Role of hydrological model uncertainties in climate change impact studies

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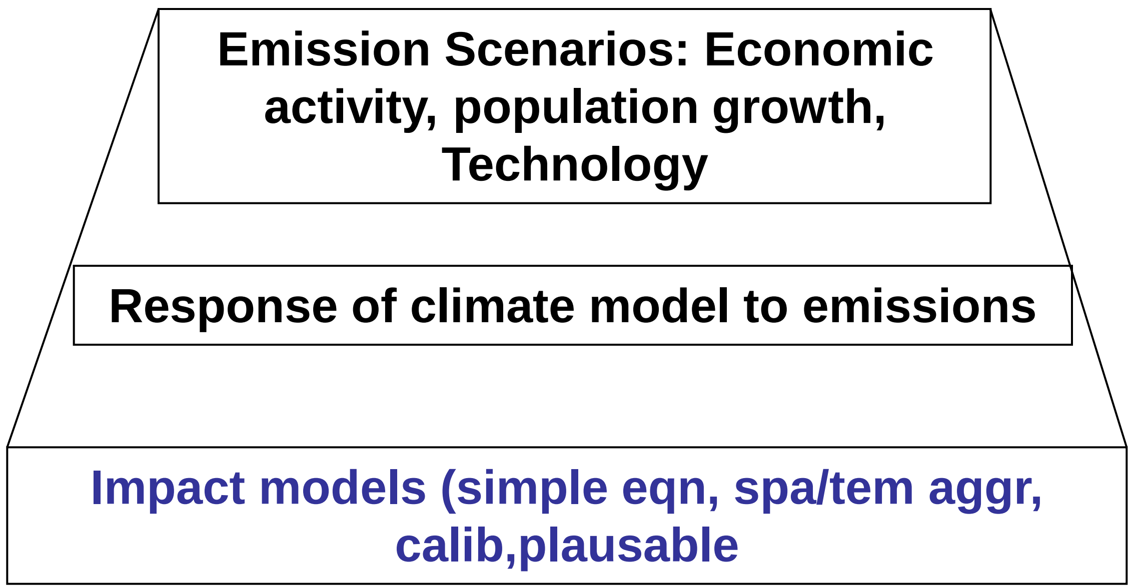
Uncertainty that cascade through a climate change impact assessment

•Projected changes in future climate are inherently uncertain



•Considerable work have focused on Emission and GCM uncertainty but have mostly neglected uncertainties in impact models

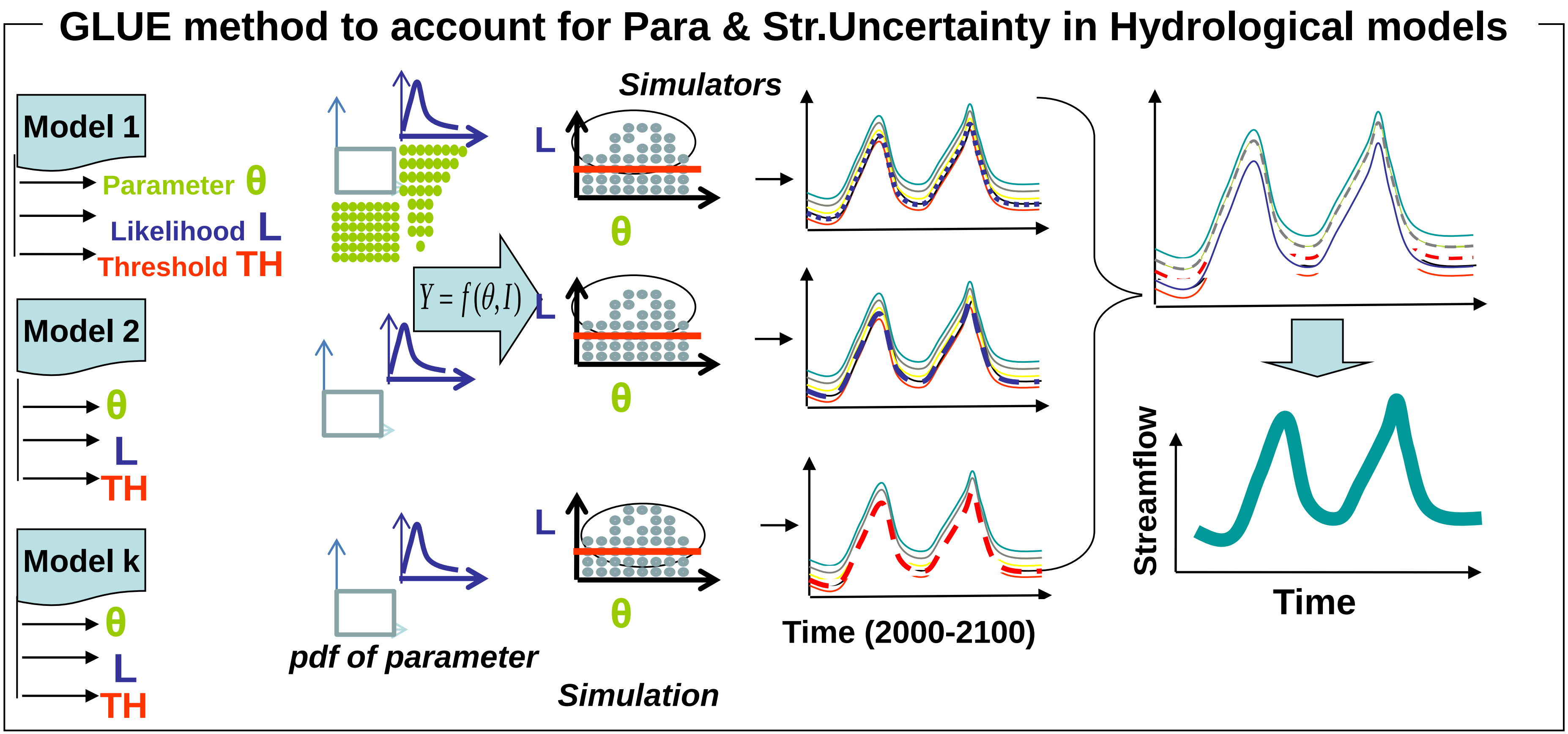
Objective

Examine the role of model uncertainty (parameter and structural uncertainty) in climate change impact studies

A. Account for hydrological model uncertainty (GLUE, BMA)

B. Quantify uncertainties that cascade through the climate change impact assessment

Schematic: accounting for uncertainty in Hydrological model using GLUE



GLUE: Generalized Likelihood Uncertainty Estimation Method (Beven and Binley, 1992)

L : Likelihood; θ: Model parameters; TH: threshold of Likelihood

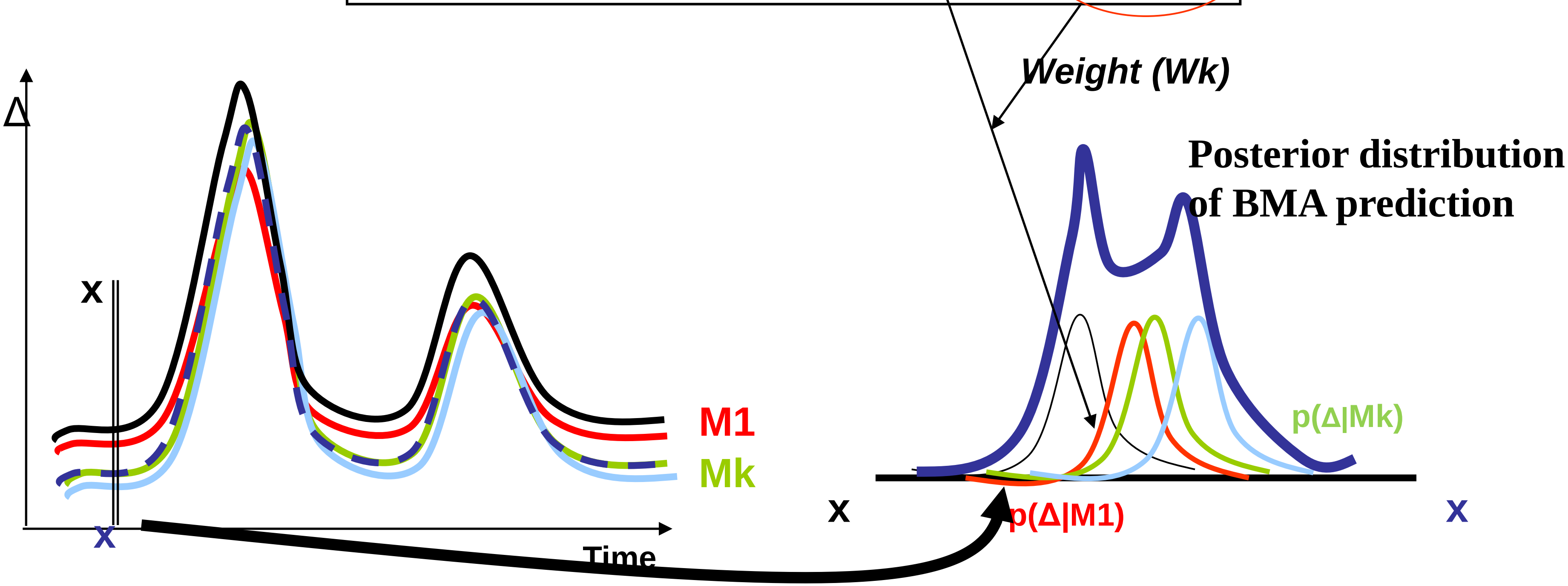
GLUE has been extensively used (e.g. Freer et al., 1996; Freer et al., 2004; Montanari, 2005 and more)

$$L(\theta_i \mid Y) = 1 - (\sigma_i^{\,2} / \sigma_{obs}^{\,2})$$

Bayesian Model averaging

In BMA the predictive probability density function (PDF) of any quantity of interest is a weighted average of PDFs centred on the individual forecasts

$$p(\Delta \mid M_1,..,M_K, D) = \sum_{k=1}^{K} p(\Delta \mid M_k, D)\, p(M_k \mid D)$$



(Tutorial on BMA: Hoeting et al., 1999)

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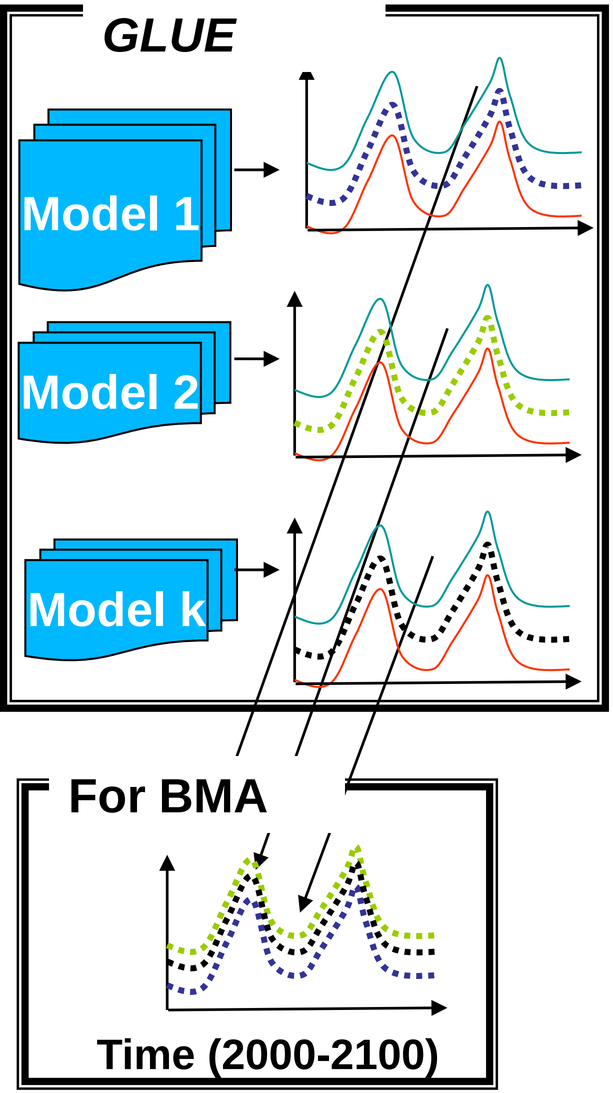
Bayesian Model Averaging



$$p(\Delta \mid M_1,..,M_K,D) = \sum_{k=1}^{K} p(\Delta \mid M_k, D) W_k$$

For each conditional PDF gamma distribution was selected

$$\Delta \mid M_k = \frac{\Delta^{\alpha-1} e^{(-\Delta/\beta)}}{\Gamma(\alpha)\theta^{\alpha}}$$

$$\alpha = \mu_k^{\;2} / \sigma_k^{\;2}; \beta_k = \sigma_k^{\;2} / \mu_k$$

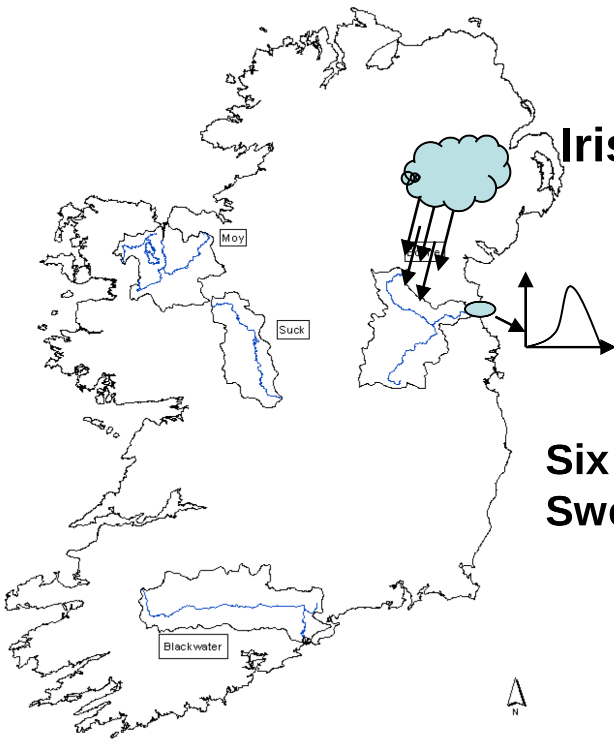
$$\mu_k = M_k; \sigma_k^{\;2} = b.M_k + c_o$$

W_1,W2..Wk, b, C_o

Weight and variance parameter of BMA were estimated using DREAM of Vrugt et al (2008).

$$l(w_1,..w_k \mid \sigma_1^{\;2},..\sigma_k^{\;2},\Delta) = \sum_{t=1}^{n} \log(w_1 P(\Delta \mid M_1) + w_2 P(\Delta \mid M_2) + ..w_k P(\Delta \mid M_k))$$

Study Region & Data



Republic of Ireland

Irish National Meteorological Service

•Office of Public works, ireland

Six regional climate scenarios from Fealy and Sweeney, 2007

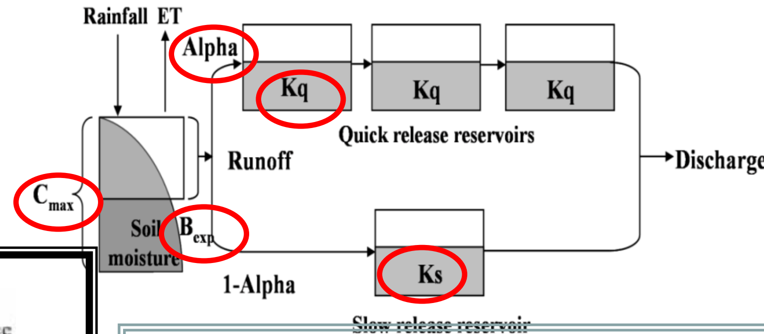
- **A2**
  - **HadCM3**
  - **CCCMA**
  - **CSIRO**
- **B2**
  - **HadCM3**
  - **CCCMA**
  - **CSIRO**

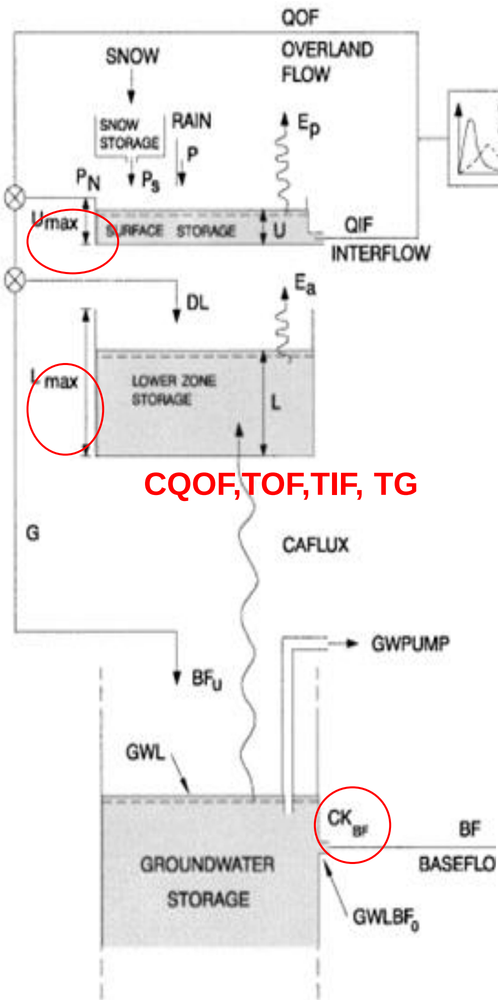
CCCma (CGCM2):canadian centre for climate modeling and analysis; CSIRO: Commonwealth Scientific and Industrial Research Organization; HadCM3:Hadley Centre Coupled Model, version 3

Hydrological model

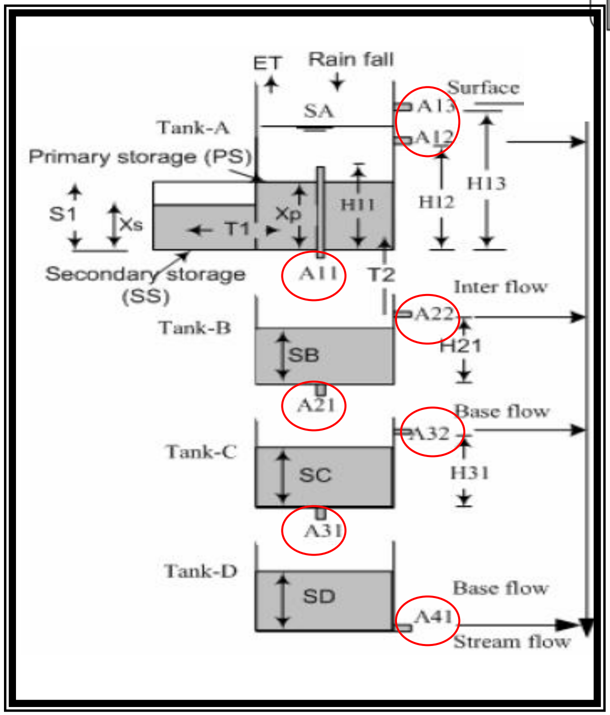
The Hymod, NAM, TANK, and TOP models describes the behaviour of each individual component in the hydrological cycle, at catchment level, by using a set of mathematical equations.

HyMOD

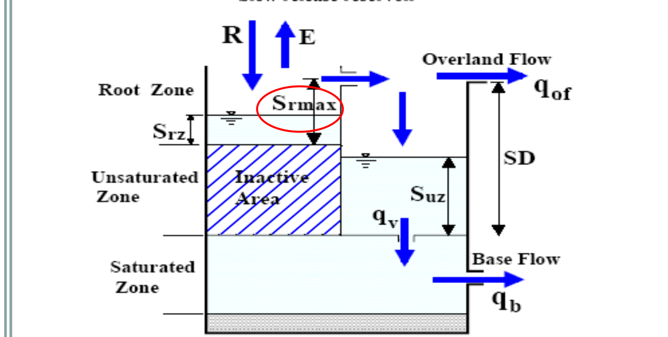




NAM (DHI)



TANK (Sugawara, 1995)



TOP Model (Beven et al1995)

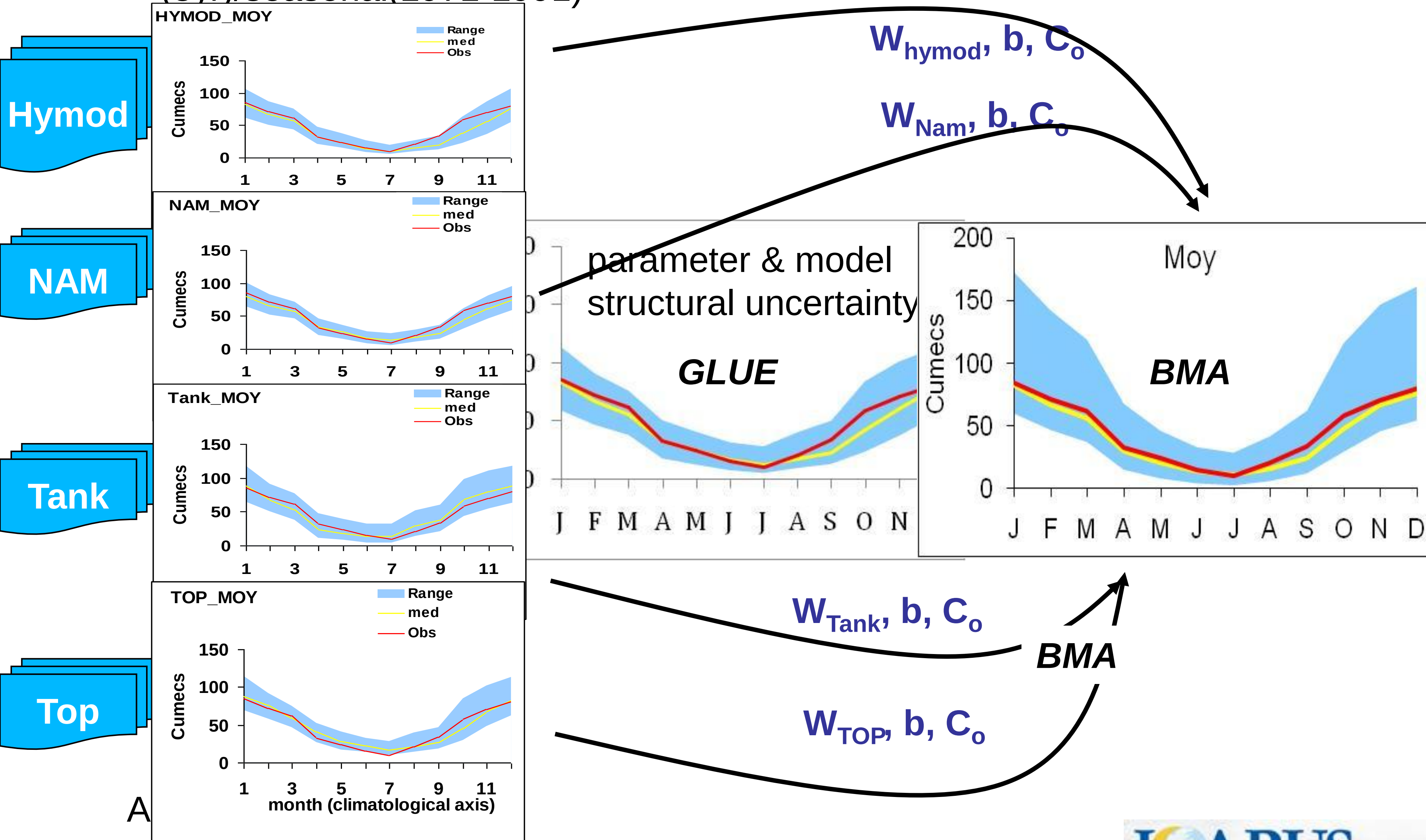
$$T_i = T_0 e^{-SD_i/m}$$ Beven,1984

$$q_v = \frac{S_{uz}}{SD_i t_d}$$ Beven and wood,1993)

$$E_a = E_p\left(1 - \frac{S_{rz}}{S_{max}}\right)$$ (Beven,1991)

Model uncertainty using GLUE/BMA

Simulated flow:Daily (3yr)/seasonal(1971-1991)



A... uncertainty

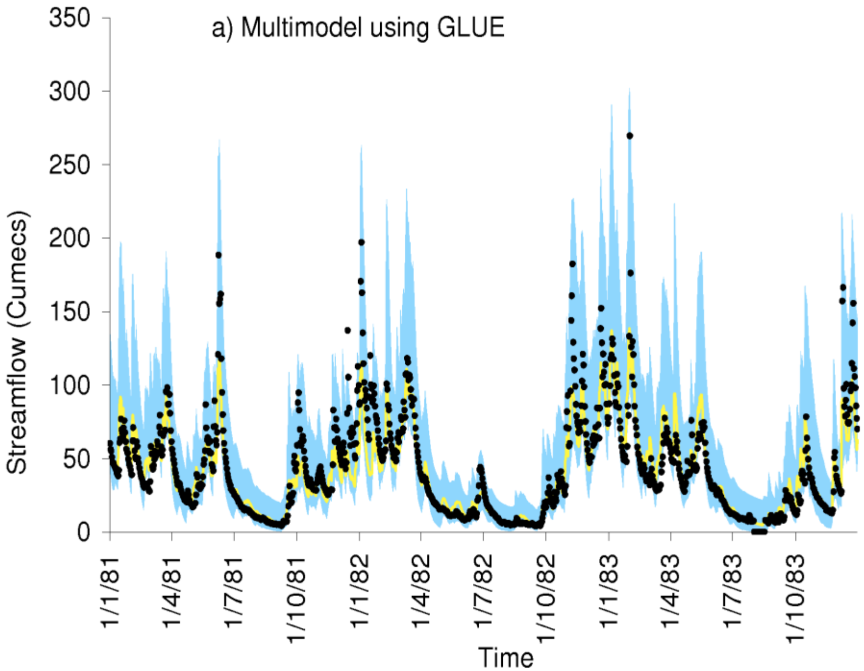
Model calibration/validation

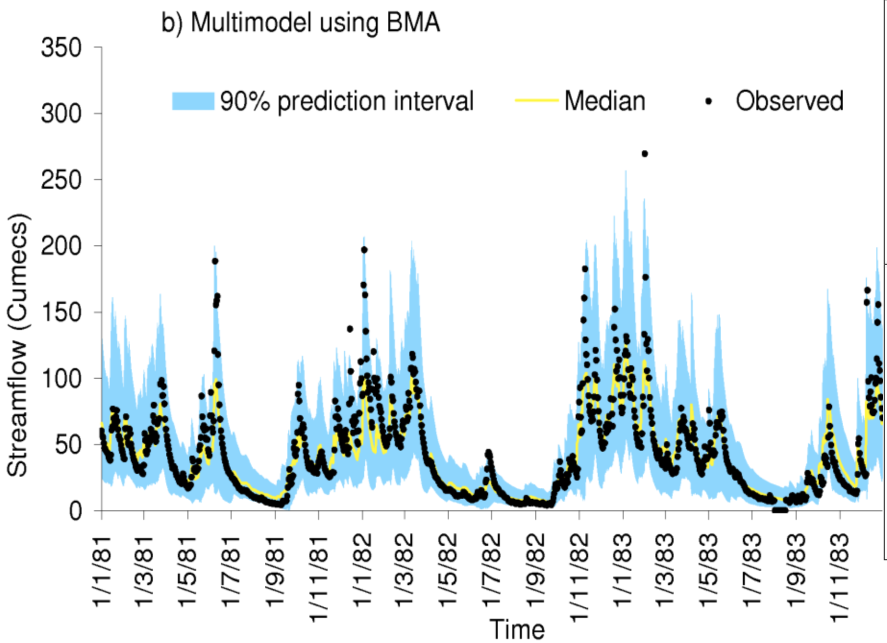
Sn	Period (Calib/Valid)	Basin (Model)	NSE (Median) Calib	NSE (Median) Valid	CE Calib	CE Valid	PI (m3/s) Calib	PI (m3/s) Valid
1	1971-1990/1991-2000	Moy (HYMOD)	0.77	0.66	0.68	0.56	30.50	33.01
2		Moy (NAM)	0.72	0.63	0.58	0.52	25.69	27.66
3		Moy (TANK)	0.80	0.69	0.80	0.77	40.88	44.55
4		Moy (TOP)	0.80	0.70	0.72	0.70	33.98	37.47
		Ensemble Med	**0.81**	**0.72**	**0.85**	**0.80**	**43.32**	**46.84**
5	1971-1990/1991-2000	Boyne (HYMOD)	0.79	0.76	0.80	0.83	28.17	29.35
6		Boyne(NAM)	0.76	0.74	0.77	0.78	23.82	25.10
7		Boyne (TANK)	0.70	0.73	0.67	0.75	25.60	27.13
8		Boyne (TOP)	0.69	0.68	0.52	0.57	23.26	24.74
		Ensemble Med	**0.80**	**0.78**	**0.90**	**0.92**	**31.78**	**33.40**
9	1971-1990/1991-2000	Suck (HYMOD)	0.78	0.68	0.70	0.68	17.27	18.75
10		Suck (NAM)	0.72	0.63	0.56	0.51	14.68	15.85
11		Suck (TANK)	0.70	0.65	0.61	0.59	17.08	18.45
12		Suck (TOP)	0.68	0.60	0.34	0.31	12.65	14.06
		Ensemble Med	**0.79**	**0.69**	**0.74**	**0.70**	**19.24**	**20.92**
13	1971-1990/1991-2000	Blackwater (HYMOD)	0.64	0.74	0.50	0.58	25.18	25.67
14		Blackwater (NAM)	0.63	0.72	0.31	0.40	15.62	16.13
15		Blackwater (TANK)	0.67	0.75	0.59	0.68	33.35	34.09
16		Blackwater (TOP)	0.64	0.71	0.33	0.31	21.77	22.69
		Ensemble Med	**0.66**	**0.74**	**0.68**	**0.76**	**36.52**	**37.32**

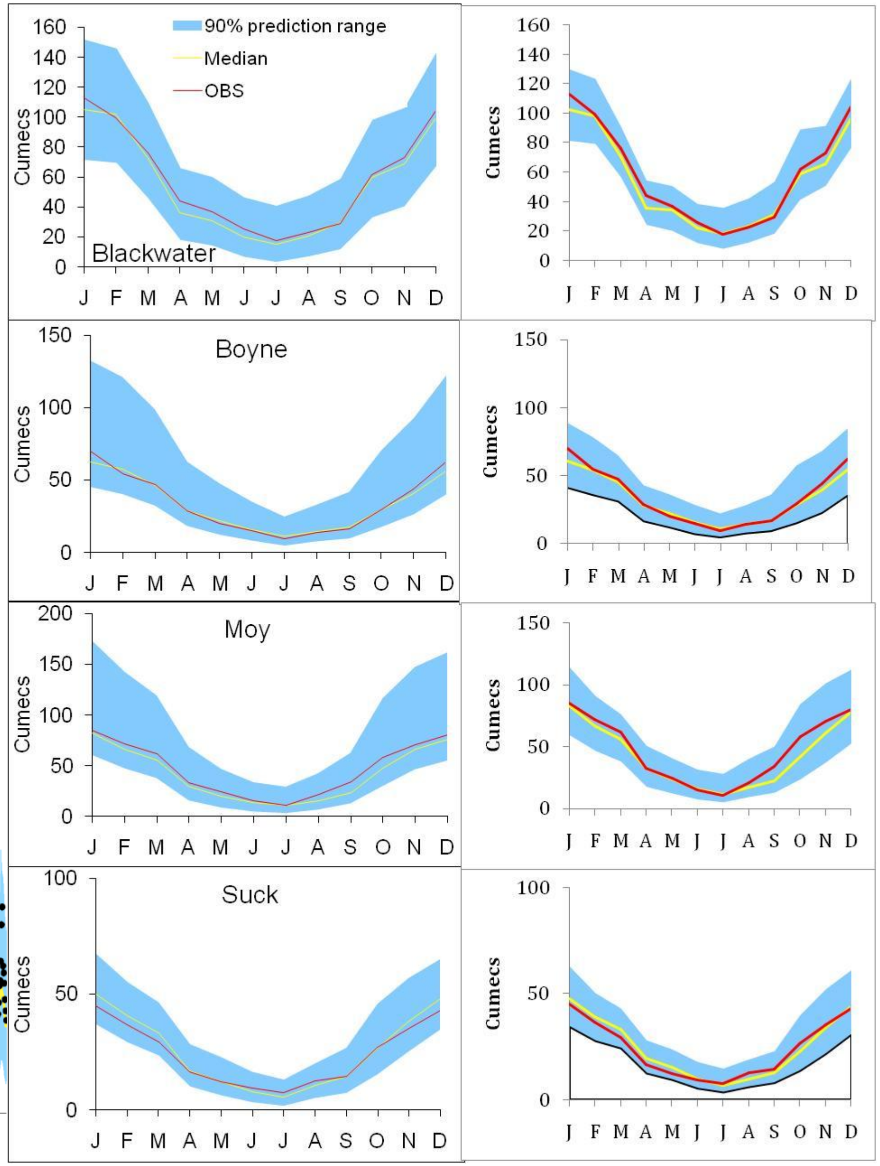
PI (Width of 90 Prediction interval);

CE (No of points with in PI/No of points)

GLUE/BMA







BMA ***GLUE***

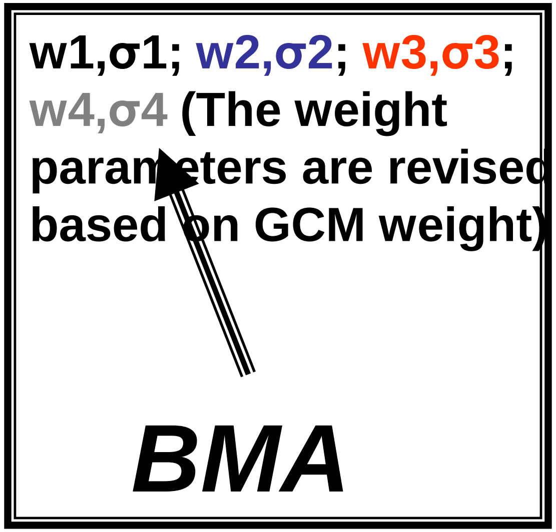
B

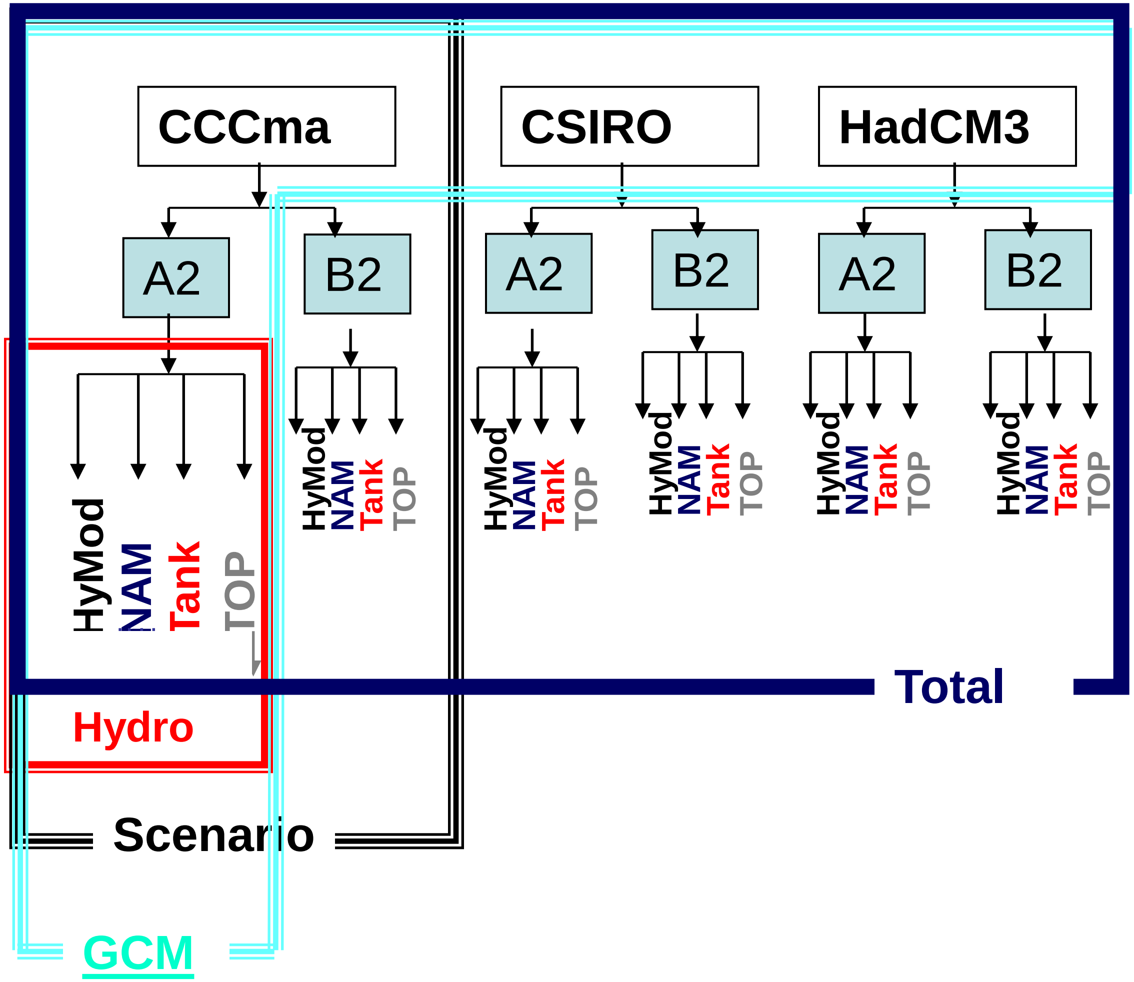
Quantify uncertainties that cascade through the climate change impact assessment

Uncertainty Envelope: Experiment design

GCM: Weighted based on Climate prediction index

Scenarios: Equally likely





Hydro: Hydrological model uncertainty (parameter & model selection)

Scenario: Hydrological + Scenario (A2 & B2)

GCM: Hydrological + Scenario (A2 & B2)

Total: Uncertainty envelop (Hydrological + Scenario (A2 & B2)+GCM)

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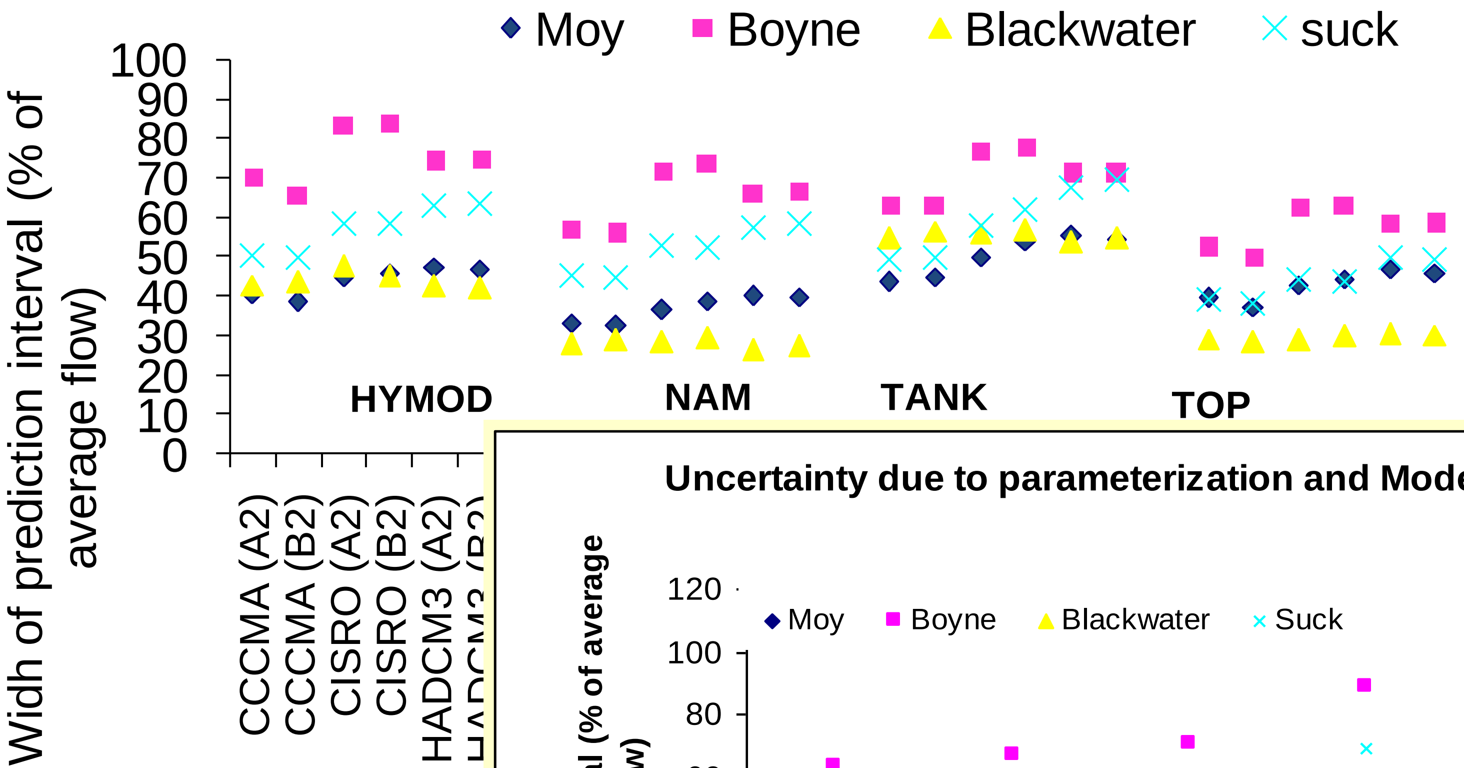
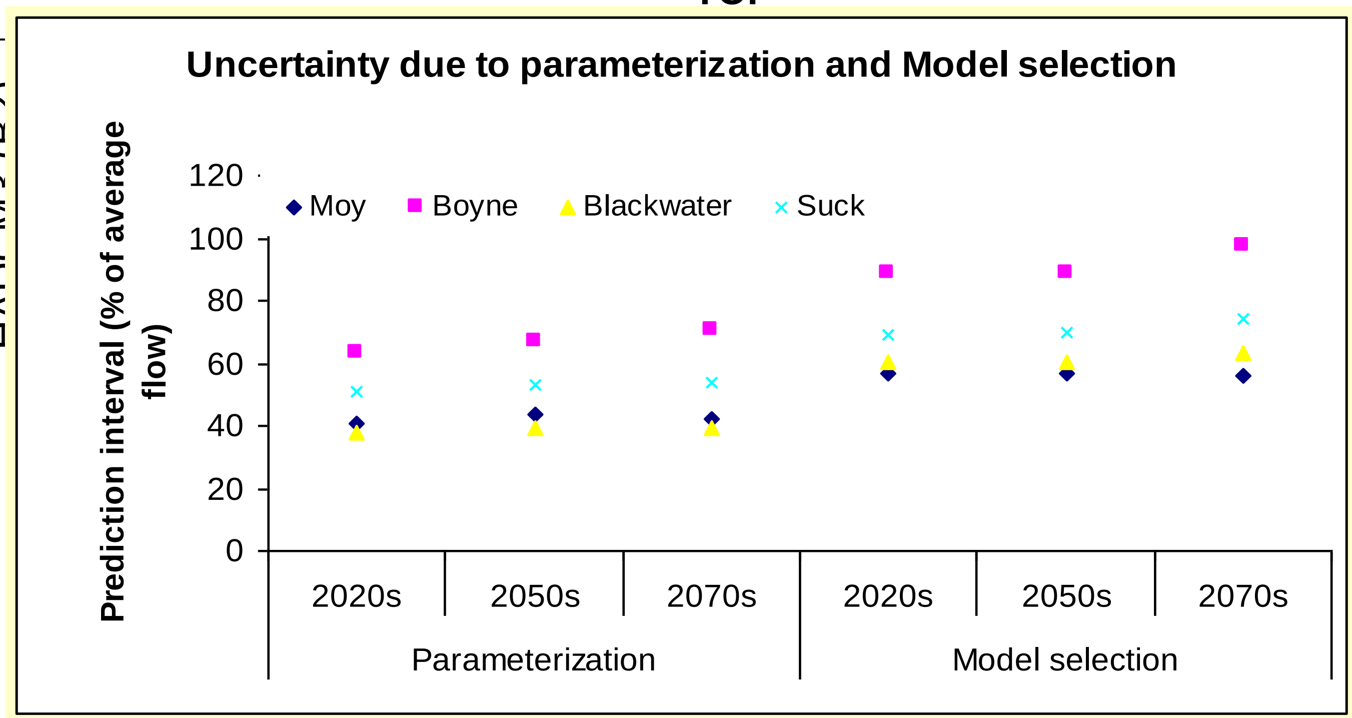
Hydrological model uncertainty

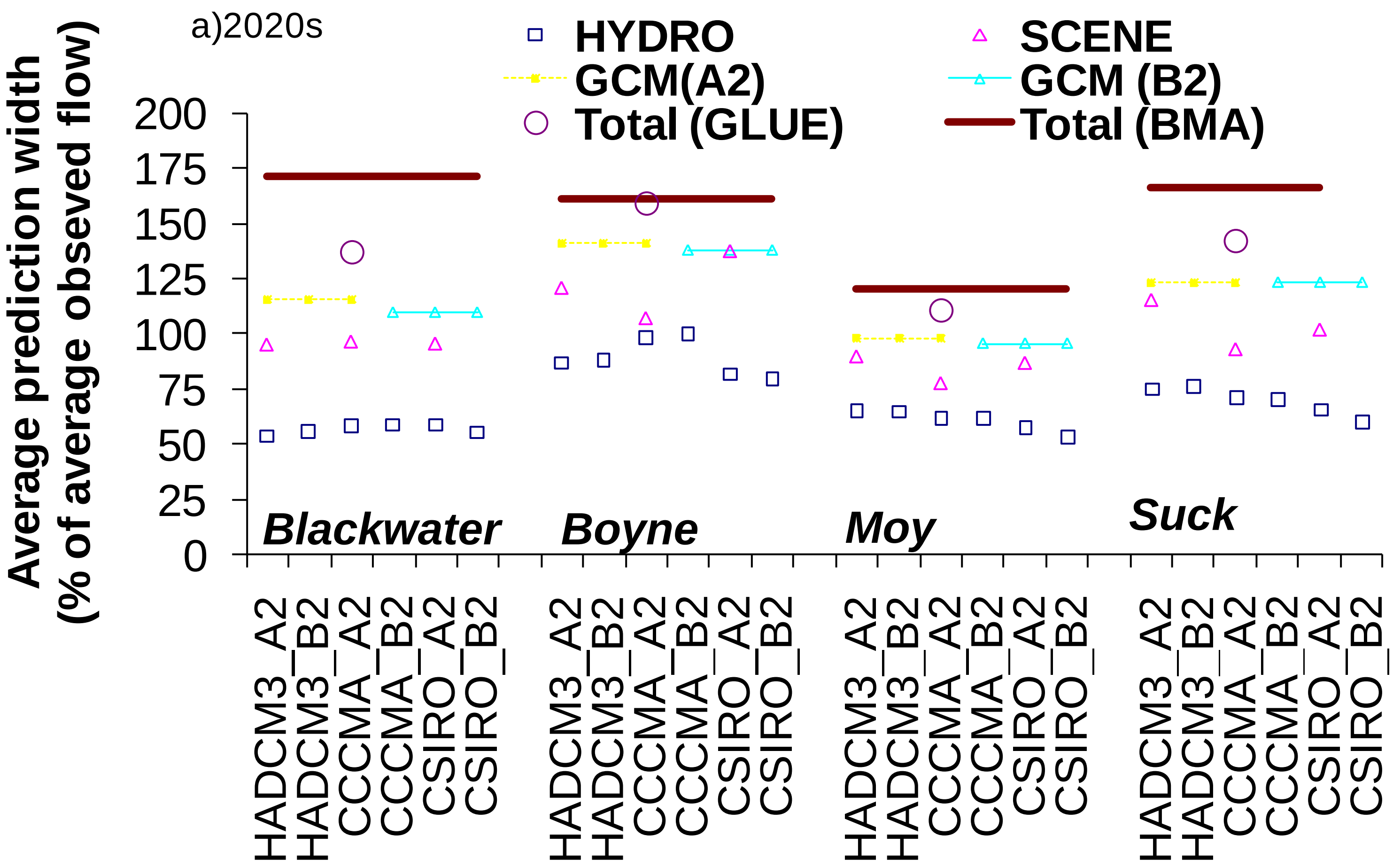


a)2050-2059



The average width of the PI from parameterization of CRR models is nearly **50%** and nearly increased to 70% when Different CRR models are included

Apportion of uncertainty



The average width of the PI is **70%** (of average streamflow) when uncertainty in hydrological response to single GCM was quantified. This increased to **100%** when two SRES scenarios were employed. Further increases to **120%** when three GCM with single scenarios was used, and further to **140%** when two SRES scenarios were used.

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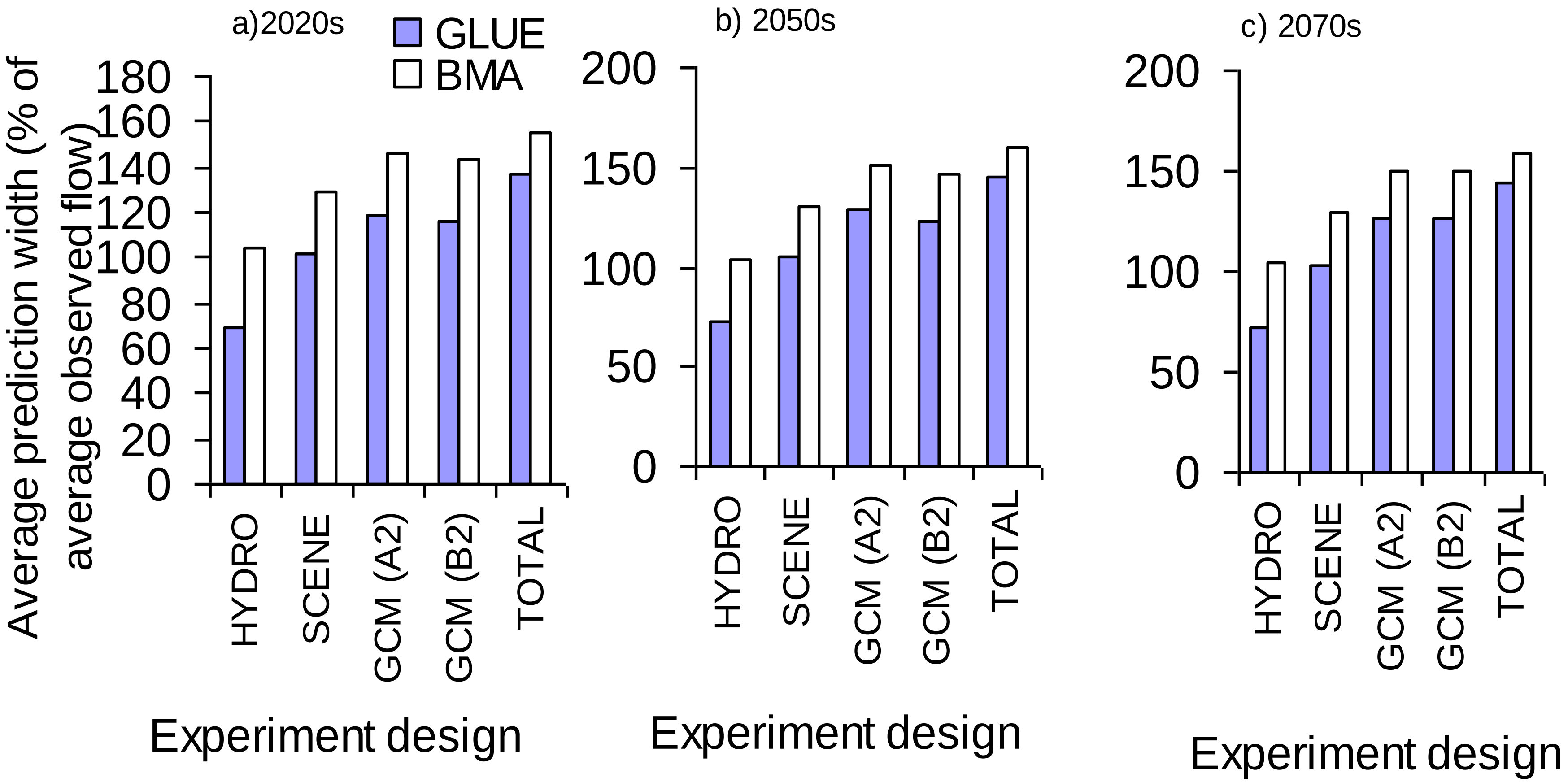
BMA/GLUE



For BMA widths of Prediction interval are higher than GLUE by a factor of 1.4, 1.2, 1.2, 1.2, 1.1 for HYDRO, SCENE, GCMA, GCMB, Total respectively.

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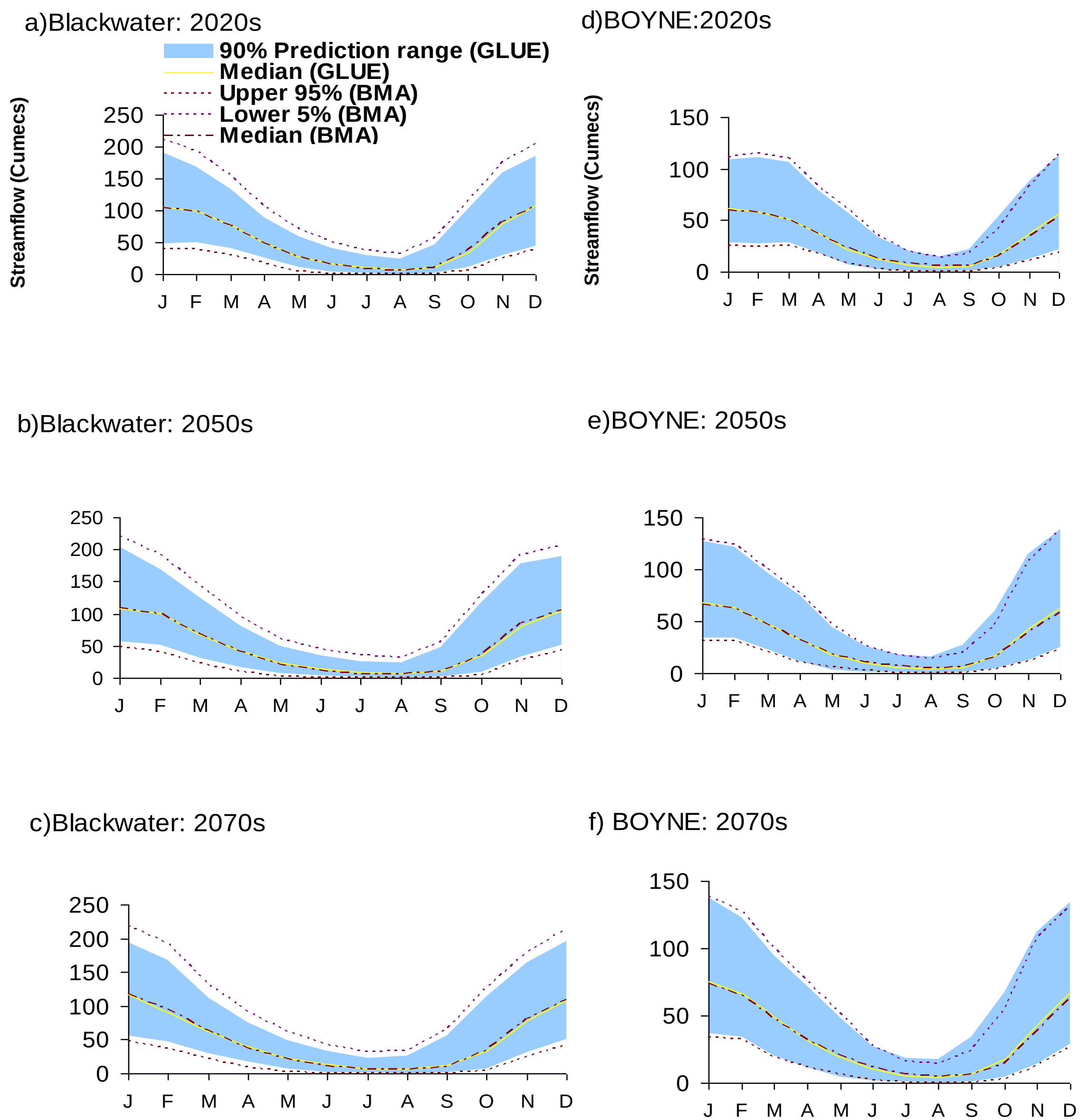
Comparison of BMA and GLUE estimated Prediction interval



Blackwater ***Boyne***

Conclusion

- **This study is an attempt to quantify the uncertainty in the projection of future water resources by incorporating four plausible yet conceptually diverse models forced with six regional climate change scenarios, using BMA and GLUE.**

- **Both GLUE and BMA approaches used here differ fundamentally in their underlying philosophy and representation of error.**

- **The role of hydrological model uncertainty is considerable and warrants inclusion in impacts assessment, particularly where robust adaptation decisions are required.**

- **When A2 and B2 SRES scenarios are considered, the GCM uncertainty was observed to be higher than emission uncertainty.**
- **Results are indicative as the full range of emission scenarios and GCM sensitivities were not sampled here.**

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Thank you very much for your attention