Science of the CLEVER Model

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What CLEVER stands for?

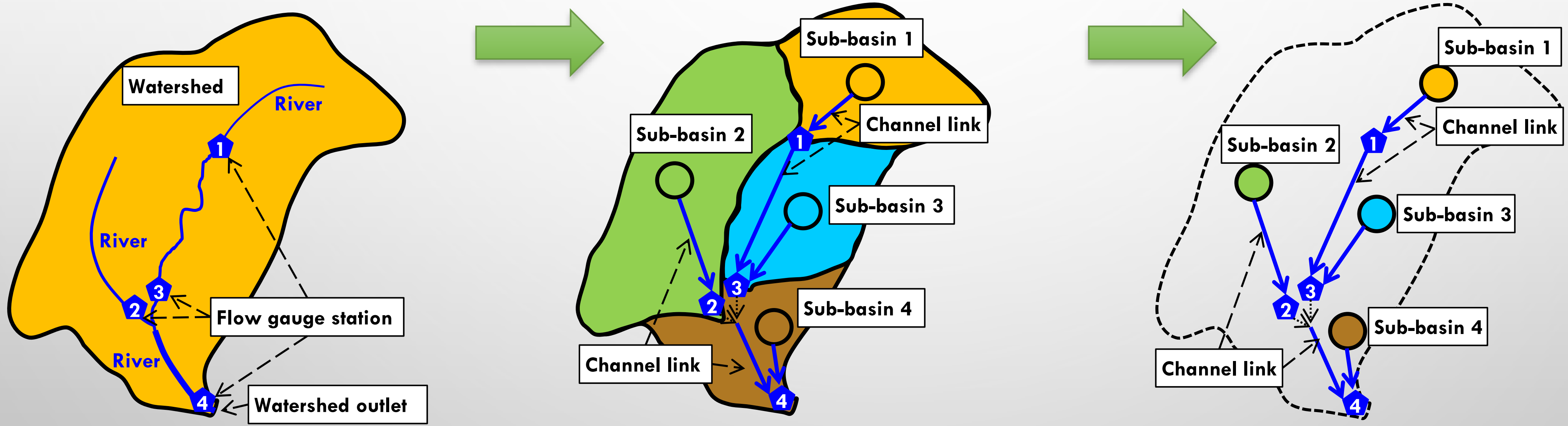
In this study, a different hybrid watershed model, the Channel Links Evolution Efficient Routing (CLEVER) Model, is developed for the purpose of real-time flood forecasting for the large-scale watersheds in BC.
--Technical Reference for The CLEVER Model – A Real-time Flood Forecasting Model for British Columbia, Charles Luo, 2015

COFFEE Model – Coastal Fall flood Ensemble Estimation model

ELF Model – Extrapolating Logarithmic Flow (ELF) Model for 30-Day Low Streamflow Forecast

What's the CLEVER Model?

How to model a big watershed - Model Structure



Watershed Skeletonization Procedure

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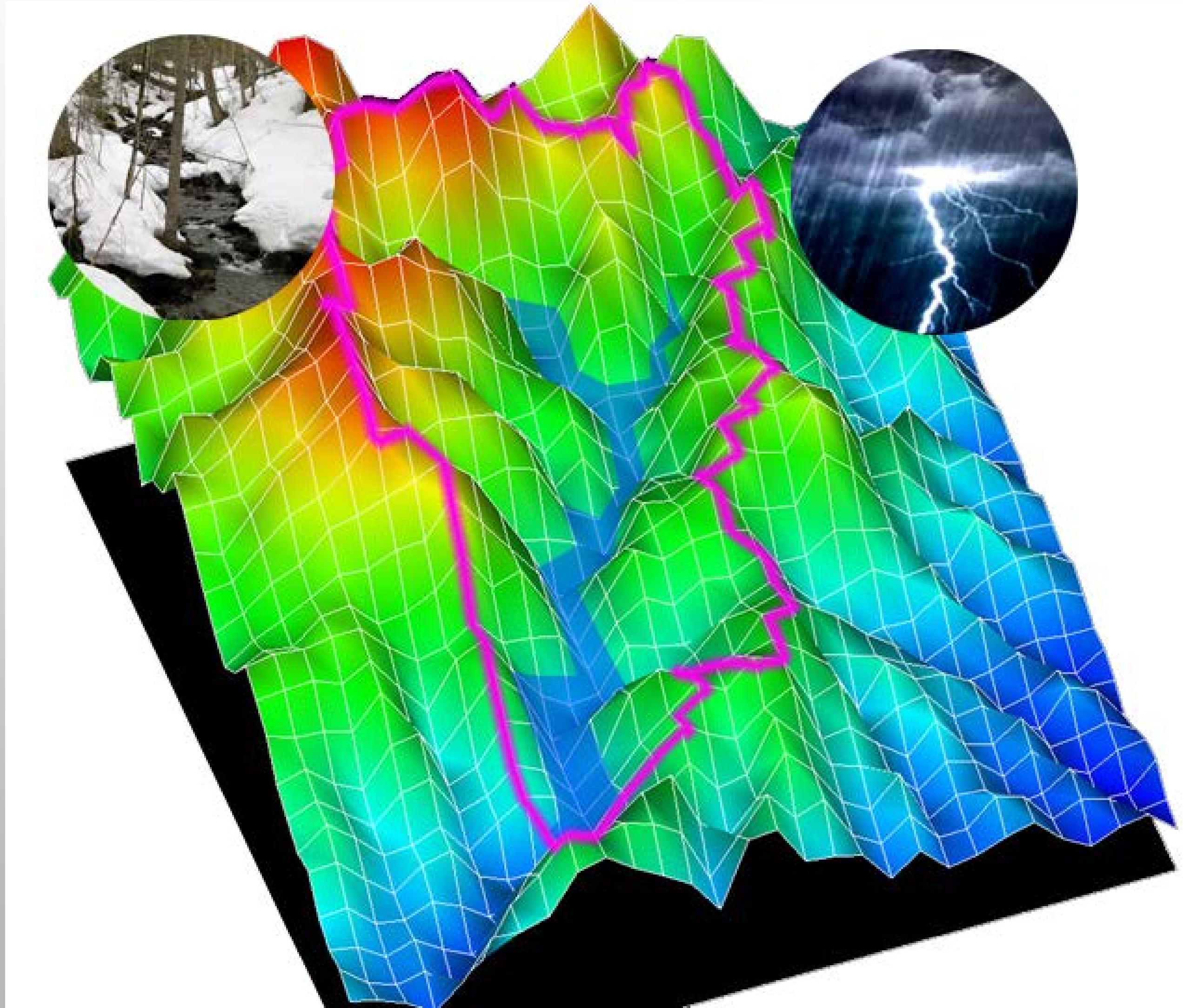
What's the CLEVER Model?

Watershed routing sub-model: Hourly Temperature Index + instantaneous. UH



$$W = R + M + G - E - I$$

$$M = c_a c_d M_f (T_i - T_b)^{\beta}$$

$$u(\tau) = \frac{t^{N-1} e^{-\tau/k}}{k^N (N-1)!}$$

$$Q_l(t) = c_q W_l A u(t - t_{l0})$$

$$Q(t) = \sum_{l=1}^{L} Q_l(t)$$

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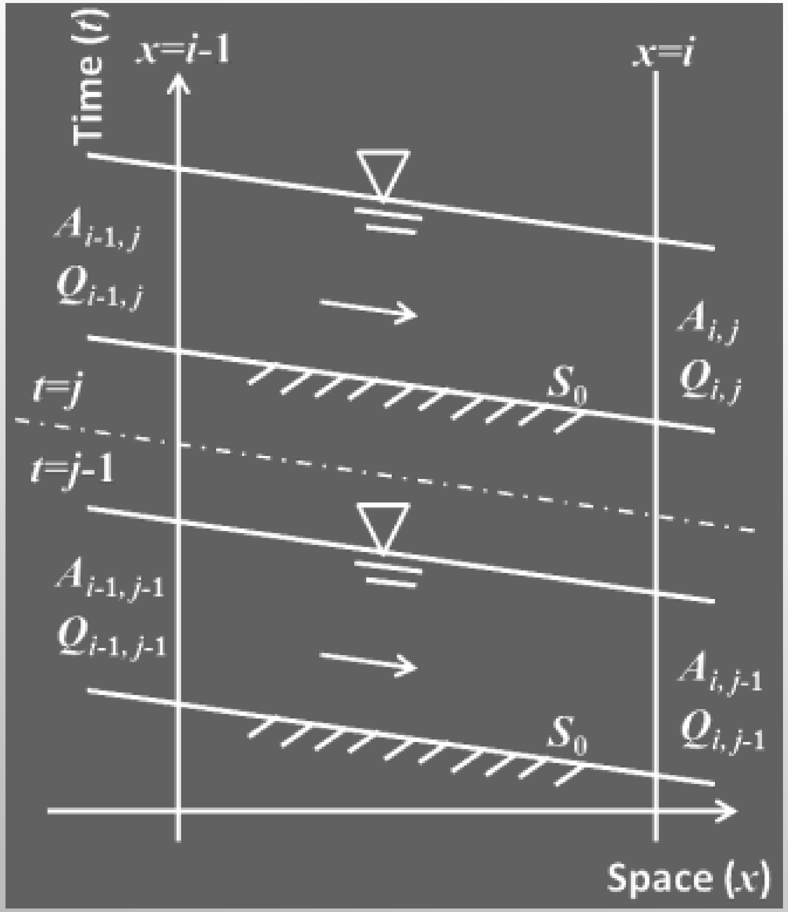
What's the CLEVER Model?

Channel link routing sub-model: kinematic wave routing



$$\begin{cases} \dfrac{\partial Q}{\partial x} + \dfrac{\partial A}{\partial t} = 0 \\ S_0 = \dfrac{n^2 Q^2}{A^2 R^{4/3}} \end{cases}$$

$$\frac{1}{\Delta x}\left[\frac{Q_{i,j} + Q_{i,j-1}}{2} - \frac{Q_{i-1,j} + Q_{i-1,j-1}}{2}\right] + \frac{1}{\Delta t}\left[\frac{A_{i,j} + A_{i-1,j}}{2} - \frac{A_{i,j-1} + A_{i-1,j-1}}{2}\right] = 0$$

$$Q_{i,j} = \frac{1}{n}\sqrt{S_0} R_{i,j}^{2/3} A_{i,j} \qquad V_{i,j} = \frac{1}{n}\sqrt{S_0} R_{i,j}^{2/3} \qquad Q_{i,j} = V_{i,j} A_{i,j}$$

$$A_{i,j} = \frac{\Delta t\left(Q_{i-1,j} + Q_{i-1,j-1} - Q_{i,j-1}\right) + \Delta x\left(A_{i,j-1} + A_{i-1,j-1} - A_{i-1,j}\right)}{\Delta t V_{i,j} + \Delta x}$$

$$\left(A_{i,j}\right)^{(k)} = \frac{\Delta t\left(Q_{i-1,j} + Q_{i-1,j-1} - Q_{i,j-1}\right) + \Delta x\left(A_{i,j-1} + A_{i-1,j-1} - A_{i-1,j}\right)}{\Delta t\left(V_{i,j}\right)^{(k-1)} + \Delta x}$$

$$\left(A_{i,j}\right)^{(k)} = \frac{\Delta t Q_{i-1,j} + \Delta x A_{i,j-1}}{\Delta t\left(V_{i,j}\right)^{(k-1)} + \Delta x} + \varphi(r_{ij}) \frac{\Delta t\left(Q_{i-1,j-1} - Q_{i,j-1}\right) + \Delta x\left(A_{i-1,j-1} - A_{i-1,j}\right)}{\Delta t\left(V_{i,j}\right)^{(k-1)} + \Delta x}$$

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What's the CLEVER Model?

Model calibration and verification: Statistically and visually

$$C_e = 1 - \frac{\sum_{j=1}^{m}\left(Q_{obs}^{j} - Q_{sim}^{j}\right)^2}{\sum_{j=1}^{m}\left(Q_{obs}^{j} - \overline{Q_{obs}}\right)^2}$$

where $\overline{Q_{obs}}$ is the mean of the observed flow and is given by:

$$\overline{Q_{obs}} = \frac{1}{m}\sum_{j=1}^{m} Q_{obs}^{j}$$

C_d can be written as:

$$\begin{cases} C_d = 1 - \frac{\sum_{j=1}^{m}\left[Q_{obs}^{j} - \left(a \cdot Q_{sim}^{j} + b\right)\right]^2}{\sum_{j=1}^{m}\left(Q_{obs}^{j} - \overline{Q_{obs}}\right)^2} \\ a = (\bar{P} - \overline{Q_{obs}} \cdot \overline{Q_{sim}})/\left(\overline{Q_{sim}^2} - \overline{Q_{sim}}^2\right) \\ b = \overline{Q_{obs}} - a \cdot \overline{Q_{sim}} \end{cases}$$

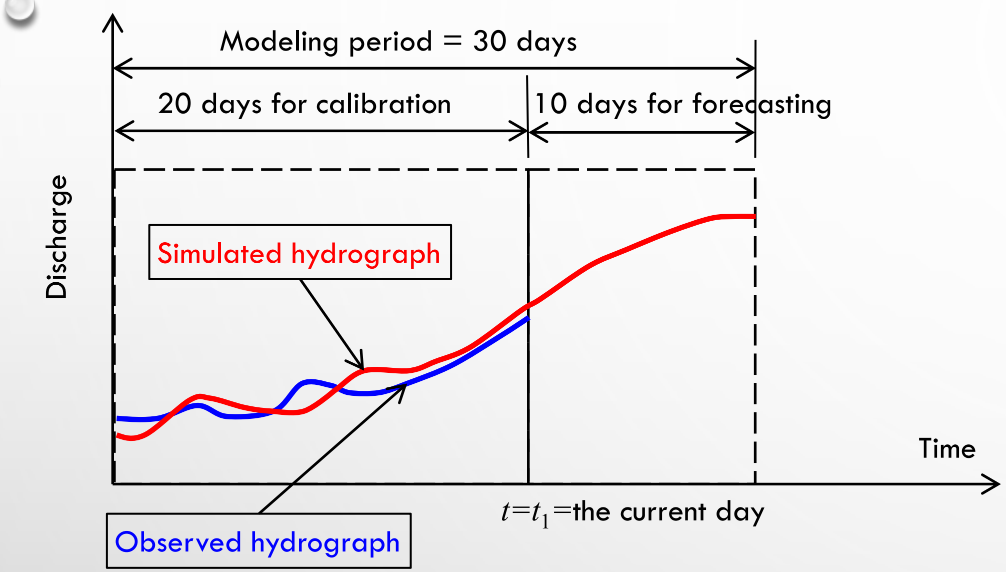
And the percentage volume difference (dV) is calculated by:

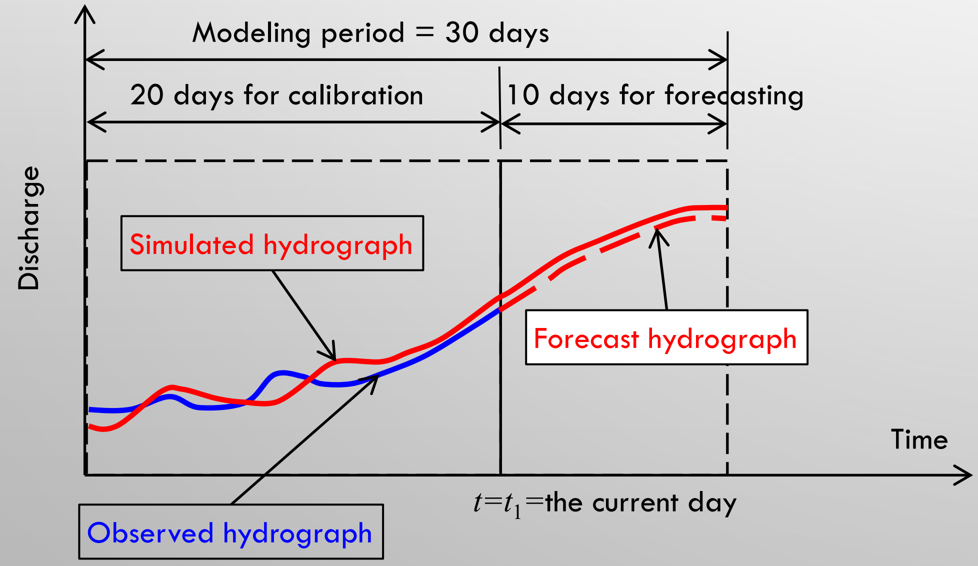
$$dV = 100 \times (\overline{Q_{sim}} - \overline{Q_{obs}})/\overline{Q_{obs}}$$

$$E_{ra} = 100 \times \left(\frac{1}{m}\sum_{j=1}^{m}\left|Q_{sim}^{j} - Q_{obs}^{j}\right|\right)/\overline{Q_{obs}}$$

$$r^2 = \frac{\left[\sum_{j=1}^{m}\left(Q_{obs}^{j} - \overline{Q_{obs}}\right)\left(Q_{sim}^{j} - \overline{Q_{sim}}\right)\right]^2}{\sum_{j=1}^{m}\left(Q_{obs}^{j} - \overline{Q_{obs}}\right)^2 \sum_{j=1}^{m}\left(Q_{sim}^{j} - \overline{Q_{sim}}\right)^2}$$

Forecast operation





Model Period: 30 day

- 20-day calibration
- 10-day forecast

Model Accuracy?

- Model calibration: Statistics (2018)

Basin	Station	CE_HR	CD_HR	DV_HR (%)
Fraser	MCGREGOR RIVER AT LOWER CANYON (08KB003)	0.926	0.948	-2.907
	FRASER RIVER AT HANSARD (08KA004)	0.954	0.958	-2.648
	FRASER RIVER AT SHELLEY (08KB001)	0.910	0.936	-6.258
	FRASER RIVER NEAR MARGUERITE (08MC018)	0.926	0.949	6.491
	FRASER RIVER AT HOPE (08MF005)	0.978	0.988	3.289
	NECHAKO RIVER AT ISLE PIERRE (08JC002)	0.962	0.963	0.652
	WEST ROAD RIVER NEAR CINEMA (08KG001)	0.894	0.902	9.246
	QUESNEL RIVER NEAR QUESNEL (08KH006)	0.991	0.992	1.386
	LILLOOET RIVER NEAR PEMBERTON (08MG005)	0.905	0.907	1.260
Thompson	NORTH THOMPSON RIVER AT MCLURE (08LB064)	0.982	0.989	5.045
	SOUTH THOMPSON RIVER AT CHASE (08LE031)	0.982	0.986	2.755
	NICOLA RIVER NEAR SPENCES BRIDGE (08LG006)	0.946	0.947	-0.567
	THOMPSON RIVER NEAR SPENCES BRIDGE (08LF051)	0.982	0.991	5.361

Model Accuracy?

Model verification (forecast): Statistics (2018)

Basin	Station	ERA(%)	RSQU
Fraser	MCGREGOR RIVER AT LOWER CANYON (08KB003)	22.534	0.375
	FRASER RIVER AT HANSARD (08KA004)	16.927	0.465
	FRASER RIVER AT SHELLEY (08KB001)	14.599	0.522
	FRASER RIVER NEAR MARGUERITE (08MC018)	12.651	0.560
	FRASER RIVER AT HOPE (08MF005)	10.030	0.606
	NECHAKO RIVER AT ISLE PIERRE (08JC002)	9.383	0.644
	WEST ROAD RIVER NEAR CINEMA (08KG001)	31.511	0.462
	QUESNEL RIVER NEAR QUESNEL (08KH006)	9.655	0.622
	LILLOOET RIVER NEAR PEMBERTON (08MG005)	26.486	0.343
Thompson	NORTH THOMPSON RIVER AT MCLURE (08LB064)	18.448	0.504
	SOUTH THOMPSON RIVER AT CHASE (08LE031)	9.065	0.879
	NICOLA RIVER NEAR SPENCES BRIDGE (08LG006)	32.966	0.318
	THOMPSON RIVER NEAR SPENCES BRIDGE (08LF051)	9.963	0.734

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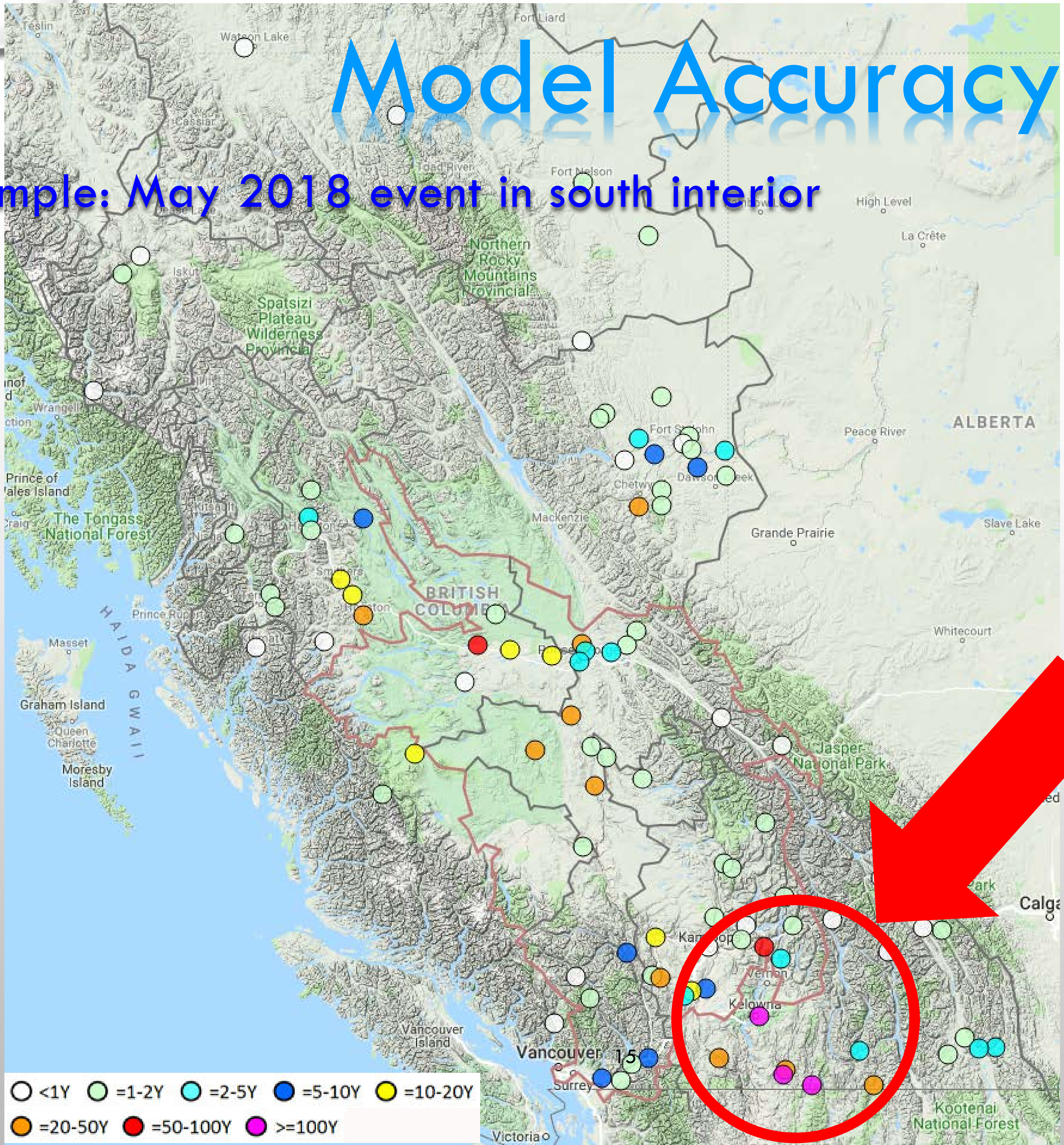
Model Accuracy?

An example: May 2018 event in south interior



On May 09, 2018, the CLEVER Model forecasts about 200 year return period floods for the south interior for the next day, May 10, 2018

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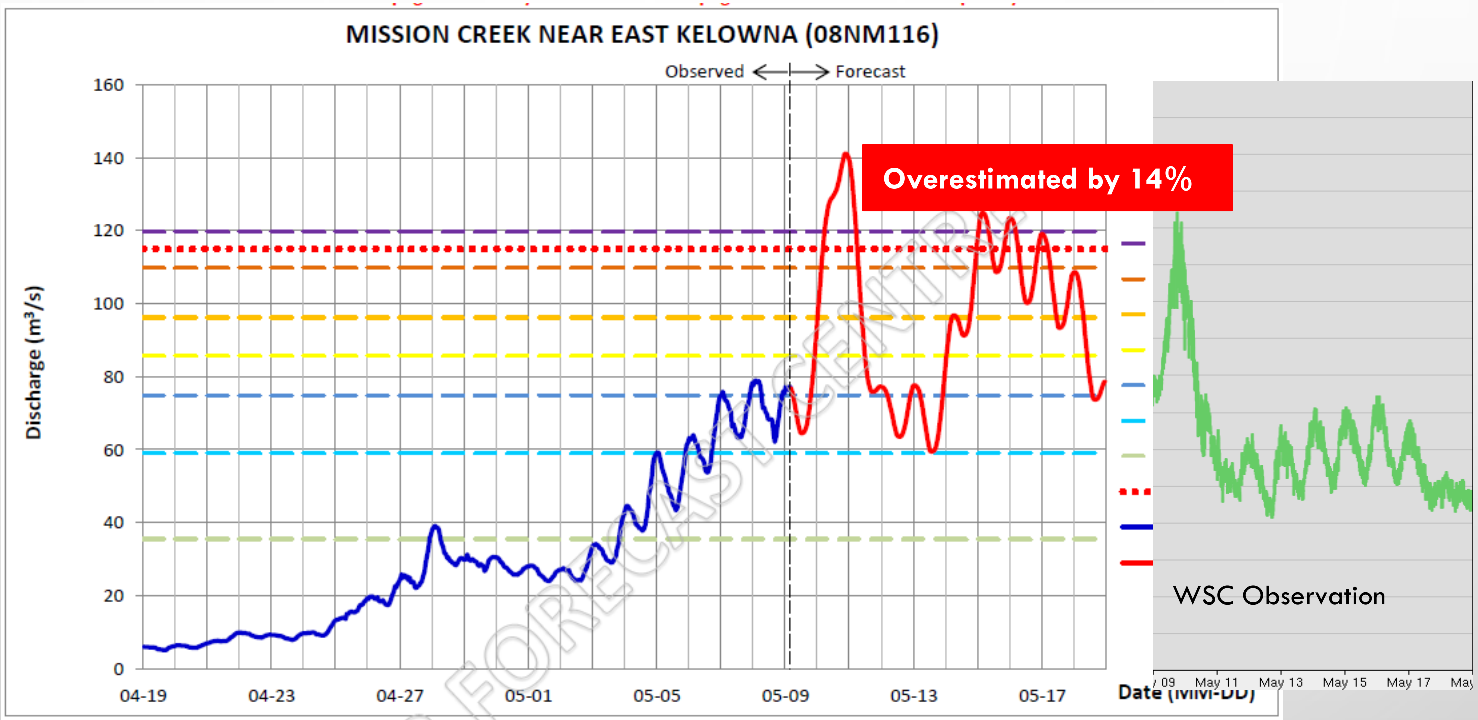
Model Accuracy?

An example: May 2018 event in south interior



Reading at 07 AM (m^3/s) Wed 2018-05-09	Forecast Daily Discharge (m^3/s): MAX / AVERAGE / MIN									
	Wed 2018-05-09	Thu 2018-05-10	Fri 2018-05-11	Sat 2018-05-12	Sun 2018-05-13	Mon 2018-05-14	Tue 2018-05-15	Wed 2018-05-16	Thu 2018-05-17	Fri 2018-05-18
	91.8	141.2	138.6	77.3	80.8	116.0	124.9	123.5	119.1	108.7
76.9	**72.3**	**126.9**	**96.0**	**70.3**	**68.7**	**96.4**	**117.3**	**111.0**	**104.3**	**86.8**
	64.5	96.7	75.9	63.6	59.5	84.7	108.6	100.2	93.4	73.7

Color Scheme for Return Periods:	RTP=1Y	RTP=2Y	RTP=5Y	RTP=10Y	RTP=20Y	RTP=50Y	RTP=100Y	2013 Peak
	35.5	59.0	74.8	85.7	96.2	109.8	119.7	115.0 (m^3/s)

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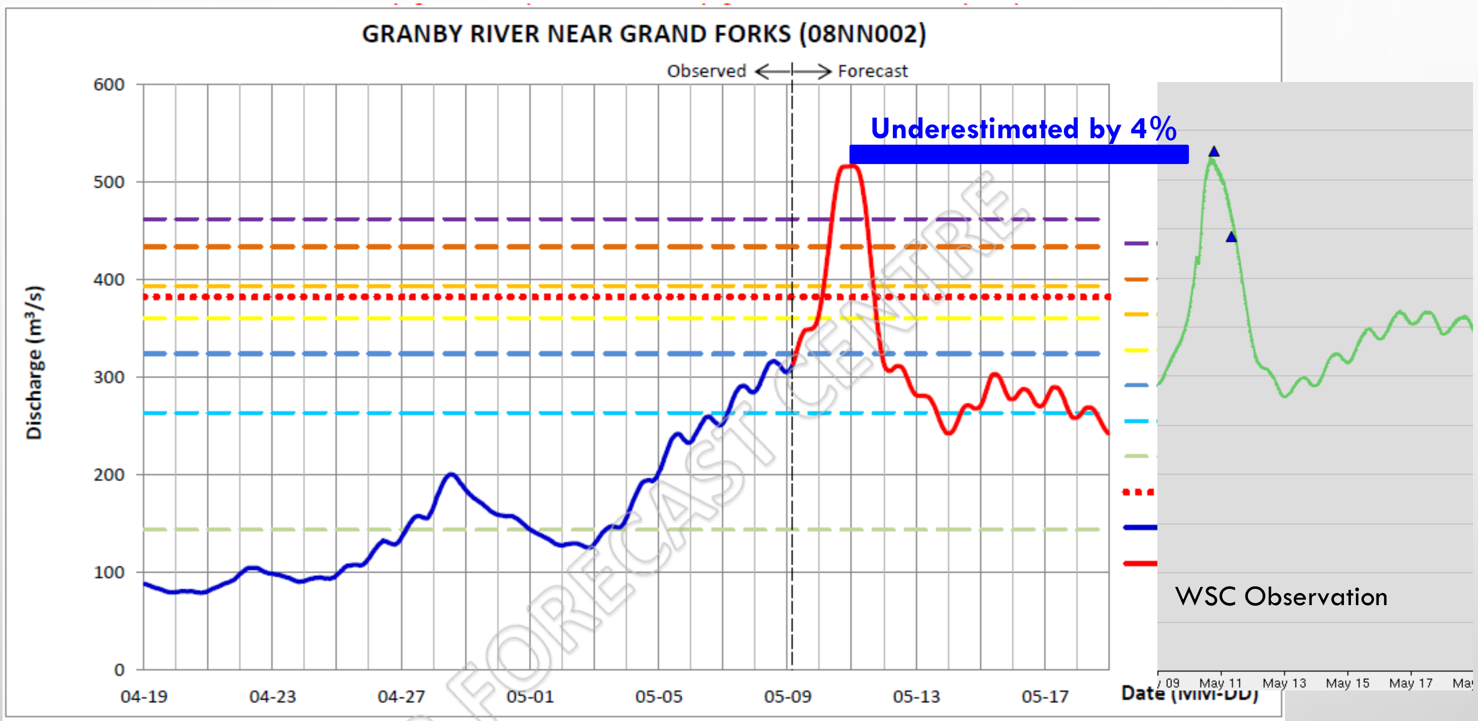

Reading at 07 AM (m^3/s)	Forecast Daily Discharge (m^3/s): MAX / AVERAGE / MIN									
Wed 2018-05-09	Wed 2018-05-09	Thu 2018-05-10	Fri 2018-05-11	Sat 2018-05-12	Sun 2018-05-13	Mon 2018-05-14	Tue 2018-05-15	Wed 2018-05-16	Thu 2018-05-17	Fri 2018-05-18
	363.4	516.1	516.3	311.7	280.9	270.7	302.9	287.2	289.4	268.7
313.3	**344.3**	**468.2**	**436.7**	**302.8**	**267.7**	**261.0**	**289.3**	**279.0**	**276.1**	**259.5**
	318.4	369.8	316.7	281.7	242.1	242.1	271.0	269.9	257.8	241.9

	RTP=1Y	RTP=2Y	RTP=5Y	RTP=10Y	RTP=20Y	RTP=50Y	RTP=100Y	2017 Peak
Color Scheme for Return Periods:	143.2	263.1	323.6	360.2	393.2	433.4	461.8	382.0 (m^3/s)

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Model Accuracy?

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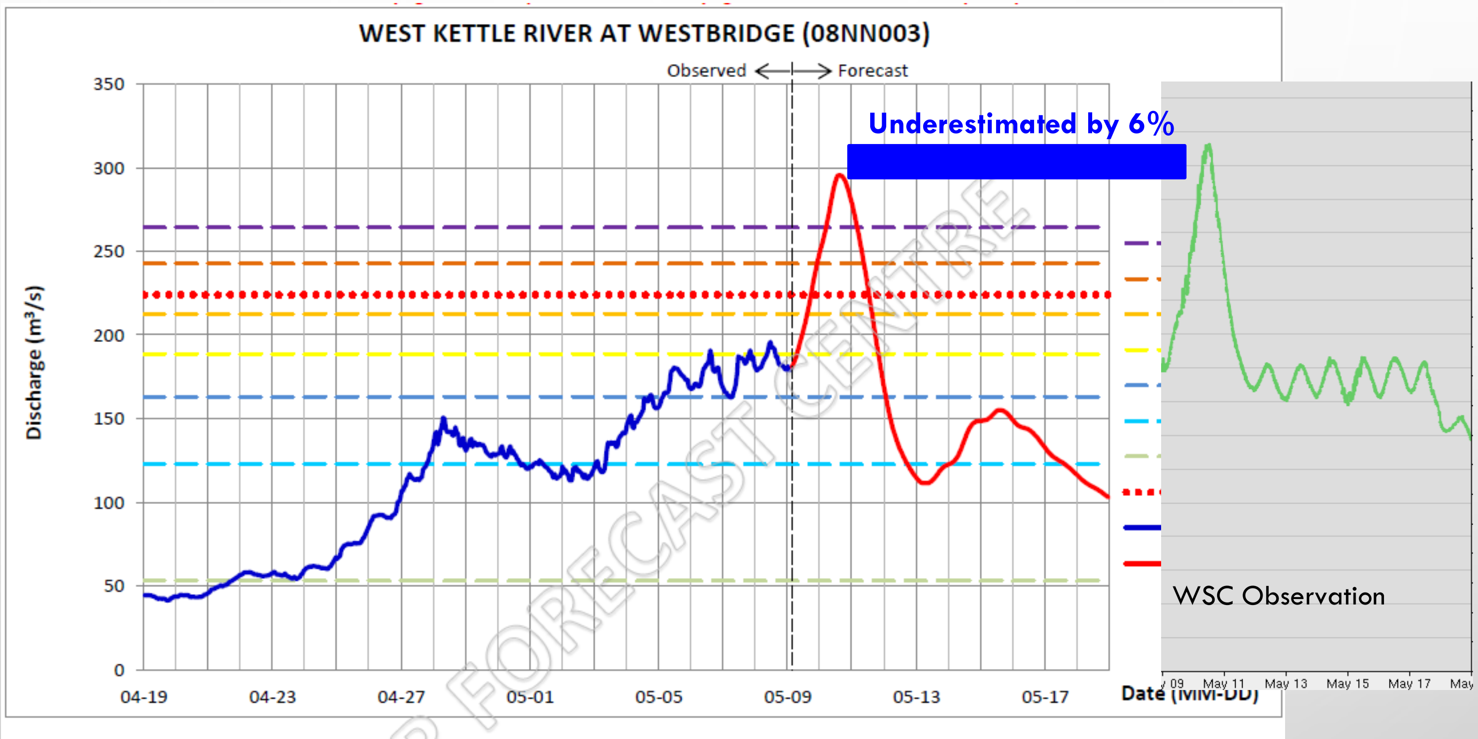

Reading at 07 AM (m^3/s) Wed 2018-05-09	Forecast Daily Discharge (m^3/s): MAX / AVERAGE / MIN									
	Wed 2018-05-09	Thu 2018-05-10	Fri 2018-05-11	Sat 2018-05-12	Sun 2018-05-13	Mon 2018-05-14	Tue 2018-05-15	Wed 2018-05-16	Thu 2018-05-17	Fri 2018-05-18
	247.0	295.4	277.6	167.1	122.4	148.6	155.1	148.9	132.4	115.9
180.7	**211.8**	**280.3**	**227.2**	**135.2**	**115.3**	**136.4**	**152.0**	**142.2**	**124.3**	**109.2**
	182.4	250.1	171.6	115.4	111.3	122.7	148.7	133.4	116.7	102.9

	RTP=1Y	RTP=2Y	RTP=5Y	RTP=10Y	RTP=20Y	RTP=50Y	RTP=100Y	2017 Peak
Color Scheme for Return Periods:	53.1	122.8	163.0	188.6	212.5	242.5	264.2	224.0 (m^3/s)

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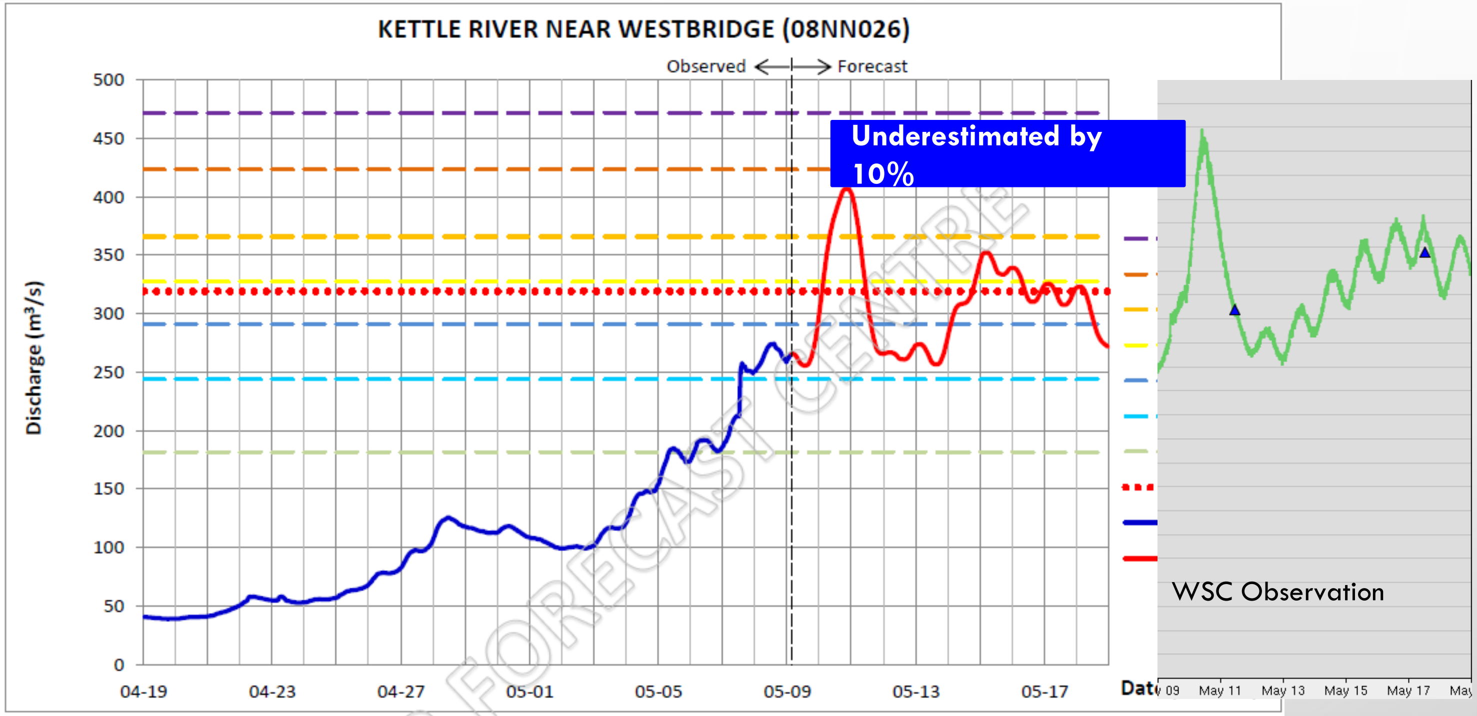
Model Accuracy?

An example: May 2018 event in south interior



Reading at 07 AM (m^3/s)	Forecast Daily Discharge (m^3/s): MAX / AVERAGE / MIN									
Wed 2018-05-09	Wed 2018-05-09	Thu 2018-05-10	Fri 2018-05-11	Sat 2018-05-12	Sun 2018-05-13	Mon 2018-05-14	Tue 2018-05-15	Wed 2018-05-16	Thu 2018-05-17	Fri 2018-05-18
	294.3	406.7	401.5	272.3	277.3	341.9	352.2	338.9	325.3	322.9
265.8	**264.7**	**374.7**	**321.1**	**264.8**	**265.7**	**310.7**	**342.0**	**321.7**	**316.3**	**297.7**
	255.6	302.9	265.5	260.7	256.5	282.4	333.3	309.9	307.4	271.4

	RTP=1Y	RTP=2Y	RTP=5Y	RTP=10Y	RTP=20Y	RTP=50Y	RTP=100Y	2017 Peak
Color Scheme for Return Periods:	181.4	243.8	290.9	327.0	365.8	423.0	471.6	319.0 (m^3/s)

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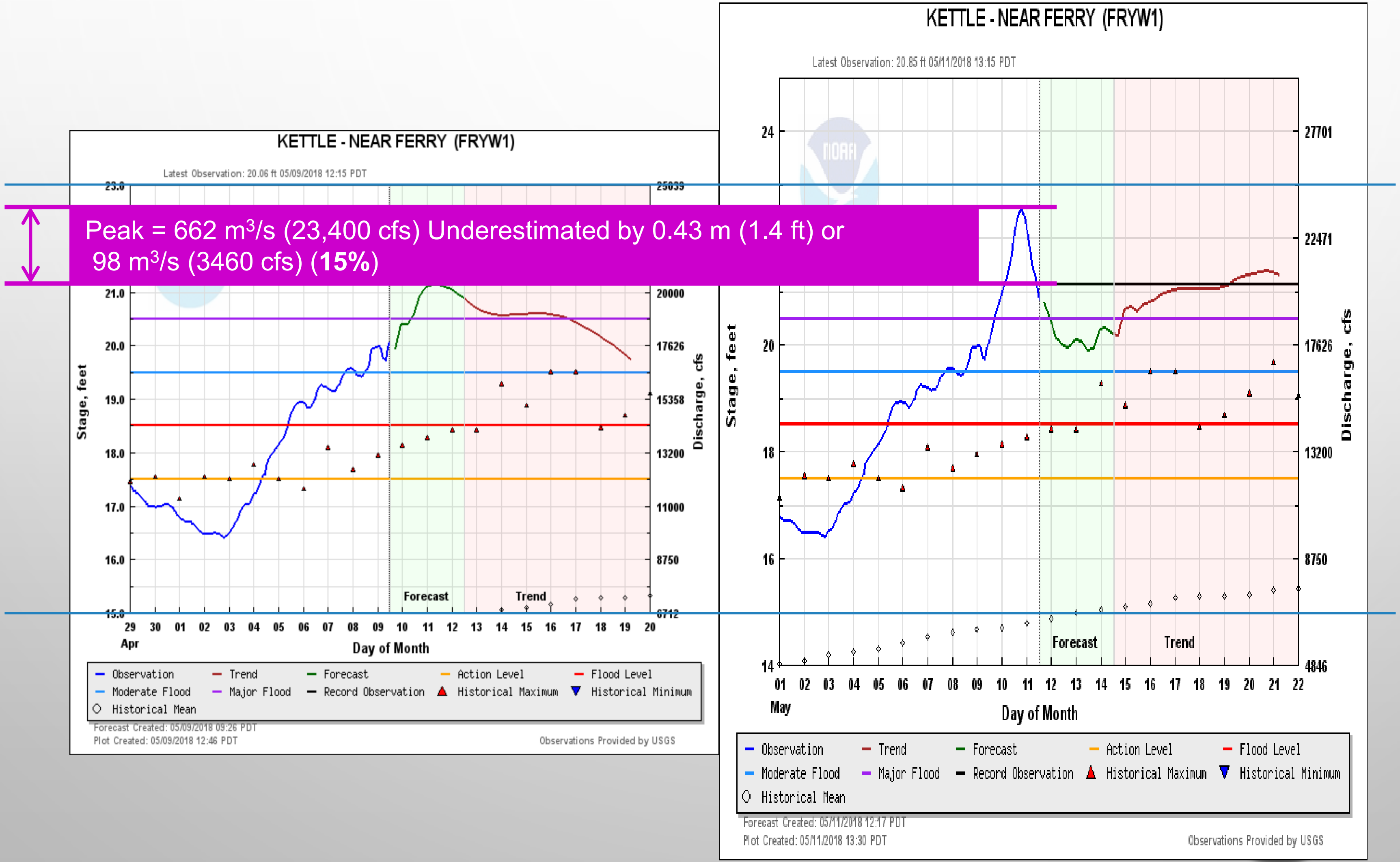
Model Accuracy?

An example: May 2018 event in south interior



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