limb of the hydrograph but offer little reduction to the peak flow and total runoff for large rainfall events.

Project 1.6: Towards a Flood Estimation Manual for Canada

Donald H. Burn

Canada, unlike many other countries, does not have a unified approach for the estimation of extreme event quantiles. This FloodNet project is combining research results from other FloodNet projects to create a flood estimation manual for Canada along with associated software for implementing the developed techniques. This presentation provides an overview of the progress on this project including techniques for sites that are gauged or ungauged and for stationary or non-stationary conditions. Input is sought from potential users of the manual with regard to the desired capabilities of the system.

Project 1.6: Gridded Relative Changes in 24-h Extreme Rainfall Intensity for Canada

Ana Requena & Donald H. Burn

The effect of climate change needs to be considered in extreme rainfall intensity estimation to allow for more reliable urban infrastructure design and risk assessment. The present study proposes an approach for estimating gridded relative changes in 24-h extreme rainfall intensity in Canada based on pooled frequency analysis. The pooled approach allows for a more accurate estimation of quantiles associated with long return periods for baseline and future rainfall intensity. The study uses regional climate models at a common 0.5Ëš latitude-longitude grid from the North American Coordinated Regional Climate Downscaling Experiment. Future rainfall simulations from two representative concentration pathways (RCP 4.5 and RCP 8.5) are considered for two future horizons (2050 and 2080). Associated multi-model 10th, 50th and 90th percentile relative changes are analyzed for six return periods. Smooth variation of estimated relative changes is found across the country, presenting small clusters. Relative changes for RCP 8.5 are recommended for 2050, whereas either those for RCP 4.5 or RCP 8.5 could be considered for 2080. For instance, smaller and coherent mean multi-model 50th percentile relative changes over return periods are found for Halifax, Quebec City, Victoria and Winnipeg for the three RCP â€“ horizon combinations (ranging from 5% to 21%), whereas larger values (ranging from 24% to 49%) are found for Edmonton, Iqaluit and Whitehorse. Estimated relative changes may be used for updating 24-h observation-based rainfall intensity quantiles at a particular location, city or catchment in Canada. Estimated relative changes need to be updated as additional regional climate models become available.

Project 1.6: Estimation of design levels in nonstationary context using regression techniques.

Martin Durocher & Donald H. Burn

Due to either climate change or anthropogenic causes, the frequency of floods events is expected to continue to change in the future. Studies proposing methodology adapted for modeling nonstationary series of flood events have mostly considered sites with long record period. However, sites of interest may have limited observations and still present clear signs of trends. This presentation presents a robust method for conducting a regional frequency analysis that is adapted to nonstationary context. For peaks over threshold models, trends can be found in the threshold or/and the parameters of the exceedance distribution. An automatic procedure is proposed to calibrate a model that combines trend tests, regression techniques and L-moments. This approach deals with different forms of trends by integrating a time-dependent scaling factor to the index-flood model and by forming pooling groups including both stationary and nonstationary sites. The properties of the investigated method are compared to those of existing likelihood-based method in a simulation study and case study.

Theme 2

Project 2.2: Hydrological post-processing of streamflow forecasts issued from single-model/multimodel ensemble prediction systems

Jing Xu, François Anctil, Marie-Amélie Boucher & Emixi Valdez

Multivariate post-processing of streamflow forecasts is essential to convert ensemble forecasts obtained through a standard hydrometeorological modeling chain into predictive distributions that are unbiased and reliable. Two post-processors, namely Bayesian model averaging (BMA) and the integrated copula-BMA, are compared for deriving a pertinent joint predictive distribution of daily streamflow forecasts issued by five different single-model hydrological ensemble prediction systems (H-EPSs). BMA suffers from limitations pertaining to its conditional probability density functions (PDFs), which must follow a known parametric distribution form (e.g., normal, gamma). On the other hand, copula-BMA predictive model fully relaxes the assumptions on the form of its posterior distribution and eliminates the power transformation step. In this study, eleven univariate marginal distributions and six copula functions of different levels of complexity are explored in a copula-BMA framework for comprehensively reflecting the dependence structure between pairs of forecasted and observed streamflow. Results demonstrate the superiority of the copula-BMA in efficiently eliminating the forecast biases and maintaining an appropriate ensemble dispersion as the forecast lead-time increases.

Project 2.2: What have we learned comparing in the loop and out of the loop hydrologic prediction systems?

Philippe Richard

With the advent of digital age, automation, ever-increasing computing power, and constant progress of artificial intelligence, the future of human-machine roles and interactions in the light of new innovations is subject to inevitable changes. The field of operational hydrology is not indifferent to this new reality. Indeed, Pagano et al. (2016) highlighted three categories of hydrologic prediction systems: inclusive (in-the-loop), passive (out-of-the-loop), and supervised (over-the-loop). Here, the in the loop system consists of the chain of models and tools used operationally by the QuÃ©bec Government for issuing 3-hourly streamflow forecasts, while out of the loop resorts to the fully automated "HydrOlOgical Prediction LAboratory" (HOOPLA) MATLAB toolbox developed at UniversitÃ© Laval. The primary motivation for this research project is to improve the tools available to carry out hydrological forecasts in the St. Lawrence Valley while leaving room for the knowledge and experience of hydrologists and forecasters. To do this, the performance of two operational in-the-loop and out-of-the-loop systems are compared and a third over-the-loop system is under development. Thus, the comparison can be carried out on the three categories of forecasting systems. Preliminary results for 30 Quebec watersheds from 2 different systems show considerable consistency between the forecasts issued, but some discrepancies. However, the operation of the two systems in parallel reinforces the advantages and benefits of pluralism in science and practice.

Project 2.2: When it is worth applying meteorological post-processing to improve the hydrological forecast?

Emixi Valdez

The presentation will provide an assessment of the ensemble precipitation forecasts from the ECMWF over the last decade and its impact on the quality of hydrological forecasting. The analysis was performed in two Québec catchments under two scenarios: 1) the raw forecast and 2) the corrected by the statistical post-processing method censored, shifted gamma distributions (CSGD). Both forecasts were used as forcing variables to the hydrological models contained in the HydrOlOgical Prediction Laboratory (HOOPLA) to produce ensemble streamflow forecasts. The results highlight a correlation between the improvement of the raw forecast and the inefficiency of the CSGD. Likewise, the gain in meteorology does not correspond proportionally with the hydrological forecast. The evolution of the first is greater.

Project 2.4: Short-Term Ensemble Water Level Forecasting

Mohammed Amine Bessar

In this presentation, we'll analyze the reliability of water level forecasts from a river model coupled to a hydrometeorological ensemble prediction system, on an event-driven basis. The 1D hydraulic model of the Chaudière river is informed at the boundary conditions by ensemble streamflow forecasts accounting for three sources of uncertainty: meteorology, initial conditions, and hydrologic model structure with data assimilation. The forecasts precision and reliability are assessed and the results show that the ensemble water level forecasting approach improves the system reliability.

Project 2.5: Analyzing the relationship between statistical scores and the economic performance of probabilistic hydrologic forecasts

Michael Osina & Amaury Tilmant

Hydrologists often rely on statistical scores like the continuous ranked probability score (CRPS), the normalized root-mean-square error ratio (NRR), the Nash-Sutcliff efficiency (NSE) to assess the reliability and accuracy of hydrological ensemble prediction systems (H-EPS). Although useful, a statistical characterization of the forecasts falls short of providing a measure of their utility to society, which is the ultimate metric for water managers and policy makers. If more reliable and accurate forecasts are desirable, it is often unclear to what extent the reliability and accuracy gains will translate into increased utility, which, depending on the characteristics of the water resources system, could be expressed in terms of flood damage reduction, increased hydropower generation, more reliable water supply, etc. We present a testbed to analyze the relationship between statistical scores and the economic performance of probabilistic hydrologic forecasts. The testbed comprises (i) 20 structurally-different hydrological models, (ii) two data assimilation techniques, (iii) one mid-term (weekly, monthly) and (iv) one short-term (daily) water resources allocation models, (v) hydro-meteorological, infrastructural and water demand data for the case study. Using the hydropower system of the Gatineau River basin in Quebec as a case study, 20 sets of ensemble streamflow forecasts are generated by the hydrological models from the 50-member meteorological forecasts issued by the ECMWF over a period of 6 years (2011-2016). Forecasts are updated daily and have a lead time of 14 days. They are processed in a rolling-horizon mode by the short-term water resources allocation model, which seeks to maximize the energy output over the 14-days period considering the expected future value of the system derived from the mid-term allocation model. Regressions are then developed to examine the relationship between the economic performance (here the production of hydroelectricity) and the scores characterizing the 20 H-EPS. The analysis also reveals where (for what power plant) and when (for what time of the year) the improvement of the forecasts should be prioritized as well as the potential for improvement of the 20 H-EPS.

Theme 3

Project 3.1: A modified Soil Water Assessment Tool (SWAT) for assessing the impact of future climate change on reservoir inflow in the Prairie Pothole Region

Ameer Muhammad

Hydrology of the Prairie Pothole Region (PPR) is complex mainly due to existence of a large number of pothole wetlands that creates intermittent surface water connectivity and reduces the contributing area. In this study, a modified form of the Soil Water Assessment Tool (SWAT) is used to assess the future climate change effects of inflow into Shellmouth reservoir located in Manitoba. The modified form of the SWAT model has the capability of capturing the dynamics of variable contributing area and fill-spill processes, which are defining characteristics of the PPR. Future climate projections from two Regional

Climate Models (RCMs) under RCP 4.5 and 8.5 for the period 2011-2040 and 2041-2070 were fed into the calibrated model to assess the impact on inflow to the Shellmouth reservoir (Lake of the Prairie). The preliminary result suggests that future climate will lead to increased winter streamflow, decreased summer flow, and decreased spring peak flows in general. Result of this study is of critical importance to Manitoba Hydrologic Forecasting Centre to better operate Shellmouth reservoir under the impact of future climate changes

Project 3.2: In-situ soil F/T state validation using monitoring networks

Renato Pardo

This presentation provides an overview of progress made in real-time evaluation of spatial information useful for the improvement of hydrological forecasting. We will present updates on near-real time surface soil moisture initial condition monitoring and the retrieval of the freeze thaw state condition. An overview of the relationship of soil moisture initialization and subsequent rainfall-runoff response over 60 Canadian watersheds will be presented. Regions with high and low correlations to soil moisture initialization will be discussed with respect to the potential accuracy of the passive microwave soil moisture retrieval and efforts to improve soil moisture retrieval over these areas. We will also examine recent research into the sensitivity of passive microwave soil moisture estimates in boreal forest and tundra environments. The second portion of this presentation will focus on the retrieval of the soil freeze thaw state condition as the large-scale detection and monitoring of the soils frozen status may have significant importance for hydrological modeling.

Project 3.2: Evaluation of radar quantitative precipitation estimates as additional precipitation forcing for enhanced calibration of flood forecasting models

Dayal Wijayarathne, Paulin Coulibaly & Sudesh Boodoo

Mitigation measures are vital for flood prone regions in Canada as floods are the most common natural hazard to life, property, the economy, and the environment. An enhanced flood forecasting system is a key part of flood mitigation. A well-developed flood forecasting system can deliver precise and reliable forecasts with appropriate lead time. Recently, there is a significant attention in real-time Quantitative Precipitation Estimates (QPEs) derived from radar to run hydrological models for flood forecasting as it provides real-time, spatially and temporally continuous data over a large area. Since weather radar does not measure the precipitation directly, radar rainfall known to be subjected to errors and, therefore, verification is essential before using radar QPEs in operational flood forecasting with confidence.

This study evaluates QPEs from King City C-band dual polarized radar (WKR) and NEXt-generation weather RADar (NEXRAD) S-band dual-polarized radar at Buffalo, New York for two watersheds in southern Ontario. Twenty rainfall events occurred in spring, summer, and fall periods from 2011 to 2017 are separated from hourly rain gauge data at 24 locations and used as ground reference. Accumulations of C-band radar are calculated using Horizontal reflectivity (Z), differential reflectivity (ZDR), and differential phase (KDP). The modified ZPHI is used to correct reflectance for attenuation and fixed width clutter filter

with different thresholds is applied to correct for ground clutter. Rain rates are calculated using R(Z), R(Z, ZDR), and R(KDP) algorithms. The NEXRAD radar accumulation estimated from R(Z) and Precipitation Processing System (PPS) algorithm are acquired from National Oceanic and Atmospheric Administration (NOAA). Evaluation is performed by overlying observation gauge points on precipitation grids. Individual rain gauges are compared separately with corresponding grid cells for NEXRAD and nearest observed value at each point in C-band radar. Different verification and skill scores are computed for a single location across time. In future, QPE evaluation will be followed by proxy validation using events based hydrologic model run using lumped and semi-distributed hydrologic models to verify the accuracy of radar QPEs as an additional data source for hydrologic model calibration.

Project 3.2: Design of Hydrometric Networks for Flood Forecasting Applications using Entropy and Multi-Objective Optimization based Methods

Jacob Ursulak

Flood forecasters utilize observed streamflow measurements from existing hydrometric networks to validate previous forecasts and where possible improve model calibrations for future predictions. The Dual Entropy and Multi Objective Optimization (DEMO) technique has been successfully applied to facilitate the design of a robust general purpose hydrometric network. DEMO identifies a set of non-dominated (Pareto-optimal) networks by utilizing entropy based optimization objectives to maximize network information content, while simultaneously minimizing redundancy. However, the suitability of using DEMO to design networks for specific applications, such as flood forecasting, has yet to be determined. A two part research plan is proposed to resolve this issue based on the design of networks for two watersheds in western Canada: the Churchill River watershed upstream of Otter Rapids and the Fraser River Watershed upstream of the town of Hope. Firstly, Pareto-optimal networks, outputted from DEMO, will be evaluated using semi-distributed configurations of MAC-HBV and SAC-SMA to determine a subset of networks best suited for flood forecasting. Part two aims to validate the results from part one. Another multi-objective optimization process, in which hydrological modelling performance criteria (evaluated from embedded models) are applied as optimization objectives in lieu of traditional entropy metrics, will be used to determine a separate set of Pareto-optimal networks. Any overlap between the results from both parts would indicate a network or set of networks that can be considered the most suitable for flood forecasting applications.

Project 3.2: Exploring Convolutional LSTM Neural Network for Sub-hourly Precipitation Nowcasts in Toronto Area

Andre Della Libera Zanchetta

The current distributed operational precipitation forecasts available for Canada derived from Global Environmental Multiscale (GEM) model are generated every 6 hours and present a temporal resolution of 1 hour. Under scenarios of heavy rainfall caused by convective, fast forming precipitation cells that produce flash floods, such forecasts may not provide the information needed at a reasonable lead time

for operational Flood Early Warning Systems (FEWS). A data-driven system for radar-based precipitation nowcast could be considered a valuable additional component of FEWS to support decision-makers during such circumstances of convective precipitation cells formation. The present work has the objective of exploring the potential of using Convolutional Long-Short Term Memory Neural Networks (ConvLSTM) for generating sub-hourly rainfall nowcasts at the Grand Toronto Area (GTA), in Canada. The data used for training the network will be the 1-hour accumulation Level III Nexrad product from KBUF S-Band weather Doppler radar, located in Buffalo-NY, which is freely provided in nearly real-time by the US-National Weather Service (NWS), presents temporal resolution of 5 to 10 minutes and covers the GTA region at a 160-kilometers range. Results produced by the ConvLSTM will be validated against rain gage records. The poster presents an outline of the proposed work. (Poster).

Project 3.3: Enhanced Information Communication Systems

Wei Song

An important outcome of the Floodnet project is CAFFEWS, a Bayesian Flood Forecasting system that features ensemble modeling and data assimilation. This presentation proposes an experimental plan for carrying out a rigorous and objective evaluation of this flood forecasting system with data that have not been used in the developing phase. With the collaboration of partners, CAFFEWS will be compared to other existing flood forecasting systems in Canada. Such analysis will allow to identify conditions in which CAFFEWS is expected to bring substantial improvements. To ensure fair comparisons, metrics are selected for quantifying the accuracy of the forecasts in both deterministic and probabilistic frameworks. The capacity of the system to issue relevant warnings is also addressed and the significance of the observed differences is evaluated using testing procedures.

Project 3.3: Truthful Location-Protected Mobile Crowdsensing Framework for Data Collection in Flood Affected Situations

Xi Tao

Mobile Crowdsensing (MCS) is a promising paradigm for the large-scale sensing. We aim to build a truthful framework of MCS taking user mobility and incentive into account. The proposed framework is composed of two challenging problems, path planning and incentive mechanism design. In path planning, every user as a worker independently plans a tour to carry out tasks based on its own strategy. In incentive mechanism design, the platform leverages a mechanism to select the winners and determine the payments.

Project 3.3: Smart Flood Warning Systems via Massive Cellular M2M Communications

Hesham Moussa

Majority of the flooding events in Canada are river floods, which have been causing significant damages in various social and economic aspects. The gravity of the damages can be mitigated through a properly

implemented early flood warning system. To a large extent, the success of such warning system lies in building a robust and accurate data collection system. Massive machine type communication (mMTC) is seen as a plausible transformative technology that can be used to establish such a collection system. In mMTC, a massive number of low cost, low capability stationary and battery powered wireless sensors are deployed across the various watersheds of interest. The sensors use the cellular communication network to transmit their data to a collection center. Thanks to the massive number of deployed sensors, the collected data can then be used to develop an accurate flood prediction model for a successful flood early warning system. Nonetheless, with such a large number of sensors competing over a limited amount of radio resources, the efficiency of the cellular network immensely declines, leading to undesirable transmission delays and energy wastage of the devices. Transmission delays and energy wastage impact the robustness and accuracy of the data collection system. Therefore, to enable massive access on the limited radio resources without degradation in performance, in this work, we propose to use clustering and data aggregation for enabling massive cellular applications while observing various QoS requirements. Yet, as the number of devices in the network increases, optimizing the clustering and data aggregation process becomes more challenging as many trade-offs arise between different network performance metrics. Hence, we propose a novel NOMA-enabled two stage transmission architecture to enable mMTC while balancing out the various trade-offs. Techniques from queuing theory and stochastic geometry are utilized to derive tractable models for different network performance parameters such as coverage probability, network delay, number of served devices and network delay. The derived models are functions of various network parameters and hence give insightful overview into the design process of an effective two-stage architecture to enable energy and delay aware mMTC.

Project 3.4: Application of the Hydrologic Uncertainty Processor combined with ensemble weather forecasts

Shasha Han & Paulin Coulibaly

To enhance the predictability of flood forecasts and quantify the dominant uncertainties, the Hydrologic Uncertainty Processor (HUP) was applied to post-process the ensemble forecasts and produced predictive probability distribution with uncertainty estimation. The ensemble forecasts were forced by the ensemble weather predictions from Global Ensemble Prediction System (GEPS), the inherent input uncertainty is represented by the ensembles of GEPS and propagates through the model chain. Hydrologic uncertainty is quantified by HUP and is added as another layer on the top of input uncertainty. A multivariate bias correction method was used to remove the bias of GEPS, several application scenarios were developed based on the different combinations of GEPS dataset with HUP, and the performances of these scenarios were compared across different forecast horizons by multiple evaluation metrics. Results indicate that HUP could improve the accuracy and skill for both short-range and medium-range forecasts, the improvement is obvious for short lead times and weakens as lead time increases. For short-range forecasts, the performance is promising with HUP as a post-processor, and the best results are presented when applying bias correction to each ensemble together with applying HUP.

Project 3.4: Multi-model ensemble inflow forecasting for large watersheds

Frezer Seid Awol & Paulin Coulibaly

The objective of this research is to enhance reservoir inflow forecasting using multiple hydrological models, ensemble weather forecasts inputs, and bias-correction datasets. Precipitation forecasts from the Global Ensemble Forecast System (GEFS) and its second-generation reforecast ensembles (GEFSv2) were used as inputs to structurally diverse hydrological models: two lumped (SACSMA & MACHBV both coupled with SNOW17), distributed as a benchmark (WATFLOOD) and macroscale land-surface based (VIC with RVIC). Each ensemble members of precipitation forecasts were bias corrected using empirical quantile mapping method, but with two verifying datasets as a trainign dataset: the Canadian Precipitation Analysis and ground-based gridded precipitation data.

Results from different ensemble verification metrics indicate that lumped hydrological models have better overall forecast quality, skill and reliability than distributed or macroscale models for complex watersheds. However distributed model can show good reliability up to two or three days ahead lead time. Ensemble flow forecasts generated from the reforecast product an improved forecast quality than ensembles generated from GEFS forecast. Bias-correction using a reanalysis precipitation grids (Such as CaPA) as a verifying analysis appeared to show slightly superior forecast performance than using data from gridded precipitation networks.

Project 3.4: The limits of soil moisture assimilation in an urban sub-basin

James Leach & Paulin Coulibaly

The benefit of soil moisture assimilation on hydrologic forecasting in an urban environment is not clear. This work aims to identify the maximum feasible level of development (imperviousness) an urban basin can have, and still benefit from the assimilation of remotely sensed soil moisture. A synthetic experiment was set up to simulate the retrieval of soil moisture, and assimilate it into a hydrologic model of urban sub-basins. The synthetic sub-basins were set up such that they would represent areas within a retrieval grid with different levels of imperviousness. Multiple rainfall events were modeled for each synthetic sub-basin. The results of this experiment showed that a threshold exists for the viability of soil moisture assimilation for improved hydrologic forecasting in an urban basin. Beyond this imperviousness threshold, there is a decrease in model forecast performance indicating that soil moisture assimilation is not viable.

Project 3.4: Evaluation of various Bayesian Model Averaging modifications in simulating streamflow

Pedram Darbandsari

Quantification of predictive uncertainty in hydrologic modeling is equally important as possessing reliable hydrological models for many water related fields. Bayesian Model Averaging (BMA) is one of the most popular method inducing a reliable and accurate probabilistic prediction using multi-model ensemble of forecasts. There are some modifications being proposed for enhancing the BMA approach

regarding streamflow prediction. However, there is not a clear and comprehensive assessment of how these solutions affect the BMA predictive predictions. In this study, we thoroughly assess the sensitivity of BMA derived probabilistic prediction regarding different modifications. The results show that implementing heteroscedastic variance type enhance the probabilistic performance of BMA prediction while applying other modifications, including data transformation and more representative distribution types, do not dominate the classical BMA method. Moreover, considering multi-inputs besides multi-models for generating ensemble of predictions improve BMA results in data poor watersheds. In addition, it is concluded that the Expectation-Maximization algorithm is reliable enough for proper estimation of various BMA variants' parameters.

Project 3.4: Multi-watersheds and Multi-models Integration in Delft-FEWS platform towards CAFFEWS

Jongho Keum

The Canadian Adaptive Flood Forecasting and Early Warning System (CAFFEWS) targets to have (1) several hydrologic models to be able to compare them in any given area and to meet the operational forecasters' needs, (2) ability to spatially cover multiple watersheds, and (3) options to adapt recent accomplishments from researches for the enhanced flood forecasting. This presentation shows the first and the second components which were utilized based on the Delft-FEWS platform. A benchmark model, the Community Hydrologic Prediction System (CHPS) of the US National Weather Service, was configured to simulate streamflows in Don and Humber River watersheds using OHDFewsAdapter of NWS. Another hydrologic model, Raven, was also adapted in the Delft-FEWS system by revising the RavenFEWSadapter to transfer data using NetCDF format. It is expected to reduce computational time and enhance efficiency by optimizing the number of files used in data transfer between the model and Delft-FEWS platform.

Project 3.4: Entropy based approaches for catchment and model dynamics classification across Austria

Mattia Neri

The formulation of objective procedures for the delineation of homogeneous groups of catchments is a fundamental issue in hydrology. Classical methods use geo-morphoclimatic catchment descriptors or runoff signatures as metrics for grouping similar watersheds. Here we propose two approaches based on the use of entropy terms for classifying catchments with similar runoff behavior for a large dataset of more than 200 basins across Austria. In the first approach, mutual information between observed daily runoff is used as similarity measure. In the second approach, a version of the HBV model is calibrated for all the study catchments and the values of 1-day lag transfer entropy from model input and components to the simulated runoff are computed. Basin classification is then based on the distribution of the amount of information transferred within model components, which allow us to characterize different types of model dynamics. The groups obtained from both methods are consistent with previous classifications of the case study based on runoff signatures. In particular, the first results from the transfer entropy

approach are promising: they can allow us to better understand differences in model behavior across the study area and may be useful to adapt the conceptual model structure depending on the dominant processes influencing runoff. (Poster)

Project 3.5: Application and testing of CAFFEWS in selected regions across Canada

Donald H. Burn

CAFFEWS is one of the main deliverables of the FloodNet project and is anticipated to potentially provide improved forecasting capability for provincial flood forecasting centres. The goal of this project is to compare forecast results from CAFFEWS with corresponding forecast results from using existing approaches adopted by provincial flood forecasting centres. The project takes a case study approach where the focus is on evaluating CAFFEWS using watersheds that were not part of the development process for CAFFEWS.

Project 3.5: Objective evaluation of CAFFEWS in operational context

Martin Durocher & Donald H. Burn

An important outcome of the Floodnet project is CAFFEWS, a Bayesian Flood Forecasting system that features ensemble modeling and data assimilation. This presentation proposes an experimental plan for carrying out a rigorous and objective evaluation of this flood forecasting system with data that have not been used in the developing phase. With the collaboration of partners, CAFFEWS will be compared to other existing flood forecasting systems in Canada. Such analysis will allow to identify conditions in which CAFFEWS is expected to bring substantial improvements. To ensure fair comparisons, metrics are selected for quantifying the accuracy of the forecasts in both deterministic and probabilistic frameworks. The capacity of the system to issue relevant warnings is also addressed and the significance of the observed differences is evaluated using testing procedures.

Theme 4

Project 4.3: Improving the representation of the prairie pothole dynamics in hydrological models

Mohamed I. Ahmed, Amin Elshorbagy, Alain Pietroniro

The Canadian prairies are characterized by flat and undulating terrain with millions of depressions of glacial origin, known as prairie potholes. The prairie potholes can retain a significant amount of surface runoff during snowmelt or rainfall events leaving a minor portion to reach the stream network. Existing approaches to represent the connectivity and storage dynamics of the potholes either use probability distributions or very fine resolution terrain models to extract their actual properties. The former approach cannot represent the actual spatial distribution of the pothole connectivity, whereas the latter approach

is computationally expensive and inapplicable. There is a need to develop an algorithm that can predict the surface water connectivity between potholes using available digital elevation models (DEMs). This algorithm can be used as a new physically-based runoff generation algorithm for the prairies, which can identify the actual spatiotemporal variation of the pothole storage dynamics and predict the pothole flooding patterns. In this study, we introduce a novel approach that utilizes topography and rule-based method to model the connectivity and storage of water in potholes referred to as Prairie Region Inundation Mapping Algorithm (PRIMA). The direction and amount of flow, in the PRIMA algorithm, is determined using a minimization algorithm that attempts to minimize the differences of water elevation in contiguous cells, whereas the travel time is governed by Manning's equation. The PRIMA algorithm is tested over a number of pothole-dominated areas within Saskatchewan, Canada, namely, St Denis and Smith Creek watersheds. First, the PRIMA algorithm's performance is compared to the recently developed Wetland DEM Ponding Model (WDPM) for only adding and removing a specified water depth to/from the landscape to test the PRIMA's computational efficiency. Second, the PRIMA algorithm is coupled with the recently developed conceptual hydrological model for prairies (HYPR). The HYPR model handles the vertical water balance calculation and the PRIMA algorithm routes the water and determines the amount of water storage and surface runoff. Results show that the proposed PRIMA algorithm is at least 200 times more efficient that the WDPM model. The approach shows good agreement of pothole extents when compared to satellite imagery. The PRIMA algorithm shows potential to be used as a new physically-based runoff generation algorithm with a good agreement with the observed flow at the studied watersheds outlet, especially at peak flows.

Project 4.5: Flood insurance purchase behaviour in an empirically informed agent-based model

Connor Darlington

In this study we present an agent-based model predicting flood insurance purchase behaviour that is calibrated with empirical data from a hypothetical choice experiment. Primary survey data are collected on demographics, risk perception, protection motivation and social factors influencing flood insurance purchase decisions. This is followed by a hypothetical choice experiment on flood protection in which participants have to make a decision given a randomly assigned scenario. We use these data sources to create a model of flood insurance decisions. Using this model, along with Canadian census data for the City of Calgary, we observe patterns in behaviour and flood insurance purchases in the City. We vary the flood return period, flood severity, flood governance, insurance structure and other model inputs to analyze patterns of protection behaviour over time and using different scenarios. The results reveal interesting patterns in insurance demand based on a heterogeneous decision-maker model.

Project 4.5: Measuring changes in accessibility of emergency services during flooding in Calgary, Alberta

Michele Tsang

The increased frequency of flooding events in recent decades and its detrimental effects on the road network and population has raised the importance of flood management. When floods occur, emergency responders are responsible for reaching the population within targeted response times. This research models the changes in accessibility of emergency services (EMS, fire and police) during a predicted 100-year flood event and the historic 2013 Alberta floods in Calgary, Alberta. The methodology uses GIS for inundation mapping, utilizing DEMs, flood extents and hydrologic data. Using these flood maps, flooded network datasets were created by calculating maximum vehicle speeds as a function of the standing depth of water on a link. The flooded network is then used to simulate service areas for each type of emergency service, following targeted response times. Results spatially locate areas that cannot be served within these time constraints, which can be observed based on residential or work populations. The number of individuals not served is then quantified, based on the number of people or workers in a DA. EMS were found to have the greatest reduction in accessibility, with 20% to 43% of the population not served. Fire services were seen to be more resilient as 2% to 9% of the population could not be served. Police services had the same range as fire services, however, they have a greater range of response times, meaning these areas represent those that are completely isolated during the floods. This study identifies vulnerable populations and flooded links in the network, which can be used to develop evacuation plans and emergency response strategies, minimizing disturbances in the network and the number of people effected.