Modelling Flood Sensitivity to Climate Change in a Medium Sized Watershed

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Objective

- Development, testing and the application of semi-distributed stochastic tools to asses the potential effect of climate on extreme flood in flood prone James River Watershed located in major basin-Red Deer Basin of Alberta.
- Specific attention is given to flood frequency curves routinely used in design to size water control structures and flood mapping programs inter alia.

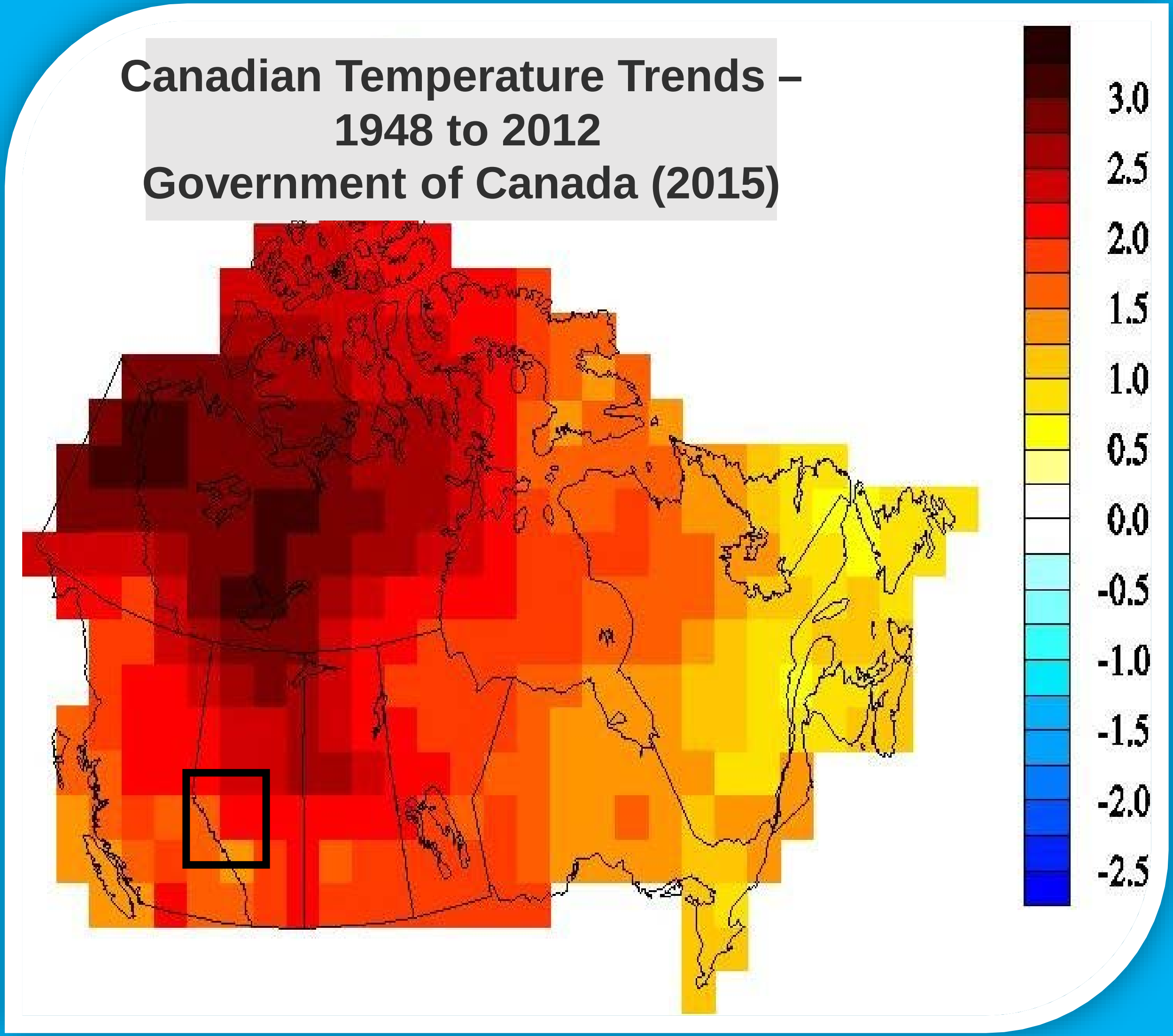
Data Sources/ Portals

- Mostly freely available online for free
- Digital Elevation Models are available for the whole of Canada with resolution up to 19x19 m; LiDAR available for only limited arears
- Land use, soils/ surficial geology
- Hourly rainfall- discharge from Environment Canada & Climate Change Canada & Provincial online portals
- Climate Model Simulations: Canadian Centre for Climate Analysis & Pacific Climate Impact Consortium

Background/Introduction

- Canada has experienced costly losses due to recent floods.
- Floods occur commonly as a result of snowmelt, heavy rainfall, mixture of rain on snow and ice break-ups.
- In 2005 and 2013 Alberta experienced some of the worst floods in the province's history. In 2013 the flood damage cost is pegged at $6B.
- It has been suggested that these extreme events are being aggravated by climate change.
- There is currently a great effort toward mitigating floods, including making high quality data easily available and testing various hydrologic and flood mapping tools to account for climate change impacts.

Background/Introduction



Previous studies indicate that climate change in Canada could potentially result in:

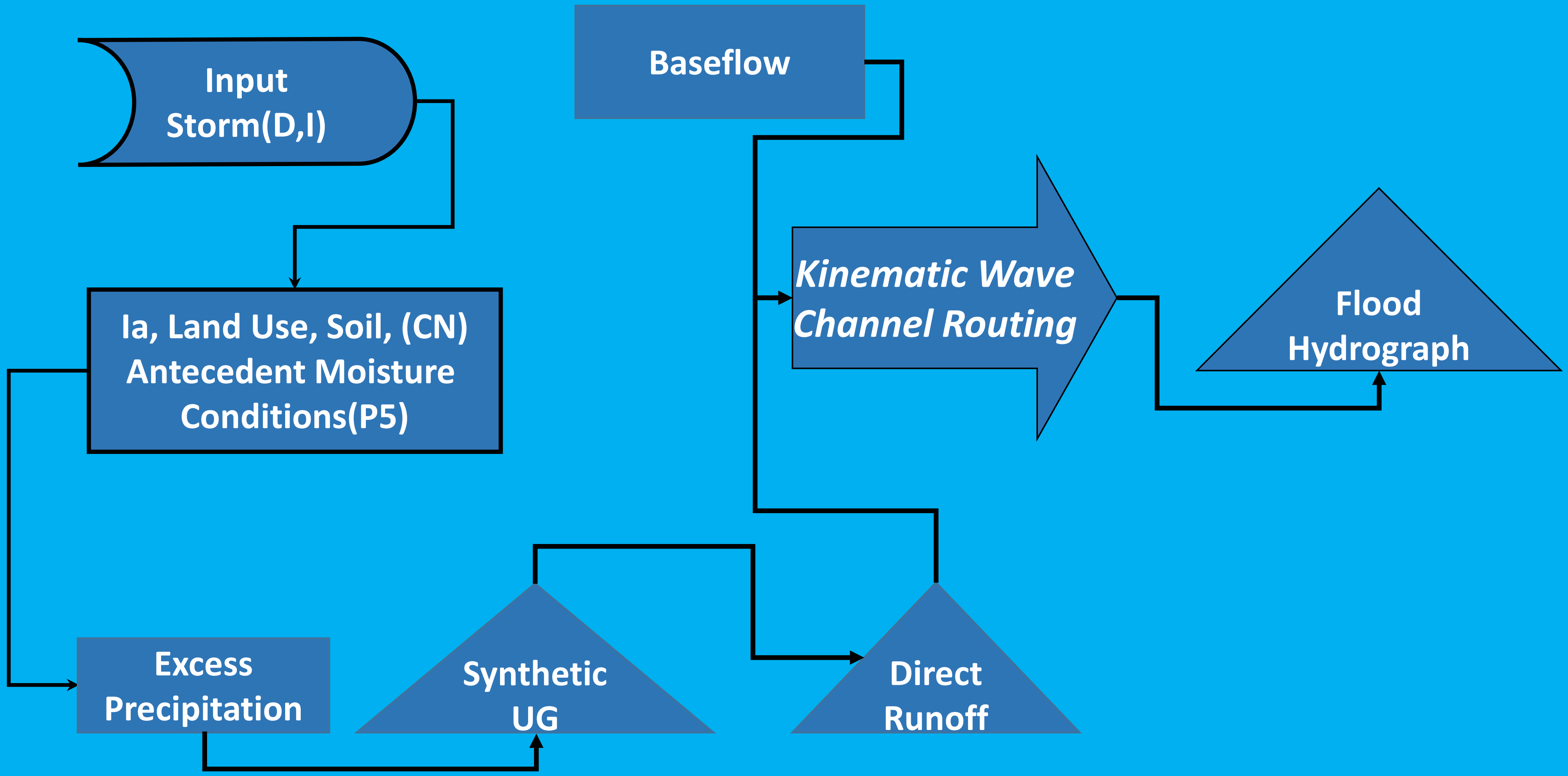
- Earlier river ice break-up
- Temperature increase ~ 2.0 °C
- Increase in precipitation over large parts of Canada, more snowfall and earlier spring runoff

Background/ Introduction

- The atmosphere's capacity to absorb moisture and its absolute water vapor content, increases with increasing temperature.
- The saturation level of the air is enhanced by about 6% for a temperature increase of 1^{o}C, creating conditions that have the potential for generating more heavy precipitation.
- Potential intensification of heavy precipitation, in form of either higher frequency events or increased intensities, can substantially enhance the likelihood of floods.

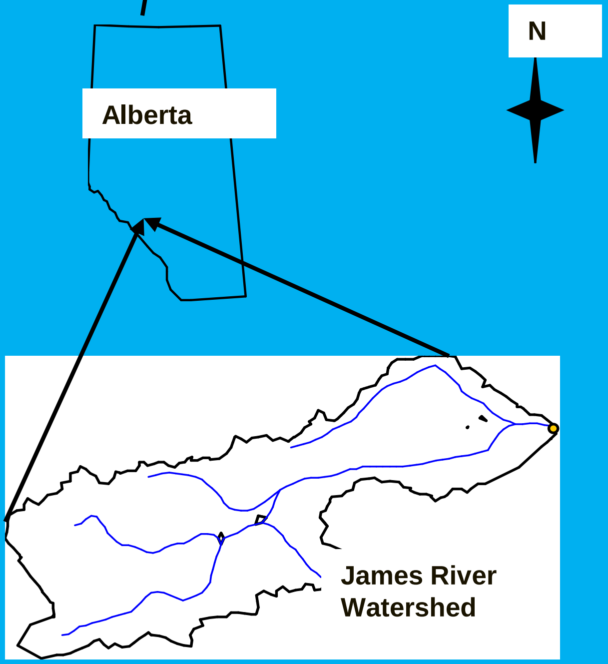
Analysis

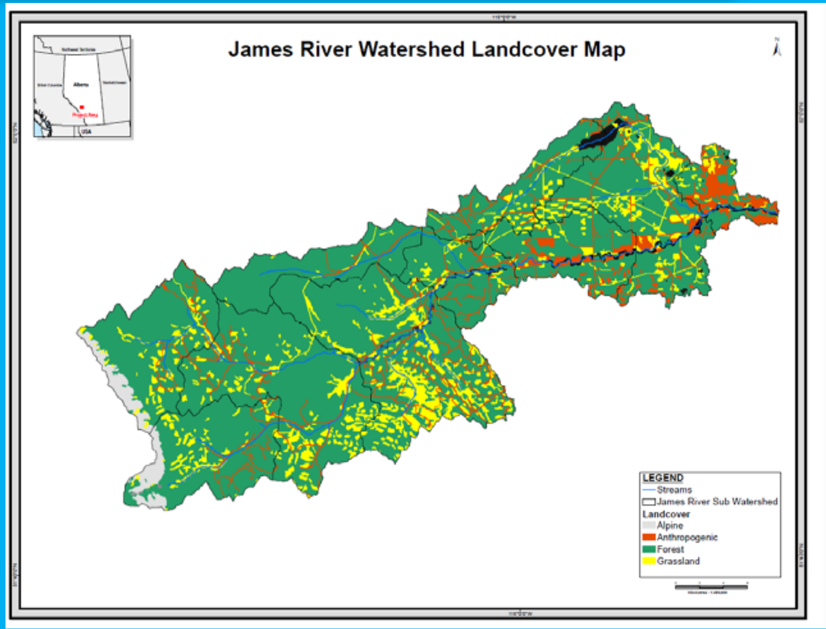
The HEC-HMS Precipitation-Runoff Model

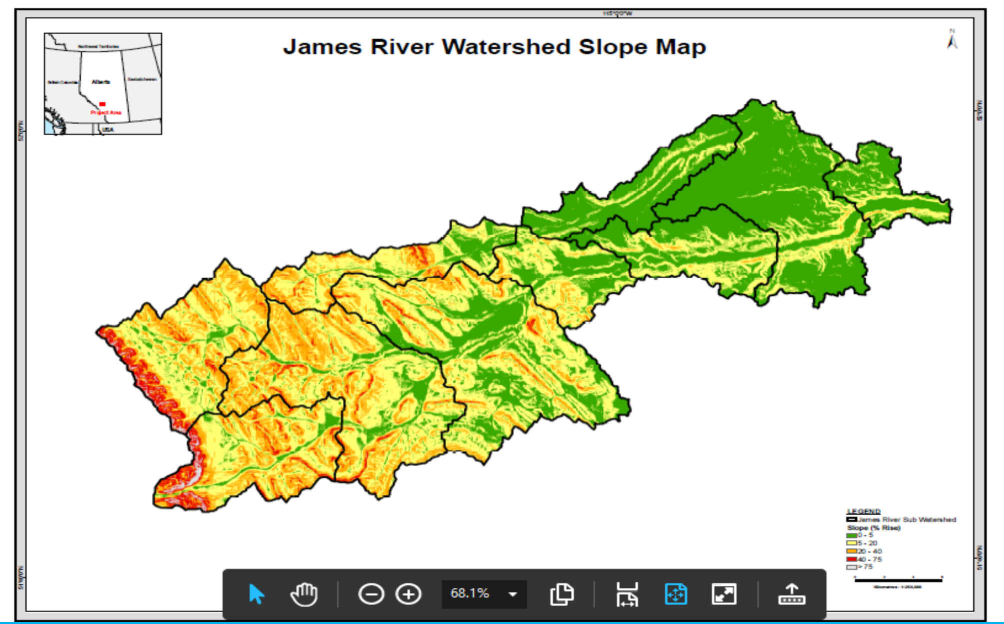


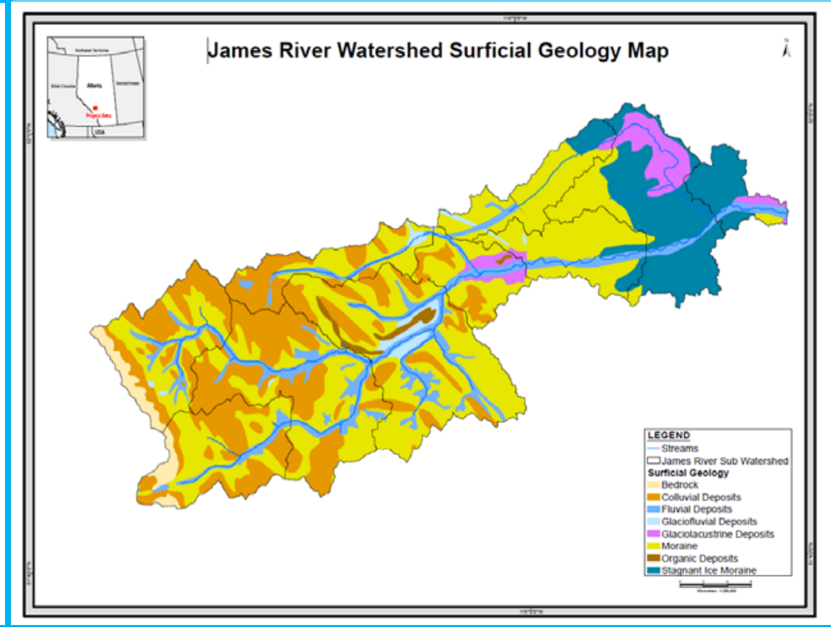
James River Watershed Location & Spatial Characteristics

- Area = 821 km^2
- In the upper reaches of one major basin; Red Deer River Basin









Classical NRCS Approach

Natural Resources Conservation Service (NRCS), formerly called the Soil (SCS) Conservation Service, runoff curve number method

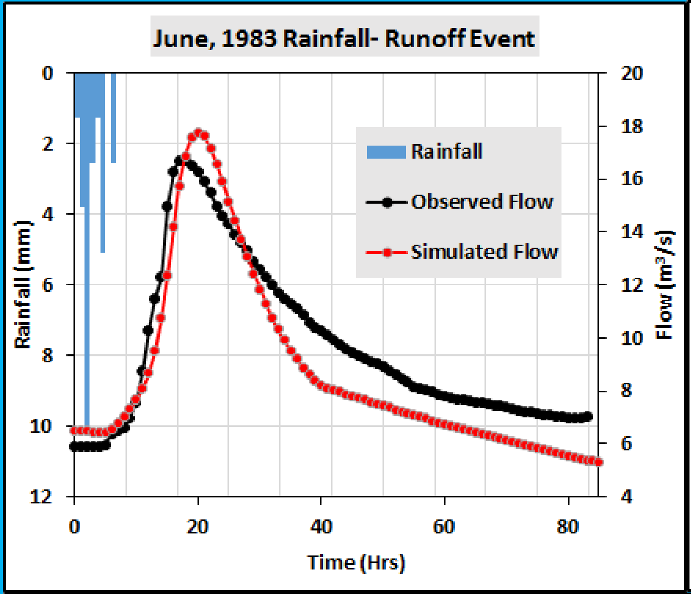
$$P_{es} = \frac{(P - I_a)^2}{P - I_a + S} \qquad S = 254\left(\frac{100}{CN} - 1\right)$$

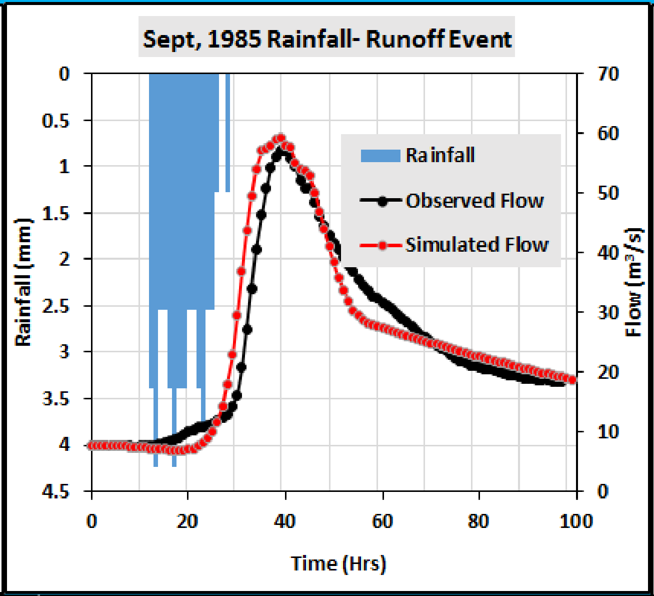
-I_a is the initial abstraction

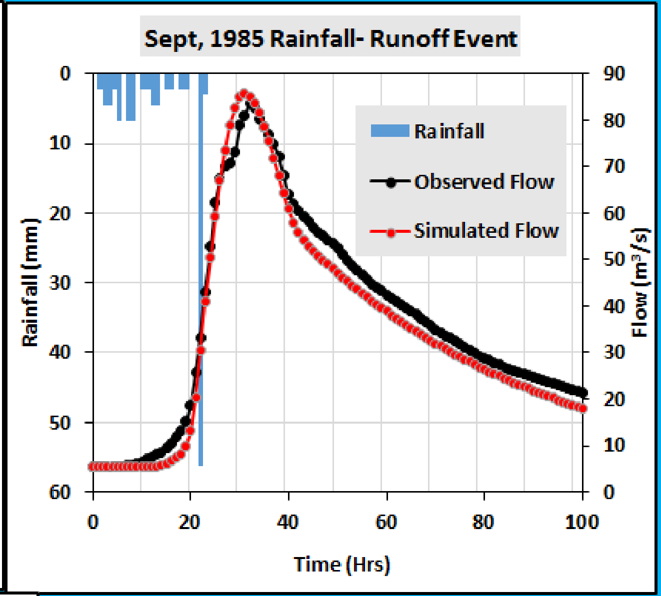
-P_e is the excess rainfall after accounting for all initial abstractions and P is the total storm rainfall depth

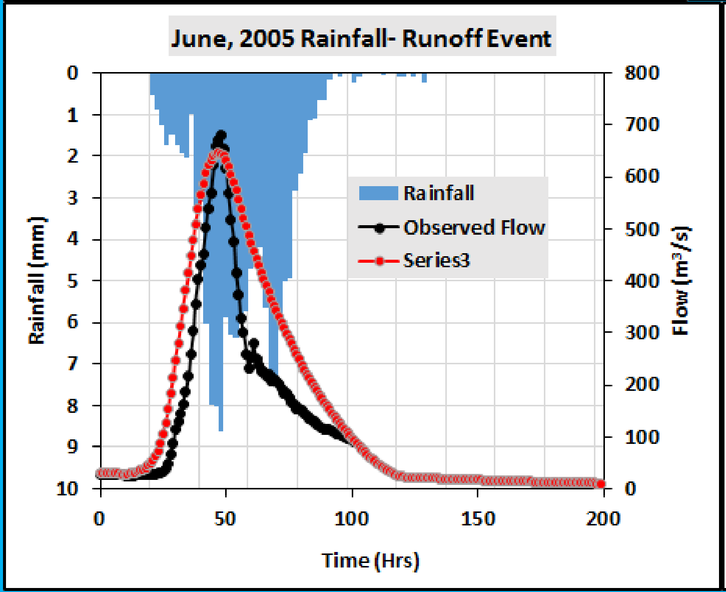
-S is the maximum potential retention and CN is the Curve Number.

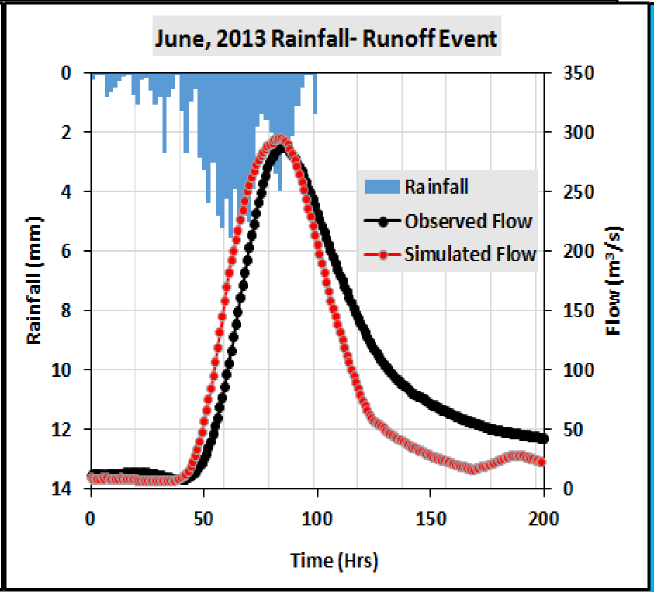
Calibration: HEC-HMS Flood Simulation Tool







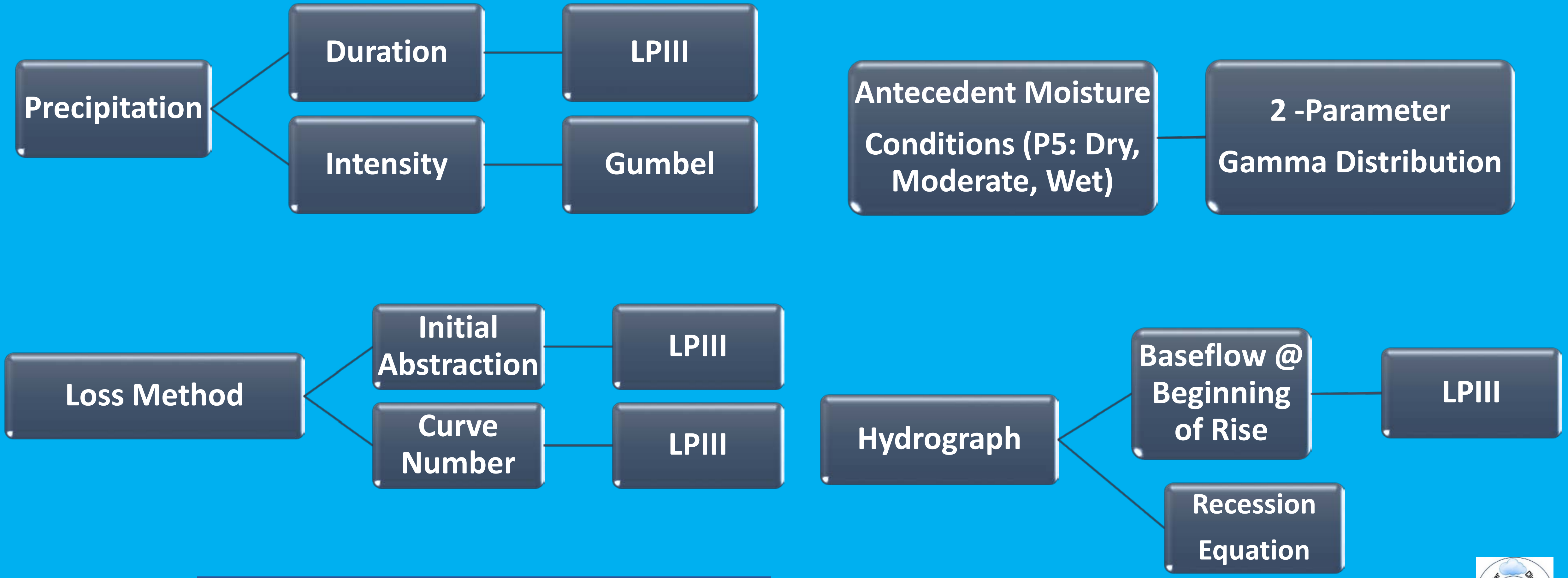




Passed Nash-Sutcliffe Coefficients and R^2 Test
-Slight overestimates of peak flows
-Ia, CN, and S within those observed for in regional Assessment

Probability Distribution Analysis & Montecarlo Simulation

Generate data required to drive the HEC Module, to validate the simulation model and to simulate flood frequency curves



Note: LPIII = Log Pearson Type 3 Distribution

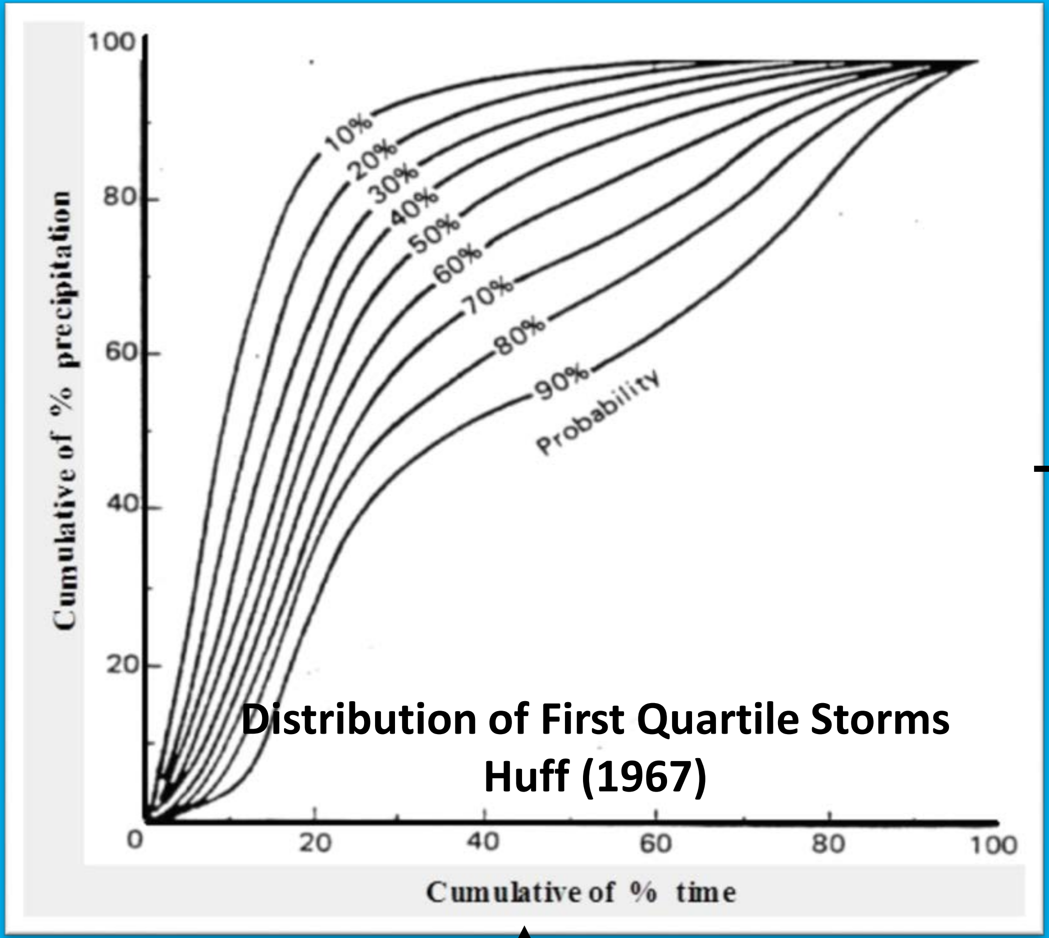
Determination of Storm Intensity, Duration and Hyetograph

Random No. Generator

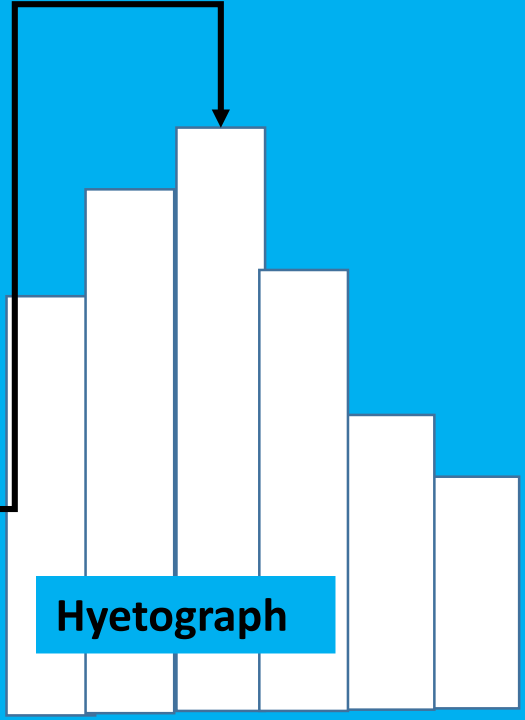
Simulate Duration
Based on LPIII

Mean Depth
& Stdev = Duration

Storm Depth



Distribution of First Quartile Storms
Huff (1967)



Loss Function Probability Distribution

$$\ln(Ia) = m + A*\left[\frac{d}{3*B^{\frac{1}{6}}} - \frac{1}{9*B^{2/3}} + B^{1/3}\right]^3$$

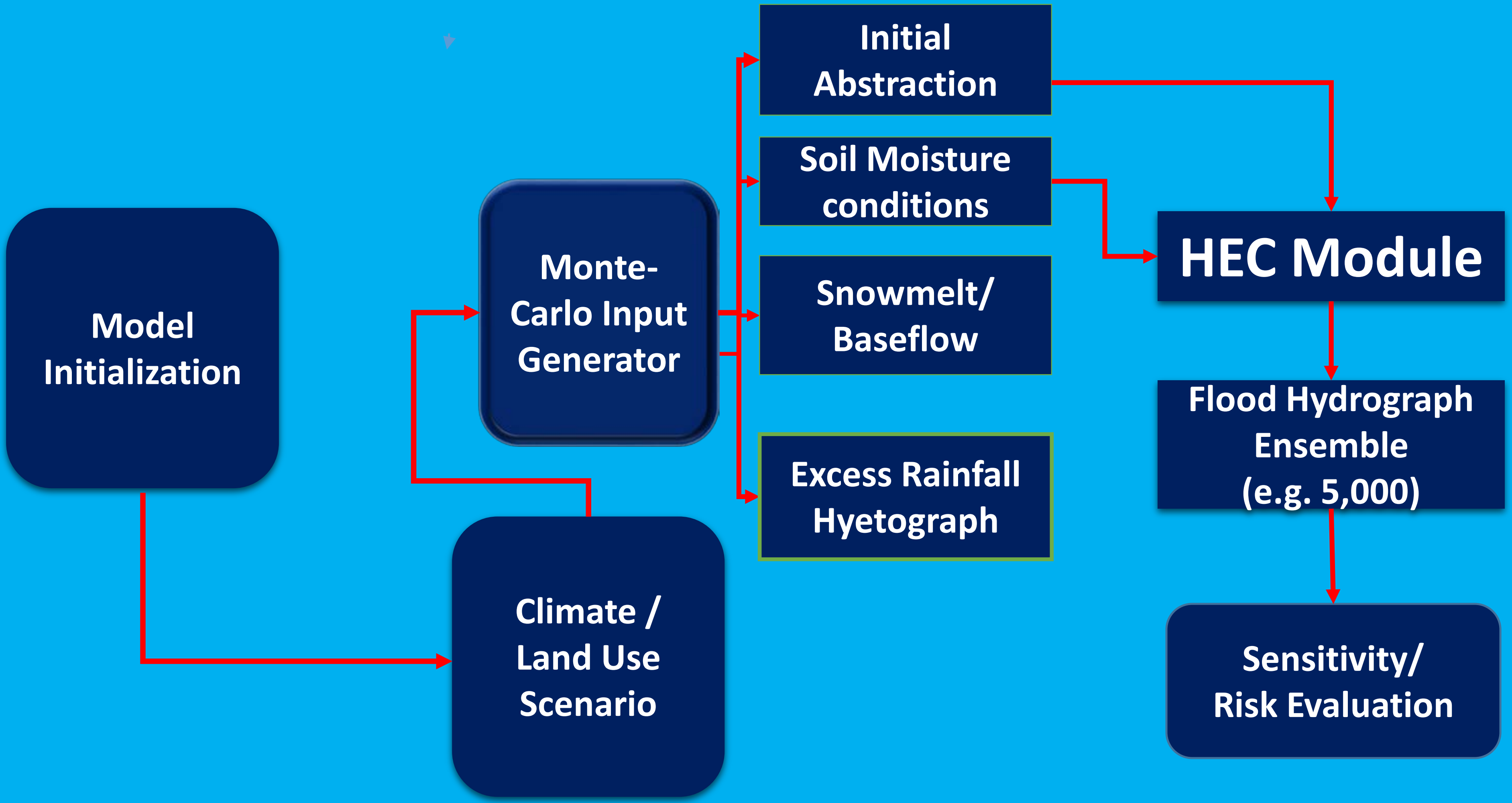
d = Standard normal deviate
A,B,m are distribution parameters
(Log Pearson Type III)

- S = 218.14*e$^{(-0.05621*P5)}$ for 0 $\leq$ P5 < 18.75 mm (Dry)
- S = 125.47*e$^{(-0.02671*P5)}$ for 18.75 $\leq$ P5 $\leq$ 60 mm (Moderate)
- S = 26.598 * e $^{(-0.0008537 * P5)}$ for P5 > 60 mm (Wet)

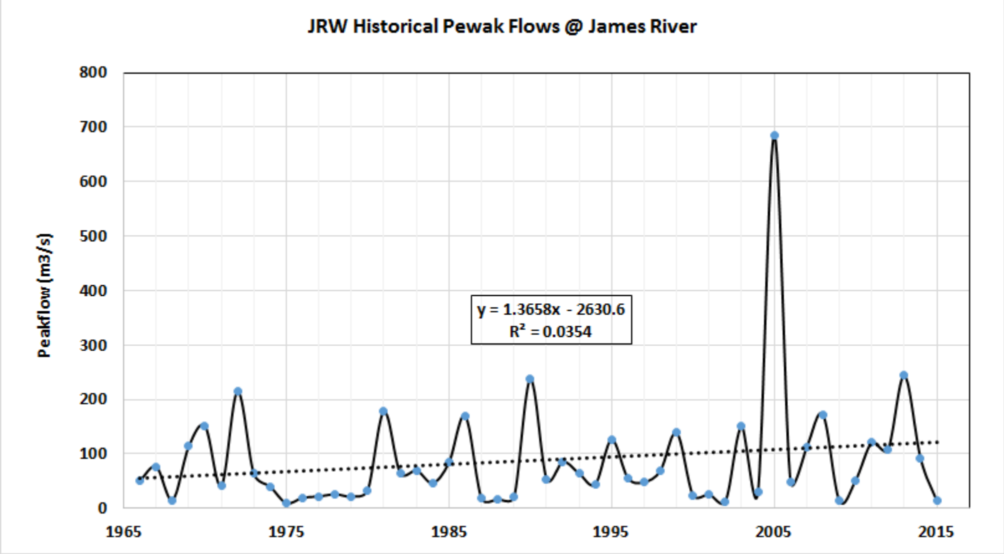
Muzik and Chang(2003)

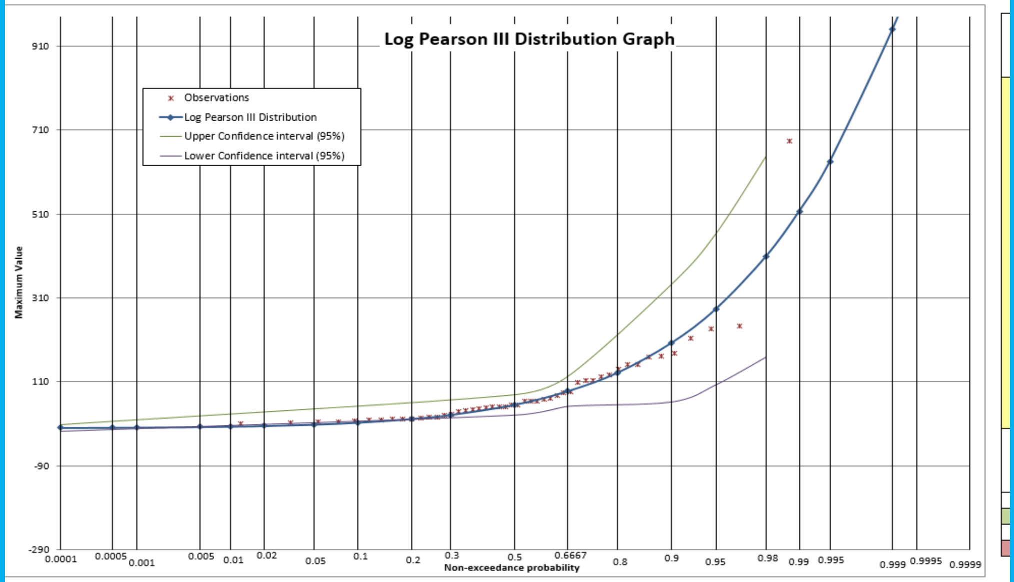
Parameters	**I_a**		
	Dry	**Mod**	**Wet**
A	-0.480	-1.344	-1.021
B	6.233	1.258	2.637
m	5.103	3.606	3.421

OVERVIEW: Montecarlo FLOOD SIMULATION TOOL



Model Validation; Flood Frequency Curve





Log-Pearson 3 [#37]

Kolmogorov-Smirnov

Sample Size	48
Statistic	0.07311
P-Value	0.9431

α	0.2	0.1	0.05	0.02	0.01
Critical Value	0.1513	0.17302	0.19221	0.21493	0.23059
Reject?	No	No	No	No	No

Anderson-Darling

Sample Size	48
Statistic	0.24852

α	0.2	0.1	0.05	0.02	0.01
Critical Value	1.3749	1.9286	2.5018	3.2892	3.9074
Reject?	No	No	No	No	No

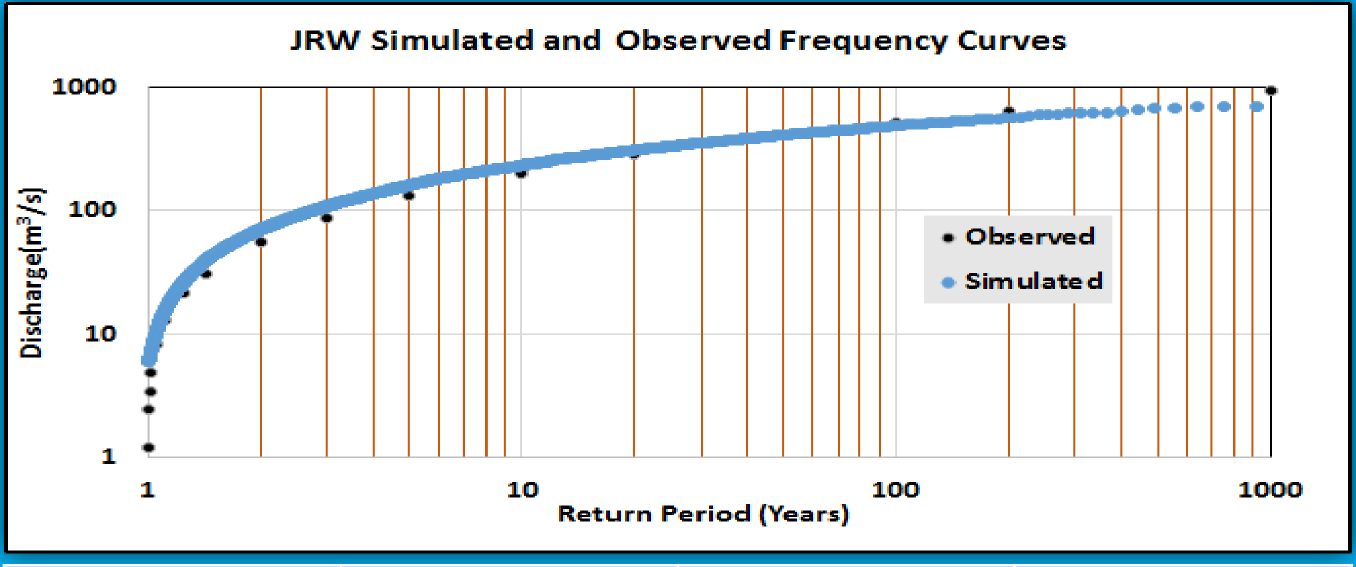
Chi-Squared

Deg. of freedom	4
Statistic	0.9744
P-Value	0.91365

α	0.2	0.1	0.05	0.02	0.01
Critical Value	5.9886	7.7794	9.4877	11.668	13.277
Reject?	No	No	No	No	No

JRW Flood Frequency Simulation Validation

Based on 5, 000 flood hydrograph peaks from Montecarlo simulations



Parameter	Observed Flow	Simulated	95% CI
Mean (m3/s)	89.45	75.618	68.35 - 126.83
Stdev (m3/s)	107.47	83.252	50.44 - 162.41
Cs	3.878	2.219	0.715 - 4.640
Cv	1.201	1.100	0.737 - 1.280

We ran a bootstrap resampling with 10,000 simulations to generate confidence intervals for each statistical measure of confidence.

Climate Models Simulations & Scenario Development

- Canadian Global Coupled Model V1, CGCM1
- Canadian Earth System Model V2 (CanESM2),
- Geophysical Fluid Dynamics Lab Earth System Model (GFDL-ESM2G)
- Institute of Numerical Mathematics Climate Model Version 4 (INMCM4)

IPCC Reference Period

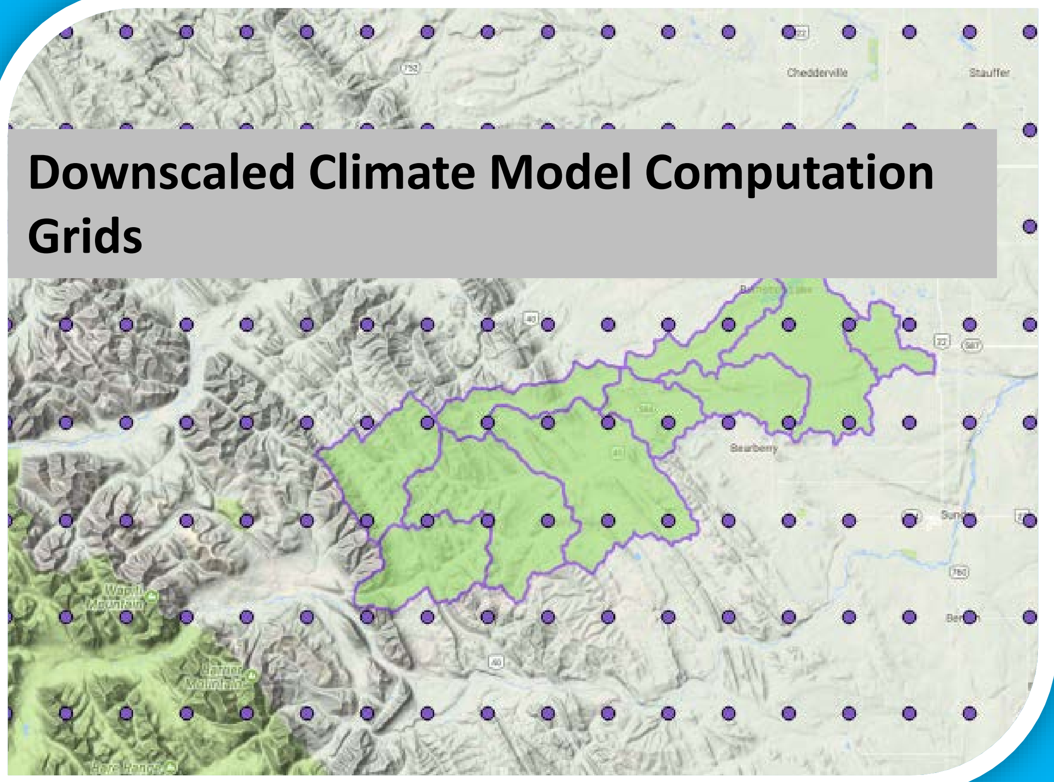
- 1961-1990; Earlier studies reference period
- 1981-2010; Recent studies reference period

Future Climate Windows (Can vary depending on study)

- 2011 – 2040
- 2041 – 2070
- 2071 - 2100

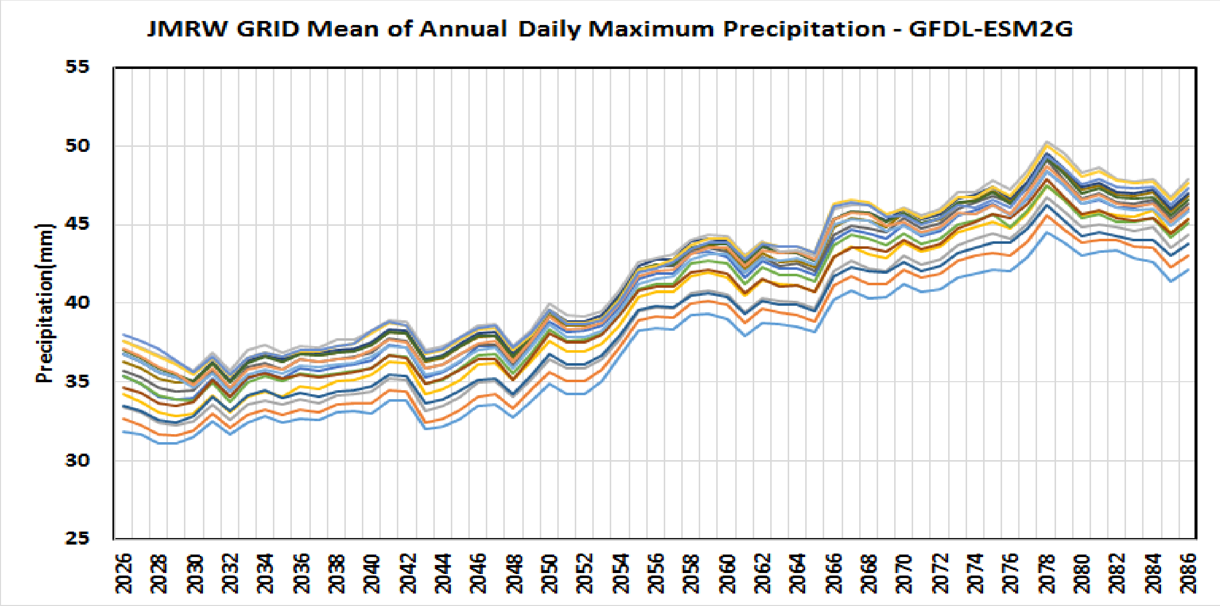
Scenario Development

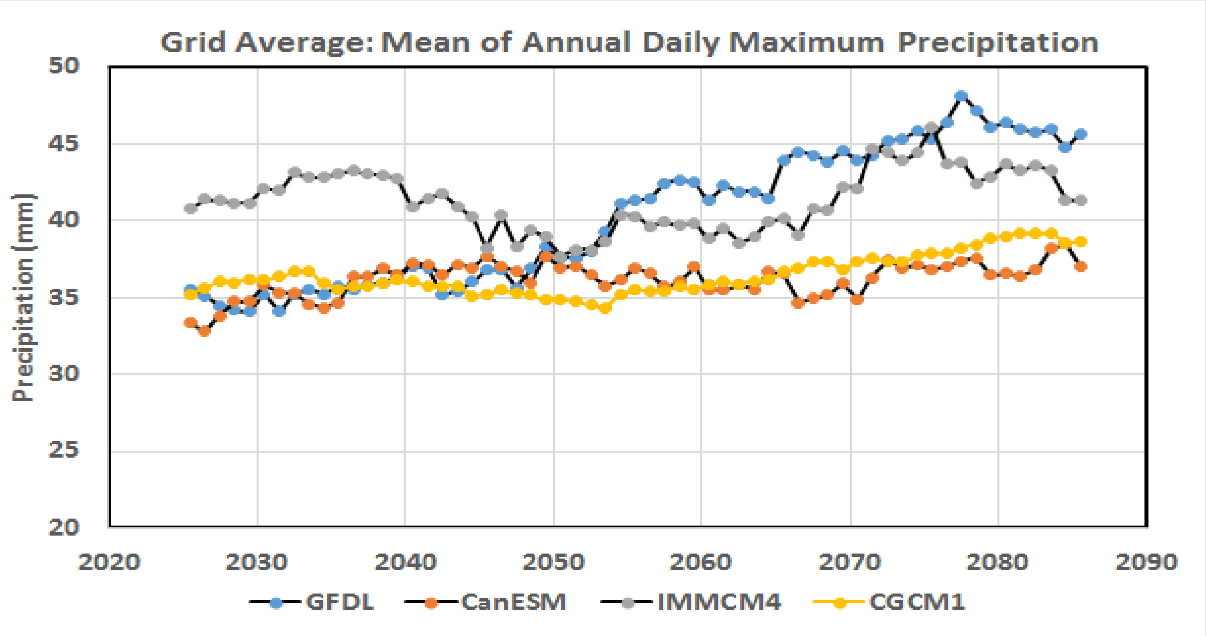
- Time Analog: Imposing historical identified warming period. (TA)
- Spatial Analogs: Northward transposition of watersheds in Montana (USA) to the study region,(SA1 & SA2)
- Modified Universal Kridging
- Bias Correction/Constructed Analogues with Quantile mapping reordering (BCCAQ) (Maurer et al. 2010).

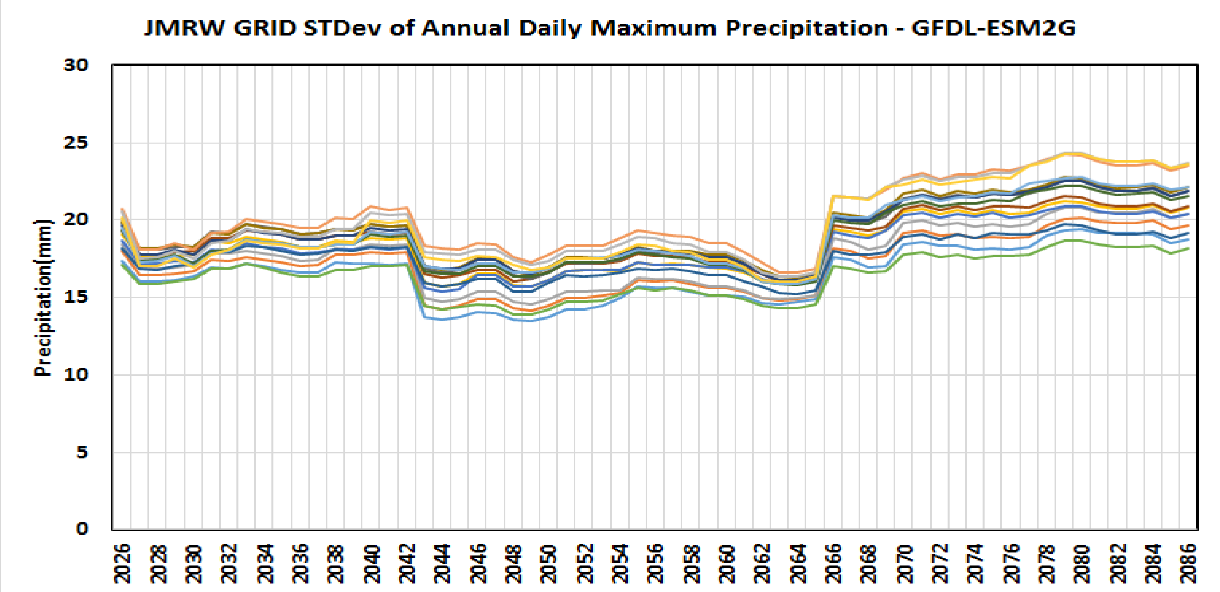


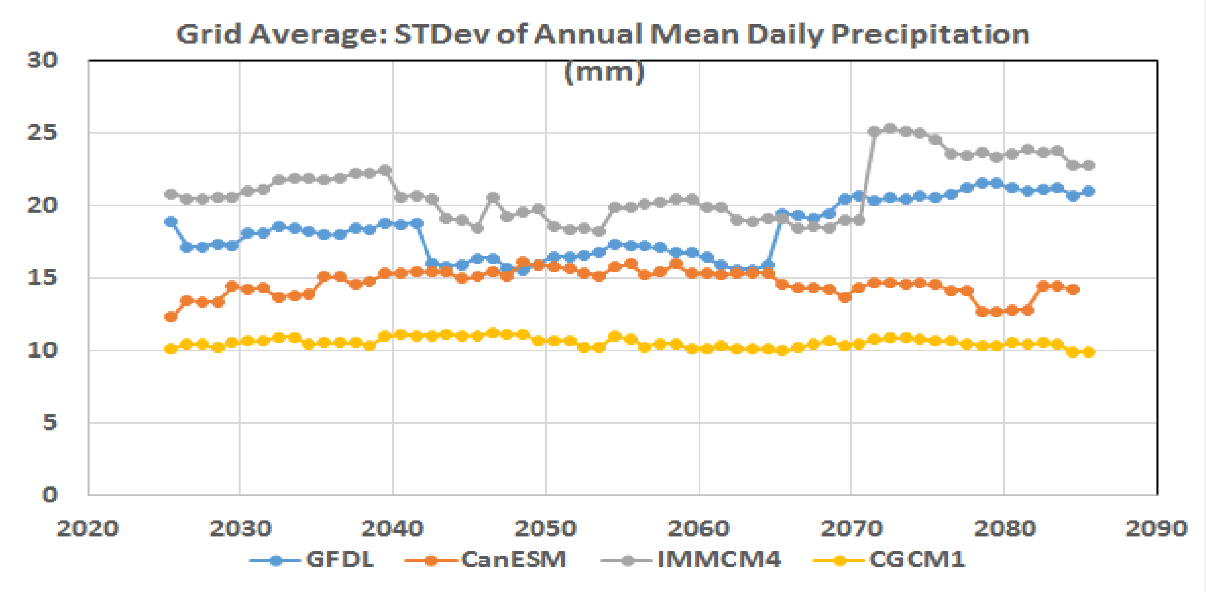
Downscaled Climate Model Computation Grids

Examples of Future Extreme Precipitation Trends









Example Changes in Input Parameters for Different Scenarios

	CGC1	SA1	SA2	TA
Annual precipitation	0.6	-7.4	8.7	1.4
Annual Daily Max. Rainfall Avg.	11.9	15.6	23.2	3.0
Annual Daily Max. Rainfall Stdev.	17.7	29.0	41.1	-2.5
5-Day Rainfall Avg.	2.5	7.9	16.7	2.0
5-Day rainfall Stdev	8.0	15.8	23.7	2.0
Curve number	0.7	0.7	0.7	0.7

Summary of % Changes in Simulated flows w.r.t. Reference Period

Based 5 frequency curves generated by Montecarlo flood hydrograph simulation

T (Years)	CGCM1	SA1	SA2	TA	Average
1.25	47.1	50.0	64.7	28.2	47.5
2.00	58.1	59.1	86.0	30.9	58.6
5.00	33.6	45.8	60.2	14.5	38.5
10.00	34.5	43.6	57.7	12.8	37.2
20.00	26.8	35.9	58.0	9.2	32.5
50.00	22.3	36.0	54.2	0.0	28.1
100.00	19.5	30.8	51.6	0.0	25.5
200.00	18.9	34.0	56.0	0.0	27.2
500.00	13.4	24.0	52.3	0.0	22.4

Concluding Remarks

- This study demonstrates the potential use of coupled stochastic methods and HEC distributed models in climate change impact studies.
- The overall results indicate increased frequency of extreme flood events in the James River Watershed.
- The approach realistically accounts for uncertainties in the hydro-climatic modelling.
- Due to large data requirements, working towards more centralized portals will benefit climate change impact studied.
- Need to apply a variety hydrologic, hydraulic and climate models to account for simulation uncertainties.

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End of Presentation

Thank you