



From Snow to Flow: Statistical Forecasting of Critical Flows

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<http://wcc.sc.egov.usda.gov/nwcc/>



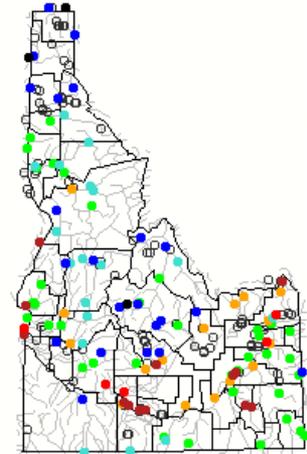
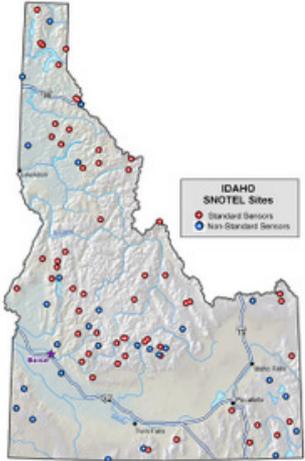
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Snow to Flow

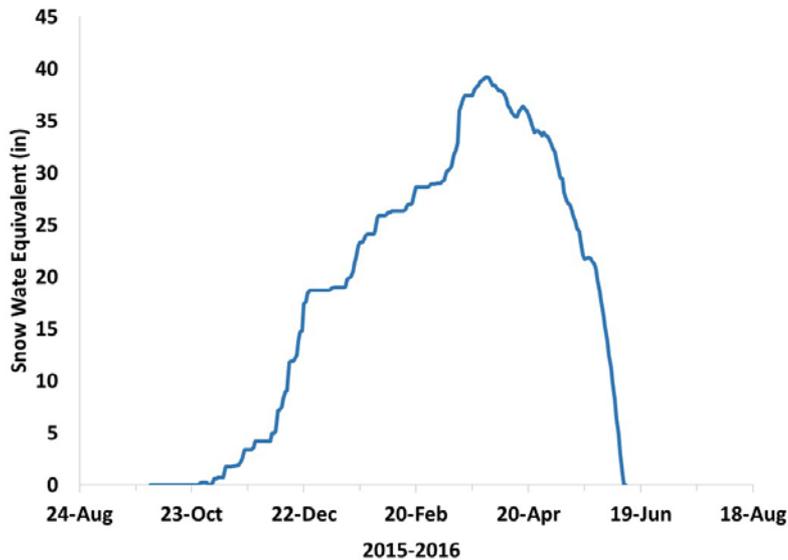
How are patterns in snowmelt and streamflow related?

Anecdotal "Rules of Thumb"

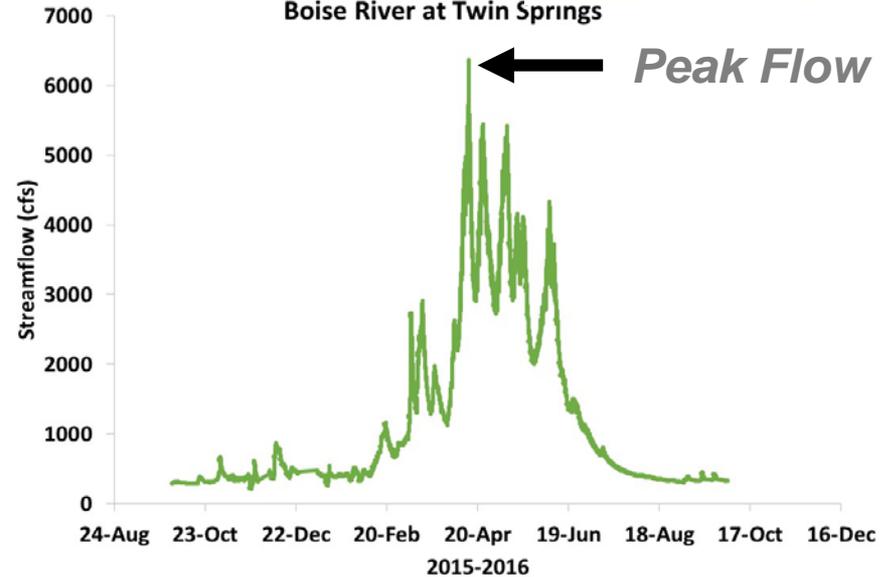
Statistical Tools



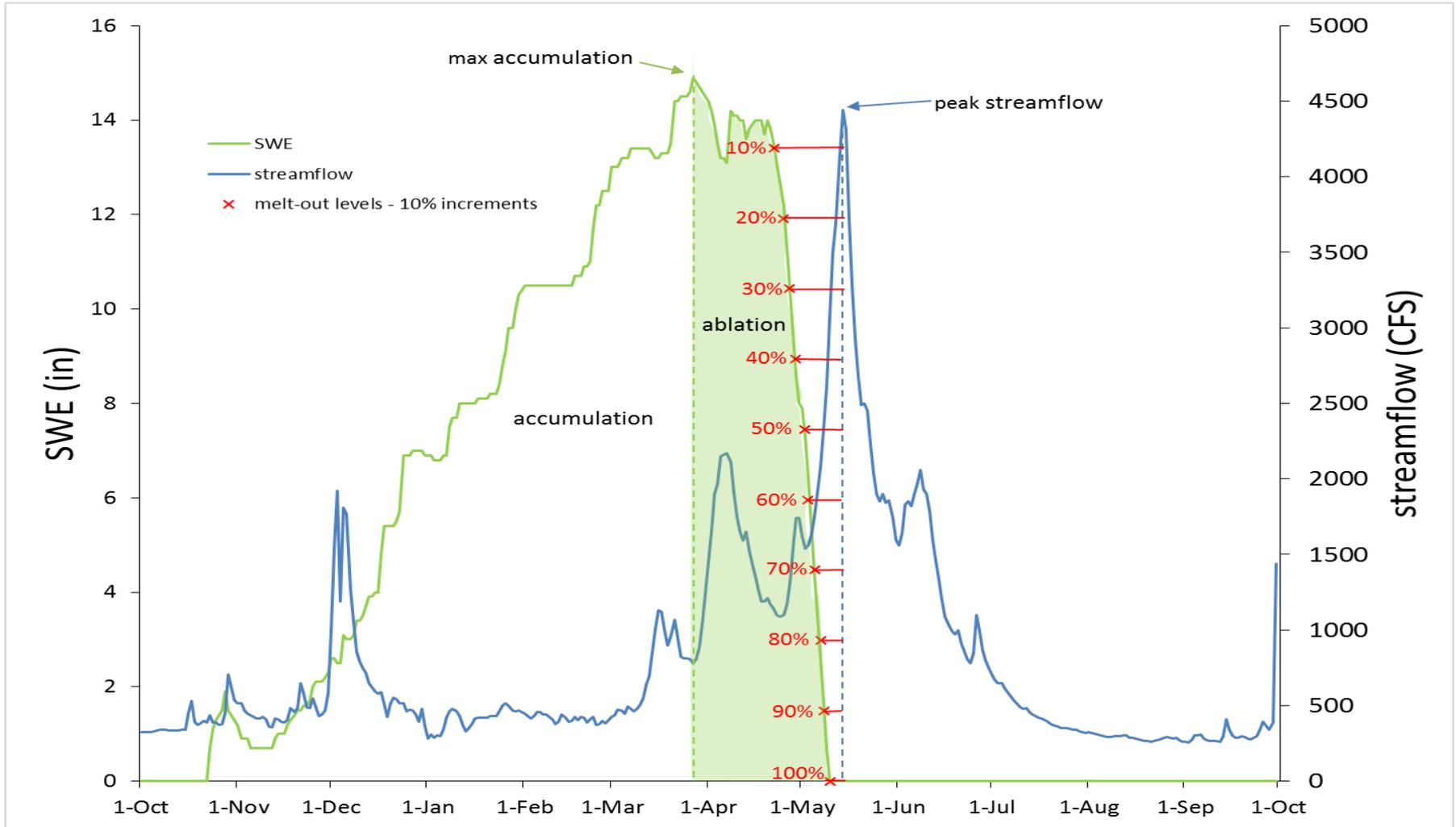
Trinity Mnt SNOTEL



USGS
Boise River at Twin Springs

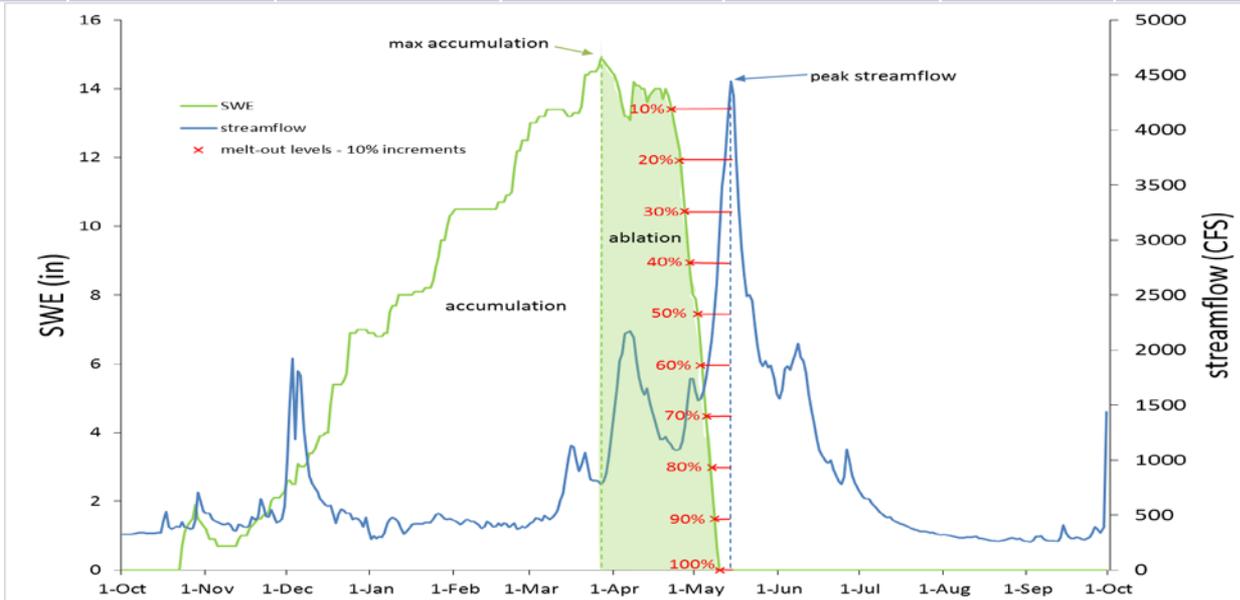


When Will Peak Flow Occur?

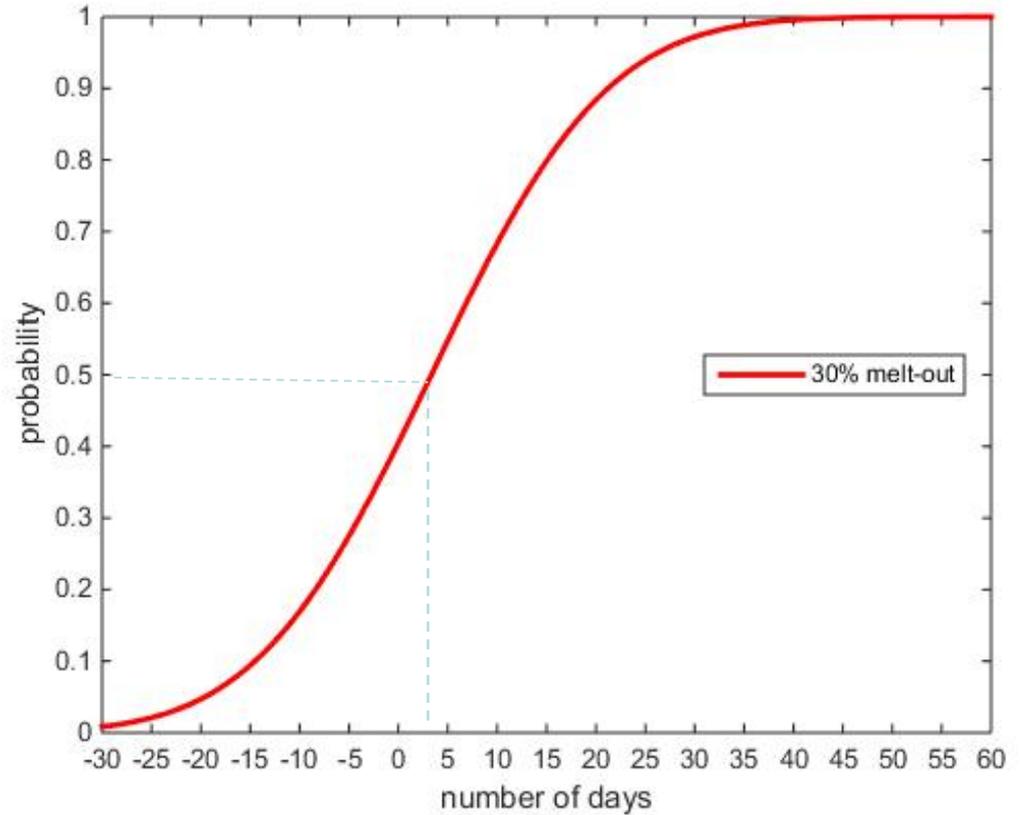
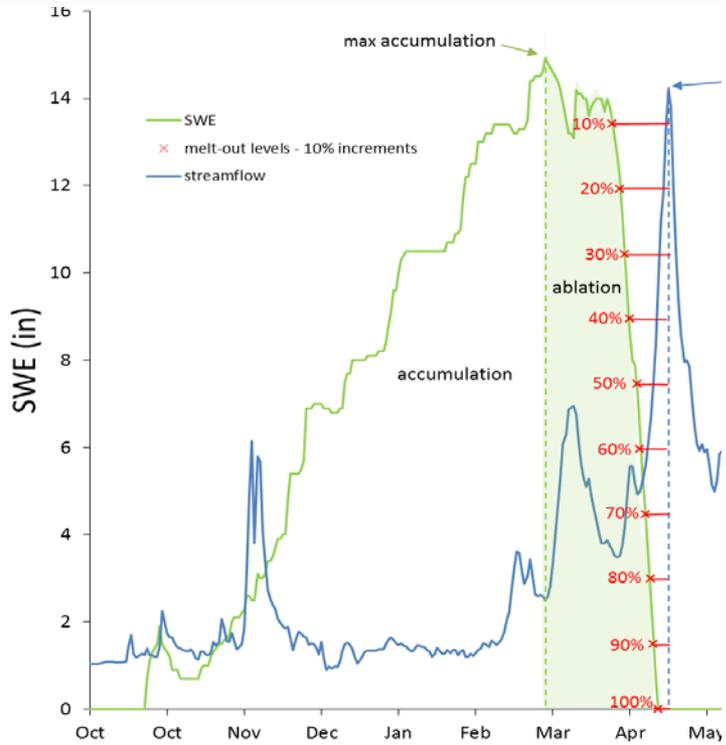


Lag Analysis

Year	Peak SWE	Peak Q	Date Peak Q	10% Melt Lag days	20% Melt Lag days	...	80% Melt Lag days	90% Melt Lag days
1985	35.8	4230	4-May	3	-3		-37	-39
1986	54.3	9060	31-May	5	1		-23	-26
...								
2013	29.7	4440	14-May	9	5		-12	-15
2014	37	5890	28-May	14	9		-10	-12



Lag to Peak Statistics





Results

- **What melt ratio typically corresponds to peak flow?**
 - Update the $\frac{1}{2}$ melt relationships
- **Based on TODAYs meltout, what is the probability that peak flow will occur in X number of days?**
 - Kara' statistics



SF BOISE RIVER BASIN SUMMARY USING FEATHERVILLE STREAMGAGE AND VIENNA MINE SNOTEL

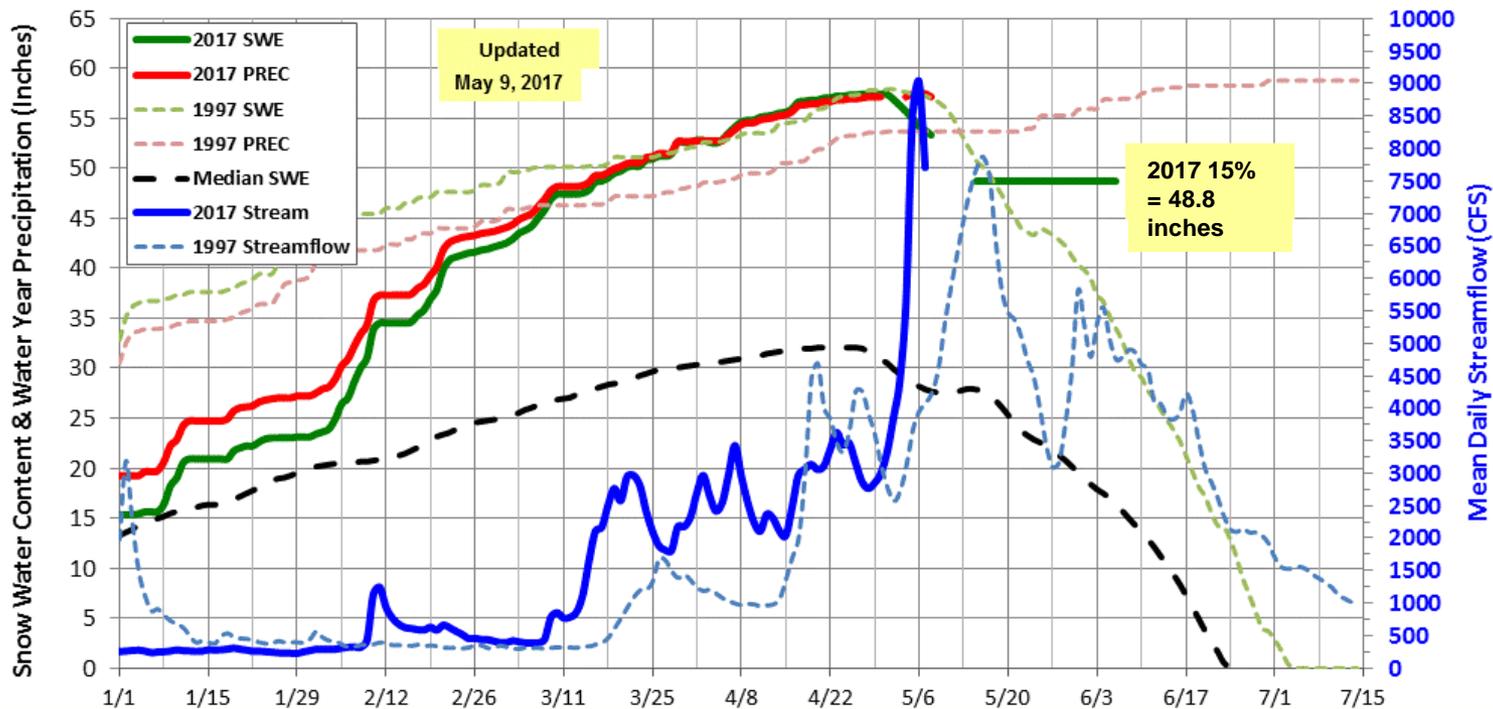
On average, peak streamflow for the SF Boise River nr Featherville, Idaho occurs when Vienna Mine SNOTEL is between **13 and 35%** melted.

Max SWE Category	Max SWE Magnitude (inches)	Number of Years in Analysis	Average percent melted at time of peak streamflow
Below average	<27.5	8	35
Average	27.5 - 41.9	17	34
Above average	>41.9	8	13

note - this analysis uses all years available and did not eliminate potential non-snowmelt peaks

The average percent meltout at the time of peak streamflow, based on all 33 years available, is 29% melted.

2017 & 1997 Vienna Mine SNOTEL and SF Boise River near Featherville



In ABOVE average years, the SF Boise River has an increase or the snowmelt peak flow occurs when Vienna Mine is about 15% melted. (2017)



NORTH AND MIDDLE FORKS BOISE RIVER BASIN SUMMARY USING TWIN SPRINGS STREAMGAGE AND ATLANTA SUMMIT SNOTEL

On average, peak streamflow for the Boise River nr Twin Springs, Idaho occurs when Atlanta Summit SNOTEL is between **22 and 62%** melted.

Max SWE Category	Max SWE Magnitude (inches)	Number of Years in Analysis	Average percent melted at time of peak streamflow
Below average	<22.7	8	62
Average	22.7 - 37.6	17	43
Above average	>37.6	8	22

note - this analysis uses all years available and did not eliminate potential non-snowmelt peaks, however, elimination of non-snowmelt peaks did not change the average percent melted

The average percent meltout at the time of peak streamflow, based on all 33 years available, is 45% melted.

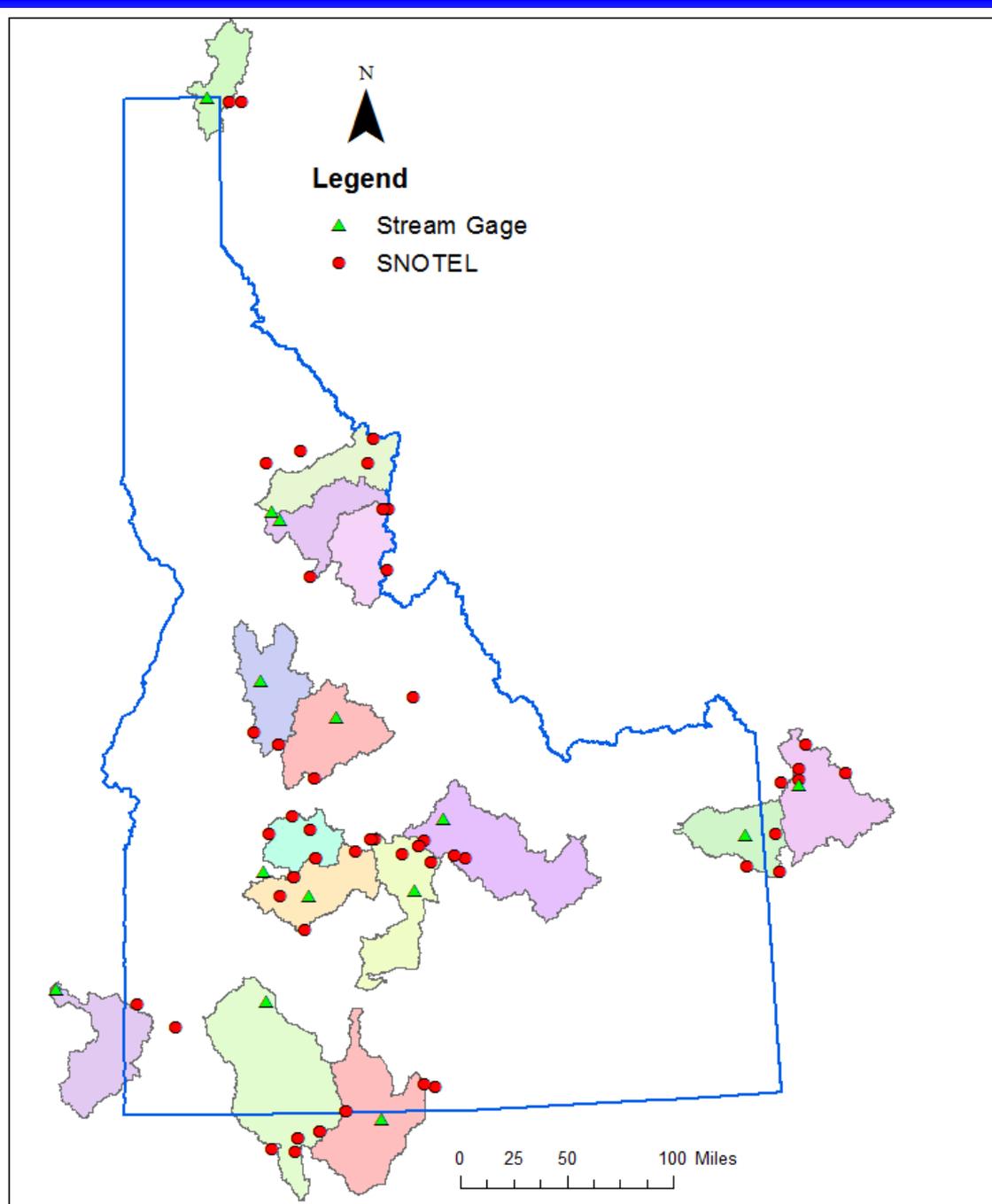




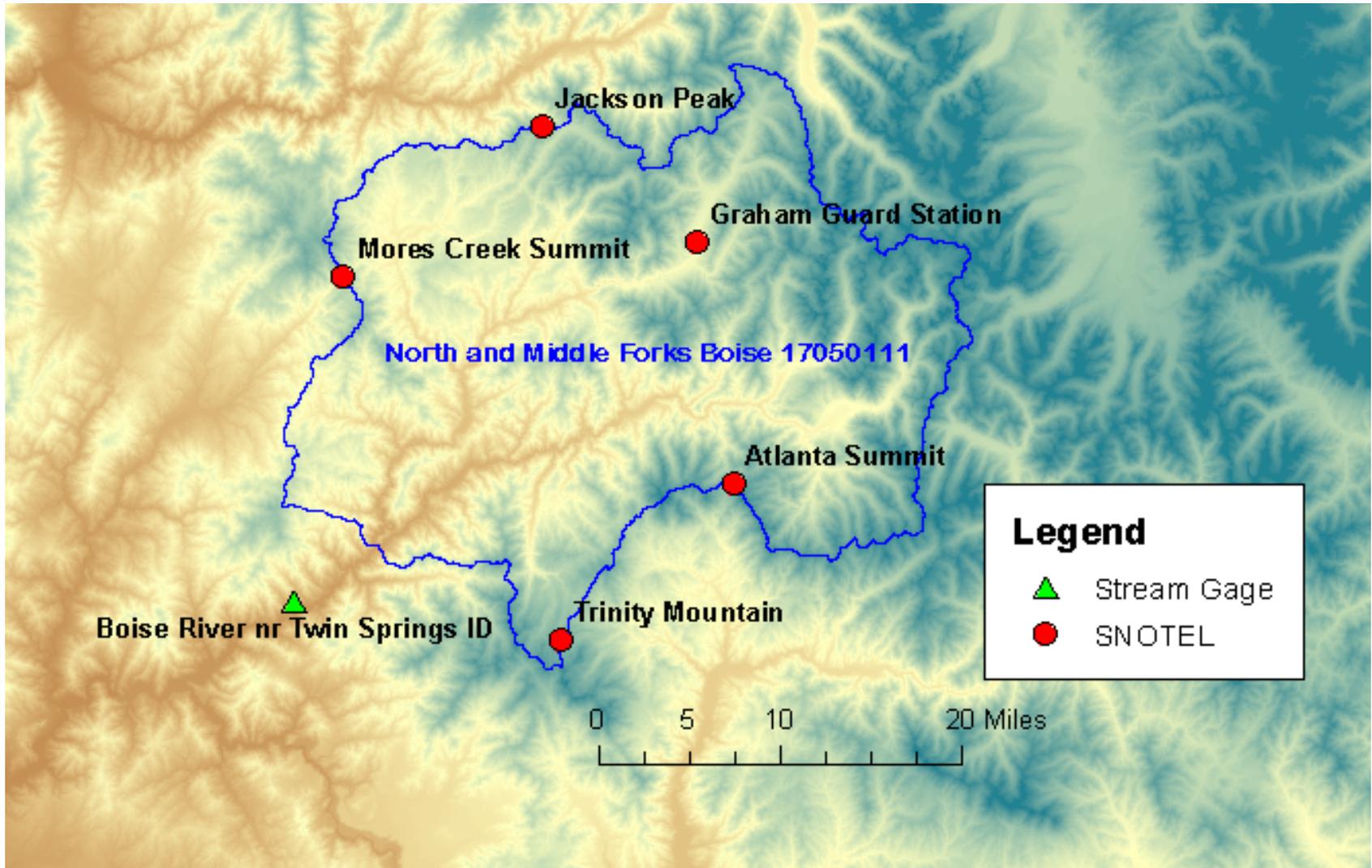
Basin / Streamgage	Big Lost River at Howell Ranch nr Chilly	Big Wood River at Hailey	NMF Boise River nr Twin Springs	SF Boise nr Featherville	Bruneau River nr Hot Springs	Bruneau River nr Hot Springs	Lochsa River nr Lowell	Moyie River at Eastport	Owyhee River nr Rome	Salmon Falls Creek nr San Jacinto NV	MF Salmon River at MF Lodge nr Yellow Pine	SF Salmon River nr Krassel RS	Selway River nr Lowell	Teton River ab South Leigh Creek nr Driggs	Snake River ab Jackson Lake at Flagg Ranch WY
SNOTEL	Lost-Wood Divide	Galena Summit	Atlanta Summit	Vienna Mine	Pole Creek RS	Bear Creek	Lolo Pass	Hawkins Lake	South Mtn	Pole Creek RS	Banner Summit	Big Creek	Twin Lakes	Phillips Bench	Lewis Lake
Current melt-out (%)	40	20	20	10	20	30	50	20	100	30	30	20	20	20	20
Probability (# of days)															
<0.03	2	-3	-75	-26	-130	-128	-78	-47	-128	-91	-11	-15	-24	-47	1
0.1	3	3	-11	-5	-61	-50	-13	-18	-85	-65	-1	4	-4	8	4
0.2	6	7	-4	1	-19	-18	-3	-12	-61	-31	7	5	0	14	7
0.3	10	10	1	4	-2	-4	2	-8	-56	-19	10	8	2	19	9
0.4	12	12	3	5	3	1	3	-5	-49	-15	11	9	4	22	11
0.5	18	18	6	8	5	6	5	-3	-43	-10	13	10	4	25	13
0.6	24	20	8	10	7	7	5	-1	-35	-6	14	14	6	33	14
0.7	28	23	10	11	11	12	9	2	-31	-1	17	15	8	37	18
0.8	34	26	15	16	18	22	11	4	-25	5	20	18	14	42	20
0.9	39	40	22	20	23	31	21	9	-8	9	28	28	18	45	26
>0.98	54	56	60	33	43	55	28	27	15	26	49	44	31	46	37
Max SWE	37.7	36.2	49.5	57.8	25.1	25.6	30.3	34.4	19.5	25.1	41	28.2	38.7	42	48.7
Max SWE date	21-Apr	4-May	30-Apr	5-May	1-May	1-May	16-Mar	4-May	9-Mar	1-May	19-Apr	30-Apr	1-May	3-May	2-May



Basin / Streamgage	Big Lost River at Howell Ranch nr Chilly	Big Wood River at Hailey	NMF Boise River nr Twin Springs	SF Boise nr Featherville	Bruneau River nr Hot Springs	Bruneau River nr Hot Springs	Lochsa River nr Lowell	Moyie River at Eastport	Owyhee River nr Rome	Salmon Falls Creek nr San Jacinto NV	MF Salmon River at MF Lodge nr Yellow Pine	SF Salmon River nr Krassel RS	Selway River nr Lowell	Teton River ab South Leigh Creek nr Driggs	Snake River ab Jackson Lake at Flagg Ranch WY
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Current melt-out (%)	40	20	20	10	20	30	50	20	100	30	30	20	20	20	20
Chance (date)															
<0.03	13-May	8-May	25-Feb	15-Apr	1-Jan	3-Jan	22-Feb	25-Mar	3-Jan	9-Feb	30-Apr	26-Apr	17-Apr	25-Mar	12-May
0.1	14-May	14-May	30-Apr	6-May	11-Mar	22-Mar	28-Apr	23-Apr	15-Feb	7-Mar	10-May	15-May	7-May	19-May	15-May
0.2	17-May	18-May	7-May	12-May	22-Apr	23-Apr	8-May	29-Apr	11-Mar	10-Apr	18-May	16-May	11-May	25-May	18-May
0.3	21-May	21-May	12-May	15-May	9-May	7-May	13-May	3-May	16-Mar	22-Apr	21-May	19-May	13-May	30-May	20-May
0.4	23-May	23-May	14-May	16-May	14-May	12-May	14-May	6-May	23-Mar	26-Apr	22-May	20-May	15-May	2-Jun	22-May
0.5	29-May	29-May	17-May	19-May	16-May	17-May	16-May	8-May	29-Mar	1-May	24-May	21-May	15-May	5-Jun	24-May
0.6	4-Jun	31-May	19-May	21-May	18-May	18-May	16-May	10-May	6-Apr	5-May	25-May	25-May	17-May	13-Jun	25-May
0.7	8-Jun	3-Jun	21-May	22-May	22-May	23-May	20-May	13-May	10-Apr	10-May	28-May	26-May	19-May	17-Jun	29-May
0.8	14-Jun	6-Jun	26-May	27-May	29-May	2-Jun	22-May	15-May	16-Apr	16-May	31-May	29-May	25-May	22-Jun	31-May
0.9	19-Jun	20-Jun	2-Jun	31-May	3-Jun	11-Jun	1-Jun	20-May	3-May	20-May	8-Jun	8-Jun	29-May	25-Jun	6-Jun
>0.98	4-Jul	6-Jul	10-Jul	13-Jun	23-Jun	5-Jul	8-Jun	7-Jun	26-May	6-Jun	29-Jun	24-Jun	11-Jun	26-Jun	17-Jun



Middle Fork Boise River



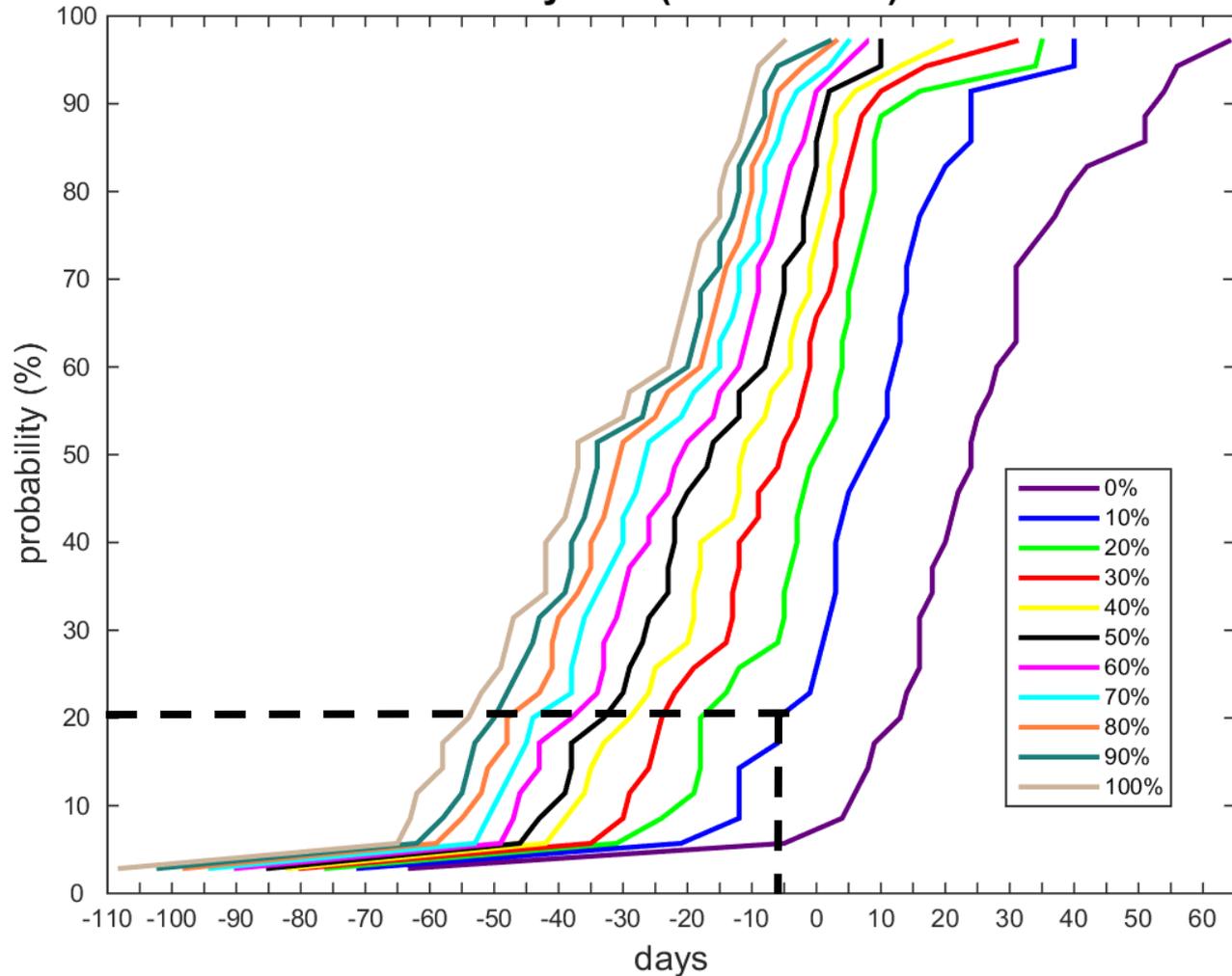


Descriptive Statistics

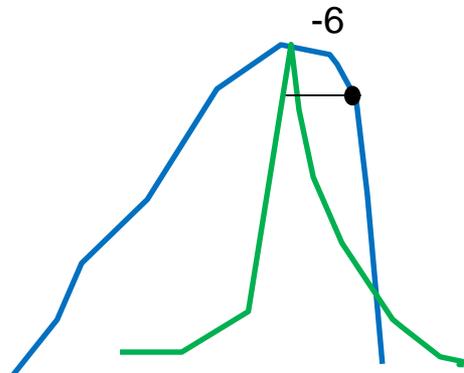
Year	Date of Peak Q	Date of Max SWE	Date of Meltout	Peak Q (CFS)	Max SWE (in)	SWE Level on day of Peak Q (in)	Percent of Max SWE Melted at Time of Peak Q (%)	Amount of Max SWE Melted at Peak Q (in)	Days of Melt	Average Melt Rate (in/day)	Max Melt Rate (in/day)	Date Max Melt (WY day)	Melt (-3 days) (in)	Precip (-3 days) (in)	Cumulative Fall Precip (in)
1981	9-Jun	14-Apr	14-Jun	6130	27.5	1.7	94	25.8	61	-0.5	-1.9	249	3.3	3	4.8
1982	25-May	24-Apr	27-Jul	7980	63	54.2	14	8.8	94	-0.7	-2.6	290	1.9	0.1	15.5
1983	29-May	8-May	15-Jul	10400	61.1	55.8	9	5.3	68	-0.9	-2.2	286	2.5	0.1	14.6
1984	15-May	11-May	8-Jul	9780	46.1	44	5	2.1	58	-0.8	-2.6	276	2	0.6	16.3
1985	4-May	31-Mar	15-Jun	4230	35.8	30	16	5.8	76	-0.5	-1.8	256	2.2	0.1	18.1
1986	31-May	4-May	30-Jun	9060	54.3	42	23	12.3	57	-1	-1.9	268	4.6	0.1	12.4
1987	1-May	31-Mar	16-May	3140	22.5	13.2	41	9.3	46	-0.5	-1.5	226	2.5	0.5	5.5
1988	25-May	13-Apr	9-Jun	3170	29.5	13.4	55	16.1	57	-0.5	-1.8	248	4.1	0	4.6
1989	22-Apr	6-Apr	23-Jun	5720	44.5	40.8	8	3.7	78	-0.6	-1.9	262	1.1	0.1	14.8
1990	Missing SNOTEL or streamflow data														
1991	12-Jun	15-May	23-Jun	3220	29.9	12.2	59	17.7	39	-0.8	-1.5	262	3.7	0	6.8
1992	8-May	24-Apr	20-May	2300	20.7	10.9	47	9.8	26	-0.8	-1.5	231	3	0	12
1993	15-May	9-May	2-Jul	8330	52.8	46.8	11	6	54	-1	-1.9	270	4.3	0.1	9.7
1994	13-May	12-Apr	31-May	2890	22	10.5	52	11.5	49	-0.5	-1.8	238	3.2	0	3.1
1995	5-Jun	12-May	12-Jul	6370	52.3	37.9	28	14.4	61	-0.9	-2.1	281	2.3	0.6	12.1
1996	16-May	8-May	4-Jul	9550	48.1	46.7	3	1.4	57	-0.9	-2.2	275	0.6	3.2	12.3
1997	17-May	27-Apr	8-Jul	10300	71.5	60.8	15	10.7	72	-1	-2.3	264	3.2	0	13.6
1998	27-May	20-Apr	4-Jul	6120	36	30.8	14	5.2	75	-0.5	-2	274	0.2	2.6	9.5
1999	26-May	17-Apr	7-Jul	8030	48.5	41.5	14	7	81	-0.6	-1.7	260	2.7	0	12.5
2000	25-May	1-Apr	15-Jun	4610	33.7	21.9	35	11.8	75	-0.5	-1.8	257	2.1	0	6.2
2001	16-May	15-Apr	26-May	3510	21.9	10.6	52	11.3	41	-0.5	-1.5	236	2.3	2.3	8.4
2002	15-Apr	20-Apr	19-Jun	7100	39.1	38.5	NaN	NaN	60	-0.7	-2	259	0.1	1.6	11.9
2003	30-May	14-May	22-Jun	8510	40.8	29.5	28	11.3	39	-1.1	-2.2	261	3.2	0.1	4.3
2004	6-Jun	3-Apr	15-Jun	3510	33.9	8.3	76	25.6	73	-0.5	-1.4	247	3.9	0	5.8
2005	20-May	25-Apr	18-Jun	6140	27.4	22.9	16	4.5	54	-0.5	-1.7	258	1.3	2.9	4.9
2006	20-May	26-Apr	28-Jun	10400	58.8	42.9	27	15.9	63	-0.9	-2.2	269	2.5	1.2	11.8
2007	13-May	25-Apr	4-Jun	3580	28.4	19.7	31	8.7	40	-0.7	-1.8	243	2.5	0	11.1
2008	19-May	3-May	30-Jun	9180	38.7	32	17	6.7	58	-0.7	-1.8	266	2.7	0	12.4
2009	20-May	7-May	26-Jun	6420	38.7	34.9	10	3.8	50	-0.8	-1.7	267	2.4	0.1	7.9
2010	5-Jun	15-Apr	25-Jun	9790	29.2	21.5	26	7.7	71	-0.4	-1.6	266	1.8	2.6	9.6
2011	15-May	6-May	12-Jul	10000	50.1	46.8	7	3.3	67	-0.8	-1.7	277	1.8	0.8	14.7
2012	27-Apr	9-Apr	24-Jun	12500	38.8	35.6	8	3.2	76	-0.5	-1.6	248	0.8	2.6	11.2
2013	14-May	22-Apr	2-Jun	4440	29.7	19	36	10.7	41	-0.7	-2	226	2.9	0	11.2
2014	28-May	7-Apr	11-Jun	5890	37	20.7	44	16.3	65	-0.6	-3.5	252	3.6	0	4.3
2015	10-Feb	14-Apr	29-May	3790	27.9	25.7	NaN	NaN	45	-0.6	-1.1	214	0	1.4	10.5

Trinity Mtn to Boise River at Twin Springs

Trinity Mtn (elev 7770 ft)



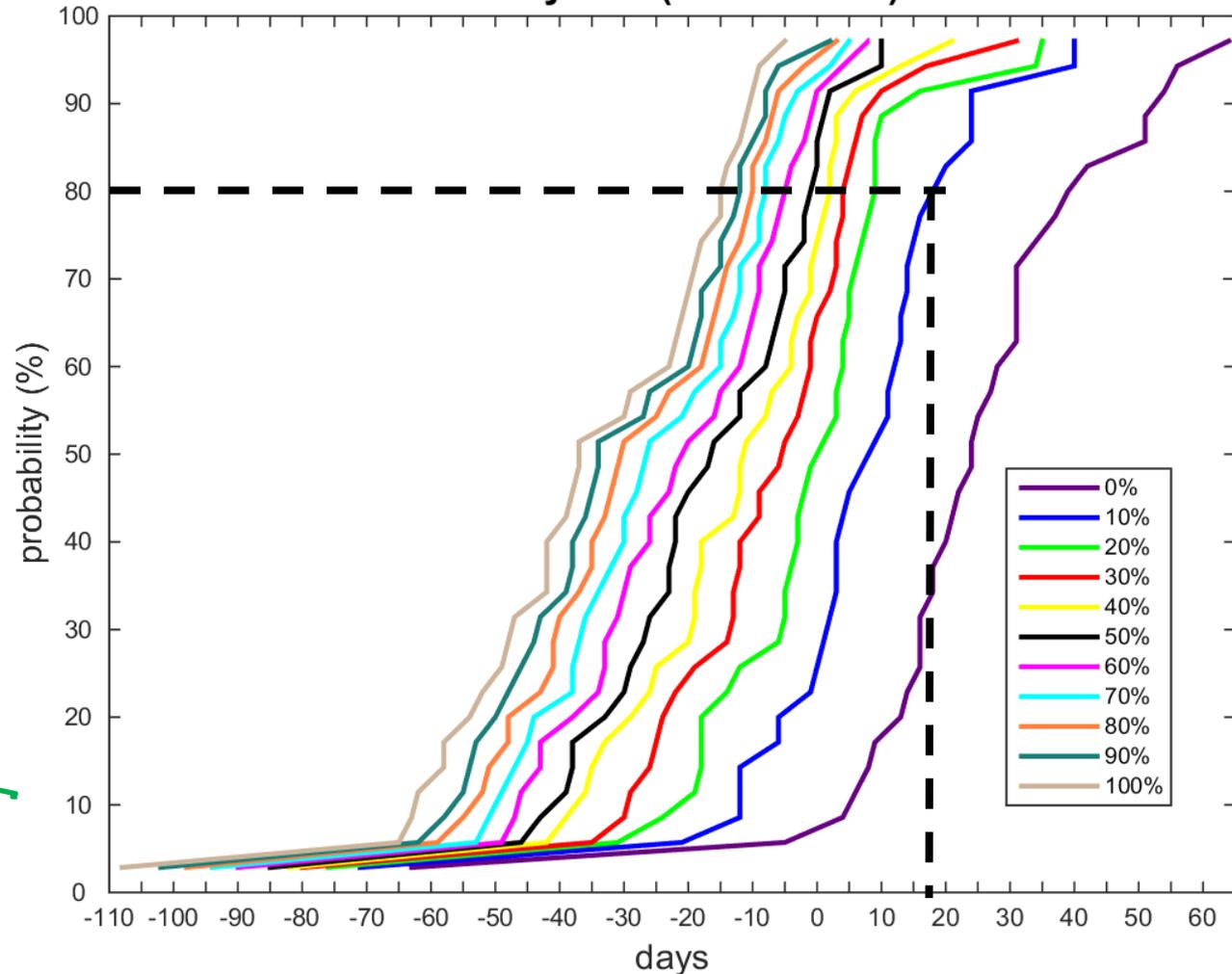
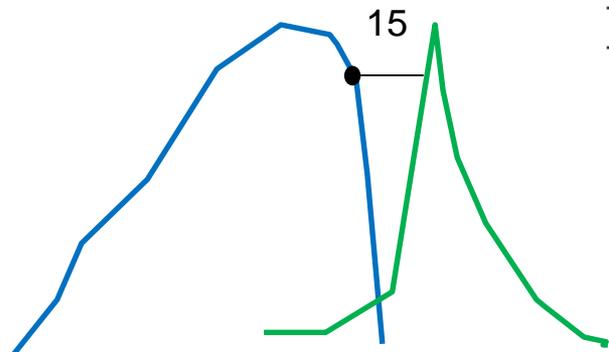
But 20% of the time peak flow happened 6 days ago



Trinity Mtn to Boise River at Twin Springs

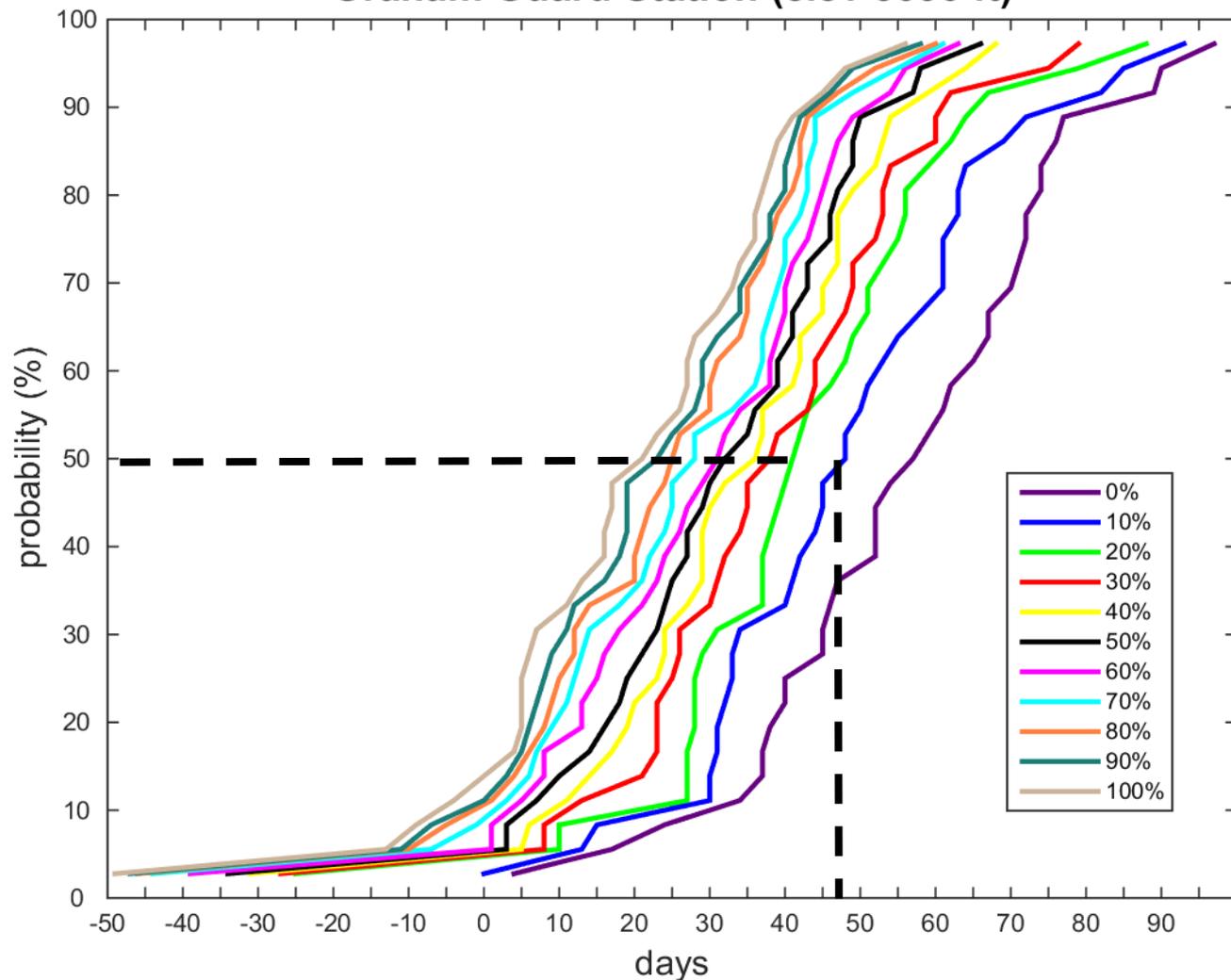
Trinity Mtn (elev 7770 ft)

And 20% of the time it will
take more than 18 days



Graham Guard to Boise River at Twin Springs

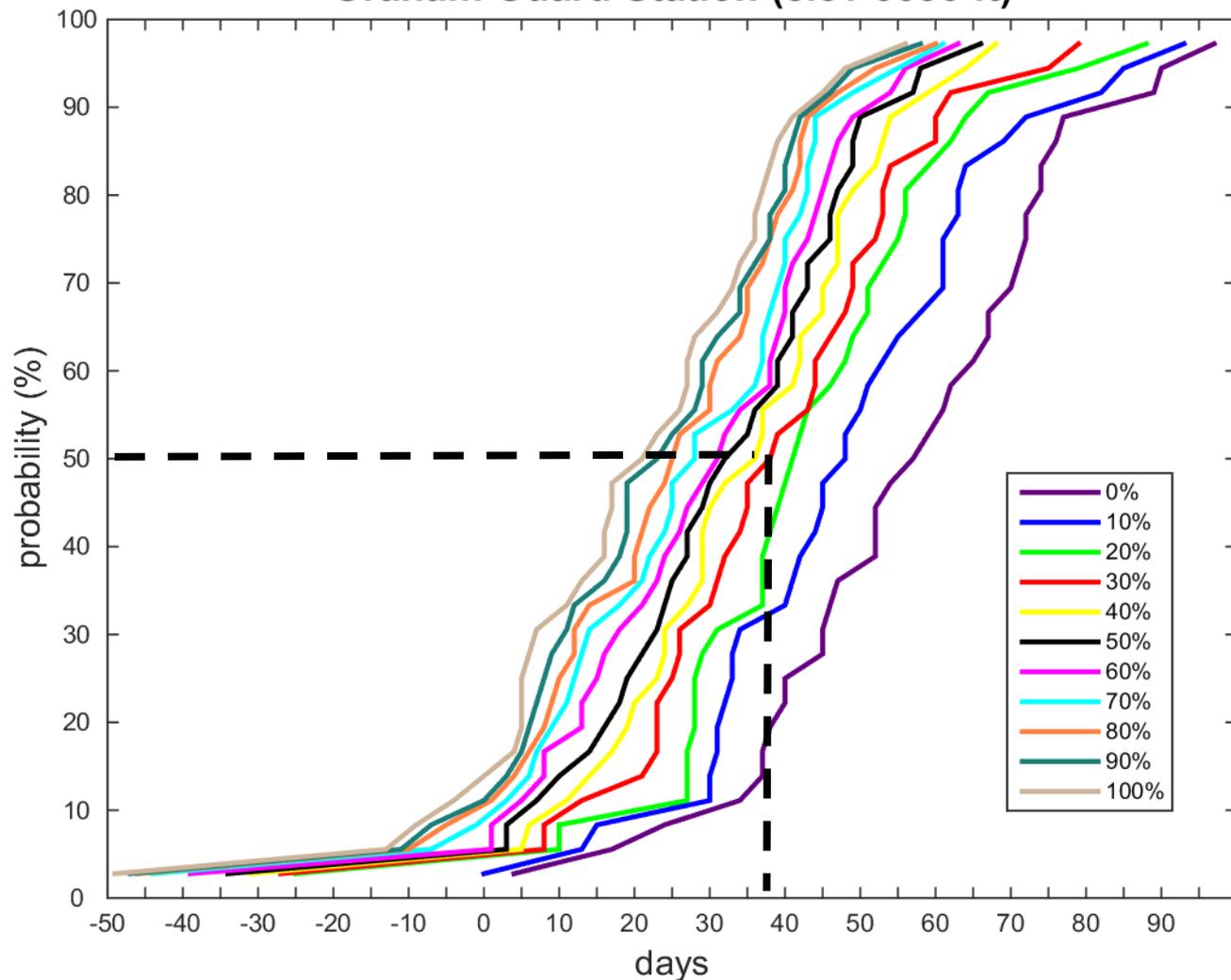
Graham Guard Station (elev 5690 ft)



When snow is 10% gone,
average time to peak is 47
days

Graham Guard to Boise River at Twin Springs

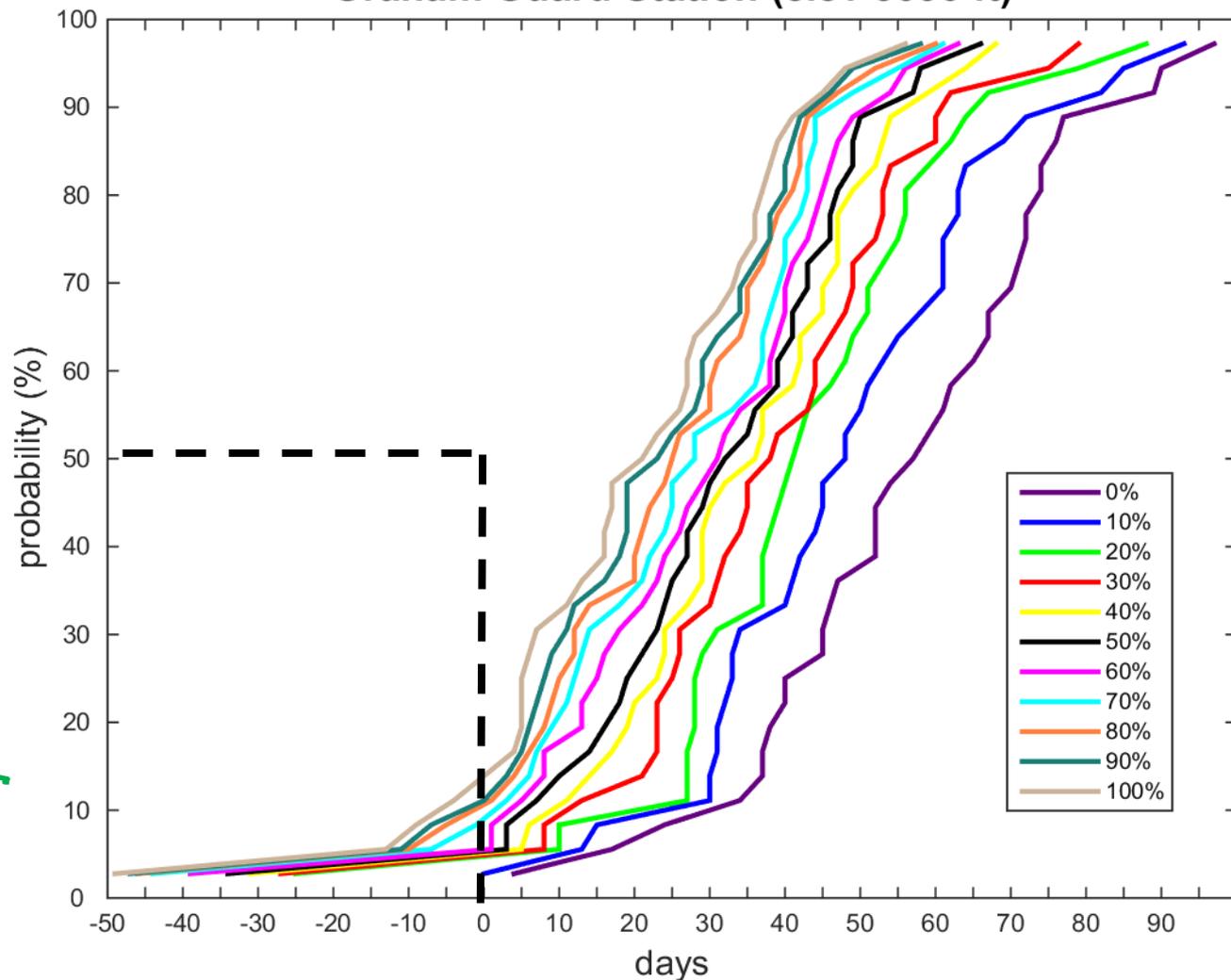
Graham Guard Station (elev 5690 ft)



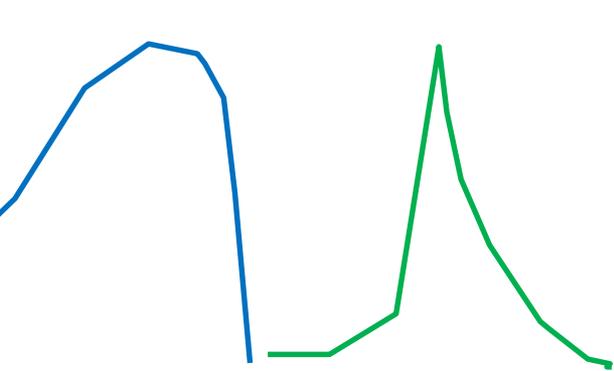
When snow is 30% gone,
average time to peak is 38
days

Graham Guard to Boise River at Twin Springs

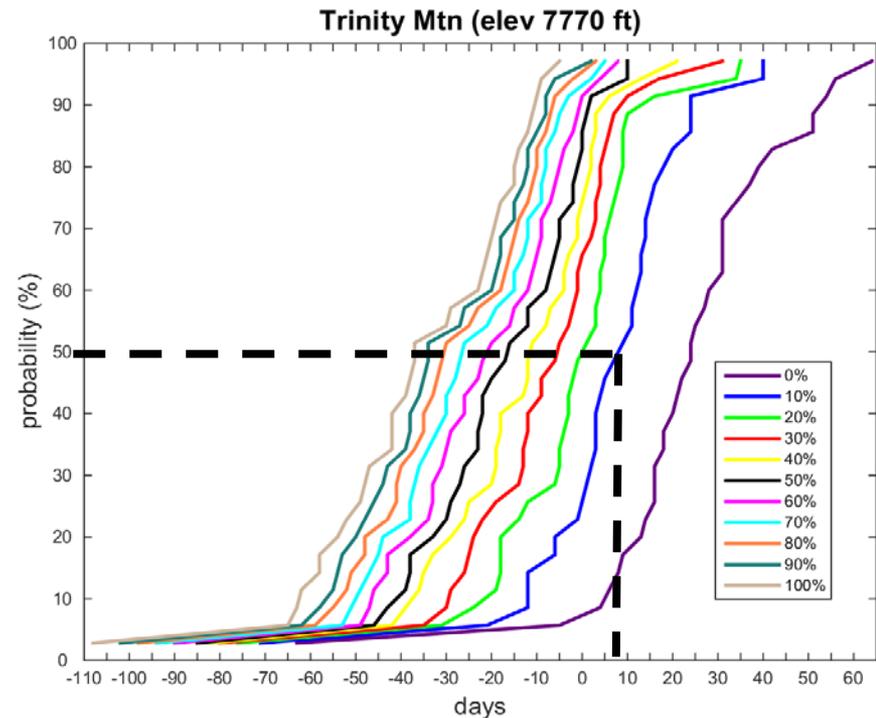
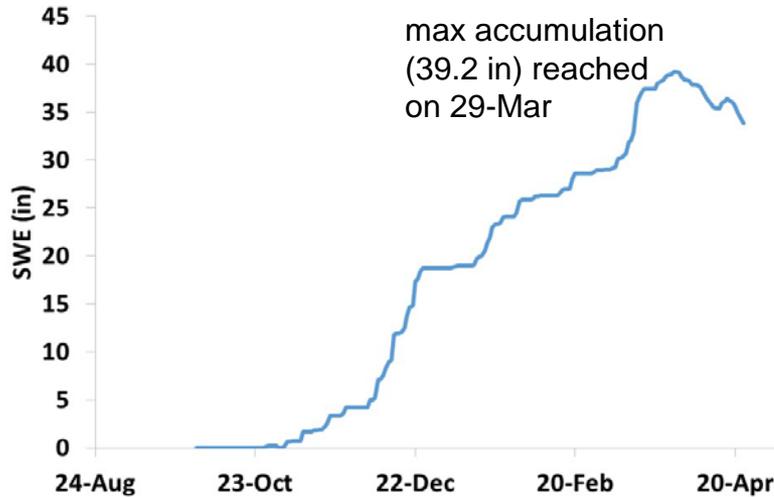
Graham Guard Station (elev 5690 ft)



At peak flow, snow is usually gone at peak flow, but not always

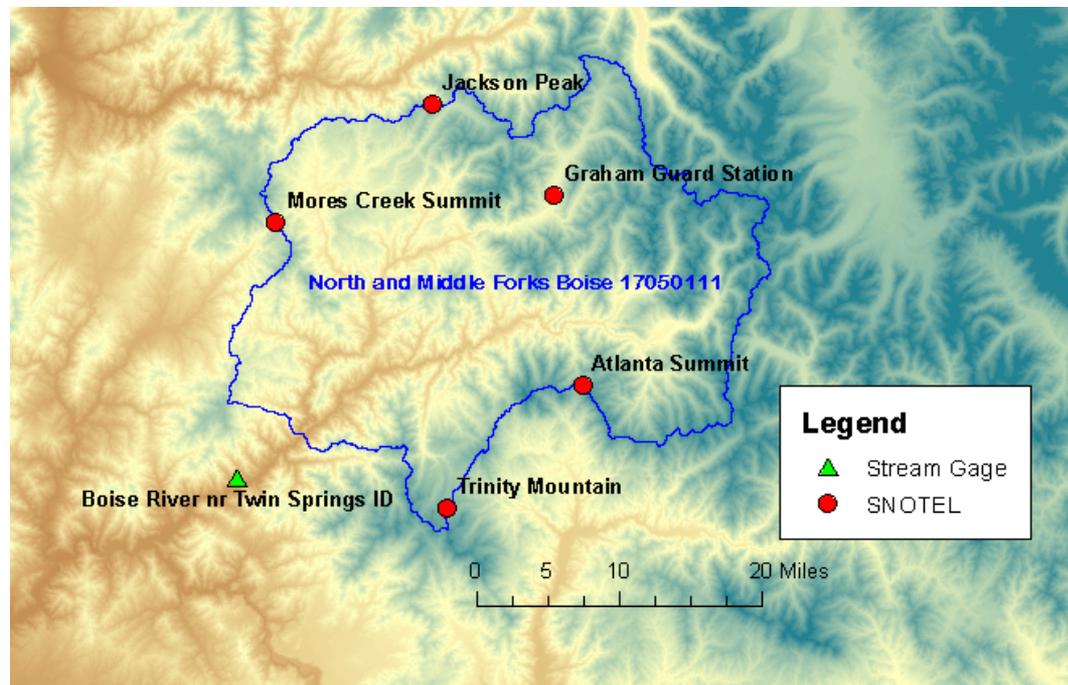


Real Time Analyses



Middle Fork Boise Rules of Thumb

Anecdotal Indices					
	Trinity Mtn (elev 7770 ft)	Atlanta Summit (elev 7580 ft)	Jackson Peak (elev 7070 ft)	Mores Creek (6100 ft)	Graham Guard (elev 5690 ft)
Average Melt % at Peak Q	20	40	40	70	21 days after complete melt-out



Ongoing Research

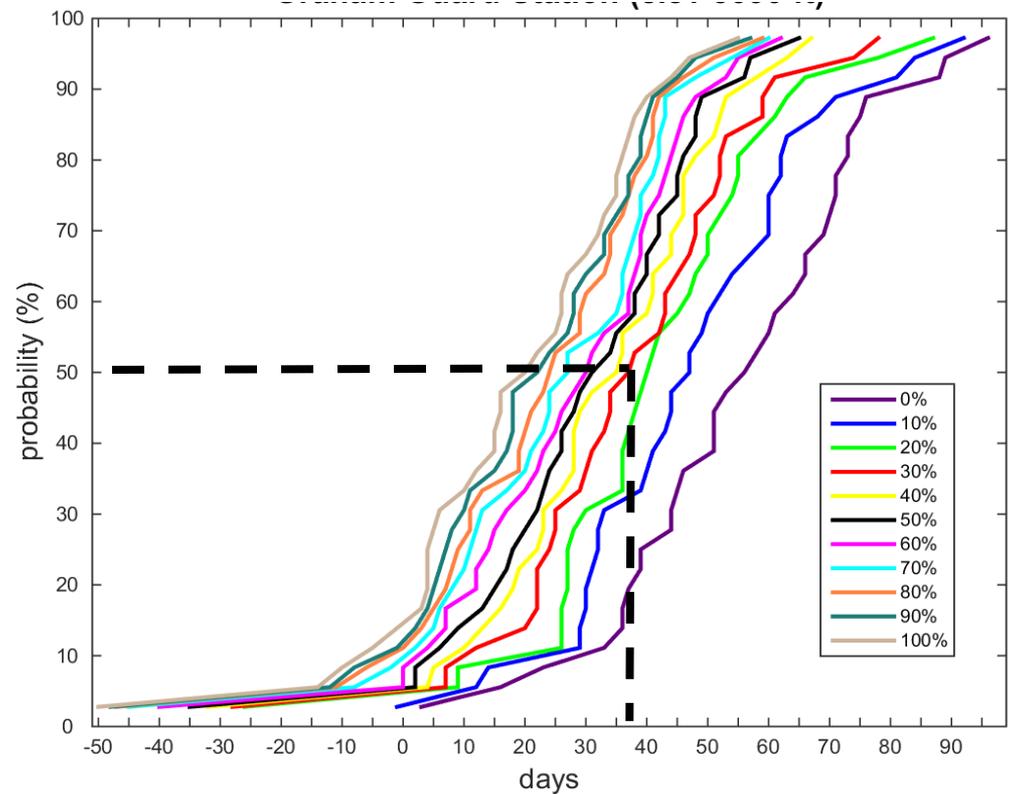
- Are there environmental conditions that will tell us if the lag will be longer or shorter than average?

Maximum snow depth?

Date of melt?

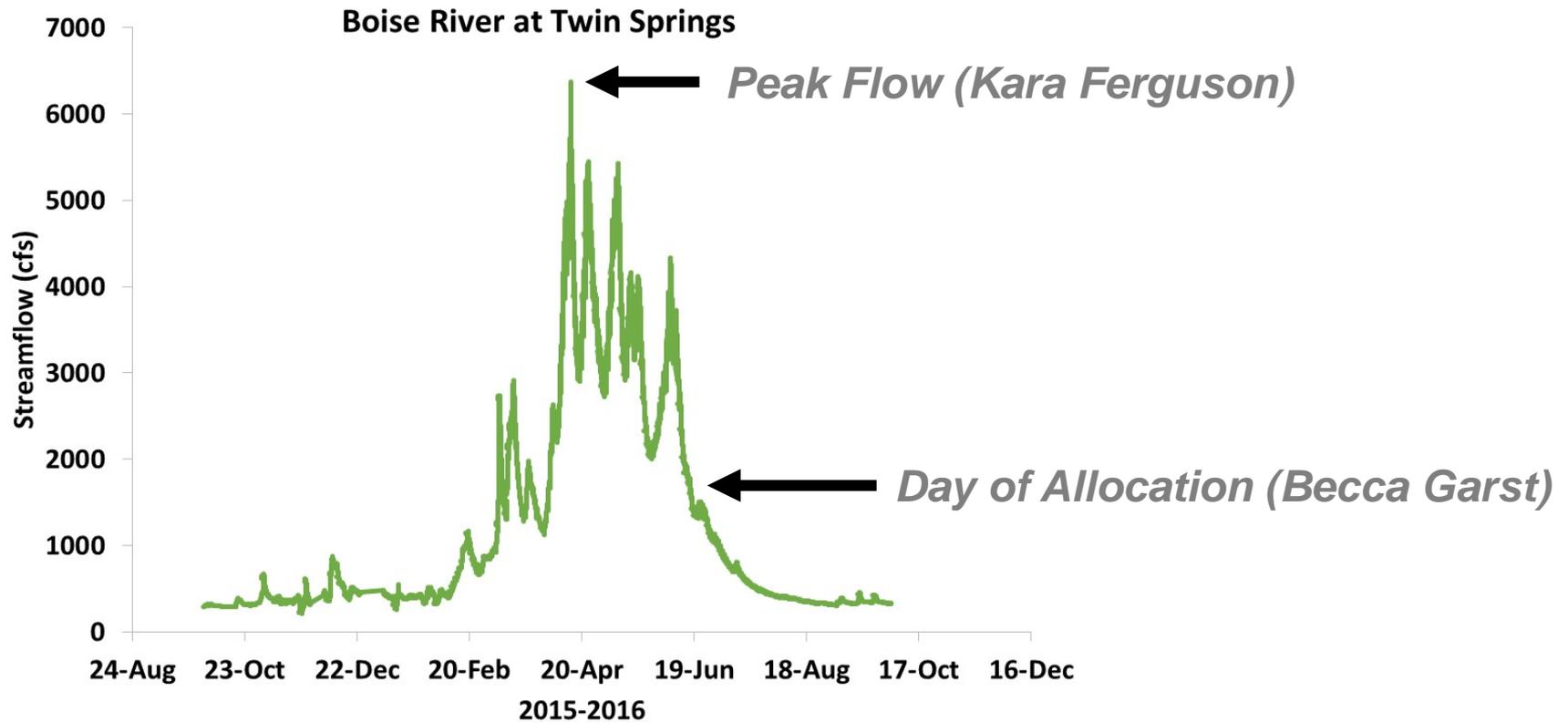
Rate of melt?

Soil moisture?



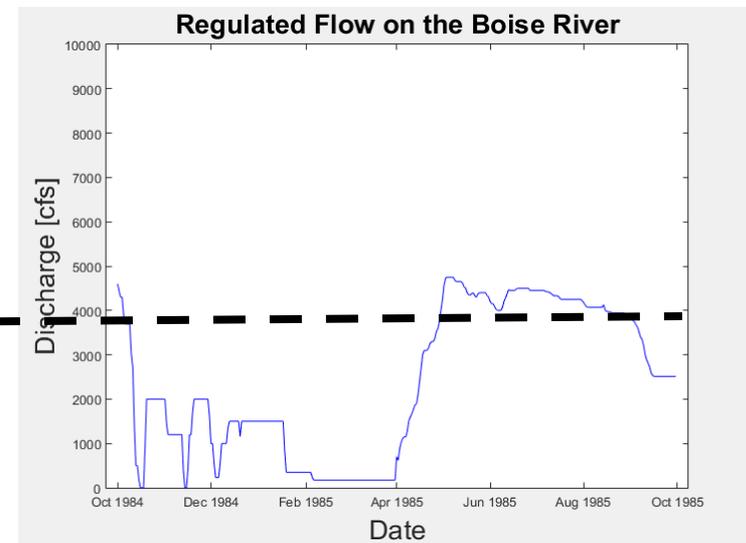
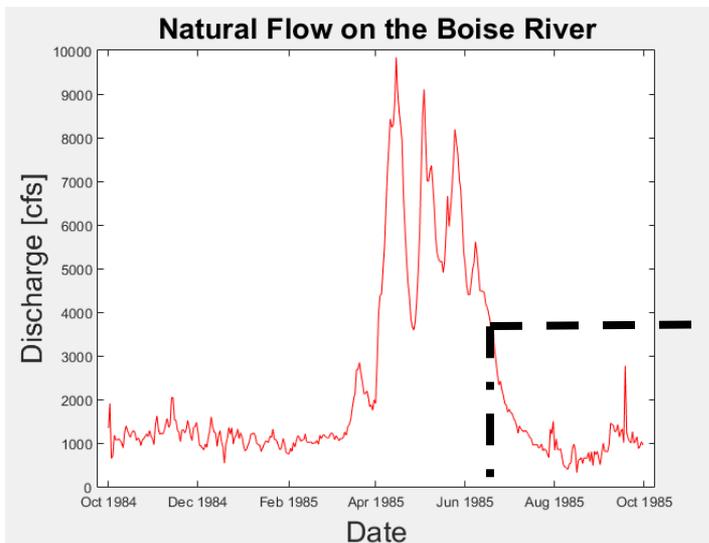


When Will Day of Allocation Occur?



Day of Allocation

When natural flow INTO a reservoir falls below demand OUT of a reservoir



**Natural
Flow**



**Reservoir
(Δ Storage)**



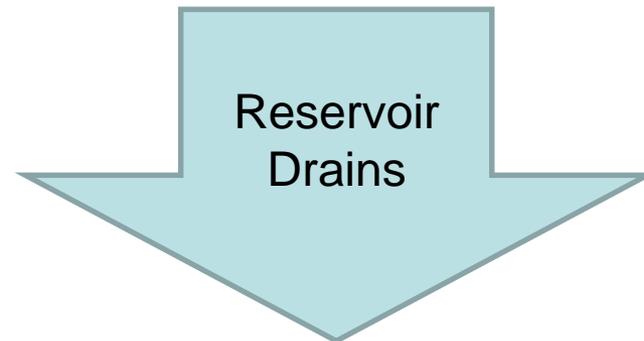
**Regulated
Flow**

Day of Allocation

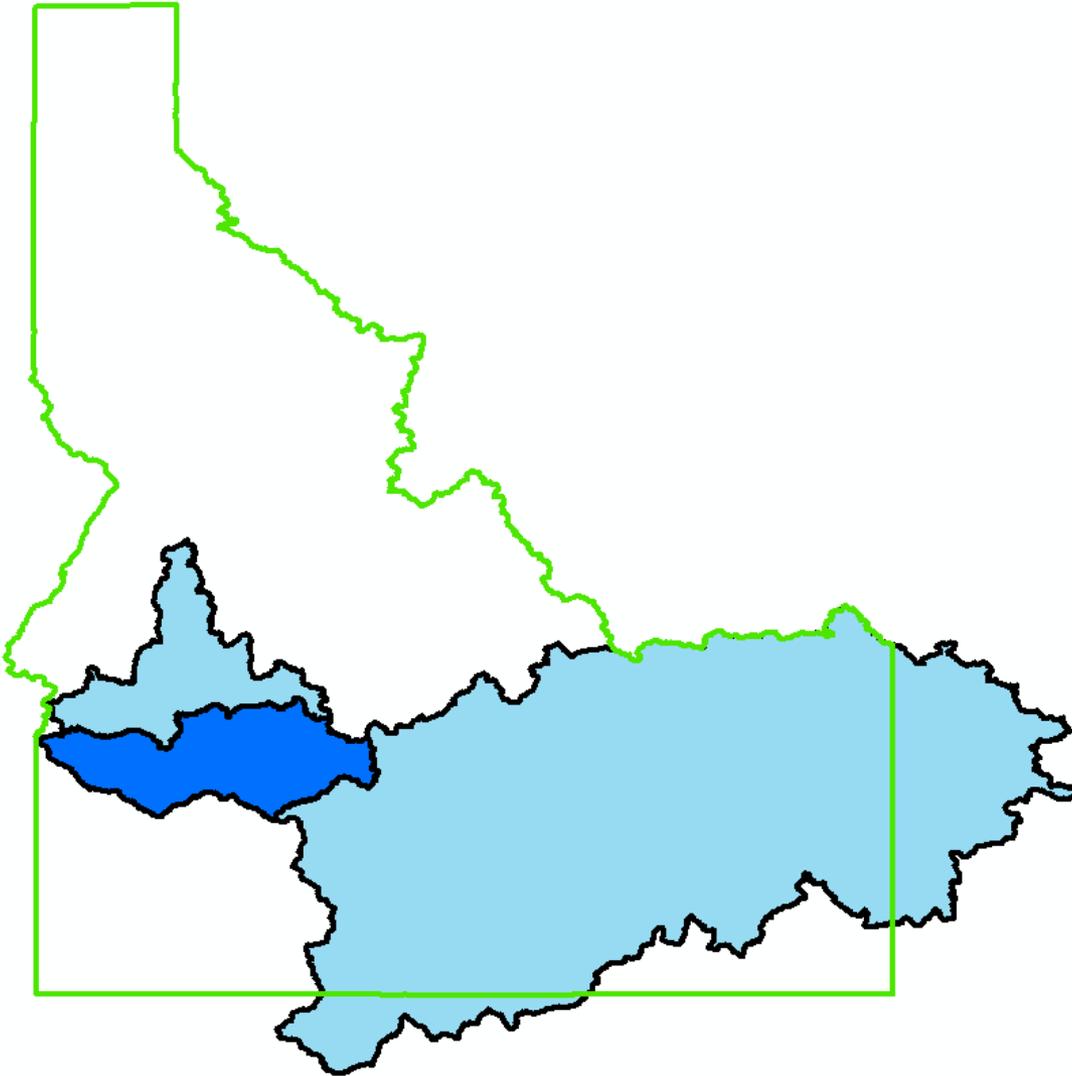
- **Before DOA**
 - Water demands are met by natural flow



- **After DOA**
 - Water demands supplemented by storage
 - Water rights curtailments begin



Can SNOTEL data improve DOA prediction?





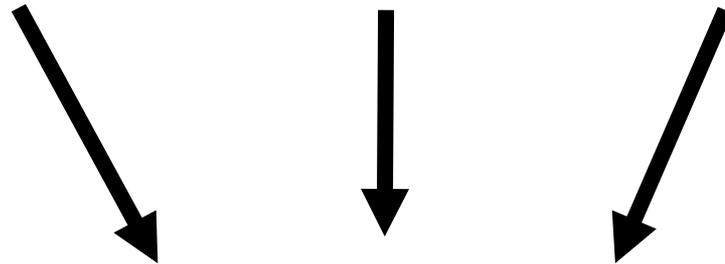
Boise River DOA occurs when

Reservoir storage is at its maximum

Diversions exceed natural flow at end of reach

Water rights at maximum for irrigation season

Day of Allocation





Boise River DOA occurs when

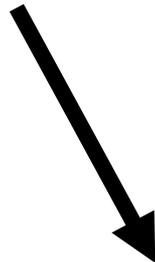
Mountain Snow



Reservoir storage is at its maximum

Diversions exceed natural flow at end of reach

Water rights at maximum for irrigation season

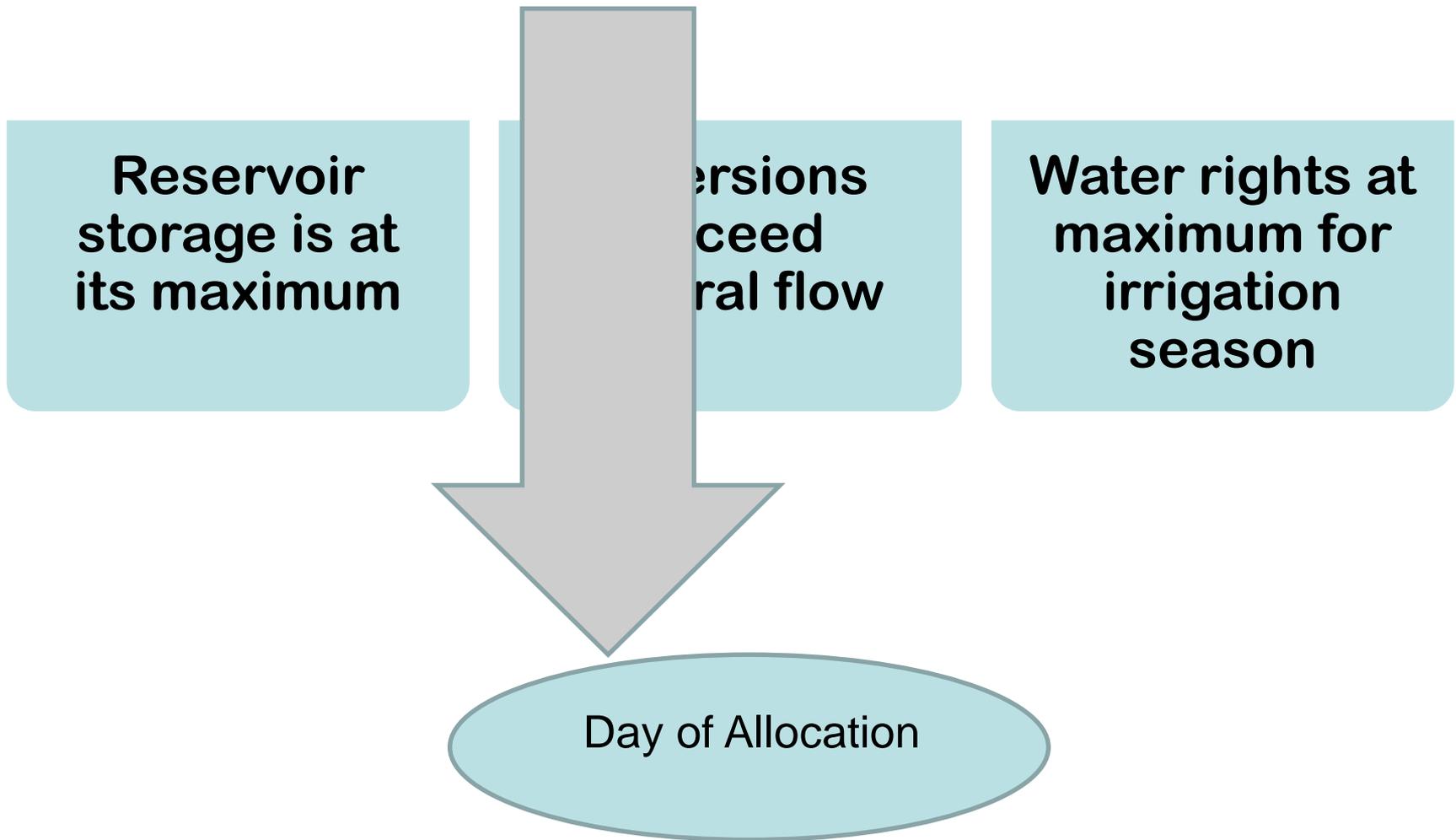


Day of Allocation



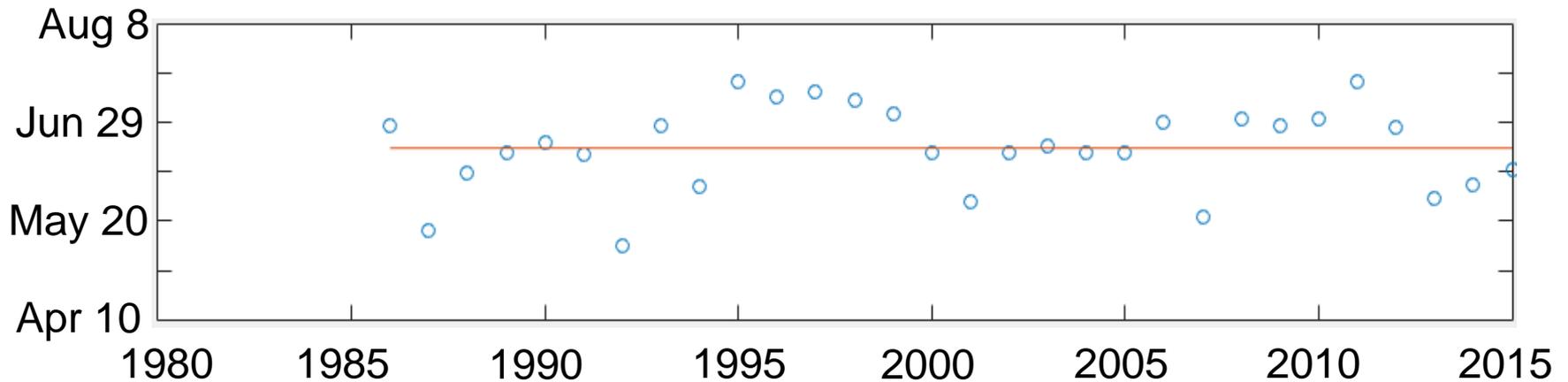
Boise River DOA occurs when

Mountain Snow

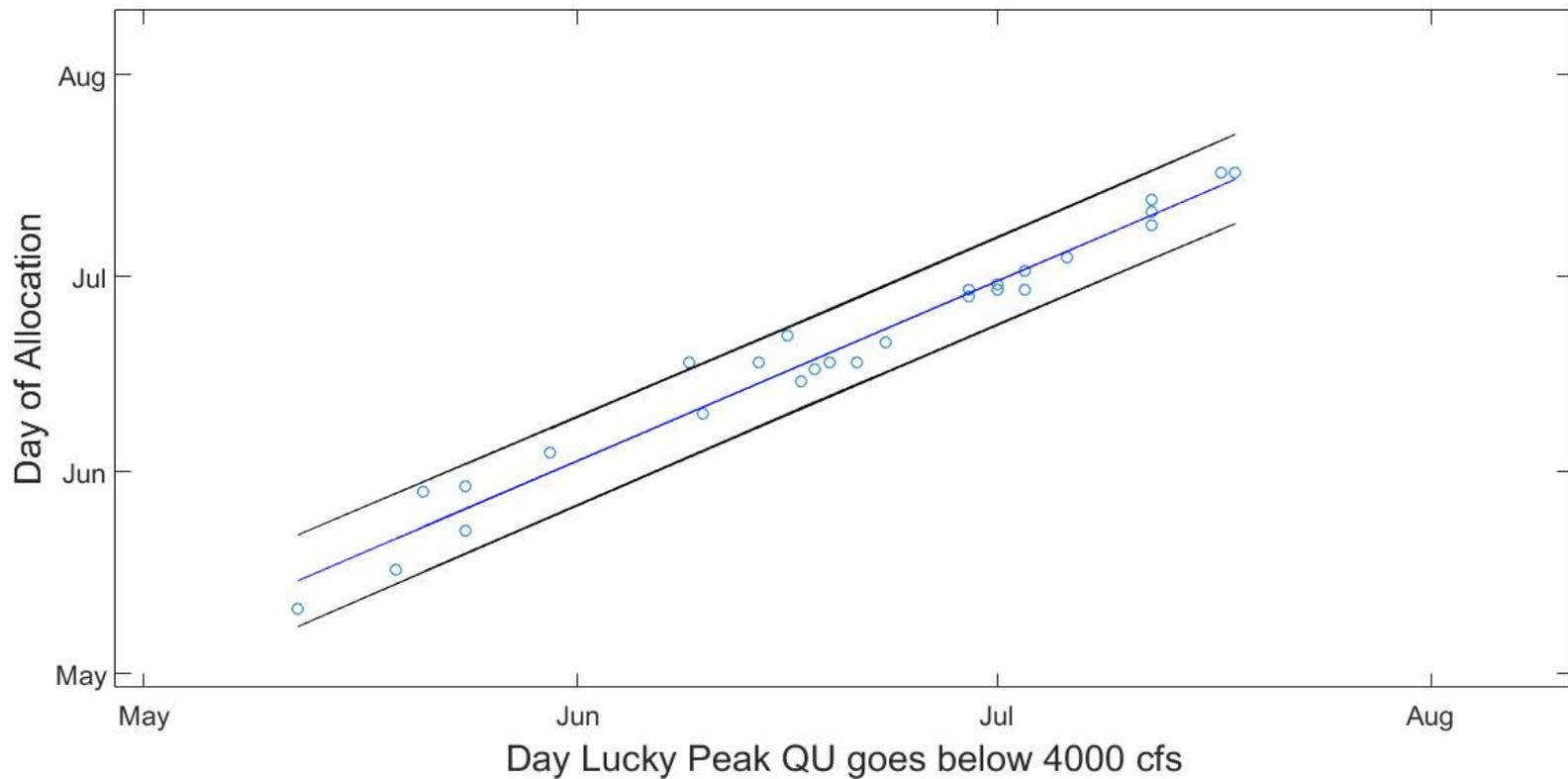




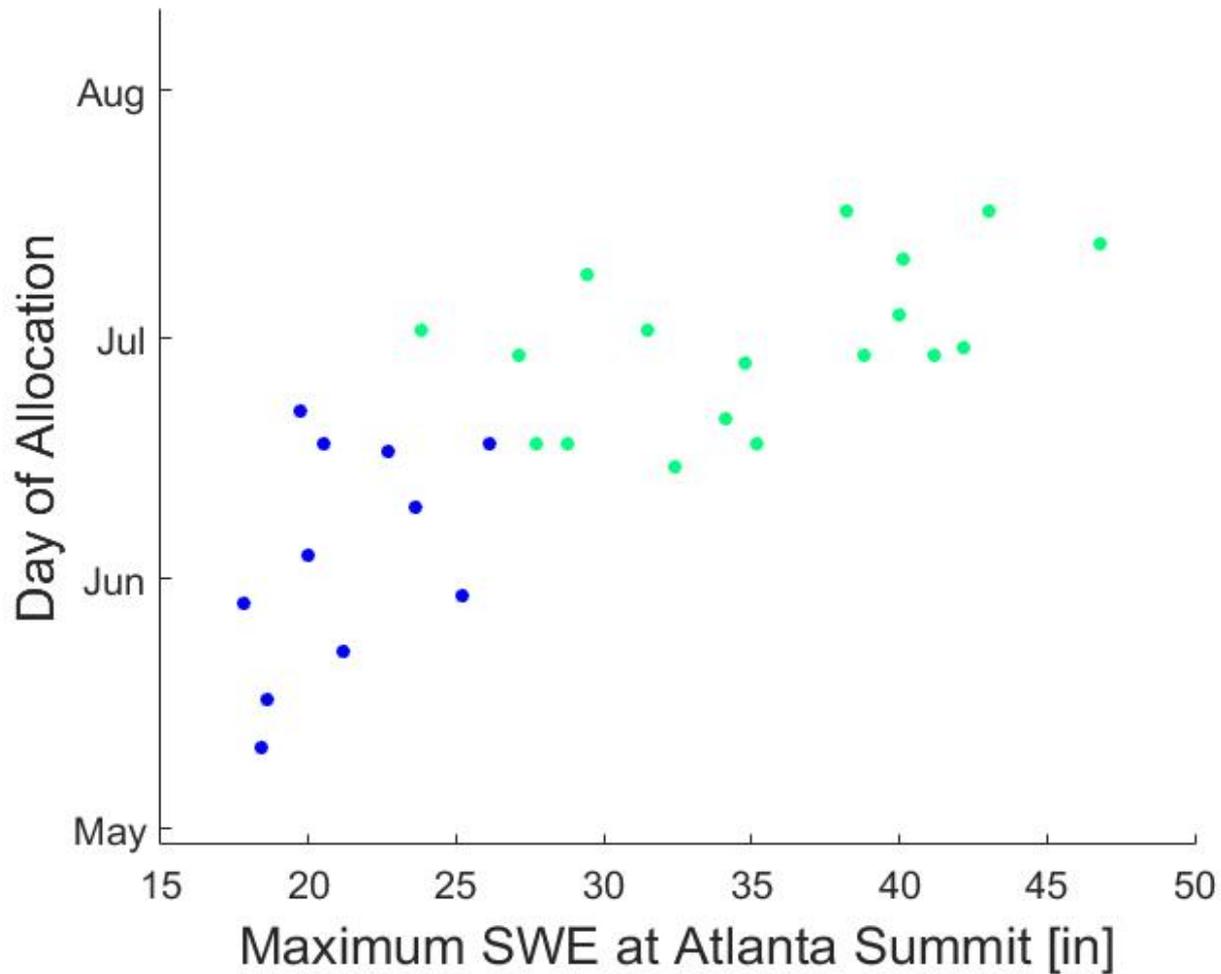
Boise River DOA Dates



DOA vs Natural Flow



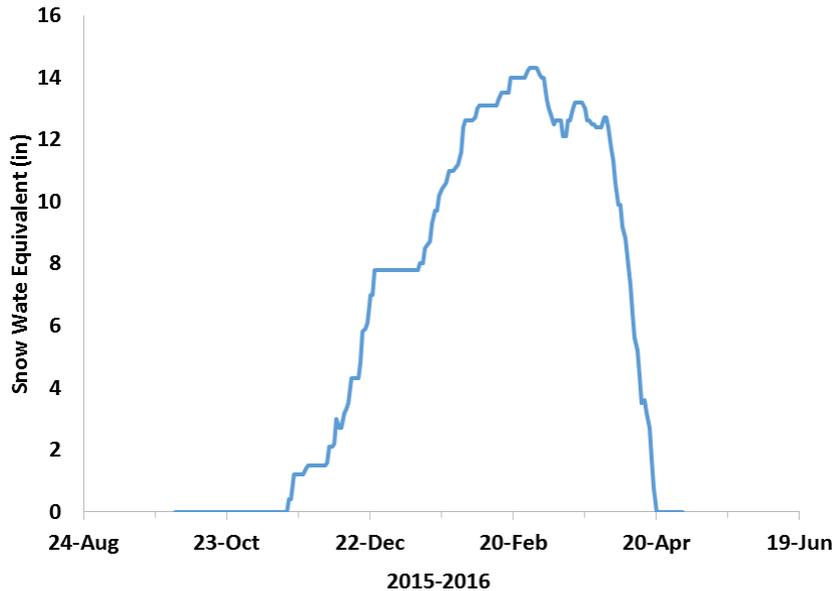
DOA vs Snow



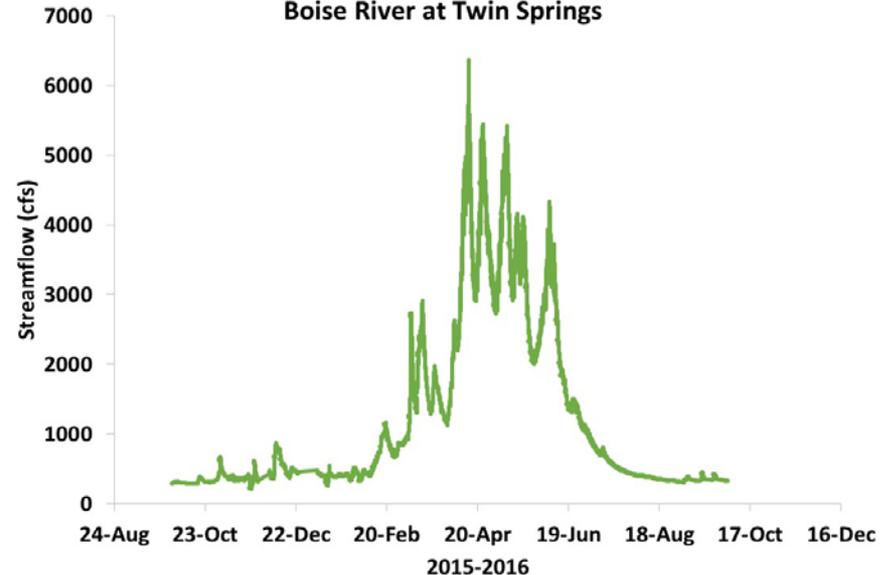
How does snow control DOA?

- How much snow?
- When does it melt?
- How fast does it melt?

Graham Gaurd Station

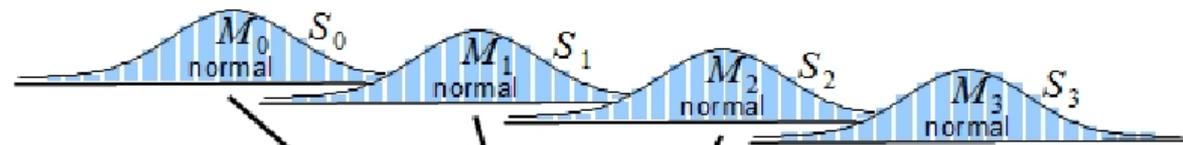


Boise River at Twin Springs



Multiple Linear Regression

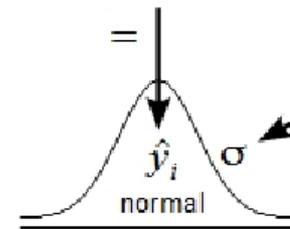
Snow and DOA data



MLR Model

$$\beta_0 + \beta_1 x_{1i} + \beta_2 x_{2i} + \beta_3 x_{3i}$$

A uniform distribution is shown as a rectangle with width H_σ and height 0 , labeled 'unif'.



DOA Prediction

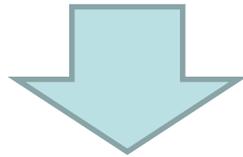
$$y_i$$

An arrow points from the predicted value \hat{y}_i down to the final prediction y_i .

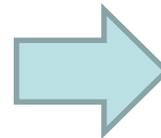
Multiple Linear Regression

Predictor Site

	Atlanta	Graham	Jackson	Mores	Trinity	Vienna
Max SWE	x1	x2	x3	x4	x5	x6
April Melt	x7	x8	x9	x10	x11	x12
May Melt	x13	x14	x15	x16	x17	x18
June Melt	x19	x20	x21	x22	x23	x24



Multiple Linear Regression
Model



Day of
Allocation
Prediction



Boise River

Day of Allocation Prediction

Inputs

Goodness
of Fit

Time Period	Inputs	Goodness of Fit
Early Season	<ul style="list-style-type: none">• Maximum SWE Values	$R^2 = .61$ Adjusted
After April	<ul style="list-style-type: none">• Maximum SWE Values• April Melt Ratios	$R^2 = .89$ Adjusted $R^2 = .81$
After May	<ul style="list-style-type: none">• Maximum SWE Values• April and May Melt Ratios	$R^2 = .94$ Adjusted $R^2 = .81$
After June	<ul style="list-style-type: none">• Maximum SWE Values• April, May, and June Melt Ratios	$R^2 = .99$ Adjusted $R^2 = .92$

Increasing Confidence



2016 Predictions

2016 DOA
Observation
June 15

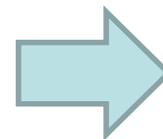
Period of Record Data

Predictor Site

	Atlanta	Graham	Jackson	Mores	Trinity	Vienna
Max SWE	x1	x2	x3	x4	x5	x6
April Melt	x7	x8	x9	x10	x11	x12
May Melt	x13	x14	x15	x16	x17	x18
June Melt	x19	x20	x21	x22	x23	x24



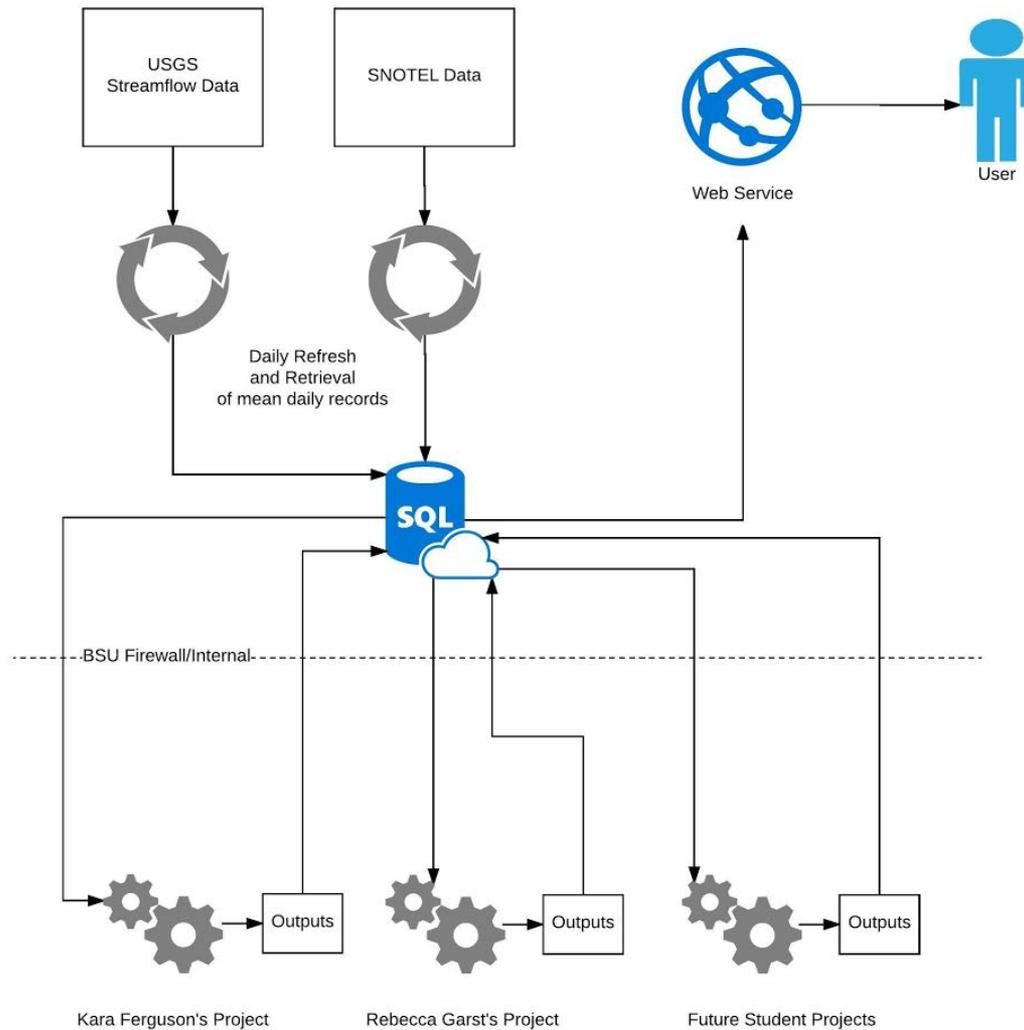
Multiple Linear Regression
Model



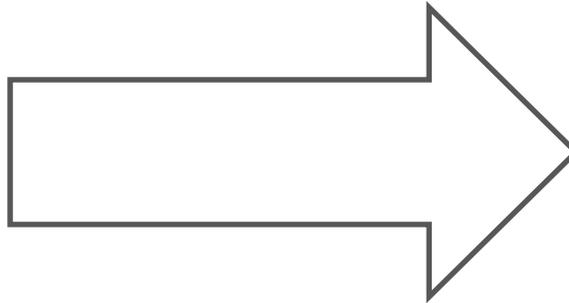
2016 DOA
Prediction
June 17

Making Research Useful

Ryan Dammrose

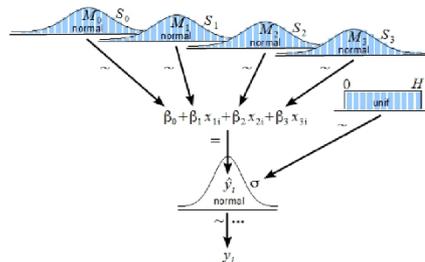
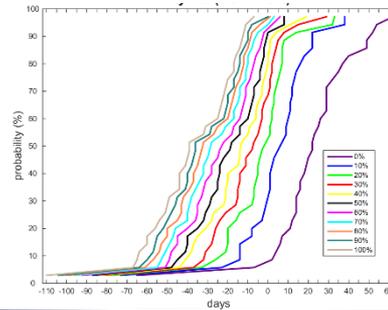
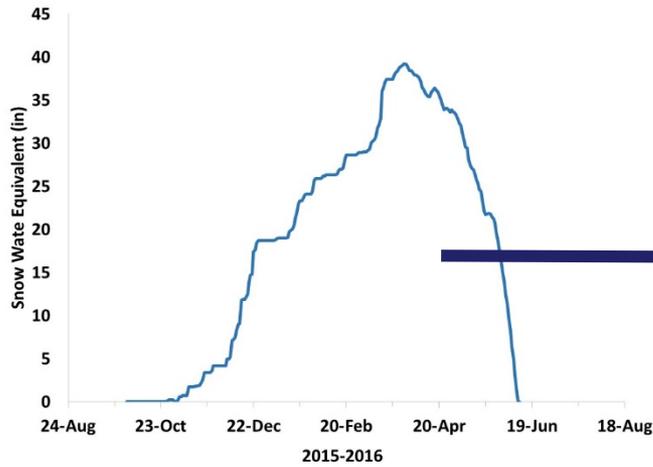


Snow to Flow



<http://www.opb.org/>

Trinity Mnt SNOTEL



Boise River at Twin Springs

