Operational Real-time Flood Forecasting under Climate Change Impacts in British Columbia (The COFFEE Model and CLEVER Model)

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May 30, 2018

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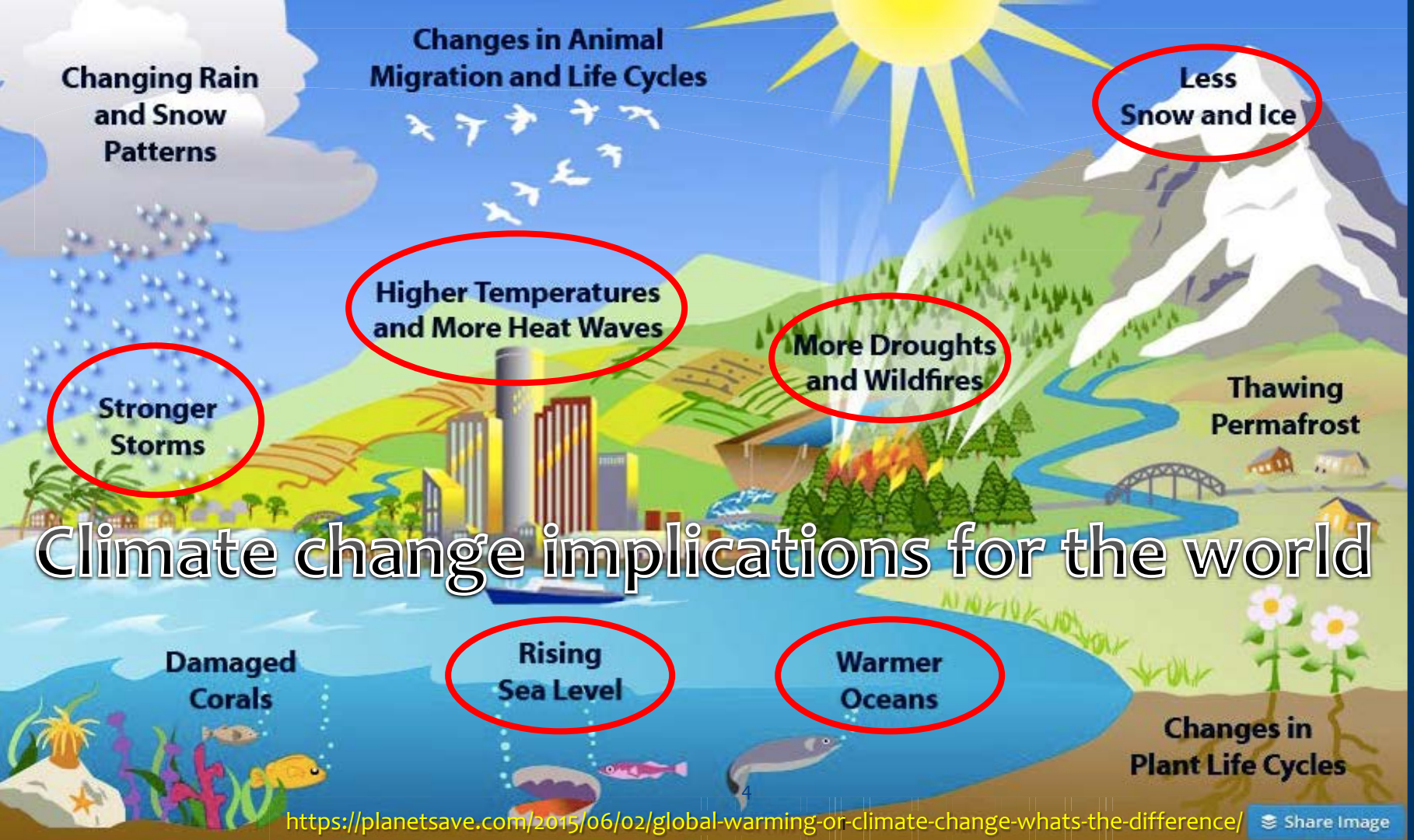
Life of the River Forecast Centre


COFFEE
Model


CLEVER
Model



Climate change implications for the world

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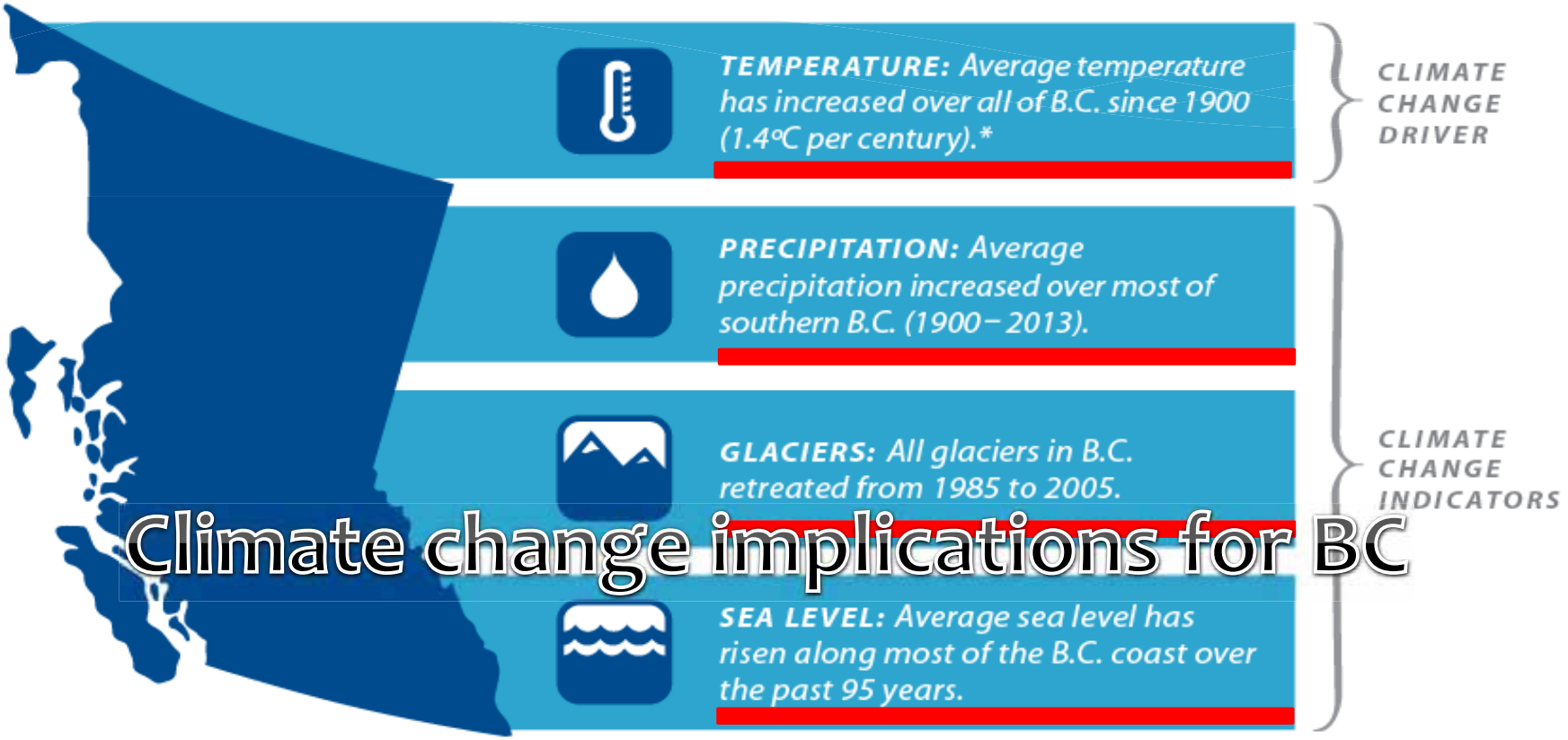
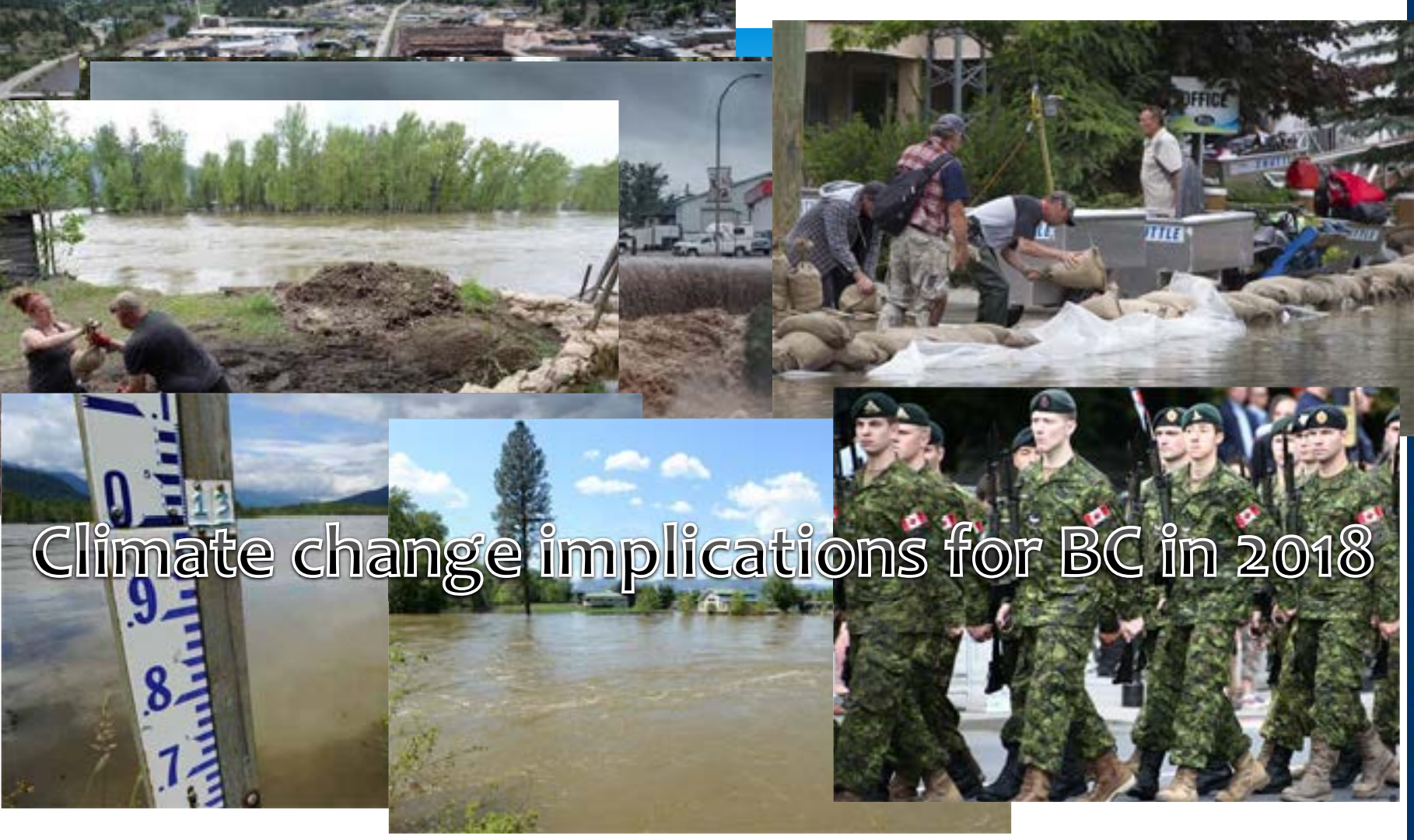
https://engage.gov.bc.ca/climateleadership/climateaction/



Climate change implications for BC

* Winter is warmer on average than it was 100 years ago. Higher temperatures drive other climate systems and affect our environment and ecosystems.



Climate change implications for BC in 2018

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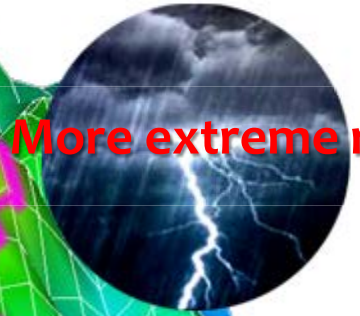
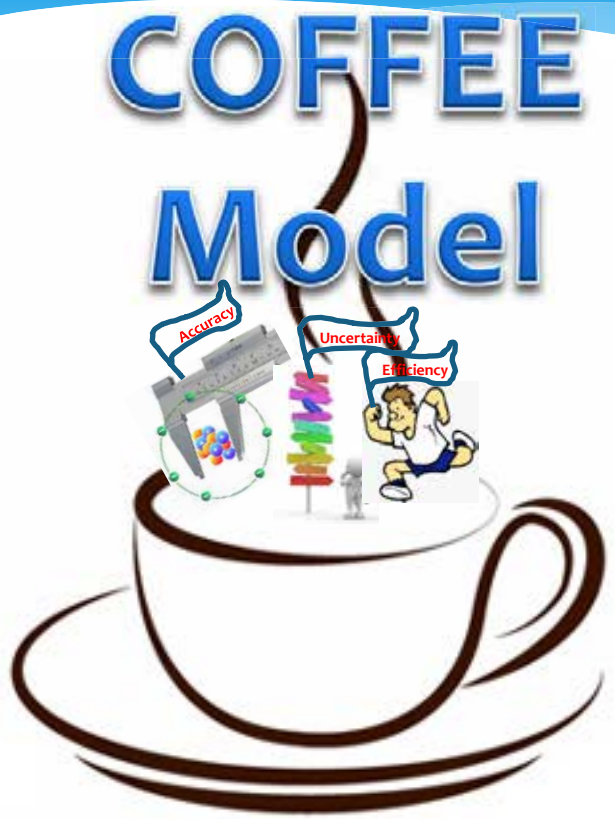
Early onset of freshet

More extreme rainfall events



Climate change implications for real-time flood forecasting in BC

Modeling Challenges under climate change impacts:



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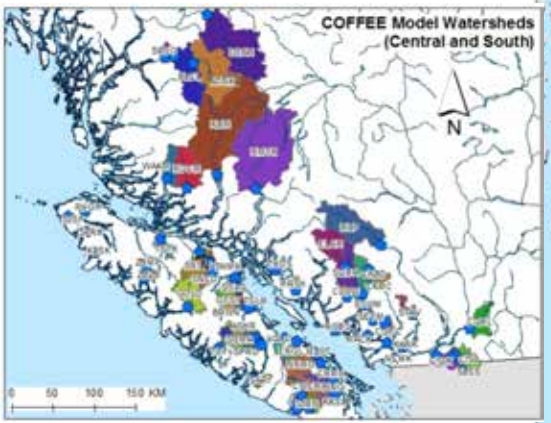
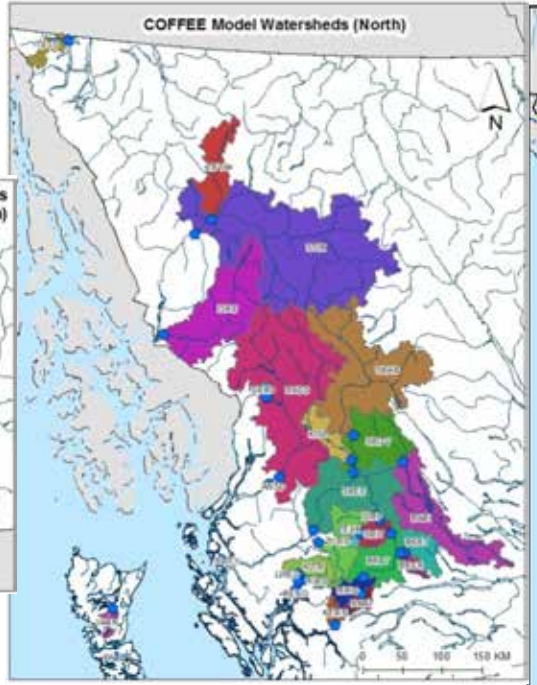
Coastal Fall Flood Ensemble Estimation Model

Where is the COFFEE Model developed for?





COFFEE Model

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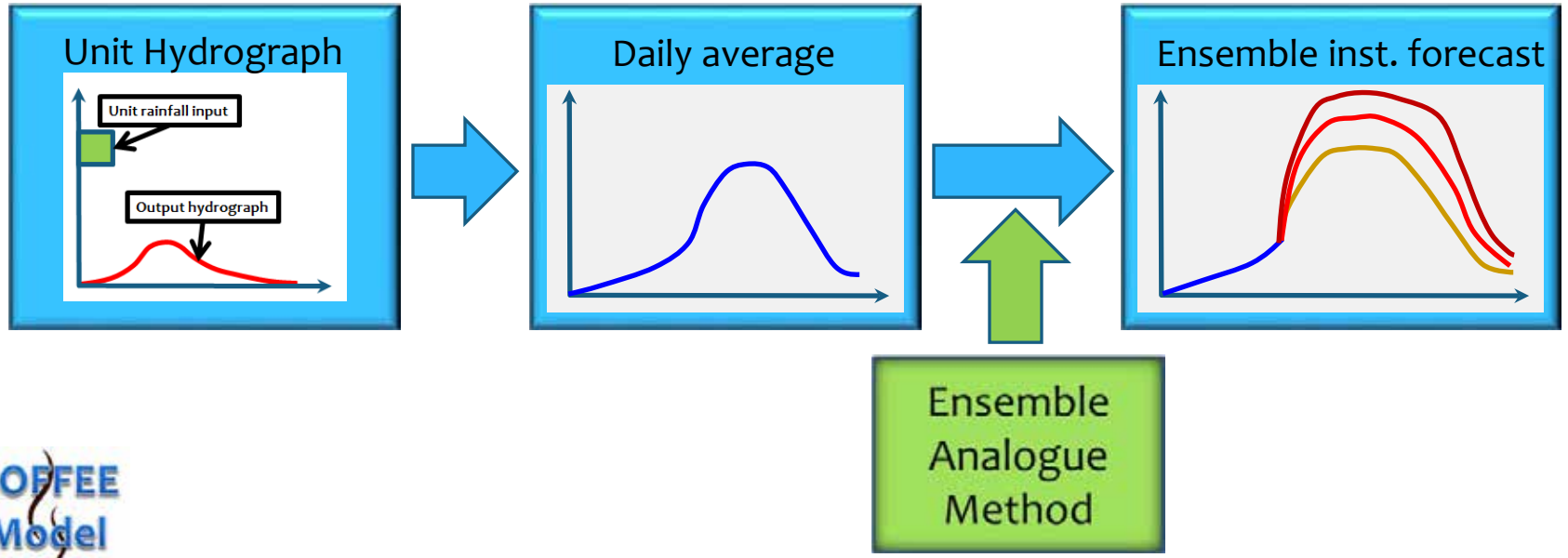
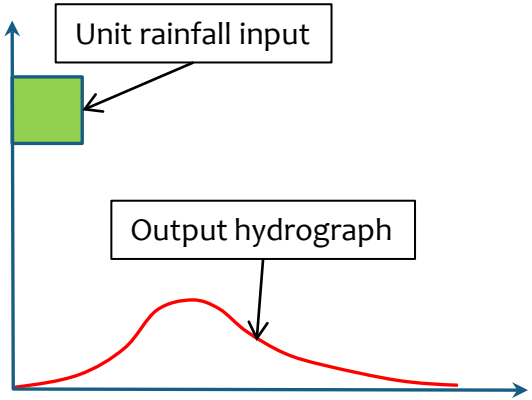
What is the COFFEE Model?

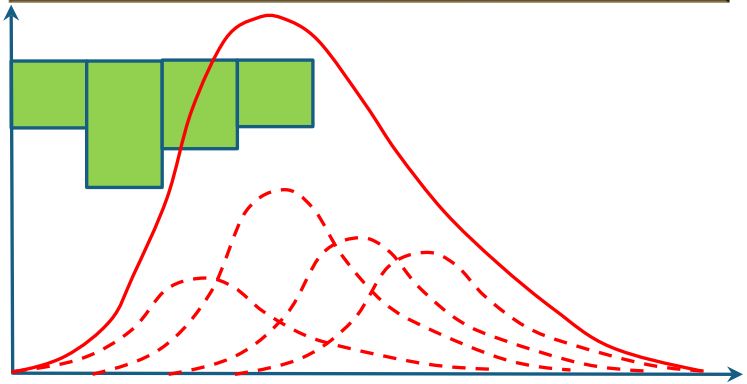


COFFEE Model

Unit Hydrograph

$$Q_n = \sum_{m=1}^{n \le M} P_m U_{n-m+1}$$





COFFEE Model

What is the COFFEE Model?

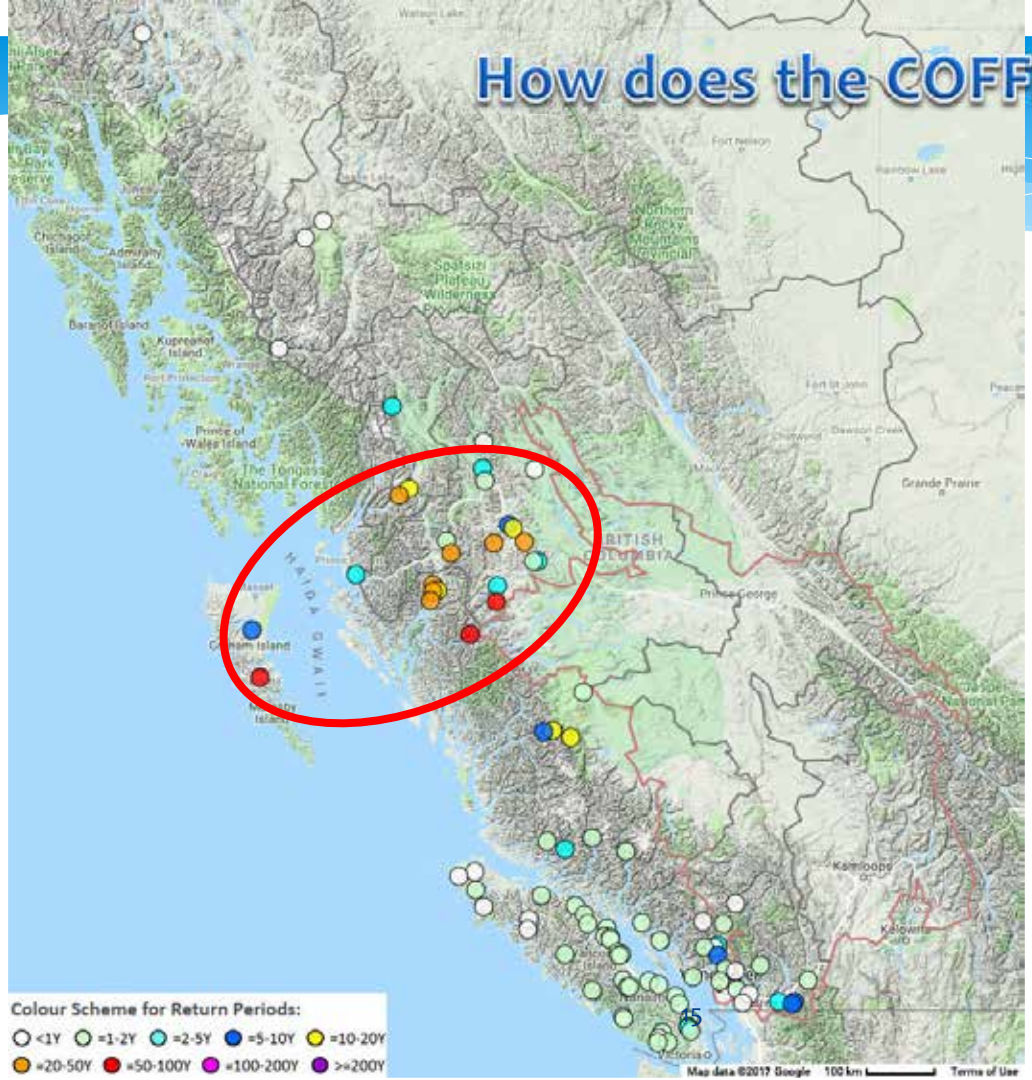
Ensemble Analogue Method

Statistical analysis for the historical discharge data to find the ratios of instantaneous peaks to the daily peaks, and the average, max and min of the ratios.

$$R_n = \frac{O_n}{D_n}$$

$$\begin{cases} R_{ave} = \sum_{n=1}^{N} R_n \Big/ N \\ R_{max} = \max(R_n) \\ R_{min} = \min(R_n) \end{cases} \qquad \begin{cases} Q_{ave,n} = R_{ave}\, Q_n \\ Q_{max,n} = R_{max}\, Q_n \\ Q_{min,n} = R_{min}\, Q_n \end{cases}$$

How does the COFFEE Model work?



Google map output from the COFFEE Model, October 22, 2017

COFFEE Model

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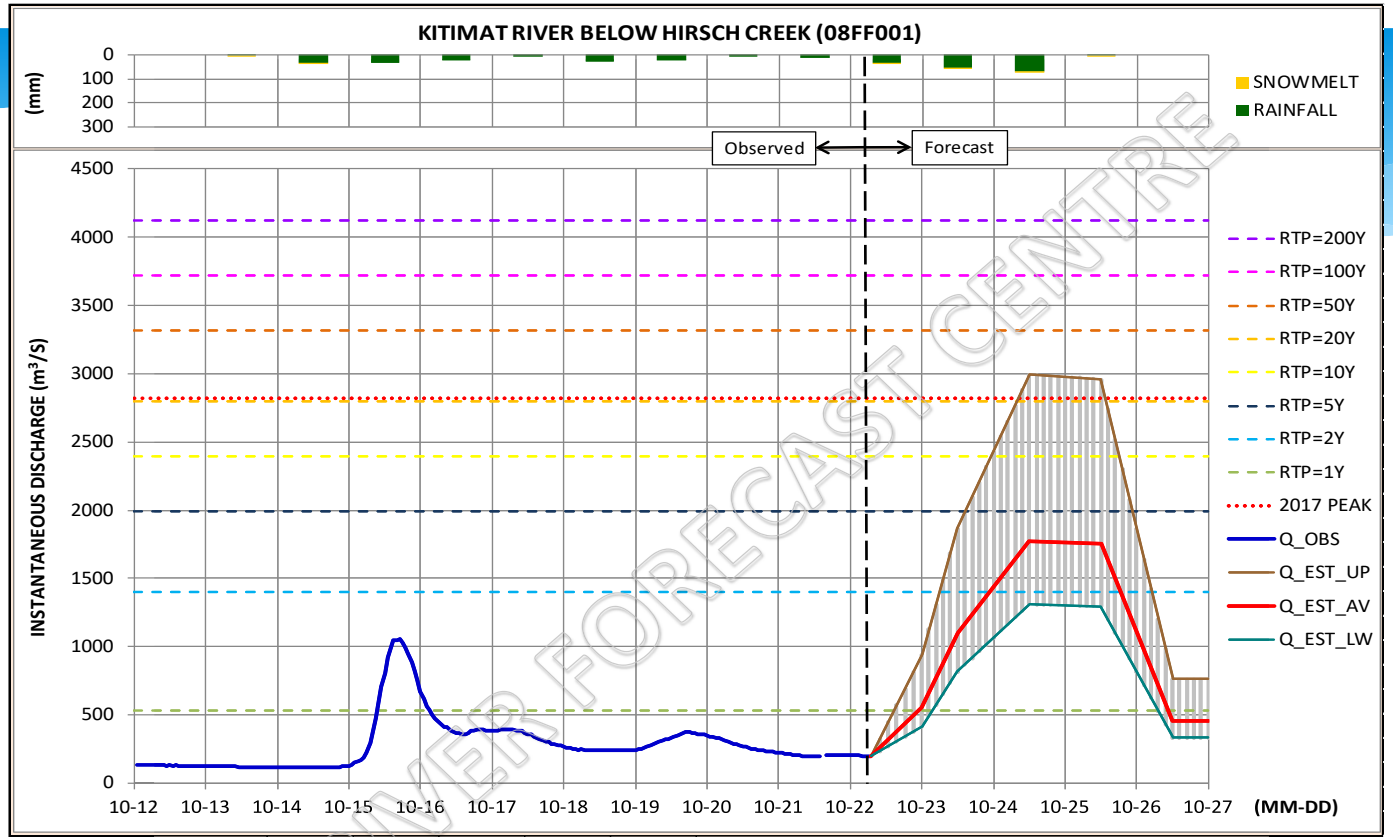


Sun	COFFEE MODEL		Sun	Mon	Tue	Wed	Thu
2017-10-22	FLOW FORECAST		2017-10-22	2017-10-23	2017-10-24	2017-10-25	2017-10-26
Current	Forec. Rain+melt (mm)		33	58	72	3	0
Reading	Forecast	Maximum	940.4	1866.0	2992.4	2957.9	763.6
(m^3/s)	Discharge	Average	**556.8**	**1104.9**	**1771.9**	**1751.5**	**452.2**
197.0	(m^3/s)	Minimum	412.2	818.0	1311.7	1296.6	334.8

Color Scheme:

Remark: This is a natural station

RTP=1Y	RTP=2Y	RTP=5Y	RTP=10Y	RTP=20Y	RTP=50Y	RTP=100Y	RTP=200Y	2017 PEAK
530.6	1403.5	1991.7	2396.0	2793.8	3321.3	3723.2	4126.4	2815.9

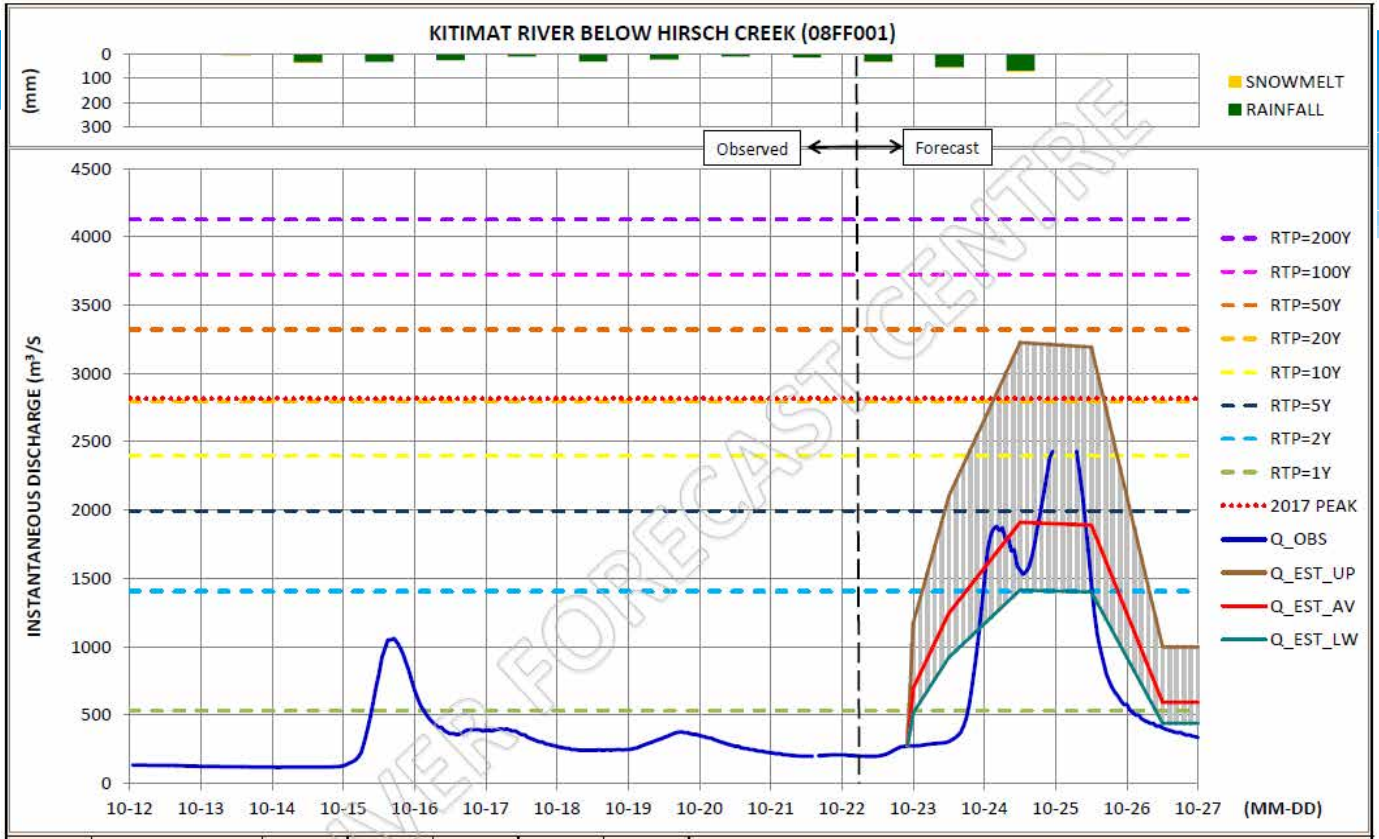
The Coastal Fall Floods Ensemble Estimation (COFFEE) Model

DISCLAIMER: The model forecast is derived by using observed/forecast climate/hydrometric data from Environment and Climate Change Canada (ECCC) and the Province of British Columbia. The model and data have limitations, inaccuracies and errors. The actual discharges/water levels will be different from the forecasts. Users of this data must accept all responsibility for their use and interpretation.

Link to Water Survey of Canada's real-time data website for this station

Note: Refresh browser frequently to view latest forecast.

COFFEE Model



Sun 2017-10-22	COFFEE MODEL FLOW FORECAST		Sun 2017-10-22	Mon 2017-10-23	Tue 2017-10-24	Wed 2017-10-25	Thu 2017-10-26
Current Reading (m^3/s)	Forec. Rain+melt (mm)		33	58	72	3	0
	Forecast Discharge (m^3/s)	Maximum	1174.0	2099.6	3226.0	3191.5	997.3
		Average	695.2	1243.3	1910.3	1889.8	590.5
272.0		Minimum	514.6	920.4	1414.2	1399.0	437.2

Color Scheme:

Remark: This is a natural station.

RTP=1Y	RTP=2Y	RTP=5Y	RTP=10Y	RTP=20Y	RTP=50Y	RTP=100Y	RTP=200Y	
530.6	1403.5	1991.7	2396.0	2793.8	3321.3	3723.2	4126.4	(m^3/s)

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COFFEE Model

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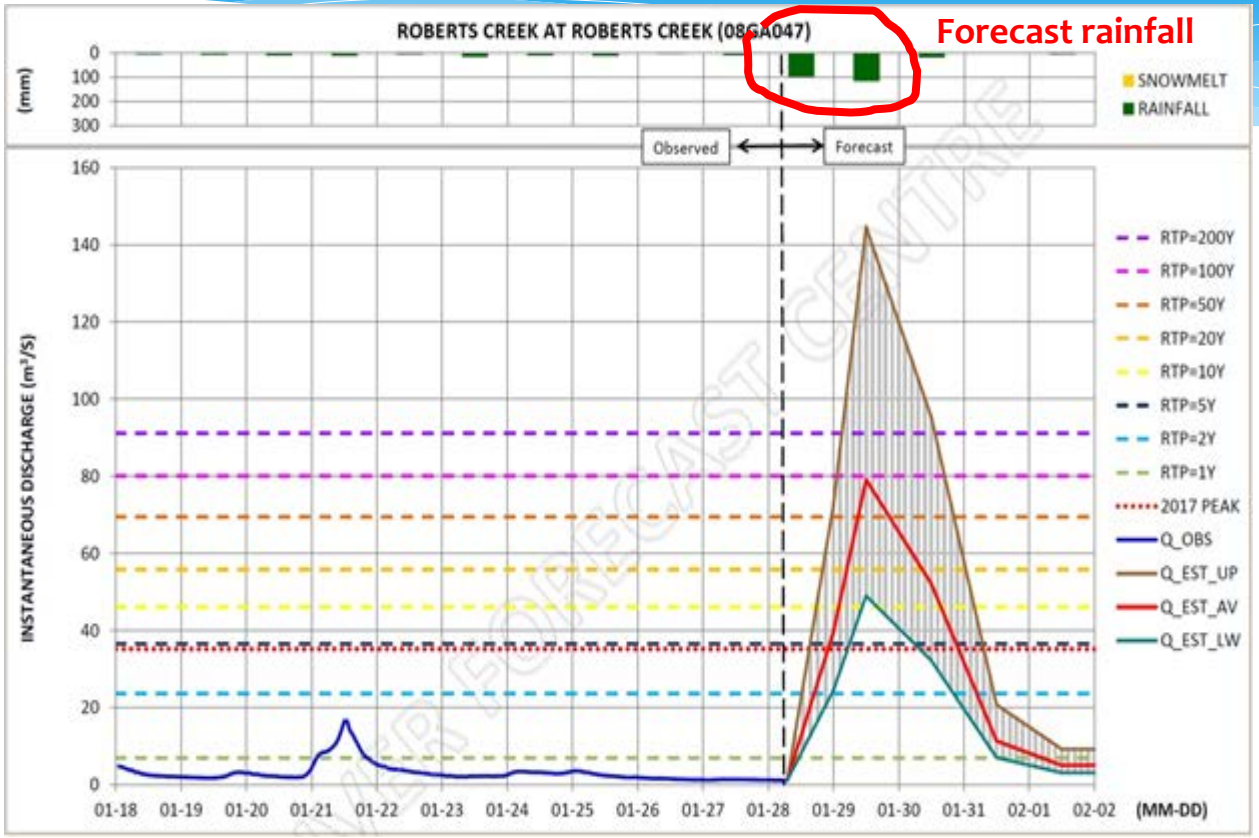
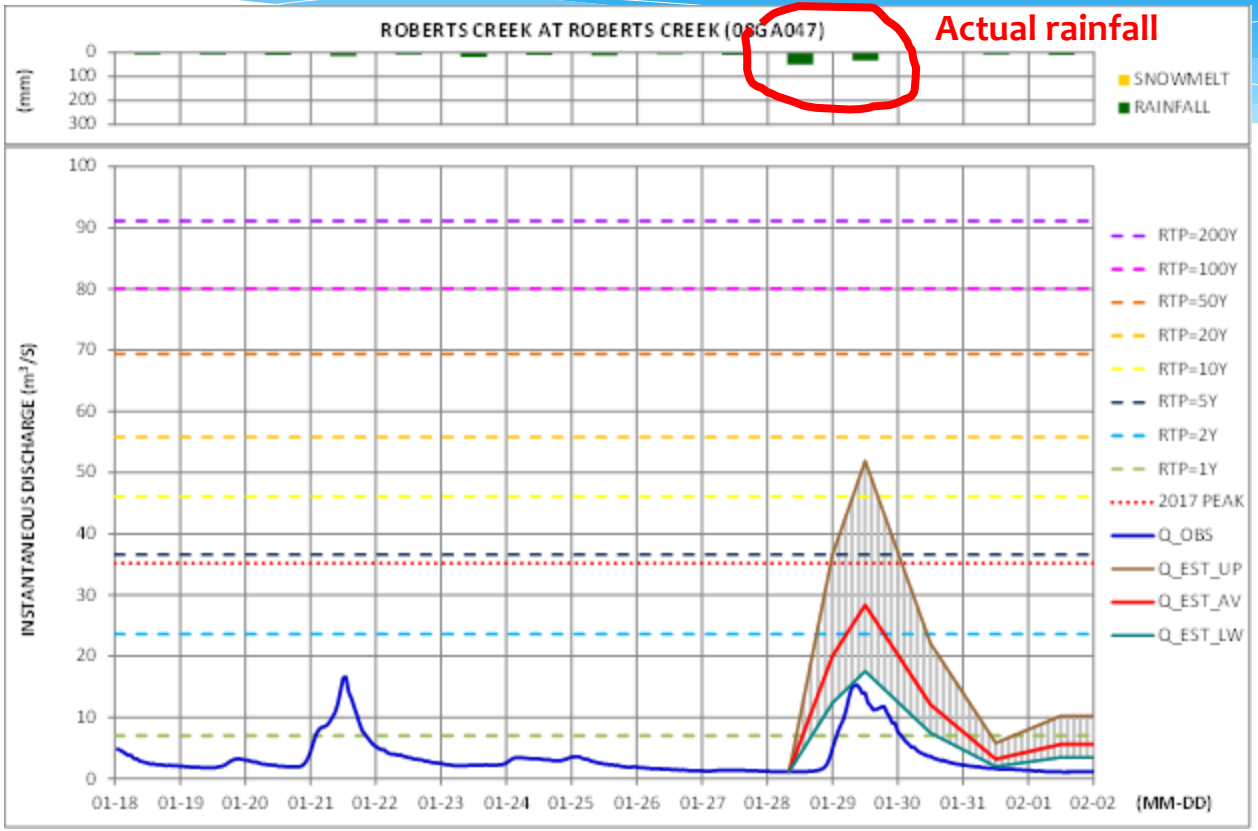
How does the COFFEE Model work?



COFFEE Model

How does the COFFEE Model work?



COFFEE Model

How does the COFFEE Model work?

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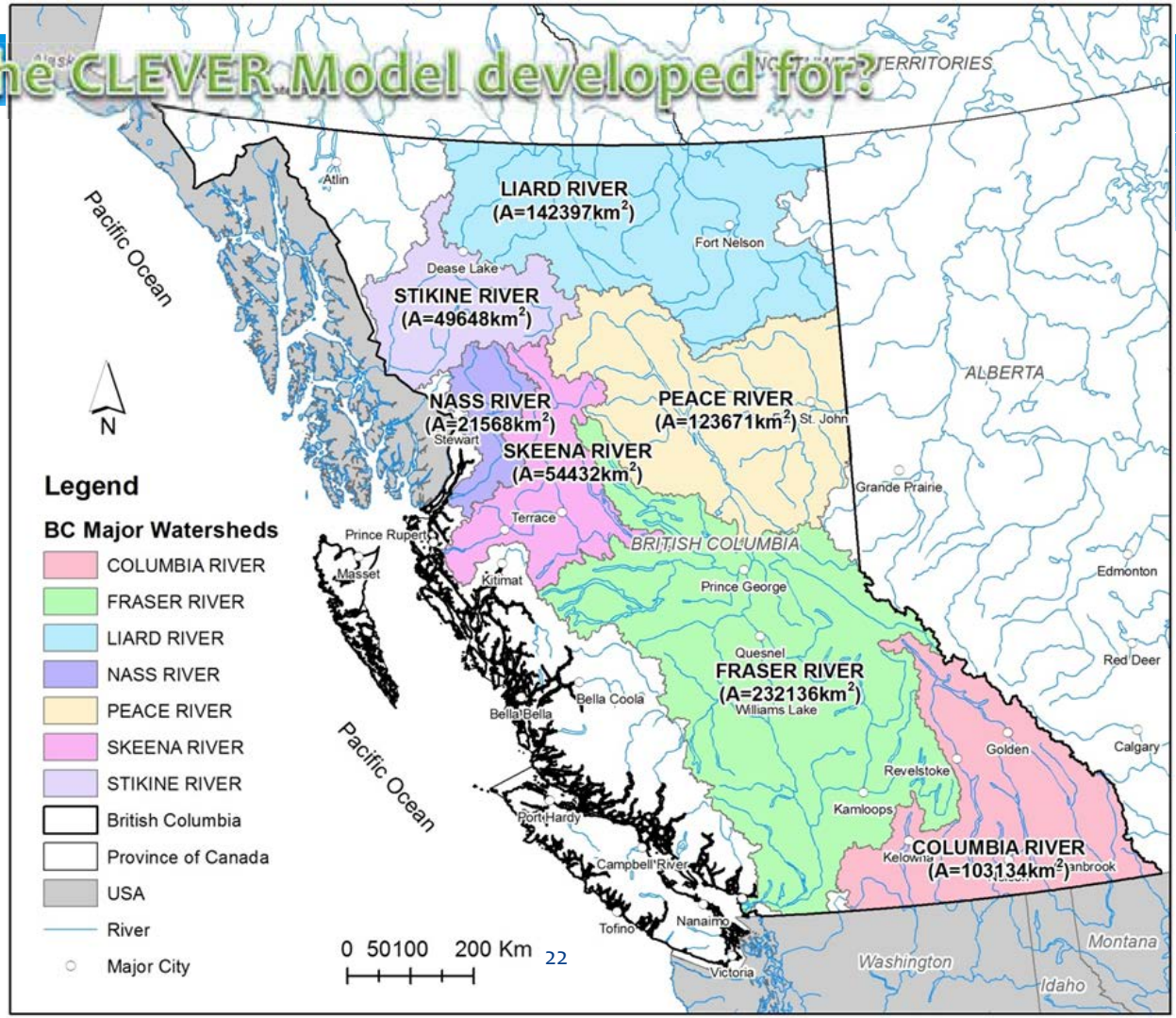
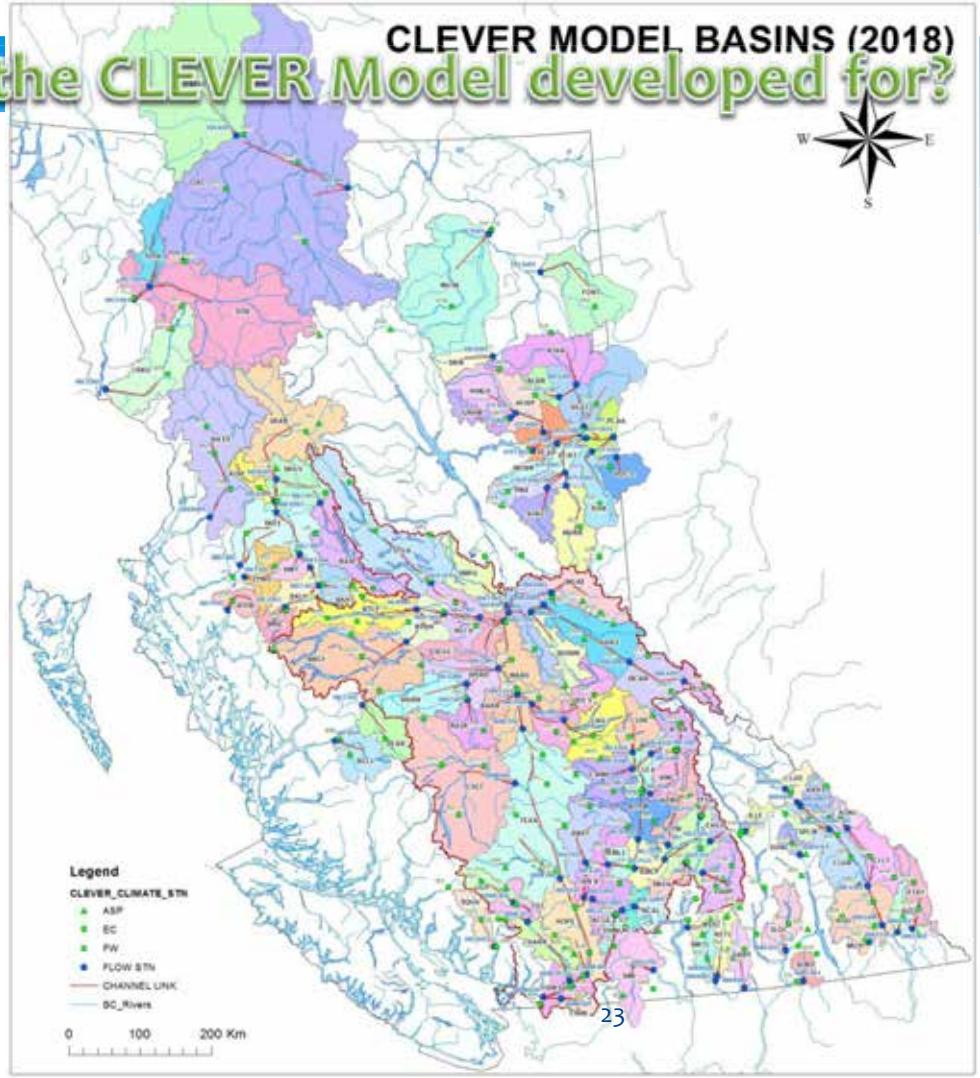
Channel Links
Evolution
Efficient Routing
Model

Where is the CLEVER Model developed for?

Snowmelt-dominated huge-scale watersheds in BC



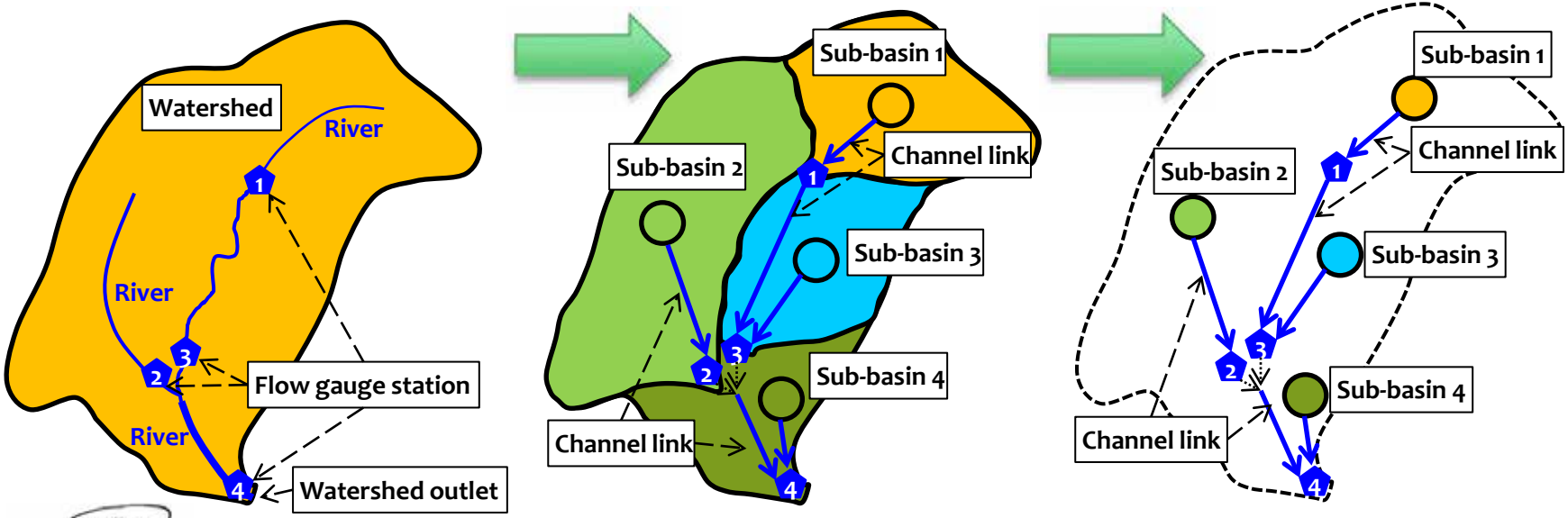
Where is the CLEVER Model developed for?



108 watersheds and sub-basins in the model for 2018

What is the CLEVER Model?

How to model a big watershed - Model Structure

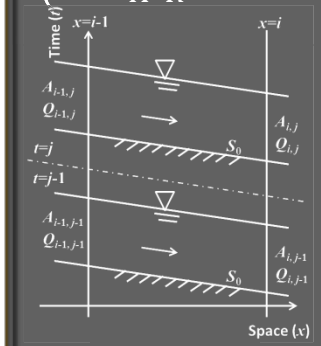


What is the CLEVER Model?

Methodology: kinematic wave & Temp. Index + inst. UH

Channel link routing sub-model:

$$\begin{cases} \dfrac{\partial Q}{\partial x} + \dfrac{\partial A}{\partial t} = 0 \\ S_0 = \dfrac{n^2 Q^2}{A^2 R^{4/3}} \end{cases} \qquad \frac{1}{\Delta x}\left[\frac{Q_{i,j} + Q_{i,j-1}}{2} - \frac{Q_{i-1,j} + Q_{i-1,j-1}}{2}\right] + \frac{1}{\Delta t}\left[\frac{A_{i,j} + A_{i-1,j}}{2} - \frac{A_{i,j-1} + A_{i-1,j-1}}{2}\right] = 0$$



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

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

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

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

Watershed routing sub-model:

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

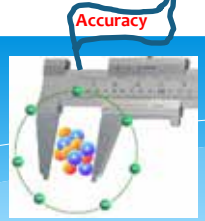
$$M = c_a c_d M_f (T_i - T_b)^{\beta}$$

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

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

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

How dose the CLEVER Model work?



Model calibration and verification:

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

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:

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

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

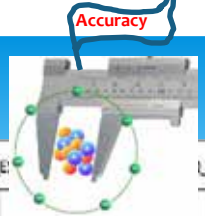
$$dV = 100 \times \left(\overline{Q_{sim}} - \overline{Q_{obs}}\right) / \overline{Q_{obs}}$$

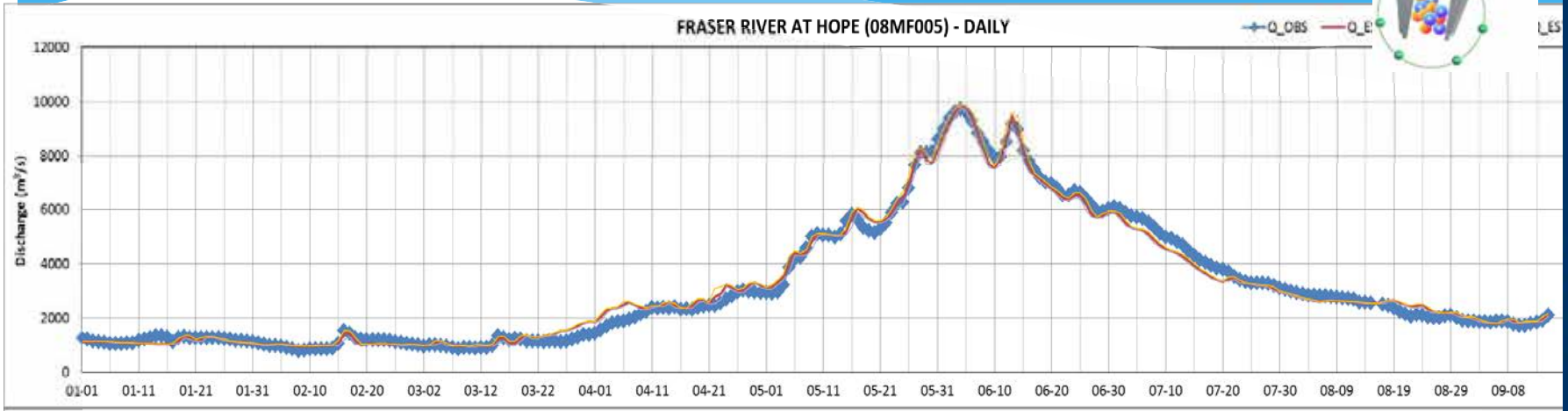
$$E_{ra} = 100 \times \left(\frac{1}{m}\sum_{j=1}^{m}\left|Q_{sim}^{j} - Q_{obs}^{j}\right|\right) / \overline{Q_{obs}} \quad (33)$$

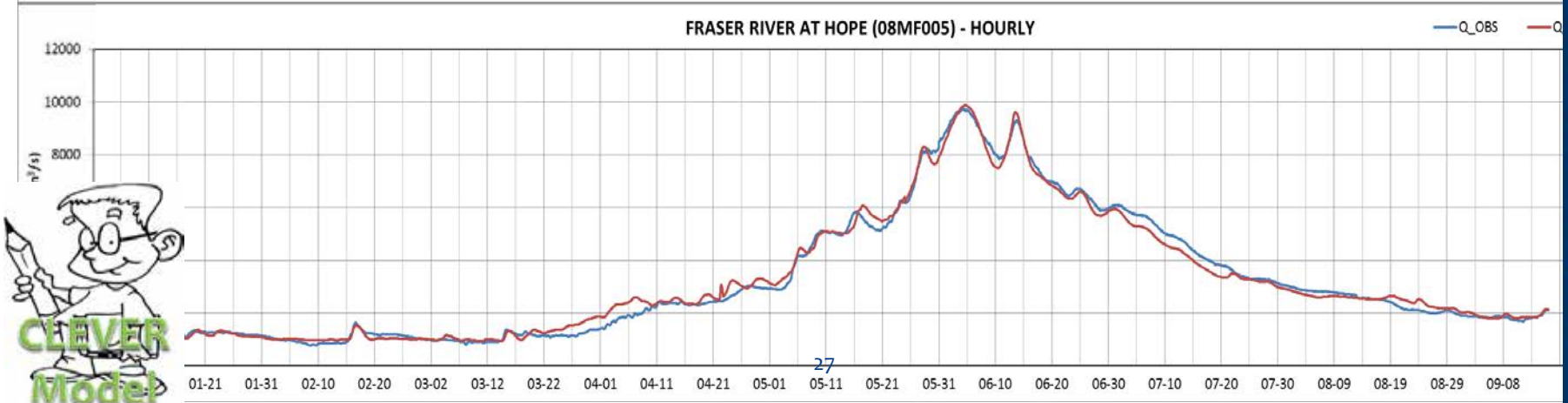
$$r^2 = \frac{\left[\sum_{j=1}^{m}\left(Q_{obs}^{j} - \overline{Q_{obs}}\right)\left(Q_{sim}^{j} - \overline{Q_{sim}}\right)\right]^2}{\sum_{j=1}^{m}\left(Q_{obs}^{j} - \overline{Q_{obs}}\right)^2 \sum_{j=1}^{m}\left(Q_{sim}^{j} - \overline{Q_{sim}}\right)^2}$$

How dose the CLEVER Model work?

Operational runs in 2017

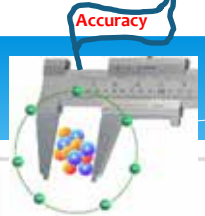


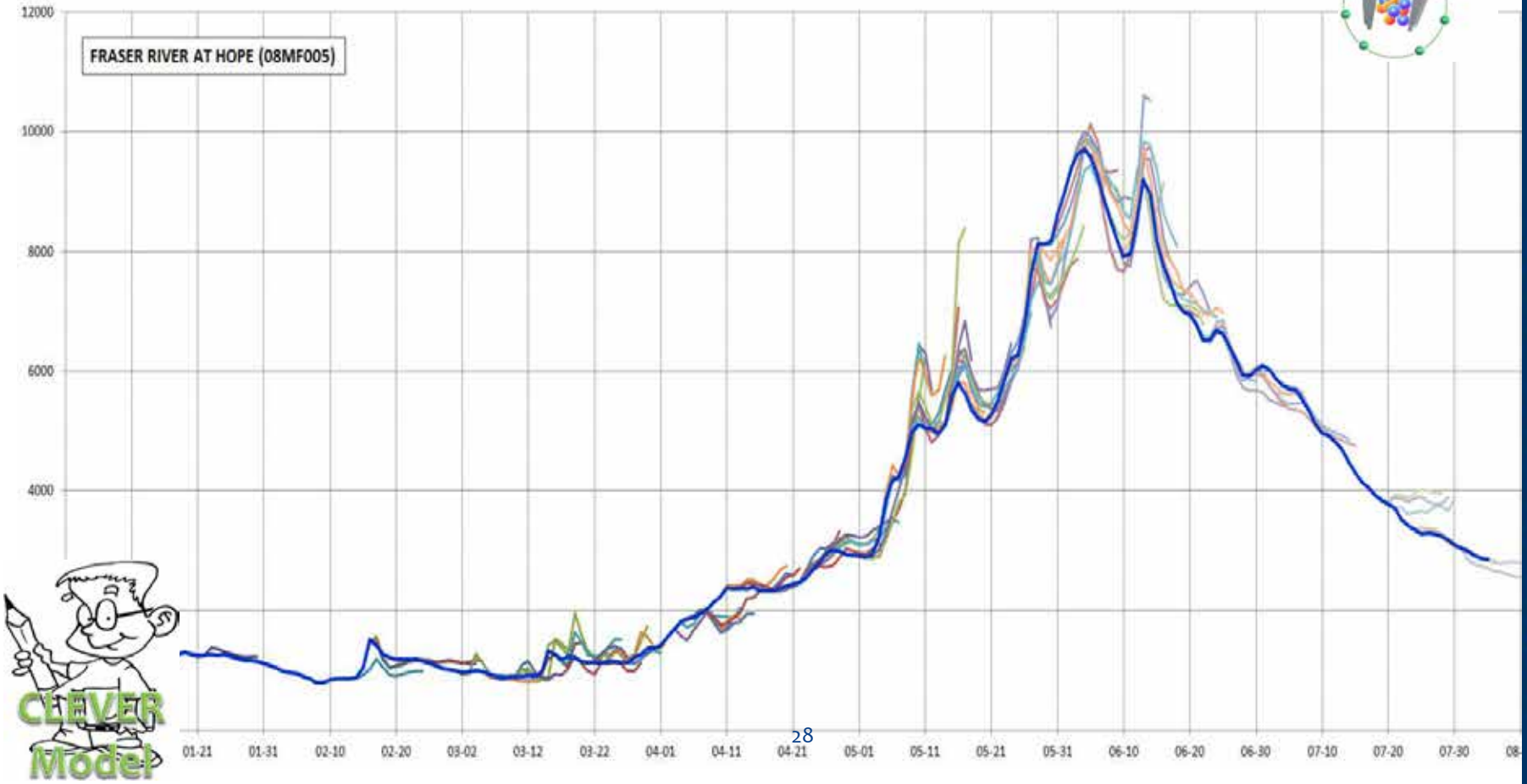




How dose the CLEVER Model work?

Operational runs in 2017





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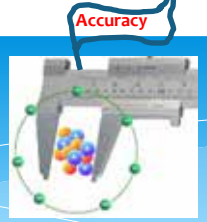
How does the CLEVER Model work?

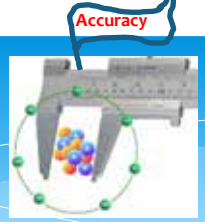
Operational runs in 2017



	CE_HOURLY	CD_HOURLY	DV_HR (%)	CE_DAILY	CD_DAILY	DV_DL (%)
Threshold	**>=0.95**	**>=0.95**	**<=1%**	**>=0.95**	**>=0.95**	**<=1%**
No of STN	31	36	21	31	36	24
% of STN	33	38	22	33	38	25
Threshold	**>=0.90**	**>=0.90**	**<=5%**	**>=0.90**	**>=0.90**	**<=5%**
No of STN	50	60	63	56	66	63
% of STN	53	63	66	59	69	66
Threshold	**>=0.85**	**>=0.85**	**<=10%**	**>=0.85**	**>=0.85**	**<=10%**
No of STN	72	76	79	78	81	79
% of STN	76	80	83	82	85	83
Threshold	**>=0.80**	**>=0.80**	**<=15%**	**>=0.80**	**>=0.80**	**<=15%**
No of STN	79	83	90	81	84	90
% of STN	83	87	95	85	88	95
Threshold	**>=0.70**	**>=0.70**	**<=20%**	**>=0.70**	**>=0.70**	**<=20%**
No of STN	86	89	93	88	92	92
% of STN	91	94	98	93	97	97
Threshold	**>=0.60**	**>=0.60**	**<=25%**	**>=0.60**	**>=0.60**	**<=25%**
No of STN	88	91	93	90	92	93
% of STN	93	96	98	95	97	98
Threshold	**>=0.50**	**>=0.50**	**<=30%**	**>=0.50**	**>=0.50**	**<=30%**
No of STN	91	93	93	92	93	93
% of STN	96	98	98	97	98	98

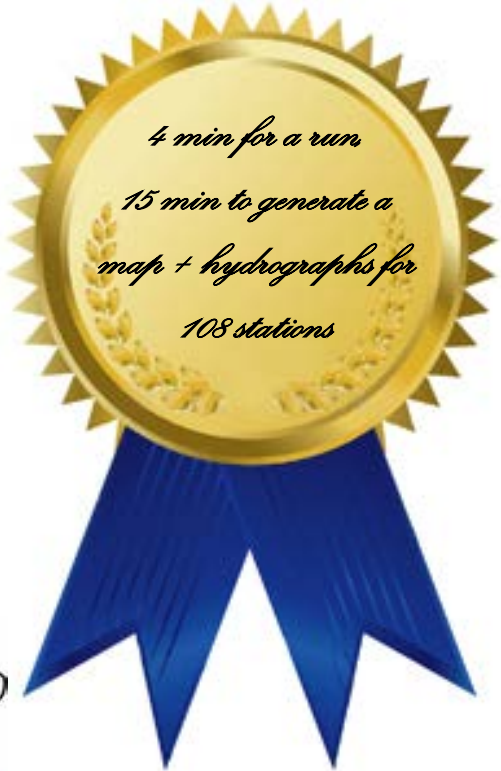
How dose the CLEVER Model work?

Operational runs in 2017

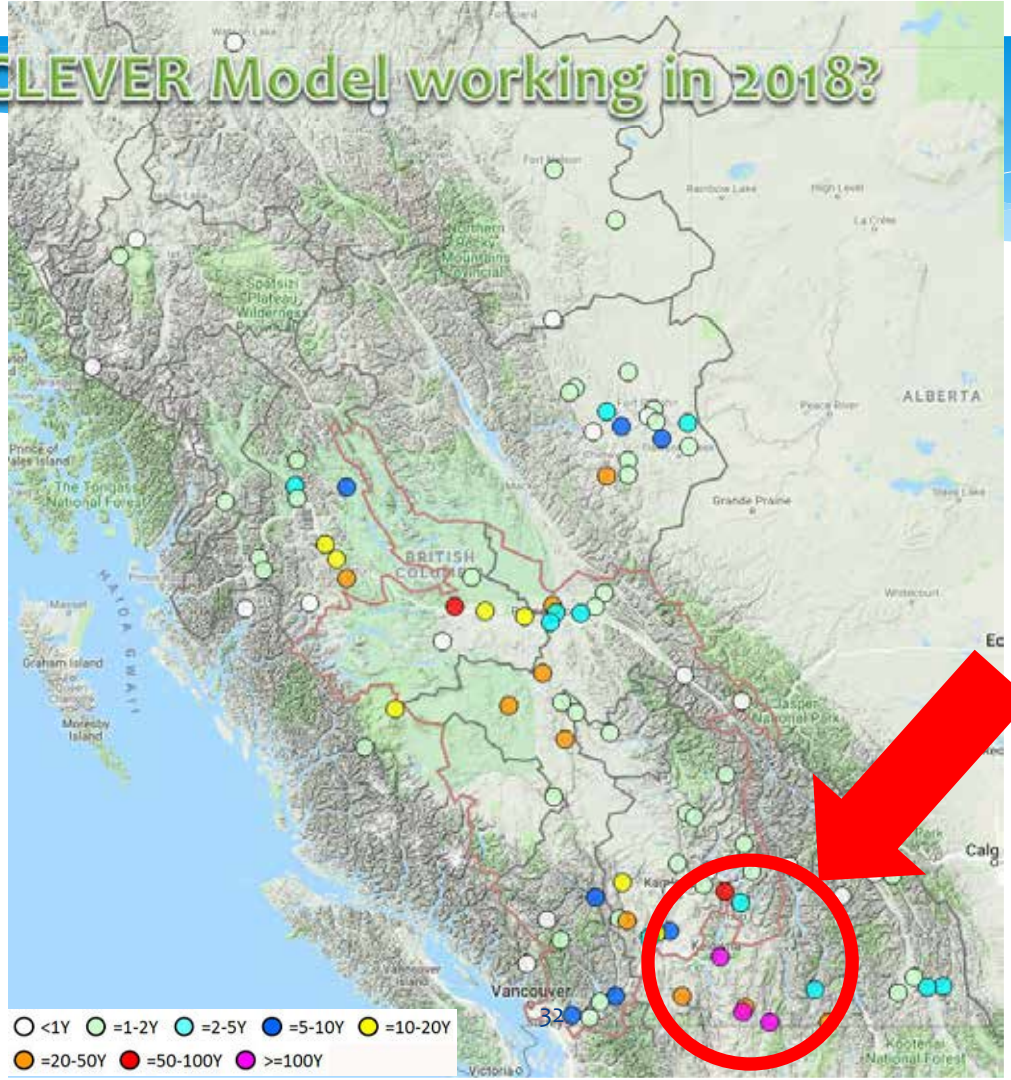


		Average Absolute Forecast Error (%)									
Basin	**Station**	**D1**	**D2**	**D3**	**D4**	**D5**	**D6**	**D7**	**D8**	**D9**	**D10**
Fraser	MCGREGOR RIVER AT LOWER CANYON (08KB003)	6	13	16	22	23	24	26	29	25	28
	FRASER RIVER AT HANSARD (08KA004)	2	7	10	13	14	15	18	20	19	19
	FRASER RIVER AT SHELLEY (08KB001)	2	6	9	9	12	13	15	17	19	15
	FRASER RIVER NEAR MARGUERITE (08MC018)	1	4	6	7	9	10	10	12	14	14
	FRASER RIVER AT HOPE (08MF005)	1	3	4	5	5	6	6	6	8	9
	NECHAKO RIVER AT ISLE PIERRE (08JC002)	1	2	4	7	6	6	6	8	9	9
	QUESNEL RIVER NEAR QUESNEL (08KH006)	7	7	6	8	14	16	17	16	14	14
	LILLOOET RIVER NEAR PEMBERTON (08MG005)	6	11	17	20	21	23	24	28	32	35
Thomp-	NORTH THOMPSON RIVER AT MCLURE (08LB064)	1	5	8	10	13	13	15	18	20	20
son	SOUTH THOMPSON RIVER AT CHASE (08LE031)	0	2	3	4	4	5	6	7	8	9
	NICOLA RIVER NEAR SPENCES BRIDGE (08LG006)	6	15	20	20	20	23	29	34	42	47
	THOMPSON RIVER NEAR SPENCES BRIDGE (08LF051)	1	3	4	5	6	6	7	7	9	10
Skeena-	NASS RIVER ABOVE SHUMAL CREEK (08DB001)	2	8	15	19	19	20	20	23	25	24
Nass	BULKLEY RIVER AT QUICK (08EE004)	3	10	13	12	12	13	15	15	17	20
	SKEENA RIVER AT USK (08EF001)	2	7	11	12	13	15	16	18	19	20

How dose the CLEVER Model work?

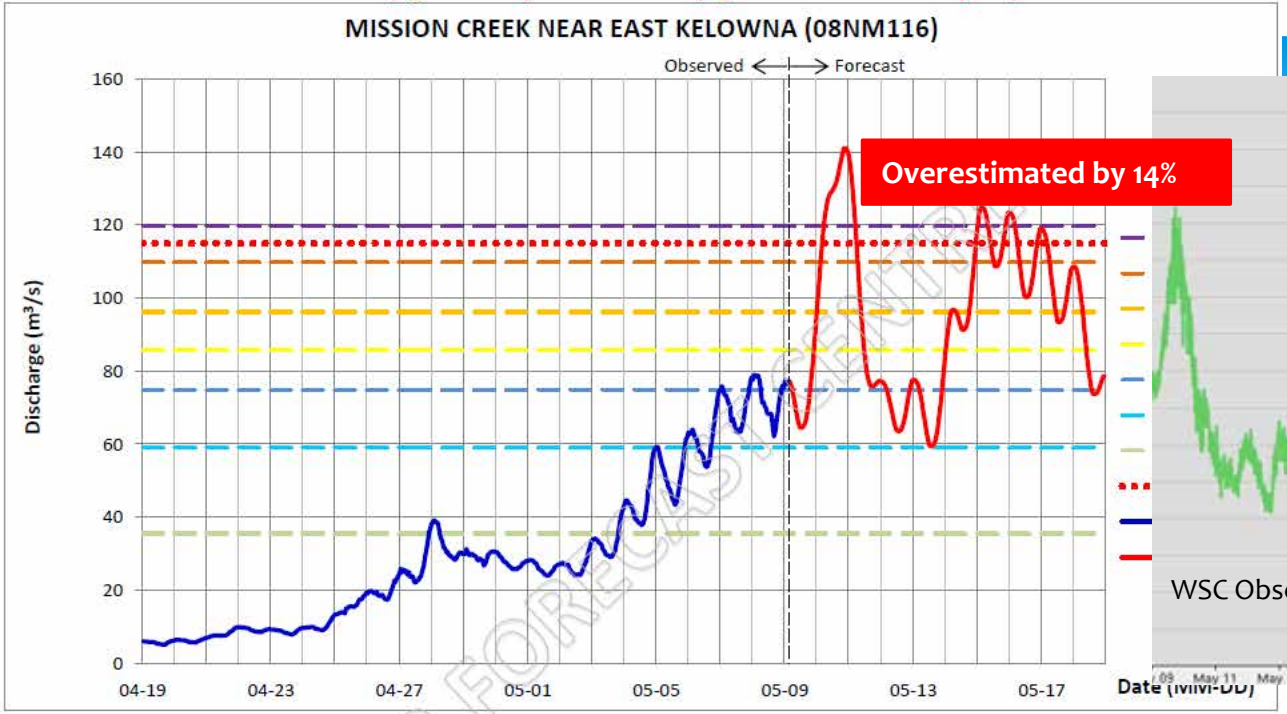


How is the CLEVER Model working in 2018?



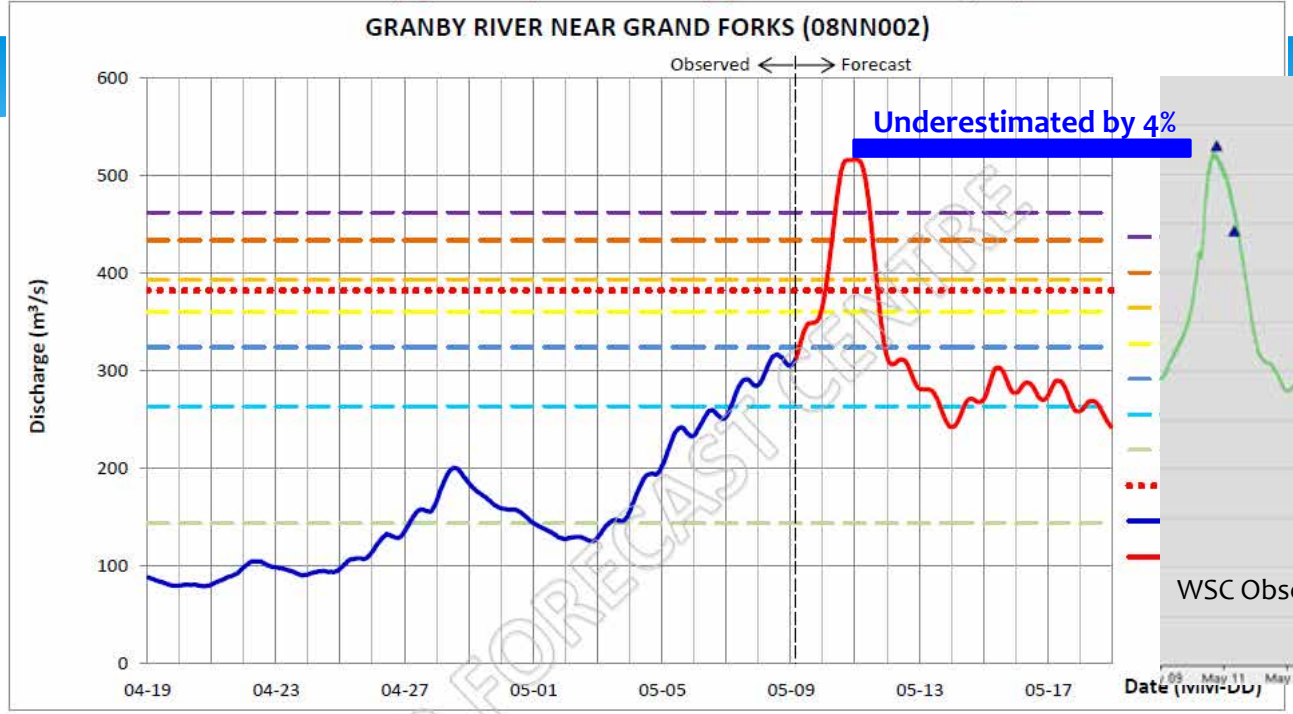
On May 09, 2018, the CLEVER Model forecasts about 200 year return period floods for the south interior for the next day, May 10, 2018

BRITISH COLUMBIA River Forecast Centre



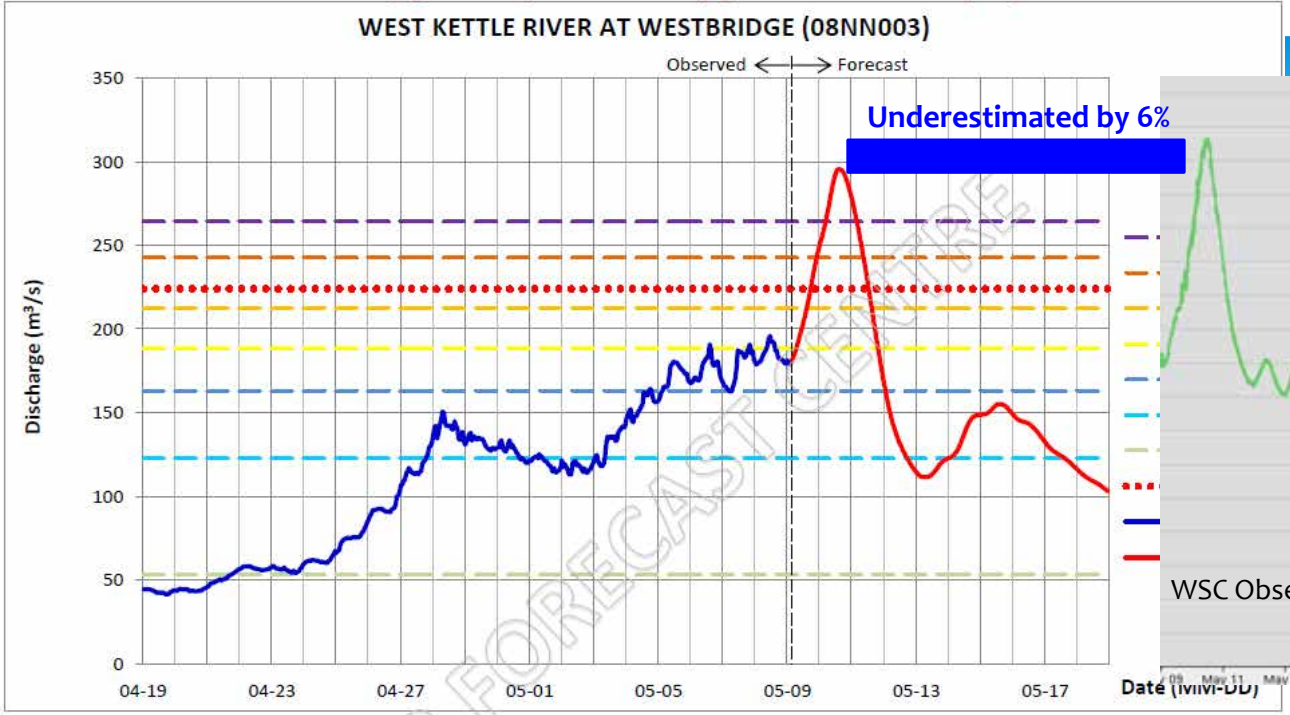
Reading at 07 AM (m^3/s) Wed	Forecast Daily Discharge (m^3/s): MAX / AVERAGE / MIN									
	Wed	Thu	Fri	Sat	Sun	Mon	Tue	Wed	Thu	Fri
2018-05-09	2018-05-09	2018-05-10	2018-05-11	2018-05-12	2018-05-13	2018-05-14	2018-05-15	2018-05-16	2018-05-17	2018-05-18
	91.8	141.2	138.6	77.3	80.8	116.0	124.9	123.5	119.1	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)



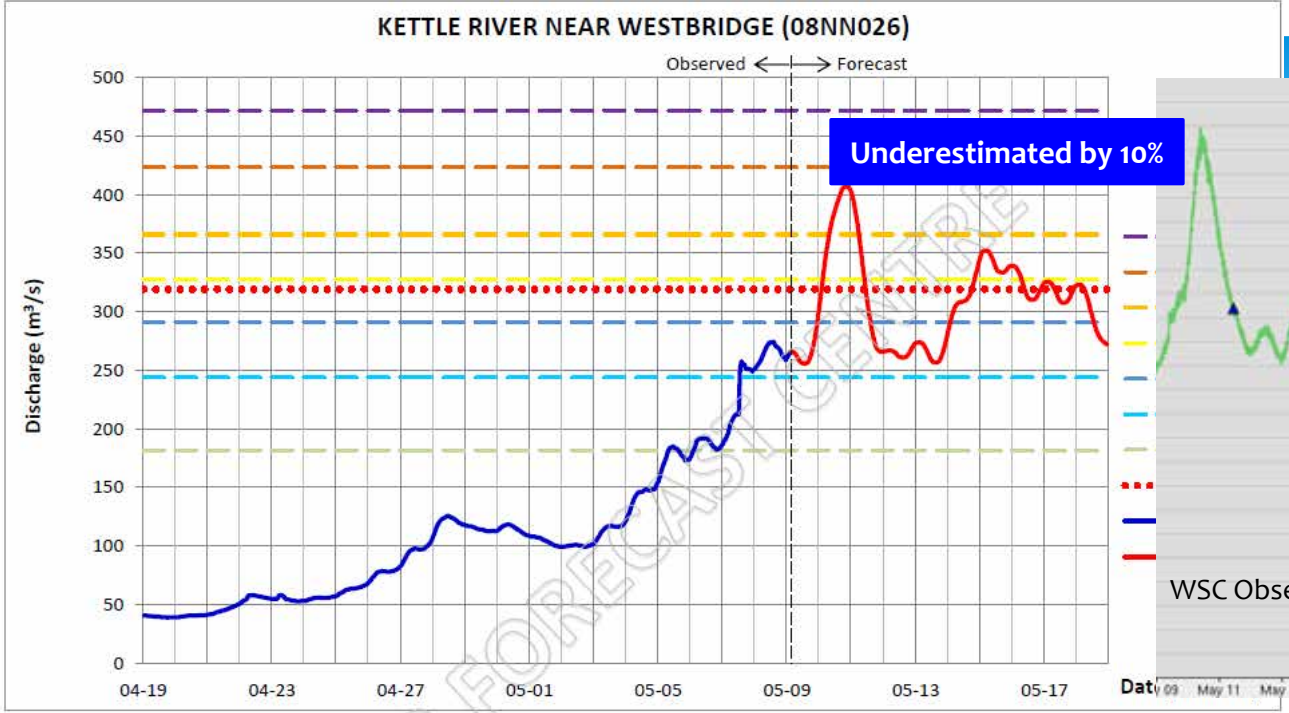
Reading at 07 AM (m^3/s) Wed	Forecast Daily Discharge (m^3/s): MAX / AVERAGE / MIN									
	Wed	Thu	Fri	Sat	Sun	Mon	Tue	Wed	Thu	Fri
2018-05-09	2018-05-09	2018-05-10	2018-05-11	2018-05-12	2018-05-13	2018-05-14	2018-05-15	2018-05-16	2018-05-17	2018-05-18
	363.4	516.1	516.3	311.7	280.9	270.7	302.9	287.2	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

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



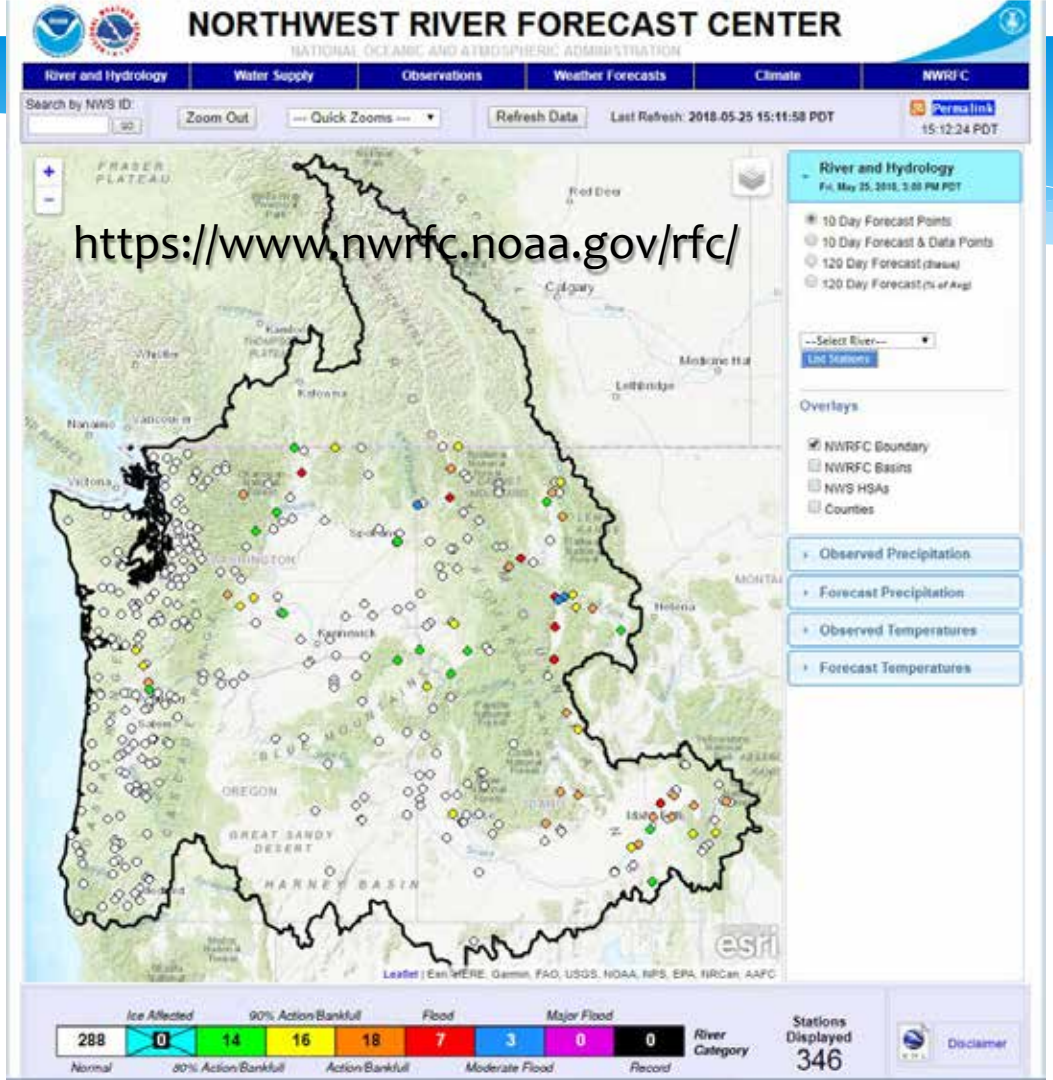
Reading at 07 AM (m^3/s) Wed	Forecast Daily Discharge (m^3/s): MAX / AVERAGE / MIN									
	Wed	Thu	Fri	Sat	Sun	Mon	Tue	Wed	Thu	Fri
	2018-05-09	2018-05-10	2018-05-11	2018-05-12	2018-05-13	2018-05-14	2018-05-15	2018-05-16	2018-05-17	2018-05-18
	247.0	295.4	277.6	167.1	122.4	148.6	155.1	148.9	132.4	115.9
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

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



Reading at 07 AM (m^3/s)	Forecast Daily Discharge (m^3/s): MAX / AVERAGE / MIN									
Wed	Wed	Thu	Fri	Sat	Sun	Mon	Tue	Wed	Thu	Fri
2018-05-09	2018-05-09	2018-05-10	2018-05-11	2018-05-12	2018-05-13	2018-05-14	2018-05-15	2018-05-16	2018-05-17	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

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



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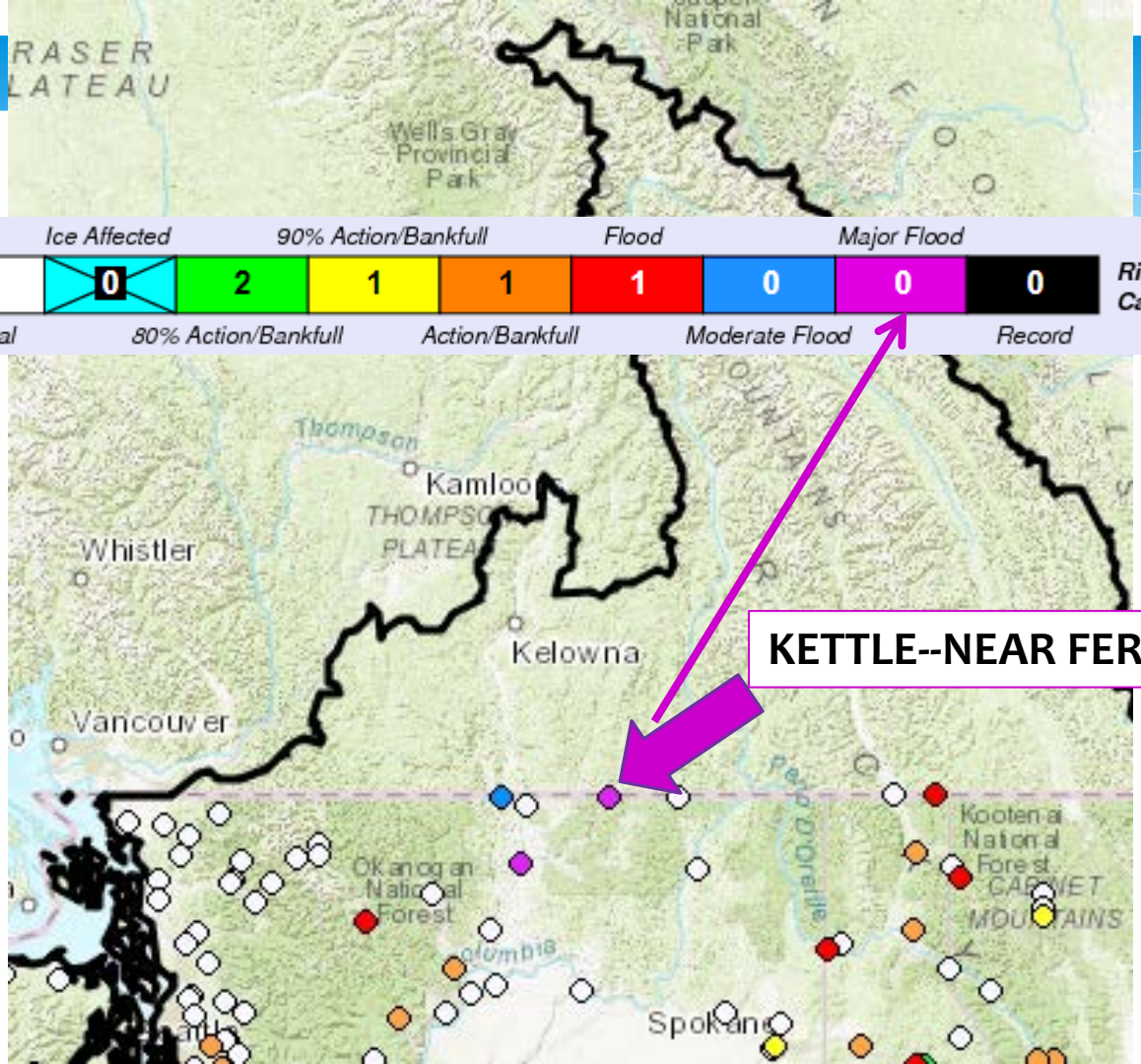
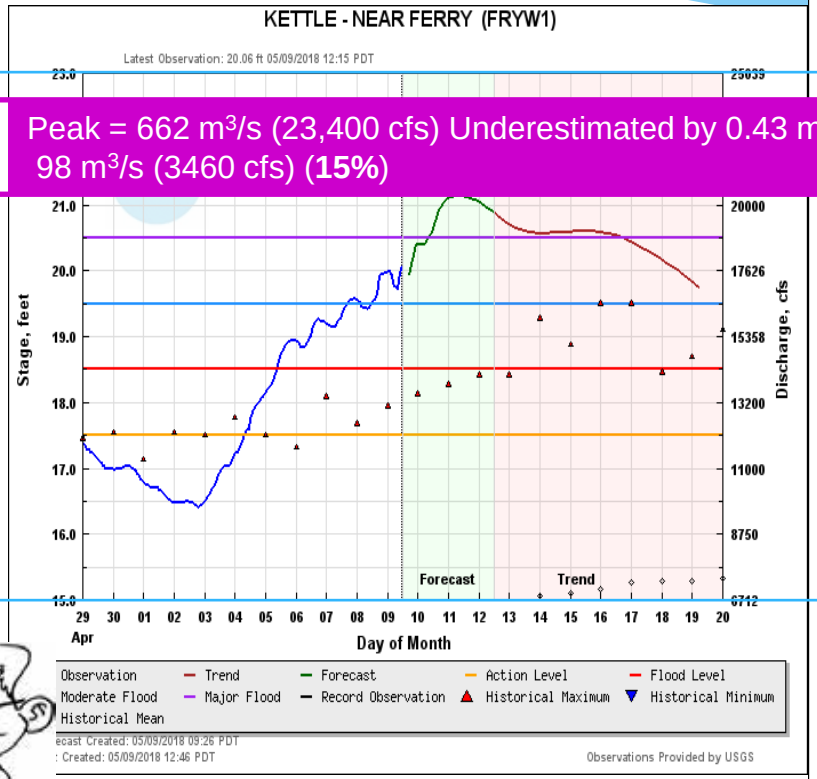
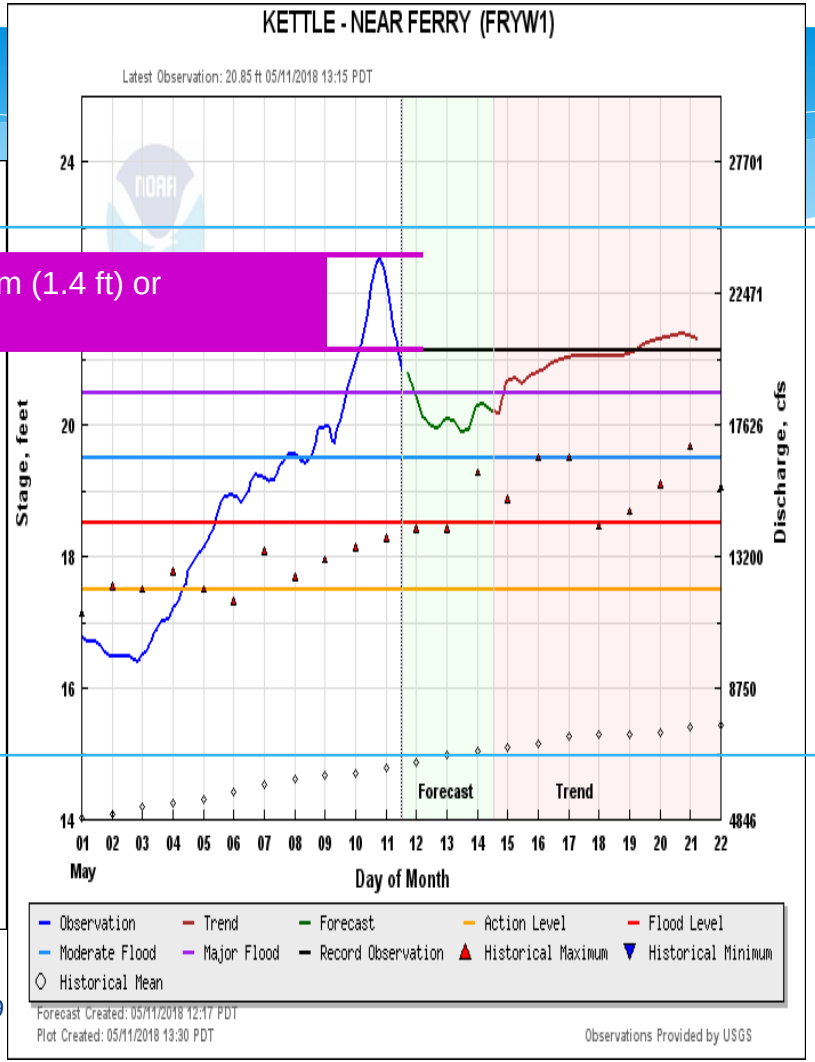


CLEVER Model

BRITISH COLUMBIA River Forecast Centre





Peak = 662 m³/s (23,400 cfs) Underestimated by 0.43 m (1.4 ft) or 98 m³/s (3460 cfs) (**15%**)

BRITISH COLUMBIA River Forecast Centre

Is the CLEVER Model useful?

Tue 2018-05-15 11:12 AM

"Although I'm just across the floor today and not at PECC/PREOC …, just want to thank you again … on behalf of everyone from the 'receiving end' of the valuable information, for this super-human work you're doing. "

"There is so much value in getting this information before noon everyday because then, and only then, the real planning can start across the province. When I was at the PECC I was like a kid waiting anxiously for my gift, and everyday around this time I keep hitting refresh button waiting for the forecast to appear! That's how critical this information…"

-- Rudy Sung, M.A.Sc., P.Eng.
Senior Flood Safety Engineer
Ministry of Forests, Lands, Natural Resource Operations and Rural Development

Is the CLEVER Model useful?

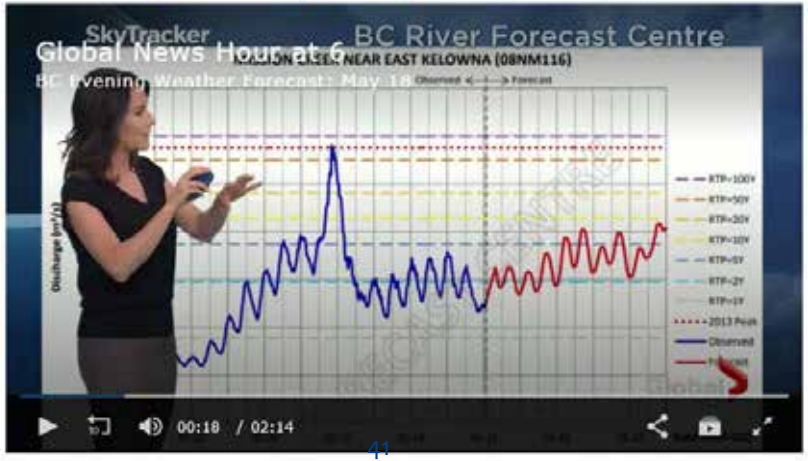
CLEVER Model in Local TV news

WEATHER

B.C.'s flood forecast is looking better, but we're still not out of the woods

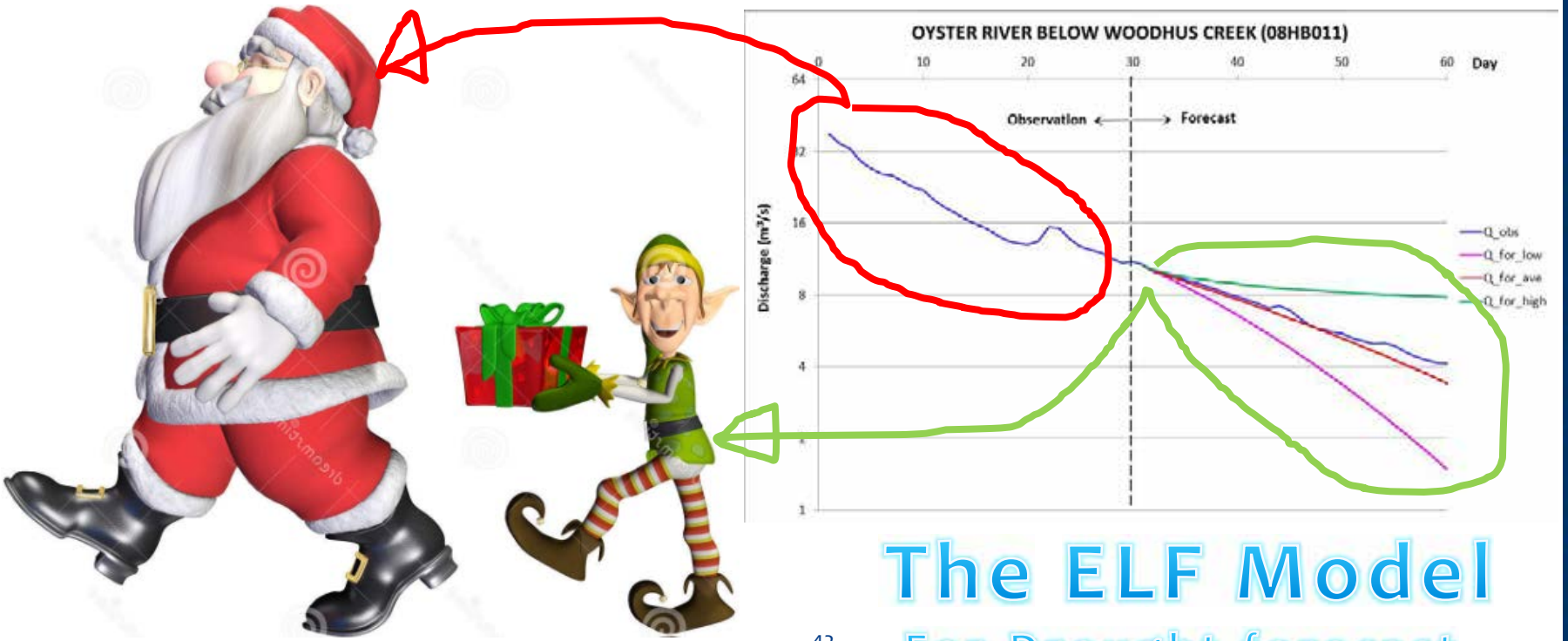
By Kristi Gordon
Senior Meteorologist Global News

Comments 1 | Facebook 79 | Twitter | Email | Print | ...



The Friday, May 18, 2018 evening weather forecast for Vancouver, British Columbia and the surrounding area.

What's next?



The ELF Model

For Drought forecast

Thank you!
Questions?

Charles Luo, Ph.D., P.Eng.
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Water Management Branch, Resource Stewardship Division
BC Ministry of Forests, Lands, Natural Resource Operations
and Rural Development
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URL: http://gov.bc.ca/riverforecast