Rainfall Intensity Duration Frequency Curves for Future Climate Scenarios: A Publicly Accessible Computer Tool

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3 | INTRODUCTION
Development team

- UWO
- ICLR

- Slobodan P. Simonović, UWO, ICLR
- Andre Schardong, UWO, ICLR
- Dan Sandink, ICLR
- Abhishek Gaur, UWO
- Roshan Srivastav, UWO

INTRODUCTION

Presentation outline

- Introduction
- Methodological background
- Implementation
- Use of the *IDF_CC* tool

Q&A

IDF_CC Methodology

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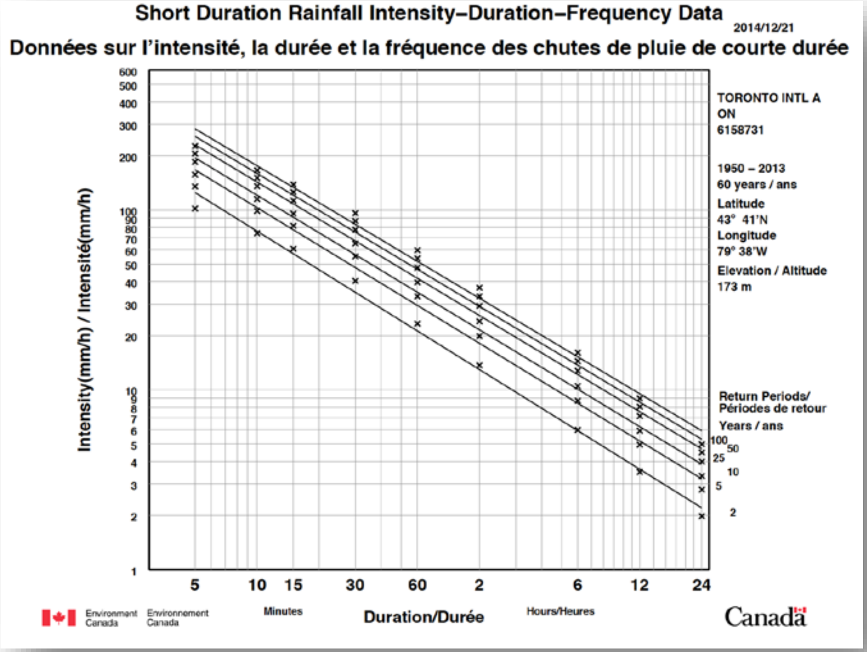
7| METHODOLOGY
IDF_CC tool

- Increase in global temperature
- Change in frequency and intensity of extreme events
- IDF curves: Frequency of extreme events for a variety of return periods and intensities
- Based on assumption of stationarity
- Updating IDF curves highly technical
- Based on work with City of London, IBC MRAT tool



METHODOLOGY

IDF_CC tool

- Initial funding from the Canadian Water Network (2013)
- ICLR

- Objectives
  - Development of the generalized methodology for updating IDF curves under climate change
  - Implementation of the web based tool for updating IDF curves under climate change

- IDF_CC ver 1 – February 2015
- IDF_CC ver 2 – August 2017
- IDF_CC ver 3 – January 2018
- IDF_CC ver 4 – August 2019

METHODOLOGY
IDF_CC tool – public engagement

Engagement step	Description
Defining the problem/assessing the need	• Early work with City of London and Upper Thames Region Conservation Authority (local watershed management agency) on updating IDF curves and incorporating climate change into IDF curves • Early work with Insurance Bureau of Canada (Canadian P&C insurance industry) on Municipal Risk Assessment Tool, including updating and incorporating climate change into IDF curves for multiple Canadian urban municipalities • Presentation of London and IBC work to technical audiences and municipal and regional decision makers • Audiences identified need for standardized, accessible approach to updating and incorporating climate change impacts into local IDF curves
Project Initiation	• Application for Canadian Water Network knowledge mobilization funding required support from practicing community (i.e., municipal stormwater management professionals)
Developing support/partnerships with target stakeholders	• Developing support from multiple urban municipalities for CWN proposal • Support letters received from storm and wastewater management departments at Cities of Toronto, Mississauga, Hamilton, London, Kingston and Region of Peel, Ontario, setting the stage for further collaboration with municipal stakeholders throughout the development process
Early, in-depth collaboration with Cities of Toronto and Hamilton	• Collaboration with stormwater management staff from cities of Toronto and Hamilton, Ontario for early and in-depth review of tool methods • Early collaborators provided with the initial iteration of the IDFCC tool to allow testing within their respective stormwater management departments • Meetings and frequent communication by email and phone to allow development team to receive feedback from early collaborators
National workshops	• Three national stakeholder workshops designed to inform, educate and engage stakeholders in draft iterations of the IDFCC tool • Users asked to perform a number of tasks using the DSS and report back to the development team with questions, comments and suggestions for improvement
National webinars	• Two national webinars with large attendance (>200 participants) to inform stakeholder communities • One webinar conducted before workshops, one conducted at end of the project
Publishing IDF_CC tool	• Publishing IDF_CC tool on the internet, open to all members of public • Providing contact information for questions and feedback about the IDF_CC tool • Providing limited support for responding to questions and feedback

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9| METHODOLOGY

Modifications of the IDF_CC tool

- Version 1 - February 2015
  - Use of 24 GCMs
  - Use Gumbel distribution
  - Quantile matching algorithm for downscaling
- Version 2 - August 2017
  - Update of the user interface
    - Google maps replaced by Leaflet and OSM
  - Addition of 9 bias corrected GCMs (PCIC)
  - Methodological modifications
    - Limiting use of Gumbel distribution only for historical IDF curves
    - Introduction of GEV distribution
    - Modification of Quantile Matching Algorithm for updating IDF curves
- Version 3 - January 2018
  - Addition of the new module for ungagged locations
    - New methodology for ungagged locations
- Version 4 - August 2019
  - Addition of 24 new bias corrected climate models (PCIC)
    - Pacific Climate Impacts Consortium of the University of Victoria
    - BCCAQ v2 (available at the http://climate-scenarios.canada.ca/portal).

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IDF_CC Methodology gauged locations

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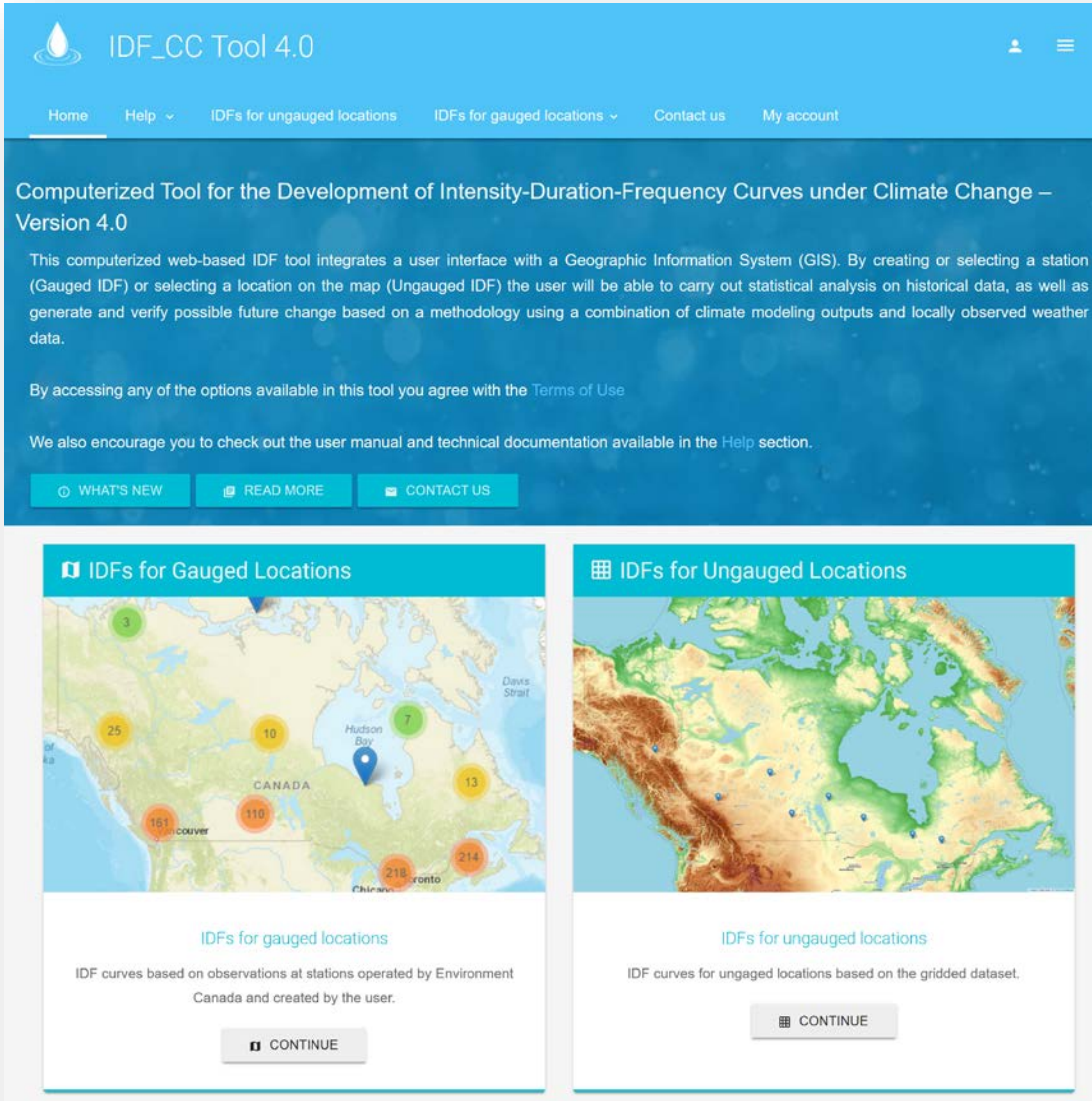
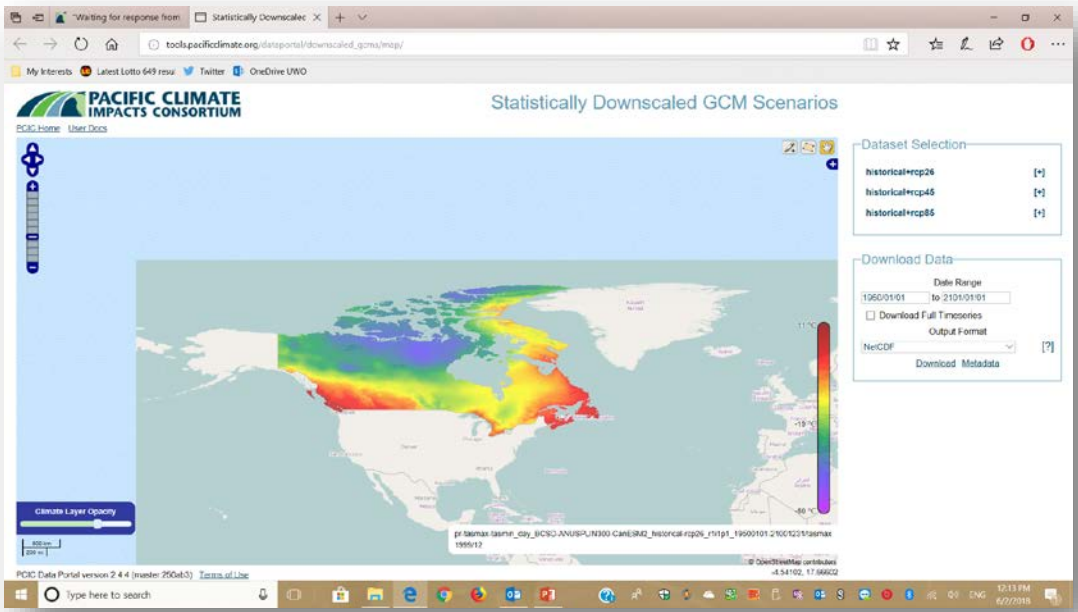
IDF_CC - Interface



12 | METHODOLOGY

IDF_CC – Climate models

- Addition of bias corrected climate models
  - 24 new statistically downscaled GCMs added to the model base
  - Models created by Pacific Climate Impacts Consortium (PCIC) for ECCC
  - BCCAQ is used as the bias correction method:
    - Quantile mapping + climate analogs
    - Combination of CMIP5 climate models and ANUPLIS (gridded reanalysis dataset for Canadian land mass)



METHODOLOGY

IDF_CC – Probability distribution

- Gumbel (EV1)
  - Used by Environment and Climate Change Canada (ECCC)
  - Fitted to observation records only in the IDF_CC tool

$$Q(x) = \mu + k_T . \sigma$$

Q(x) is the exceedance value,
μ and σ are the population mean and standard deviation of the annual extremes;
T is return period in years

$$k_T = -\frac{\sqrt{6}}{\pi}\left[0.5772 + ln\left(ln\left(\frac{T}{T-1}\right)\right)\right]$$

  - Parameters μ and σ estimated using Method of Moments

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METHODOLOGY

IDF_CC – Probability distribution

- GEV distribution
  - Better fitting of the observed extreme precipitation records then Gumbel (general recommendation of the contemporary research)
  - Fitted to the observations in the IDF_CC tool and used for the future updating algorithm
  - Calculation of quantiles:

$$Q(x) = \mu + \frac{\alpha\{1-(-lnF)^{k}\}}{k} \quad \text{for } k \neq 0$$

$$Q(x) = \mu - \alpha\left\{-exp\left[-\frac{1}{\alpha}(F-\mu)\right]\right\} \quad \text{for } k = 0$$

Q(x) is the exceedance value,
μ the location,
α the scale and
k the shape parameter of the distribution;
T is return period in years, and

$$F = \left(1 - \frac{1}{T}\right)$$

  - Method of L-moments used for estimation of parameters

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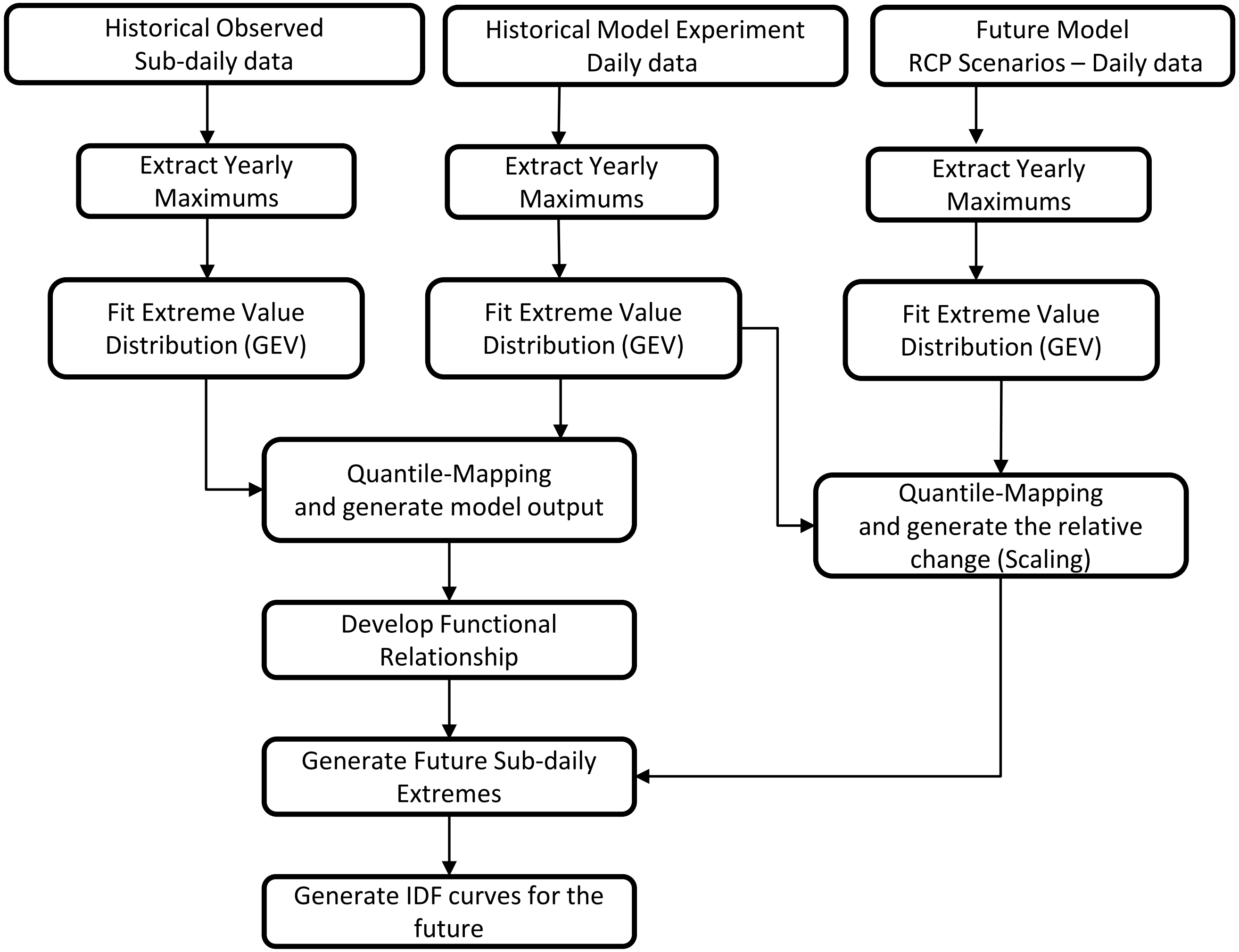
METHODOLOGY

IDF_CC – Quantile matching algorithm

- Modified algorithm for GEV



METHODOLOGY

IDF_CC – Quantile matching algorithm

- Statistical relationship between GCM model and station observations
  - Use of sampling technique to establish a statistical relationship

$$\hat{x}_{j,o,h} = \frac{a_j + x_{m,h}}{b_j + c_j x_{m,h}} + \frac{d_j}{x_{m,h}}$$

$\hat{x}_{j,o,h}$ - AMP quantiles at the station scale

  - Differential Evolution (DE) optimization algorithm used to fit the coefficients a_j, b_j, c_j and d_j
- Quantile mapping and scaling
  - For each projected future precipitation value $x_{m,f}$, calculate the non-exceedance probability $\tau_{m,f}$ from the fitted GEV $F_{m,f}$. Find the corresponding quantile ($\hat{x}_{m,h}$) from the GCM historical baseline (using $\tau_{m,f}$ and the CDF $F_{m,h}^{-1}$

$$\tau_{m,f} = F_{m,f}(x_{m,f}); \qquad \hat{x}_{m,h} = F_{m,h}^{-1}(\tau_{m,f}); \qquad \Delta_m = \frac{x_{m,f}}{\hat{x}_{m,h}}$$

  - Obtain future value

$$x_{j,o,h}^{f} = \Delta_m . \hat{x}_{j,o,h}$$

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IDF_CC Methodology ungauged locations

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IDF_CC – Gridded historical IDF

- Historical gridded IDF curves dataset:
  1. Preparation of predictors - 31 atmospheric variables (AV) for all grids within Canada for the period **1979-2013** from NARR and ERA-Interim databases
  2. Selection of relevant AVs at each station to estimate AMPs (different set for different duration)
  3. Use of SVM (support vector machines) learning algorithm to define the relationship between predictant (sub-daily AMPs series) and predictor variables at each station (different SVM model for different duration) with two polling sets (10 and 25 stations) to stabilize the relationships
  4. Prediction of preliminary IDFs using calibrated SVM model for the nearest station and time-series of predictors at each reanalysis grid
  5. Correction (spatial) factors calculated at each precipitation gauging station and used with preliminary IDF estimates to obtain final gridded IDF estimates
  6. Final dataset contains 4 (four) IDF curves for each grid (2 reanalysis products and 2 sets of average nearest (10 and 25) precipitation gauging stations)

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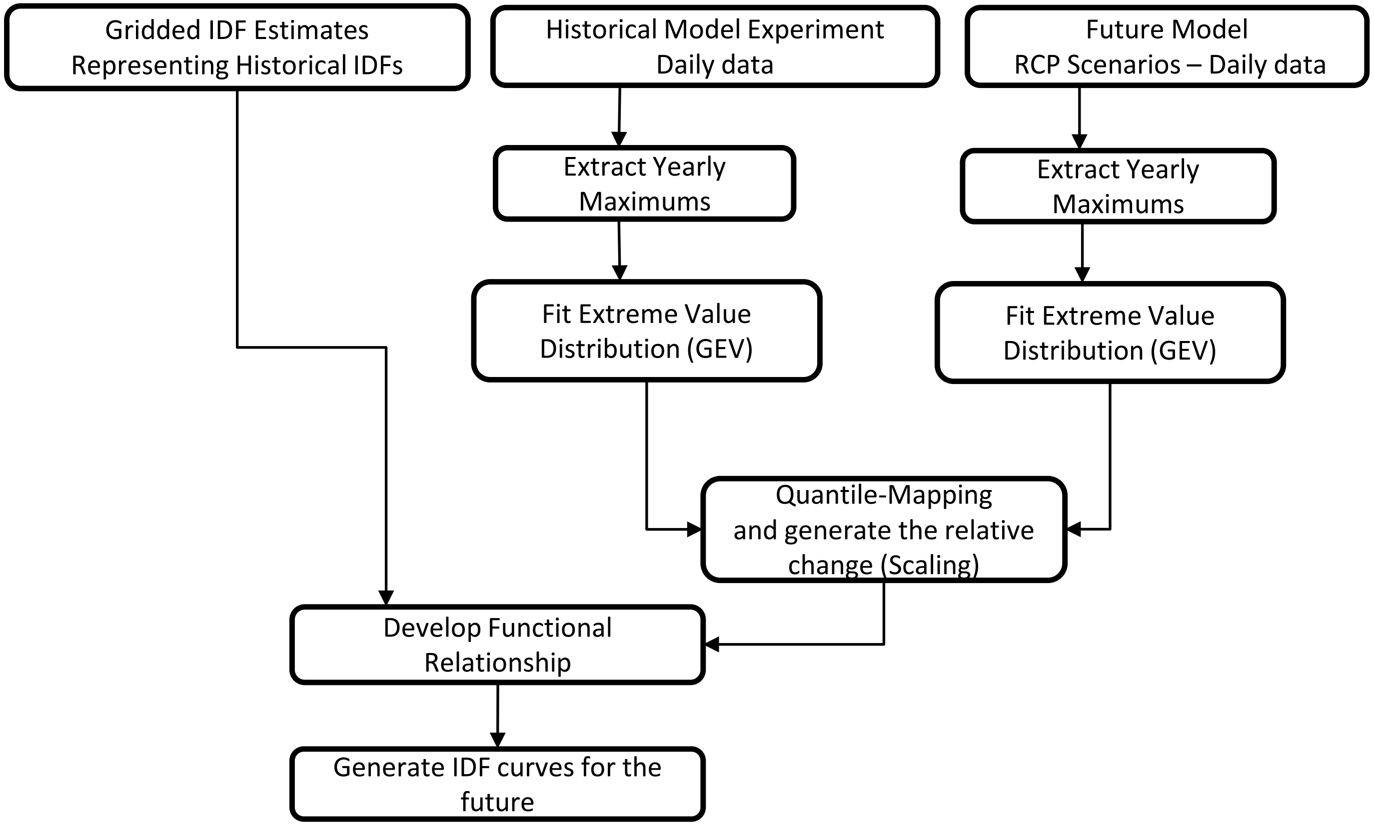
METHODOLOGY

IDF_CC – Quantile matching algorithm

- Modified algorithm for ungauged locations



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Implementation

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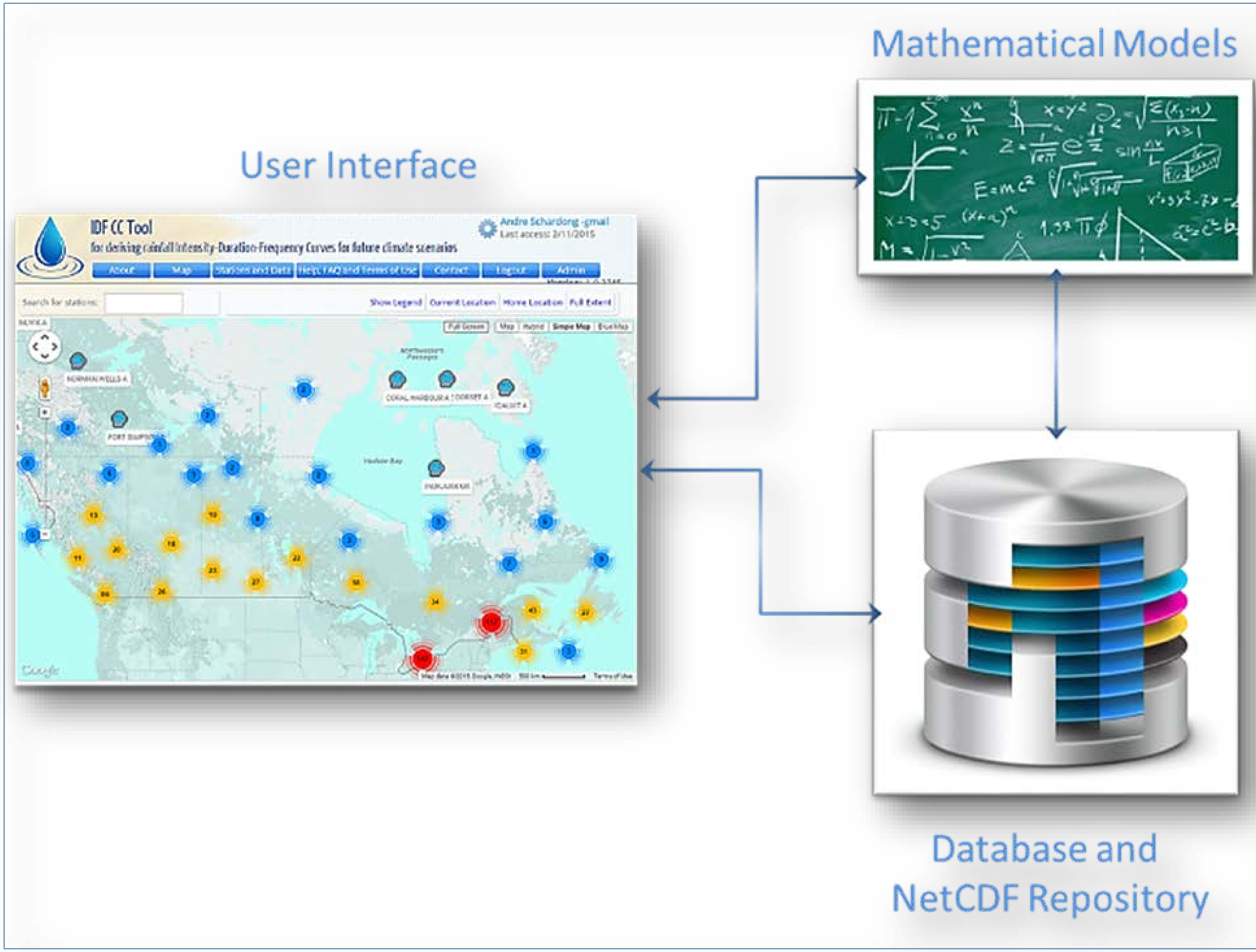
System components



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System components - details

- Database:
  - IDF repository from Environment Canada (700 stations)
  - User provided stations and data
  - Global climate models information and netCDF File repository (24 GCMs; RCP2.5, RCP4.5, RCP8.5; multiple GCM runs)
  - 24 Bias Corrected GCMs (PCIC)
  - Ungauged IDF dataset (Canada land mass)

- User interface:
  - Data manipulation
  - Results visualization (tables, equations, interactive graphs)

- Models:
  - Statistical analysis algorithms (Gumbel, GEV)
  - IDF update algorithm (the equidistant quantile matching – EQM)
  - Optimization model

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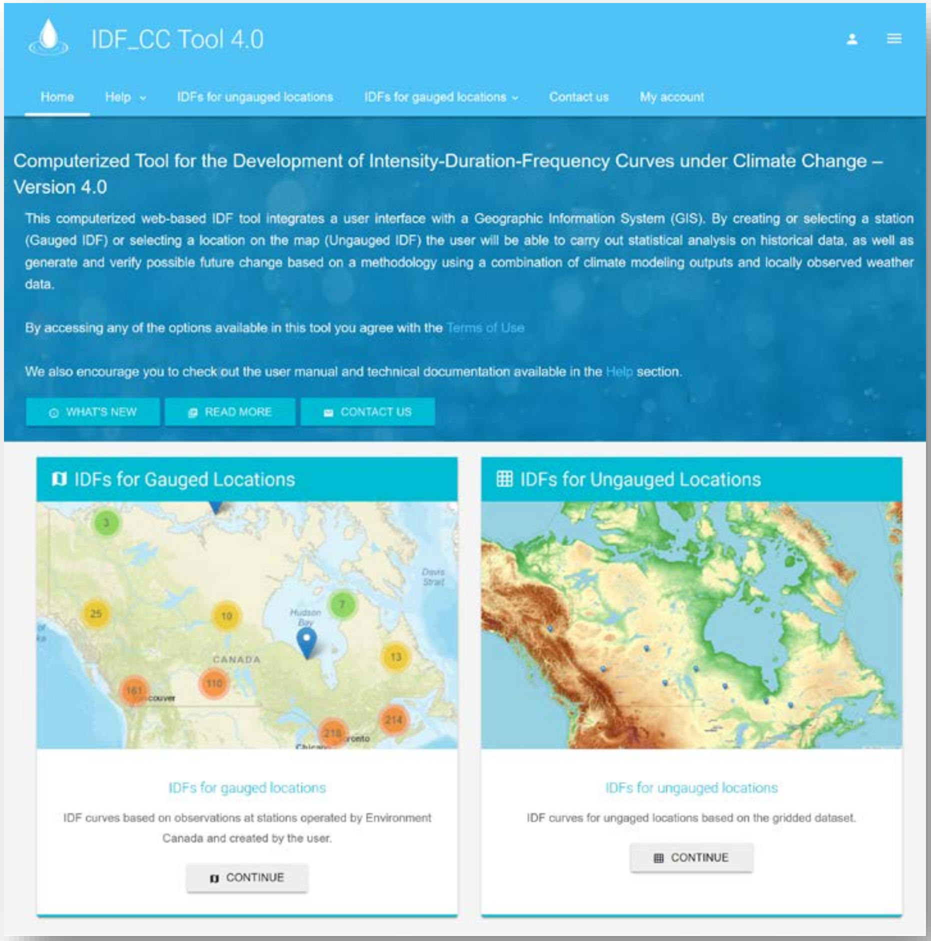
25 | IMPLEMENTATION
System components - details

- User interface



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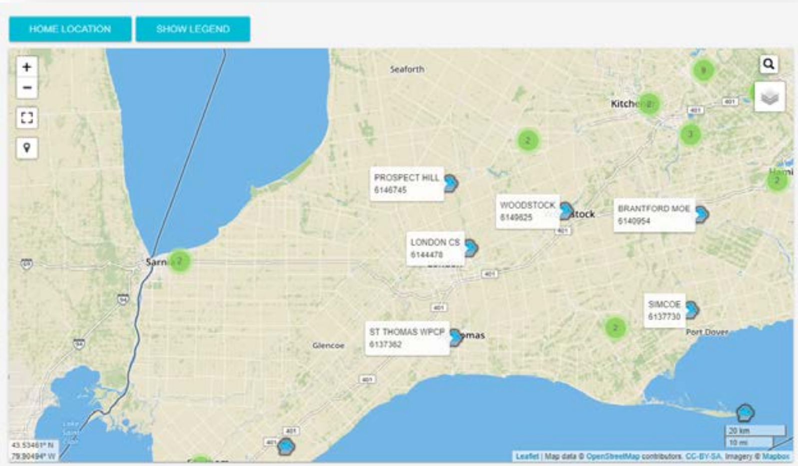
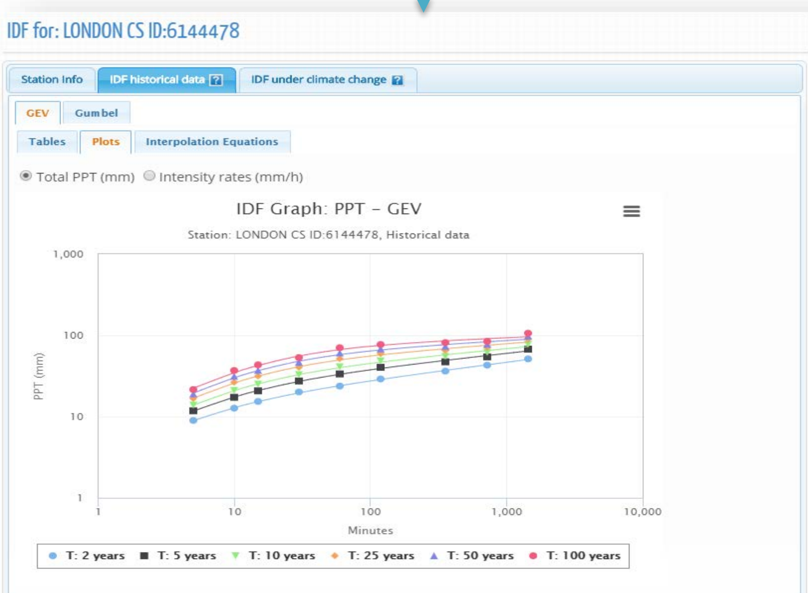
IMPLEMENTATION

Processing steps – historical IDF – gauged locations





Display map

- Read user information (account , home location, etc)
- (Read and display user created stations)
- Read and display information from Environment and Climate Change Canada

Steps for IDF generation for historical period

1. Read and organize data from the database for the selected Station
2. Data analysis (ignore negative and zero values) and extraction of yearly maximums
3. Calculate statistical distribution parameters (Gumbel and GEV)
4. Calculate IDF
5. Fit IDF equation using optimization (Differential Evolution)
6. Organize data for display (tables, plots, and equations)

IMPLEMENTATION
Processing steps – future IDF – gauged locations

Steps to generate IDF for future period

7. Read the selected GCM model
8. Extract data series from GCM grid points for the selected Station
9. Organize series and extract yearly maximums
10. Apply quantile matching algorithm
11. Calculate distribution parameters and IDFs for each future scenario (RCPs and it's ensembles)
12. Generate one average IDF from results in step 11
13. Fit equation by optimization for the average IDF from step 12
14. Organize data for display (tables, plots, and equations, uncertainty range plot)

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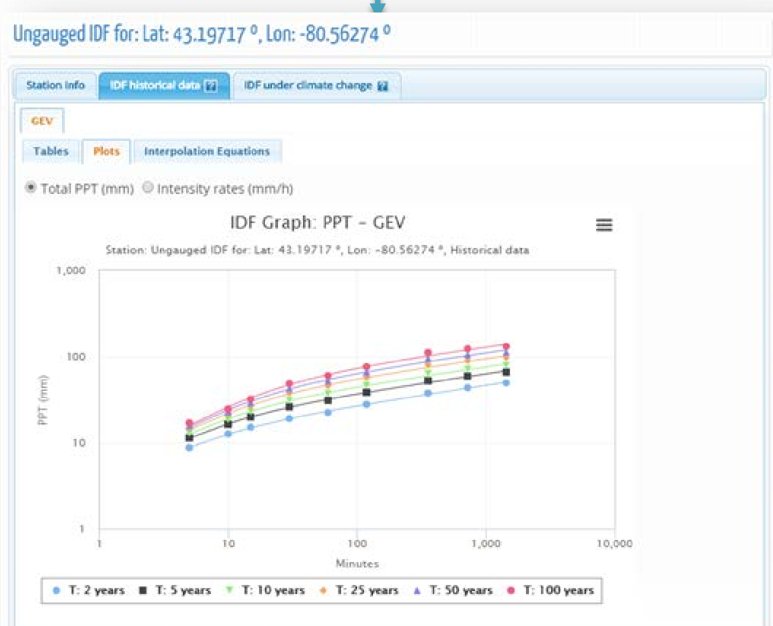
Processing steps – historical IDF -ungauged locations



Display map

- Read user information (account , home location, etc)
- Select location
- (Read and display user created stations)

Steps for historical IDF generation

1. Read and organize data from the database for the provided location (coordinates)
2. Calculate IDF curves from the parameters extracted from the ungauged dataset
3. Calculate IDFs and find the average curve
4. Fit IDF interpolation equation using optimization (Differential Evolution)
5. Organize data for display (tables, plots, and equations)

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Processing steps – future IDF – ungauged locations

Steps to generate future IDF

7. Read the selected GCM model
8. Extract data series from GCM grid points for the selected location
9. Organize series and extract yearly maximums
10. Apply quantile matching algorithm
11. Calculate distribution parameters and IDFs for each future scenario (RCPs and it's ensembles)
12. Generate one average IDF from results in step 11
13. Fit equation by optimization for the average IDF
14. Organize data for display (tables, plots, and equations, uncertainty range plot)

IMPLEMENTATION

Updating IDF

1. Updating IDF using station and data from ECCC

   1 → 2 → 3

   Select Station → Historical IDF → Future IDF

2. Creating station and updating IDF using user provided data

   1 → 2

   Create Station → Provide data

   3 → 4

   Historical IDF → Future IDF

3. Updating IDF for the ungauged location

   1 → 2 → 3

   Select Location → Ungauged IDF → Future IDF

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31 | RESOURCES

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or

Research → Products

RESOURCES

User's Manual

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Water Resources Research Report

Computerized Tool for the Development of Intensity-Duration-Frequency Curves Under a Changing Climate

User's Manual v.3

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Andre Schardong
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Report No: 104
Date: January 2018

ISSN: 1913-3219
ISBN: 978-0-7714-3108-1

VERITAS ET UTILITAS

Technical Manual

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33 | RESOURCES

Overview of tool and methods: Simonovic, S.P., Schardong, A., Sandink, D., and Srivastav, R. (2016). "A Web-based Tool for the Development of Intensity Duration Frequency Curves under Changing Climate". *Environmental Modelling and Software,* 81:136-153. 234.

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CDN regional analysis: Simonovic, S.P., Schardong, A., Sandink, D. (2017). Mapping Extreme Rainfall Statistics for Canada Under Climate Change Using Updated Intensity-Duration-Frequency Curves. *Journal of Water Resources Planning and Management.* 143 (3).

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DSS engagement practices: Sandink, D., Simonovic, S.P., Schardong, A., and Srivastav, R. (2016). A Decision Support System for Updating and Incorporating Climate Change Impacts into Rainfall Intensity-Duration-Frequency Curves: Review of the Stakeholder Involvement Process. *Environmental Modelling and Software,* 84:193-209.

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Use of the IDF_CC tool

IDF_CC TOOL USE

Uncertainty

- Uncertainty
  - Model selection
  - Scenario selection

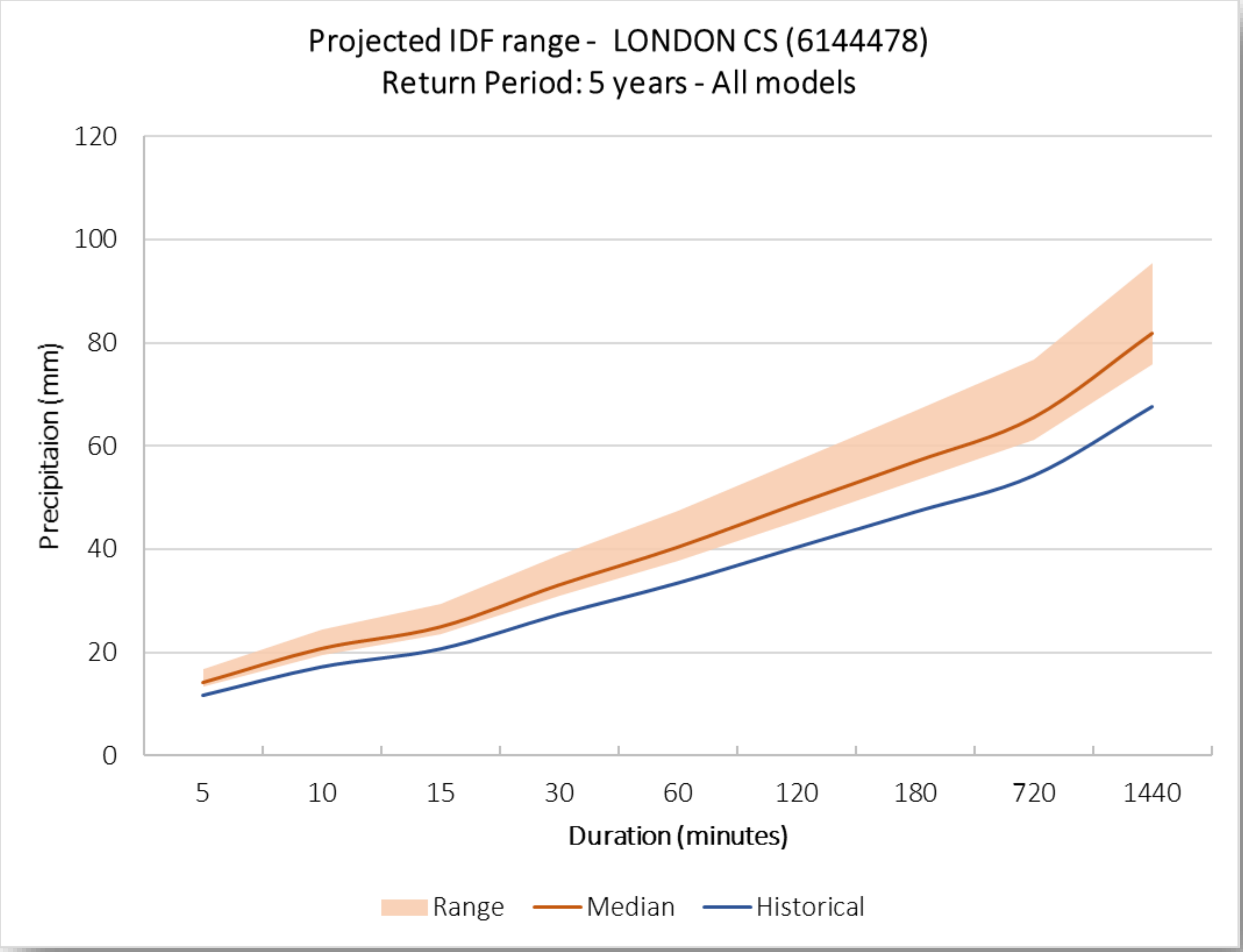
  - Significant
  - Unavoidable

IDF_CC TOOL USE

Uncertainty

IDF_CC TOOL USE

Uncertainty



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PRACTICAL CONSIDERATIONS

1. Ensemble

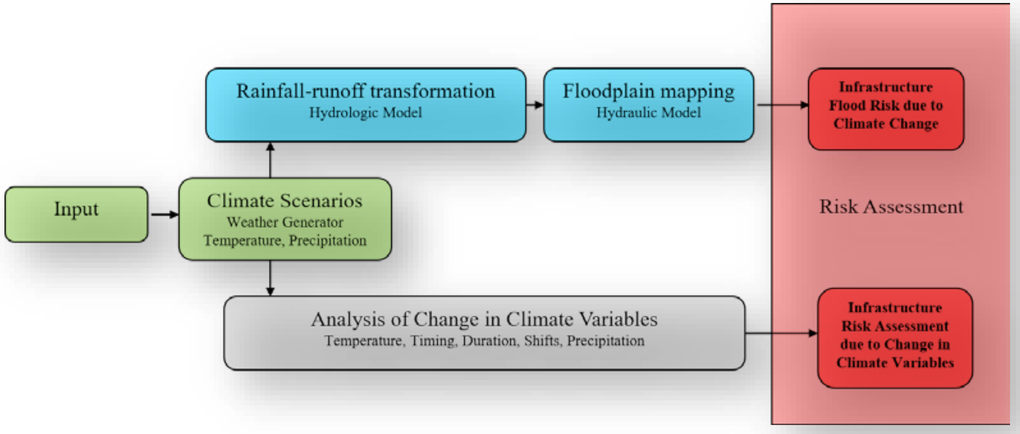
- IPCC recommendation – use of ensemble
    - Forming and interpreting ensembles for a particular purpose requires an understanding of the variations between model simulations and model set-up (e.g., internal variability, parameter perturbations, structural differences, and clarity about the assumptions)
    - ‘Best effort’ simulations (i.e., the results from the default version of a model submitted to a multi-model database)
    - ‘Perturbed physics’ simulations (useful information about the spread of possible future climate change)
    - Combining perturbed physics and best effort results from different models is not straightforward

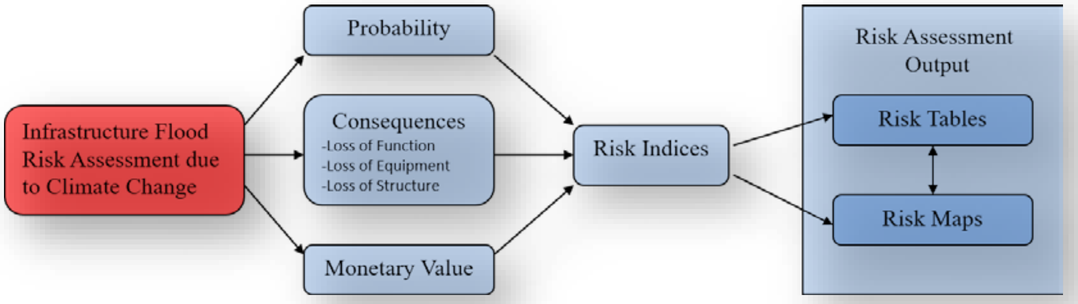
IPCC - Assessing and Combining Multi Model Climate Projections), 2010

PRACTICAL CONSIDERATIONS

2. Range

- Test the boundaries
  - Upper and lower bound of climate change
  - Assessment of risk (static, single value measure)





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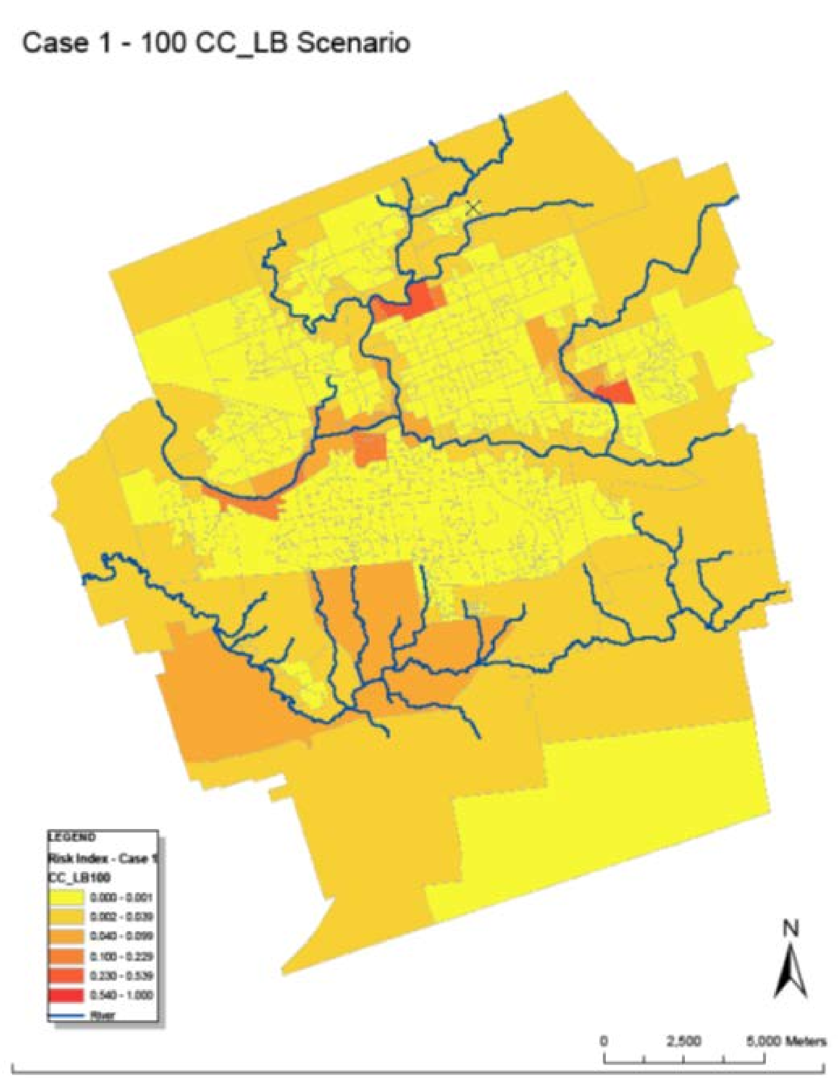
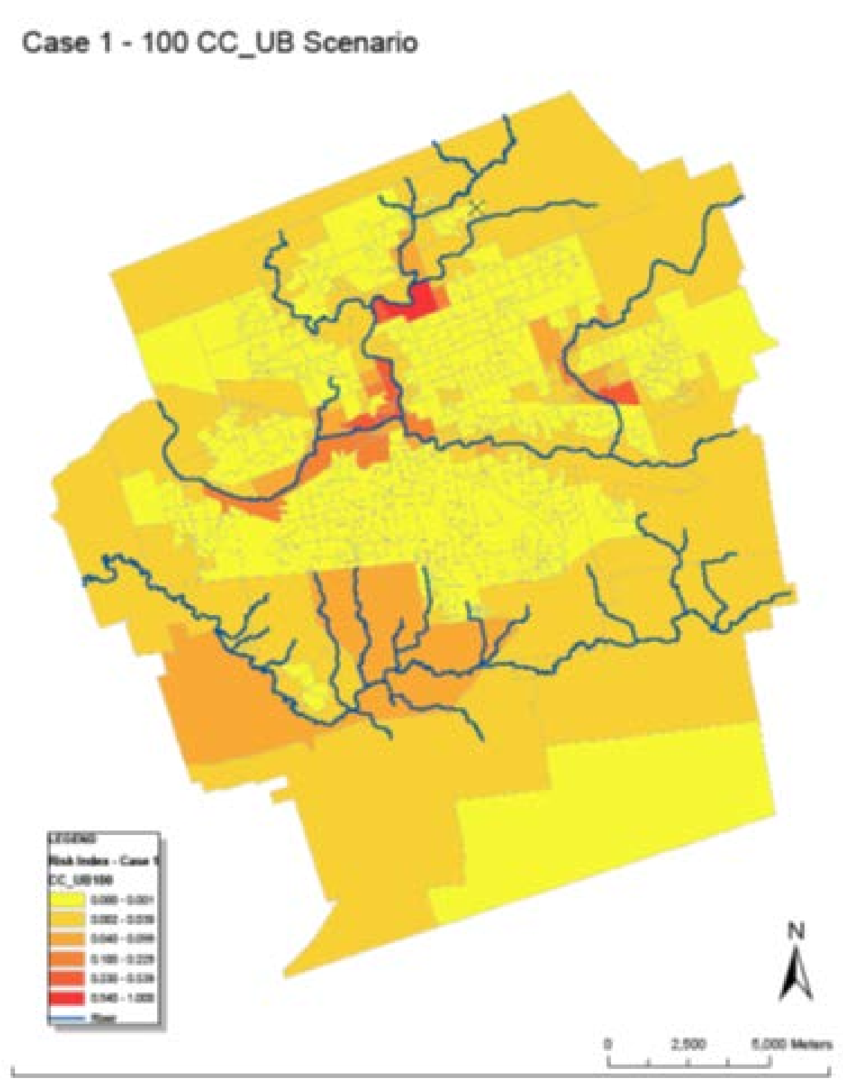
2. Range





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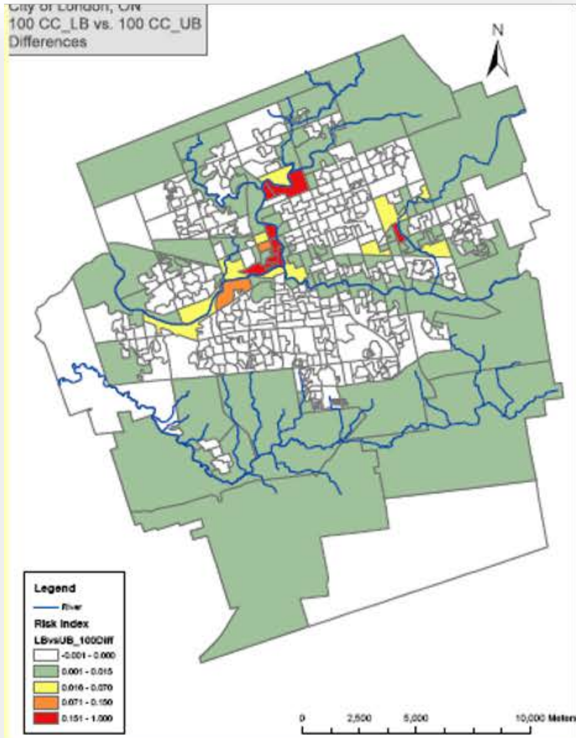
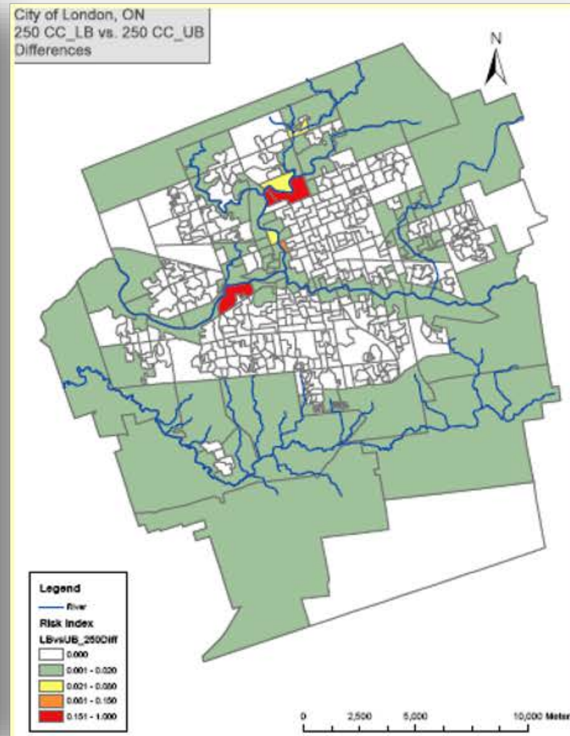
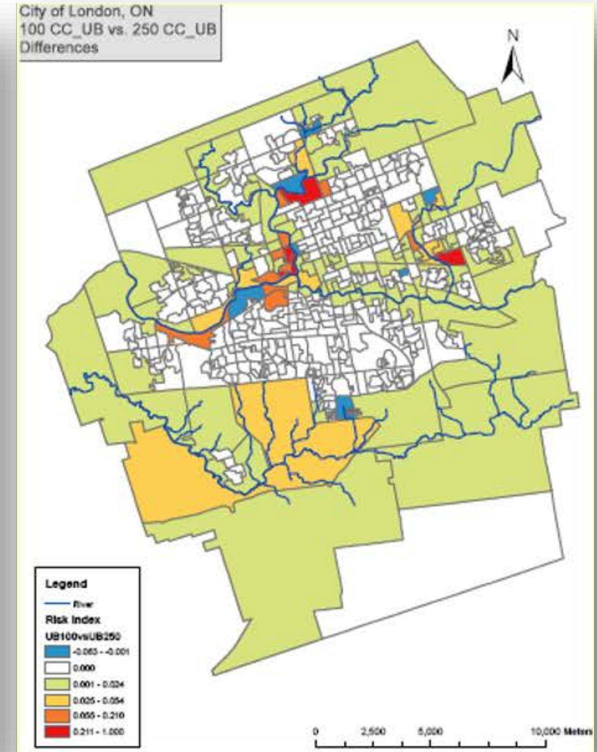
2. Range







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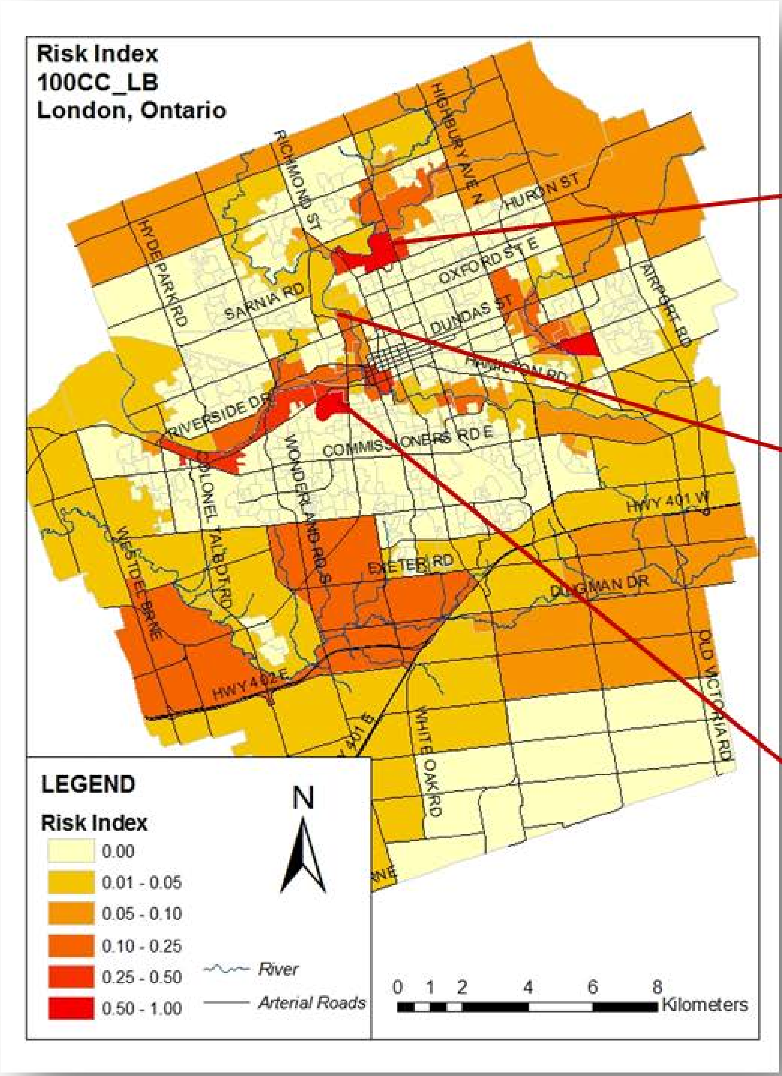
PRACTICAL CONSIDERATIONS
2. Range



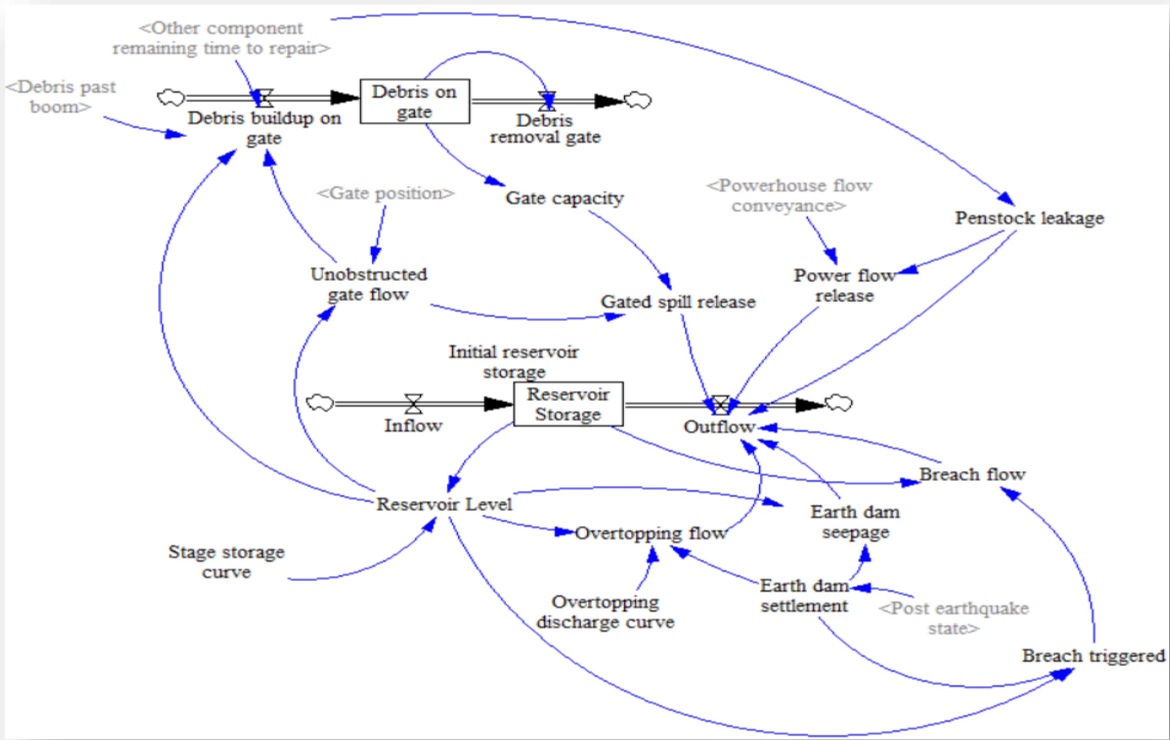
PRACTICAL CONSIDERATIONS

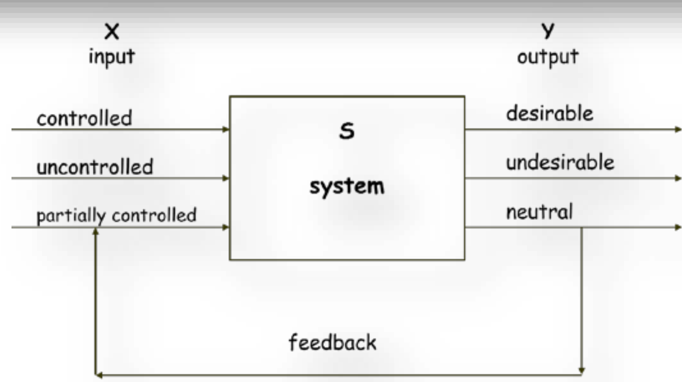
3. Performance based engineering

- Personal recommendation – performance based engineering
  - Investigate all realizations of climate change
  - Introduce the systems approach
    - Move from static risk value to dynamic response of the system to any disturbance/change
    - Use of quantitative measure of resilience

PRACTICAL CONSIDERATIONS

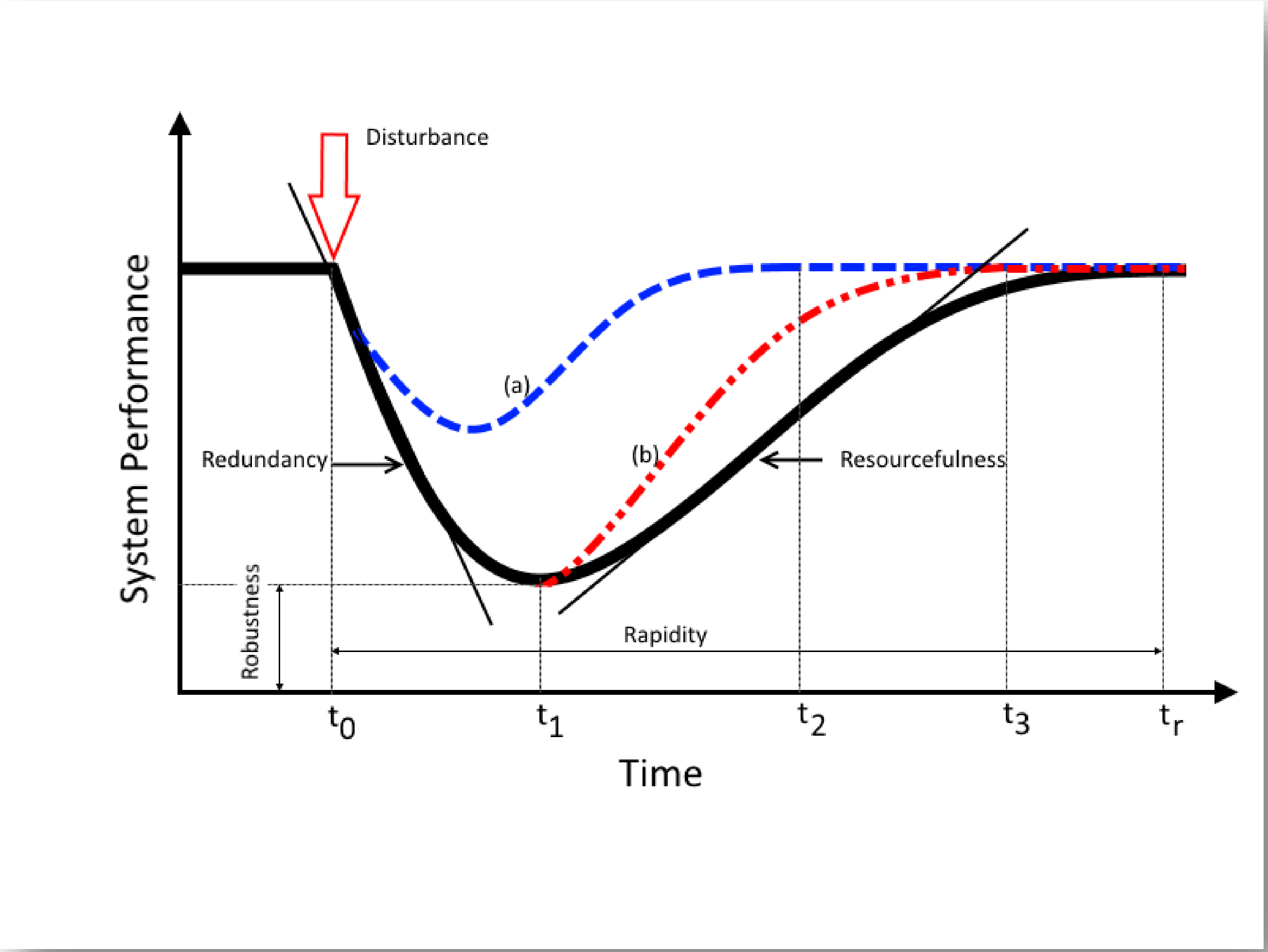
3. Performance based engineering





PRACTICAL CONSIDERATIONS

3 Performance based engineering



Q&A

- Computer-based research laboratory
- Research:
  - *Subject Matter* - Systems modeling; Risk and reliability; Water resources and environmental systems analysis; Computer-based decision support systems development.
  - *Topical Area* - Reservoirs; Flood control; Hydropower energy; Operational hydrology; Climatic Change; Integrated water resources management.
- > 70 research projects
- Completed: 11 visiting fellows, 19 PosDoc, 22 PhD and 44 MESc
- Current: 2 PosDoc, 2 PhD, 1 MESc and 1 visiting scholar

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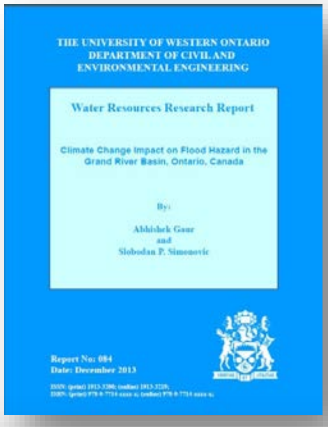
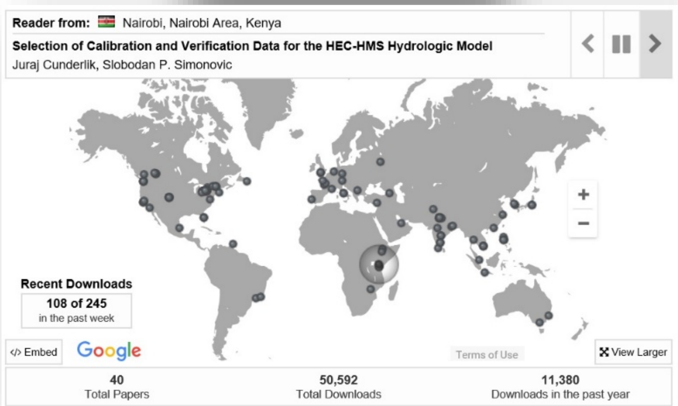
Research results

- ~ 600 professional publications
- 241 in peer reviewed journals
- 3 major textbooks

- Water Resources Research Reports 105 volumes – https://ir.lib.uwo.ca/wrrr/
- > 99,000 downloads since 2011





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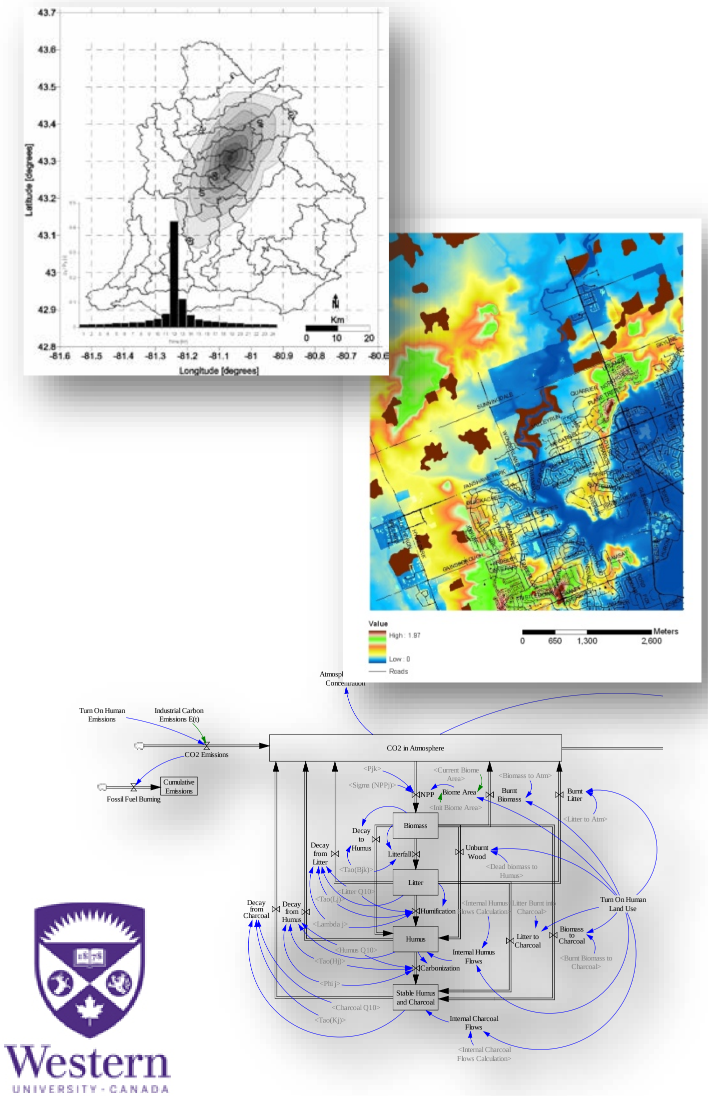
Current research projects



- Water Resources Management Capacity Building in the Context of Global Change
- Systems Engineering Approach to the Reliability of Complex Hydropower Infrastructure
- Linking Hazard, Exposure and Risk Across Multiple Hazards

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