From Snow to Flow:
Statistical Forecasting of Critical Flows

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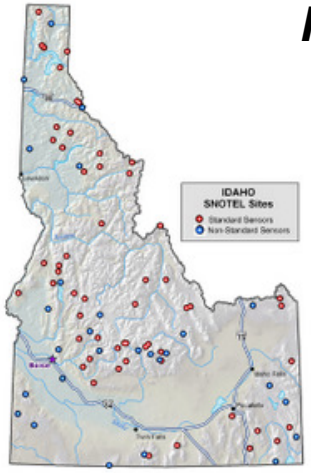
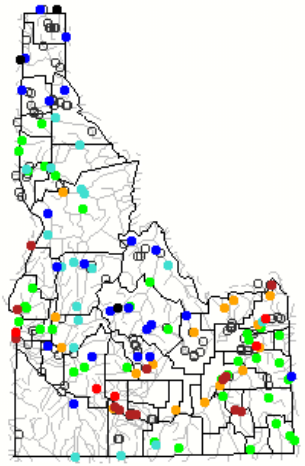
Snow to Flow

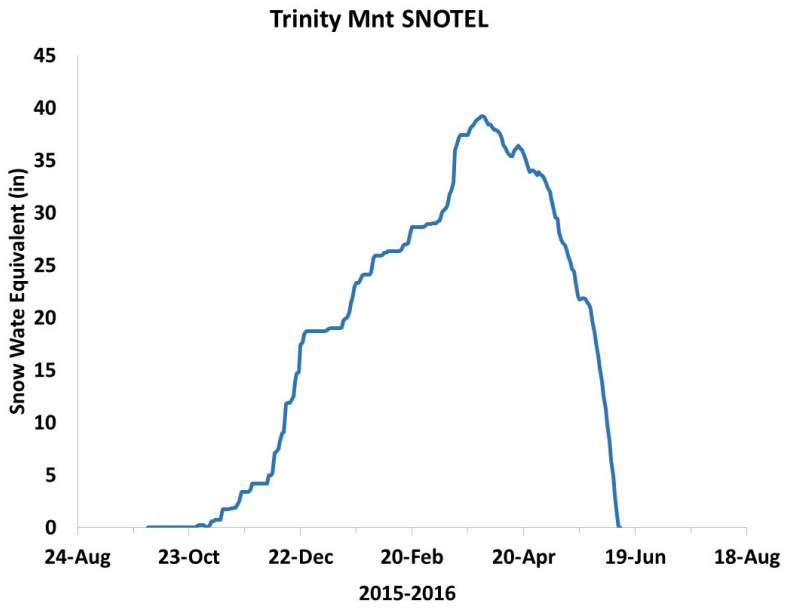


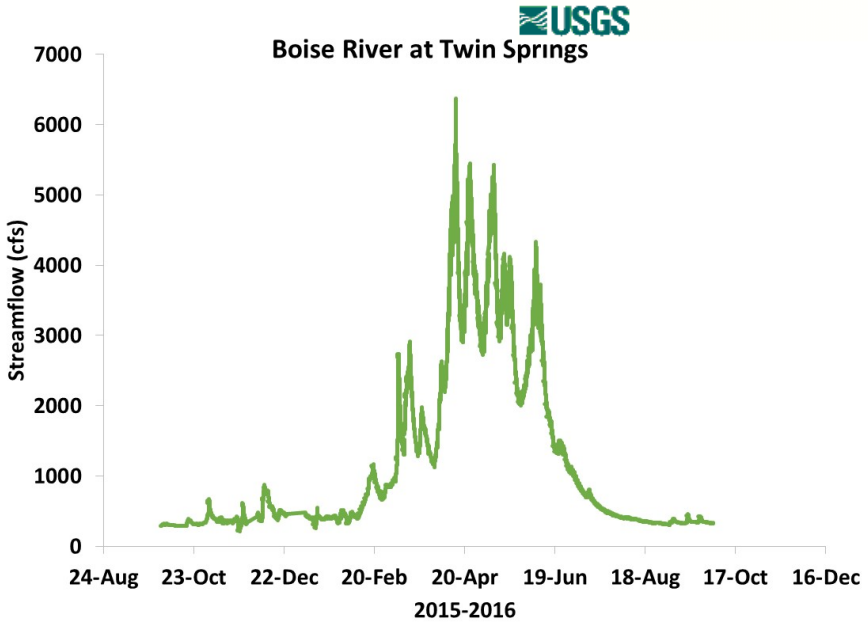
How are patterns in snowmelt and streamflow related?

Anecdotal "Rules of Thumb"

Statistical Tools

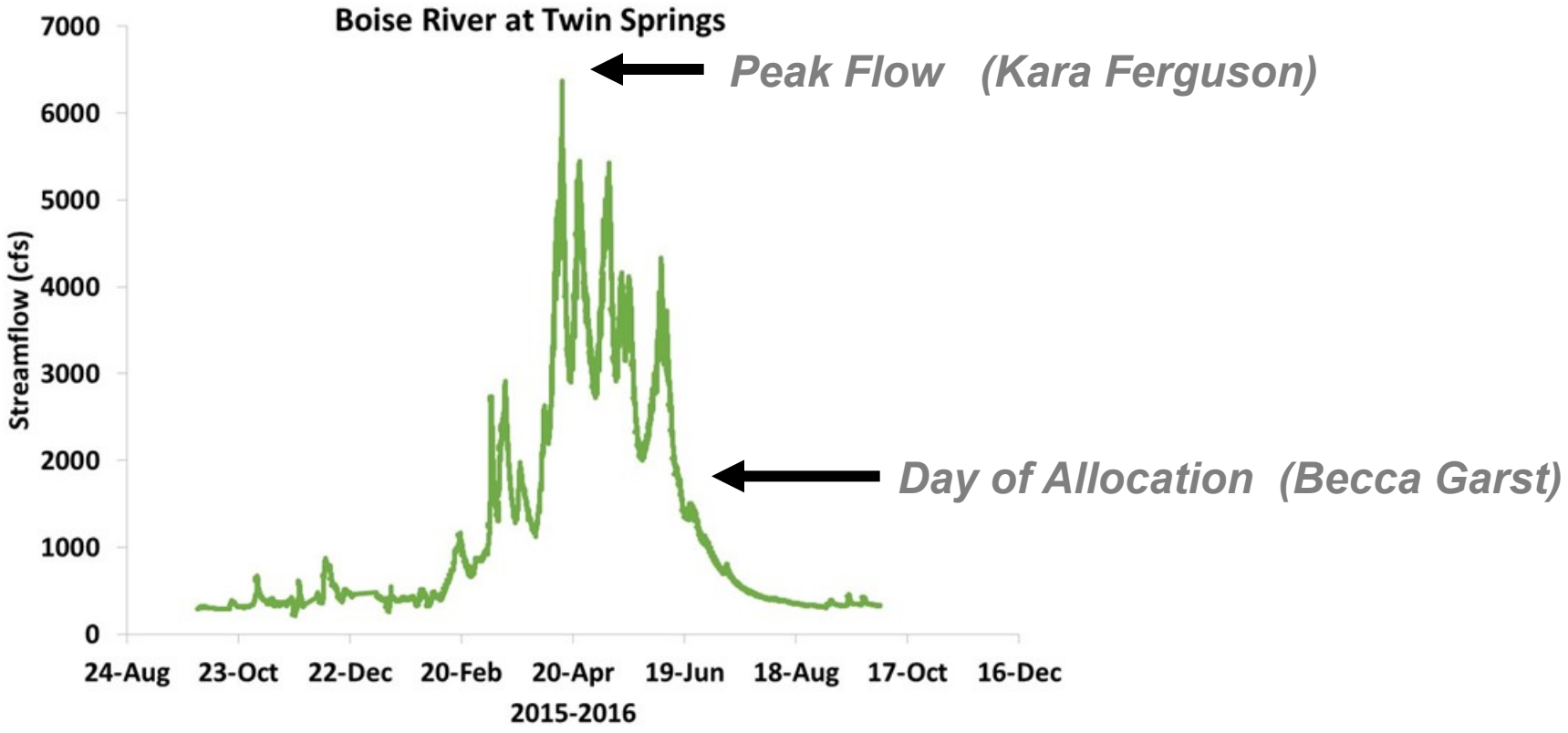




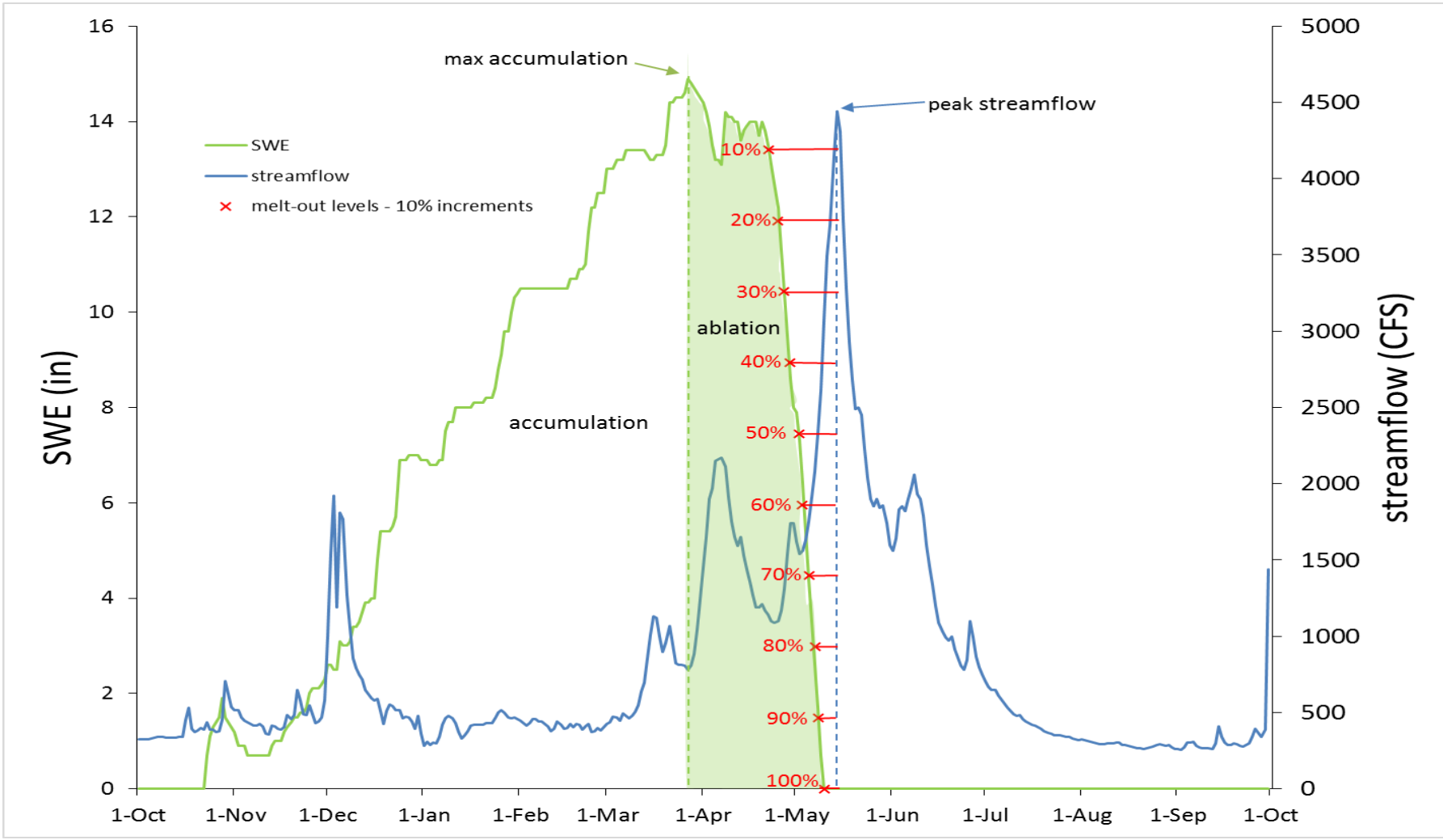


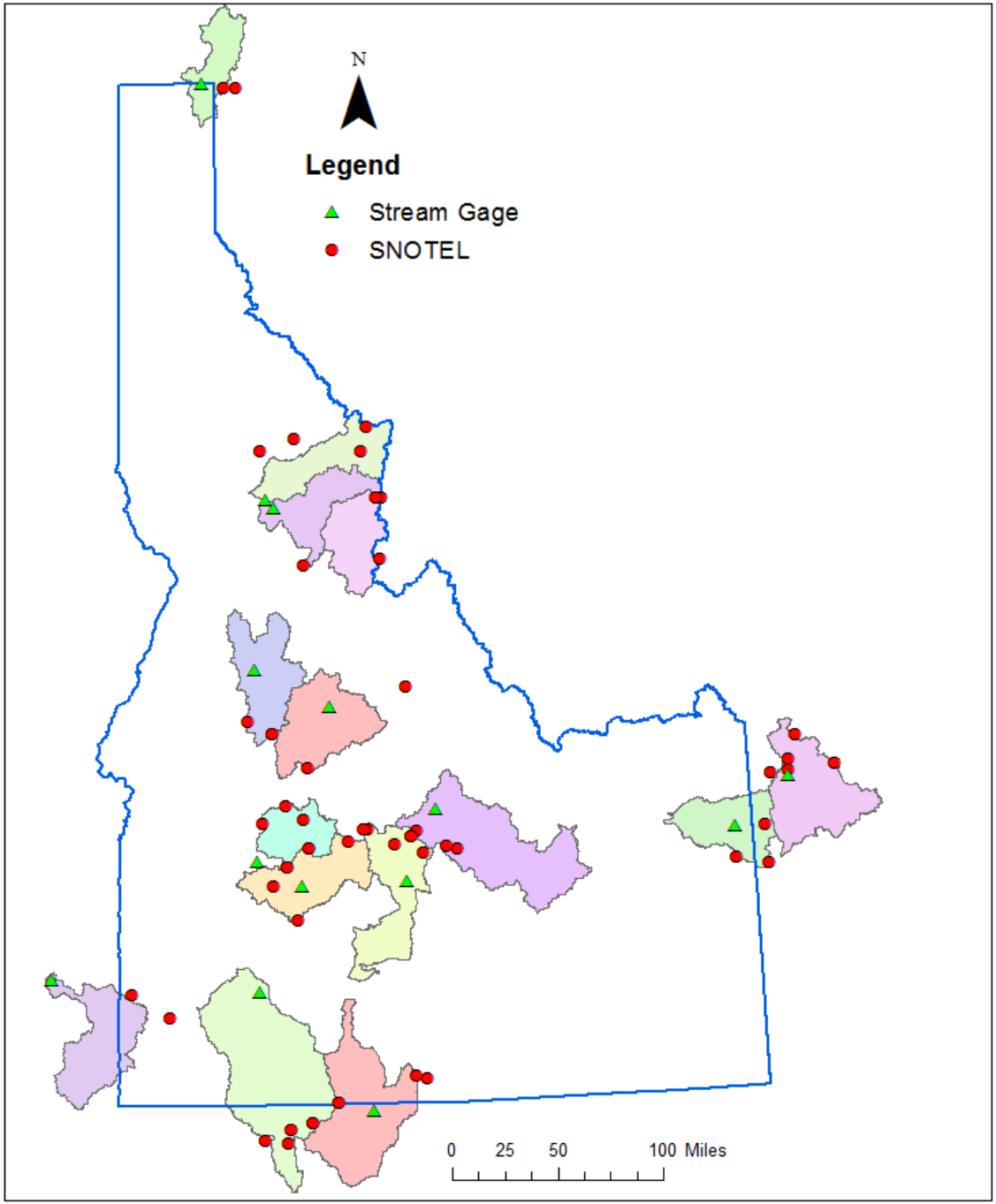
Snow to CRITICAL Flows

How can we use SNOTEL data to better understand timing and magnitude of

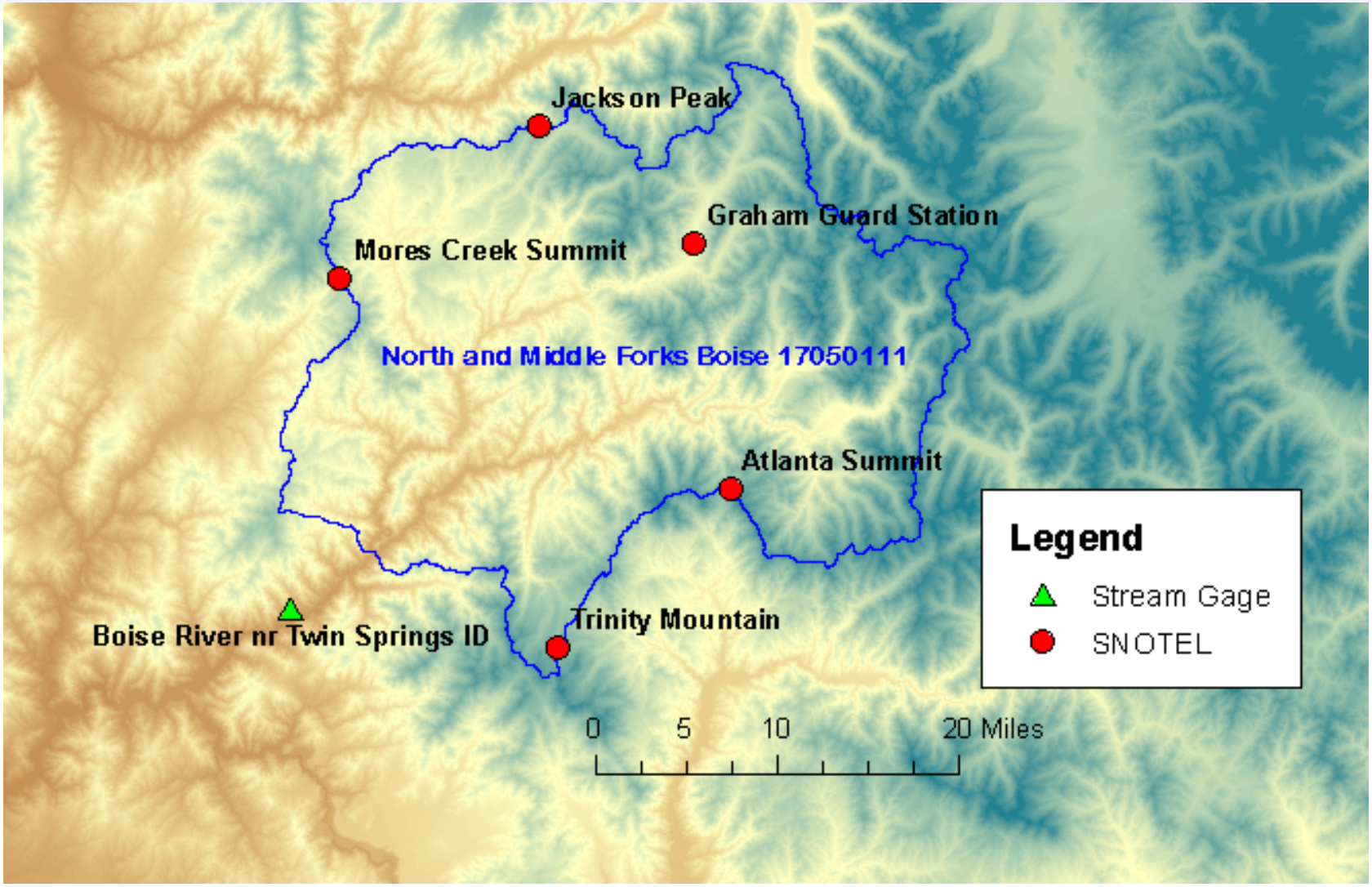


When Will Peak Flow Occur?




N
Legend
Stream Gage
SNOTEL
0 25 50 100 Miles

Middle Fork Boise River

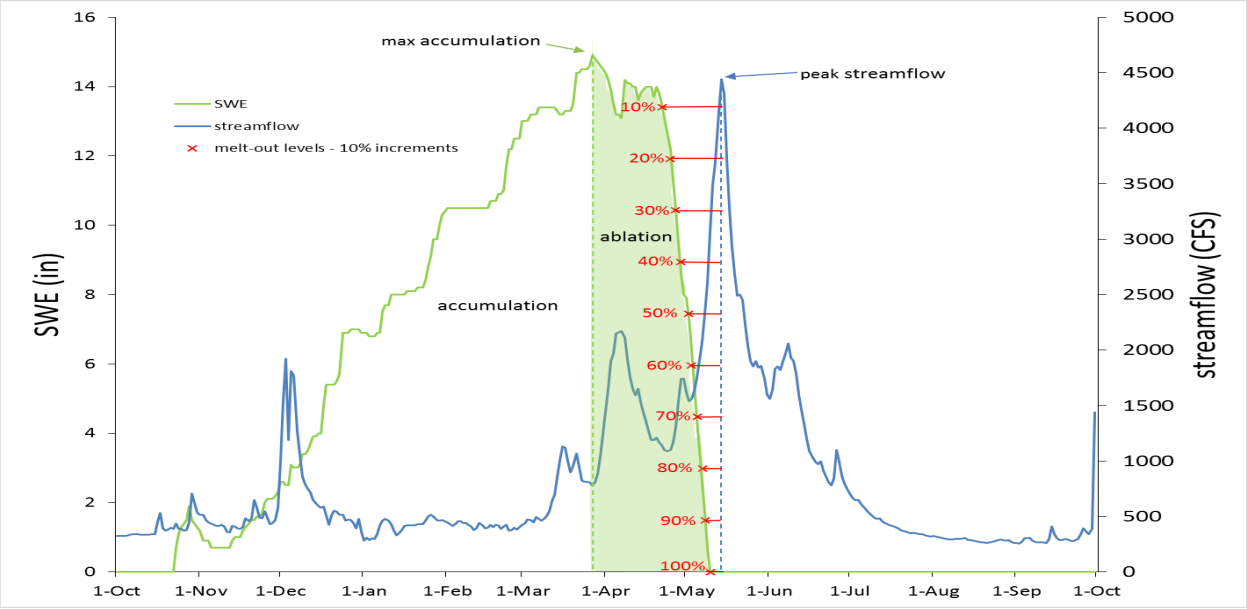


For All SNOTEL Streamflow Pairs

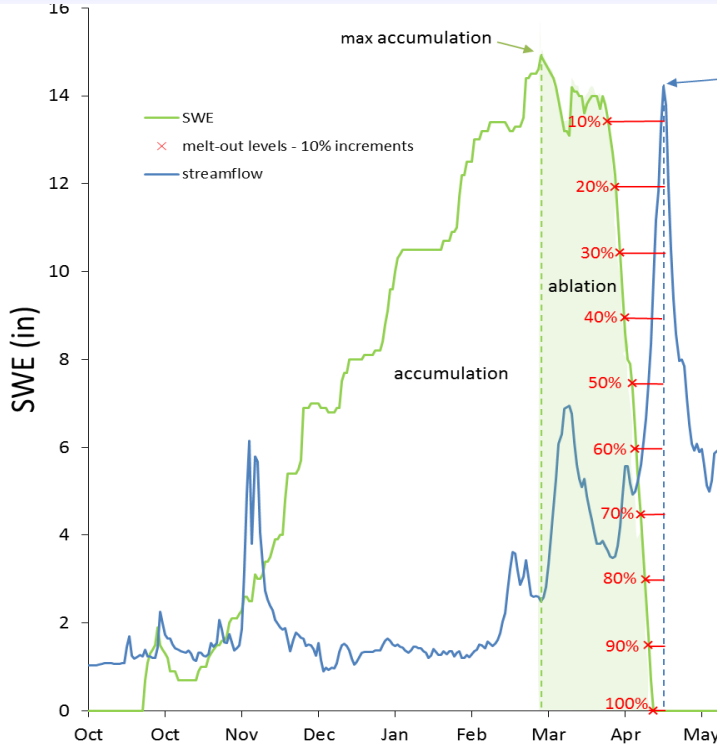
Year	Date of Peak Q	Date of Max SWE	Date of Meltout	Peak Q (CFS)	Max SWE (in)	SWE Level on day of Peak Q (in)	Percent of Max SWE Melted at Time of Peak Q (%)	Amount of Max SWE Melted at Peak Q (in)	Days of Melt	Average Melt Rate (in/day)	Max Melt Rate (in/day)	Date Max Melt Rate (WY day)	Melt (-3 days) (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

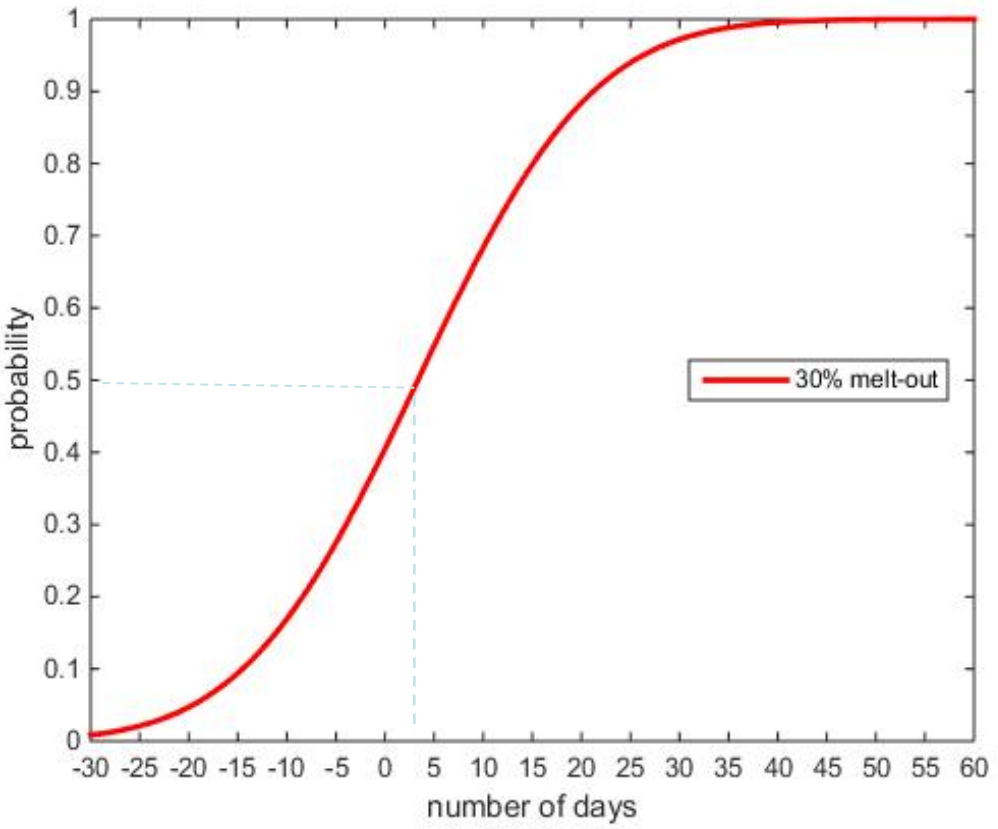
Lag Analysis

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

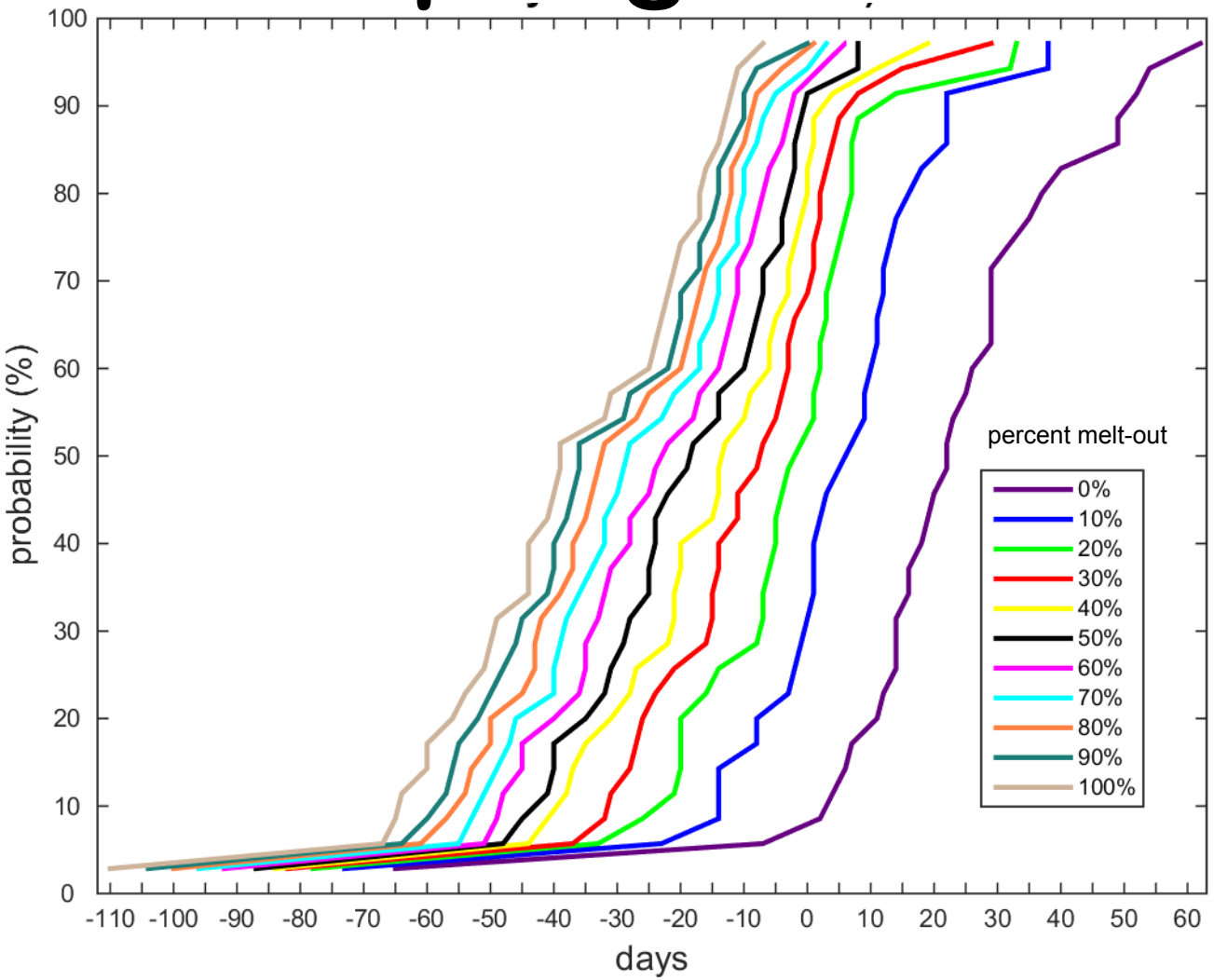


Lag to Peak Statistics



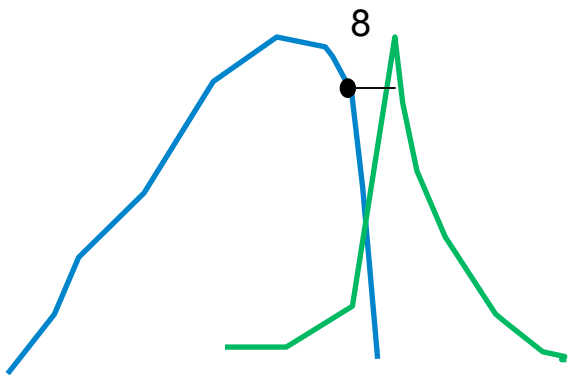


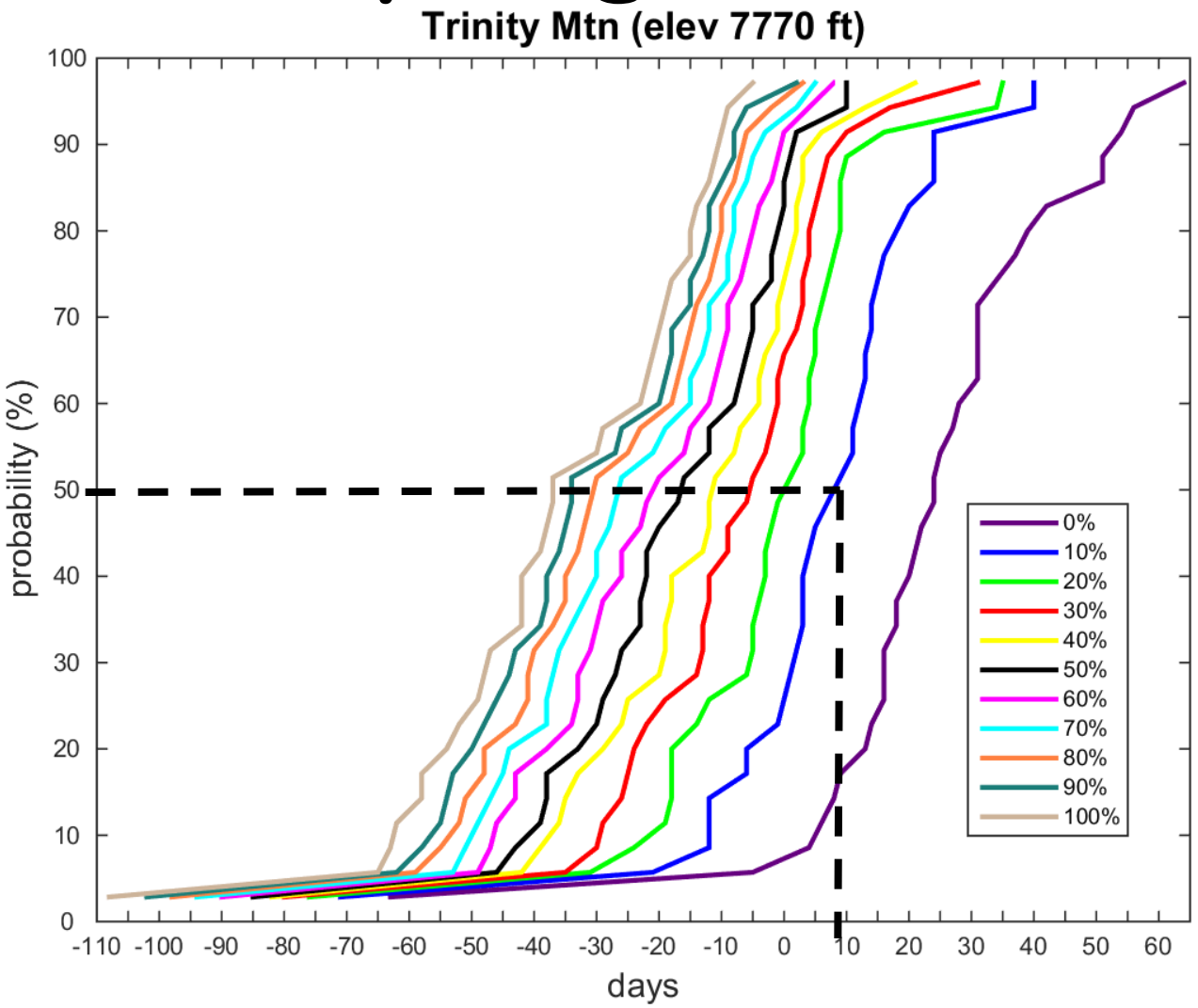
Trinity Mtn to Boise River at Twin Springs



Trinity Mtn to Boise River at Twin Springs

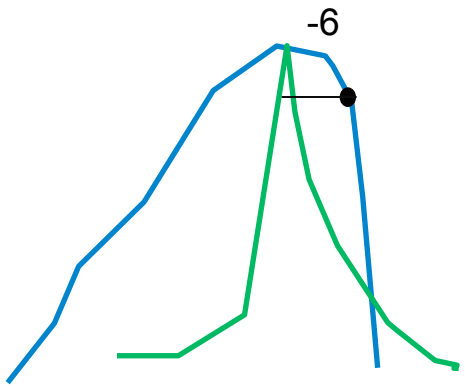
When snow is 10% gone, average time to peak is 8 days

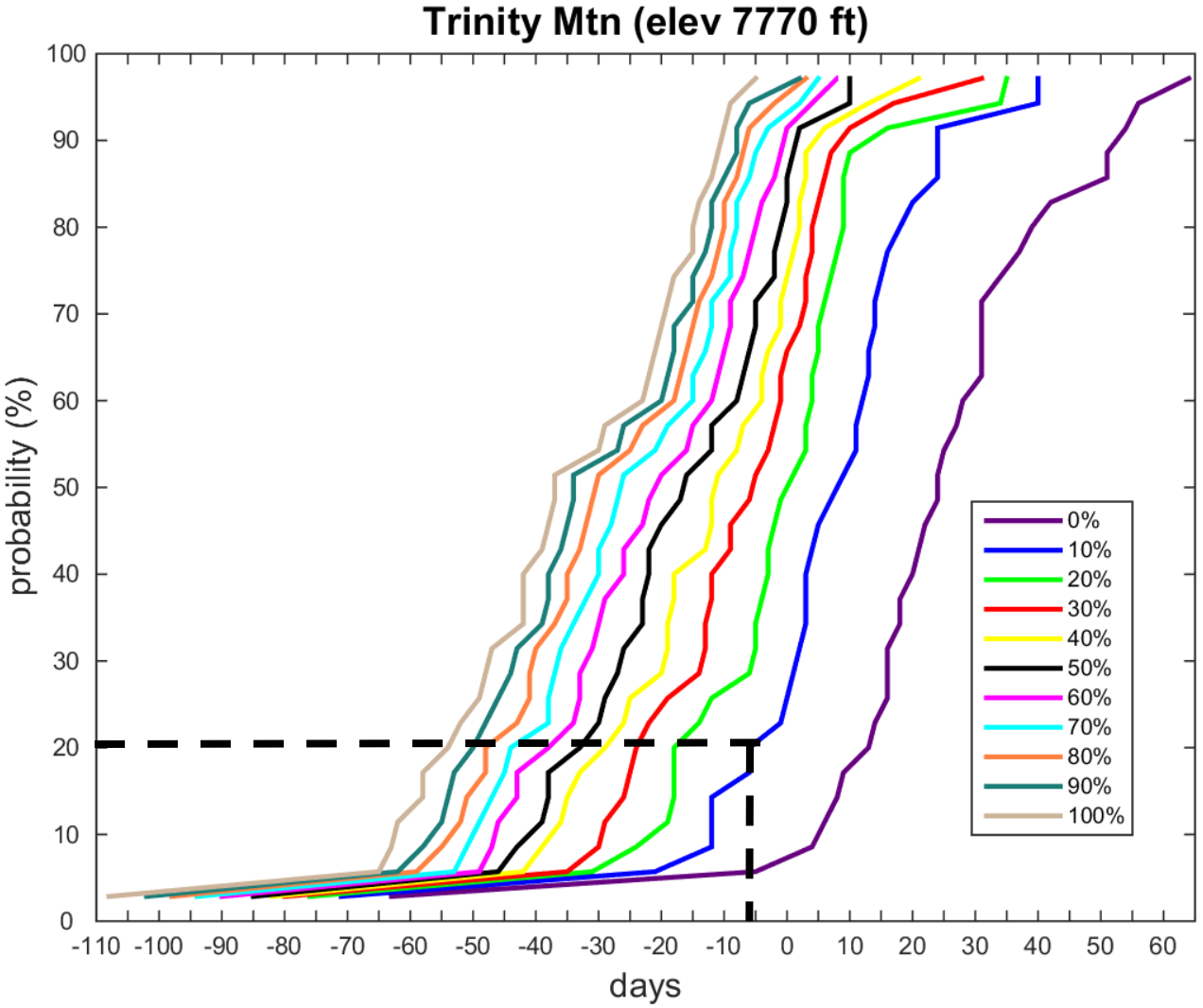




Trinity Mtn to Boise River at Twin Springs

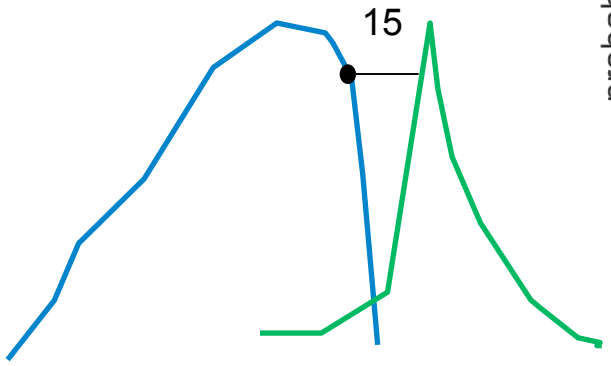
But 20% of the time peak flow happened 6 days ago

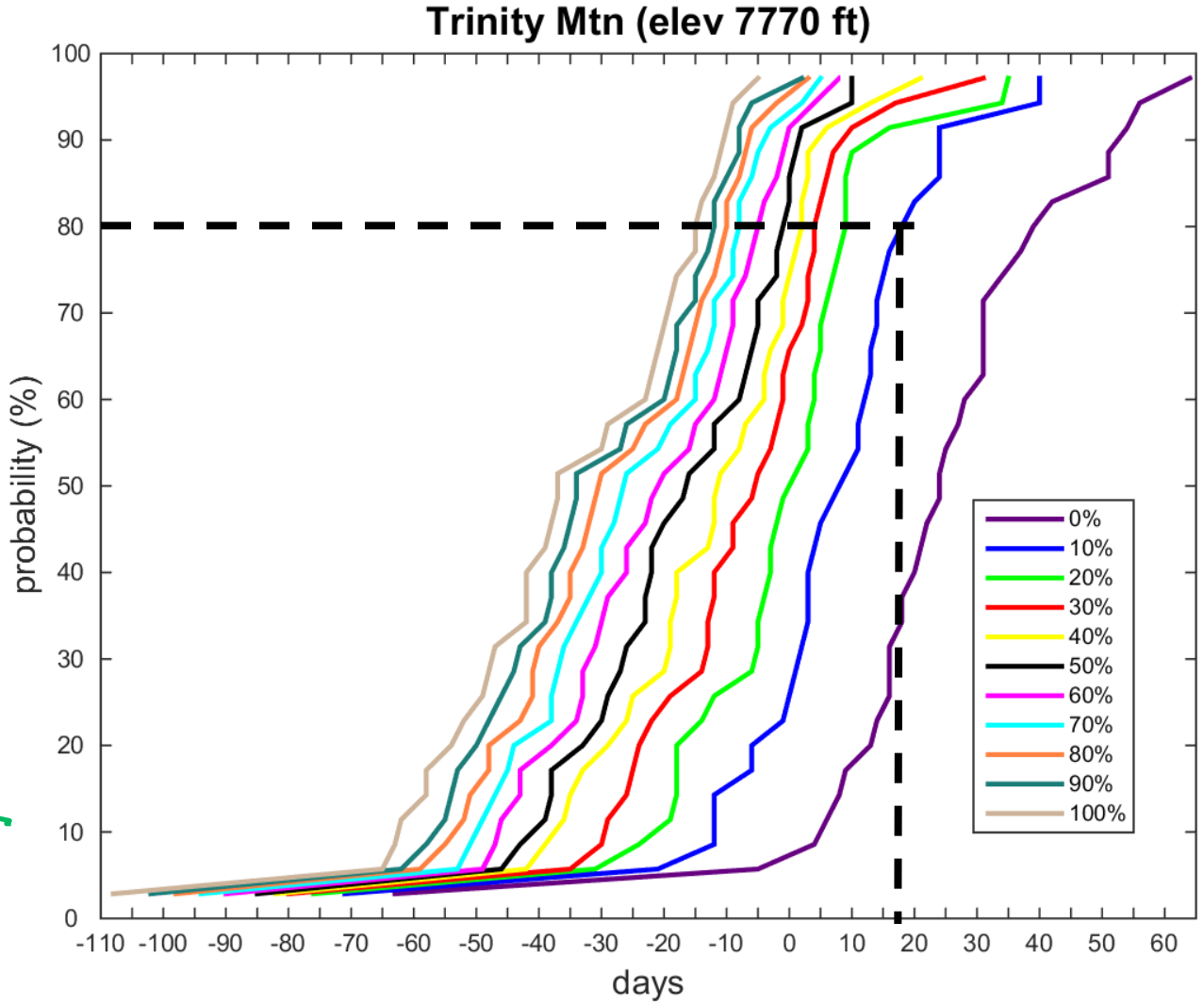




Trinity Mtn to Boise River at Twin Springs

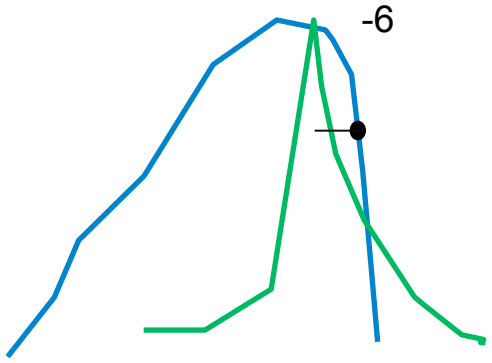
And 20% of the time it will take more than 18 days

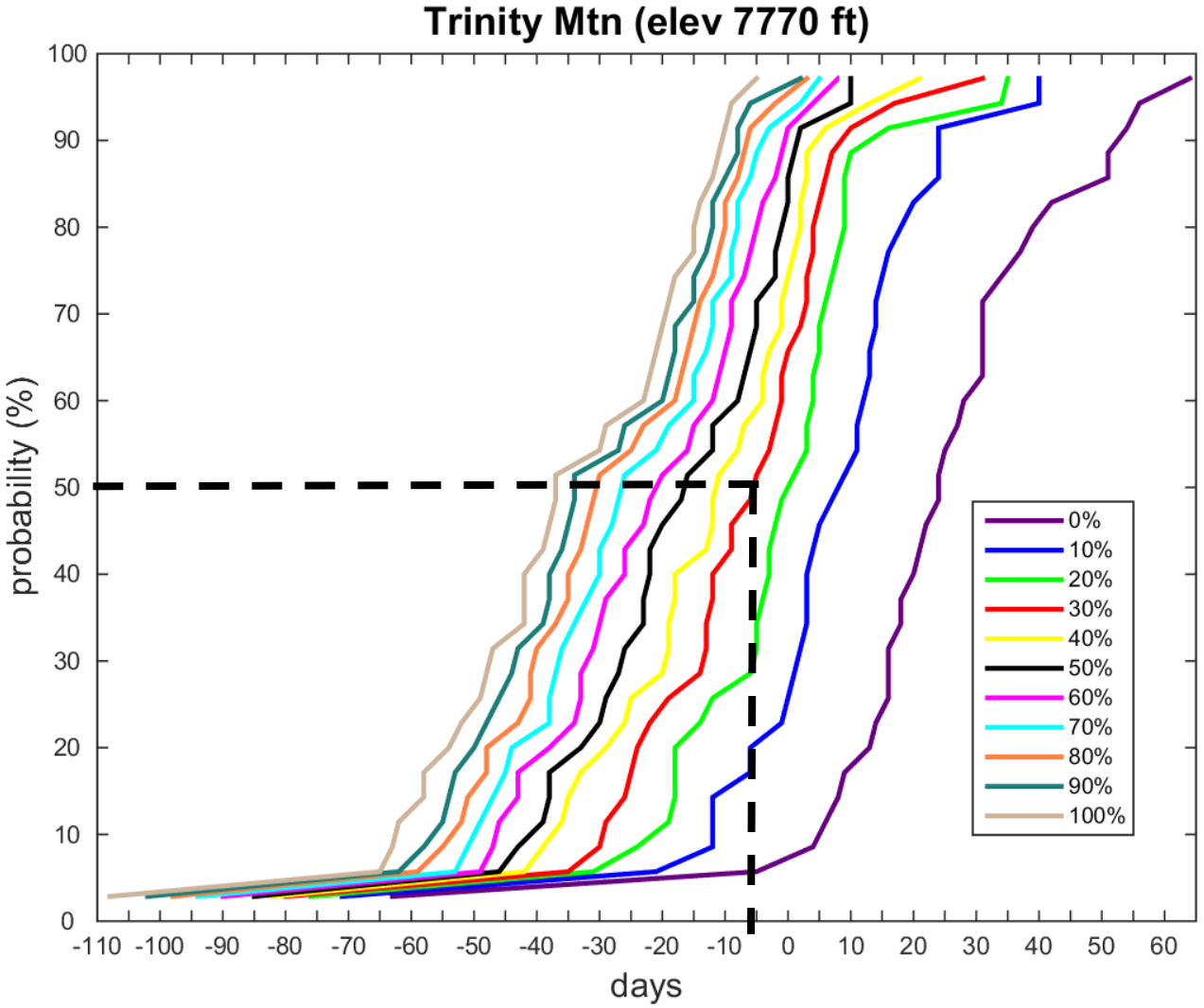




Trinity Mtn to Boise River at Twin Springs

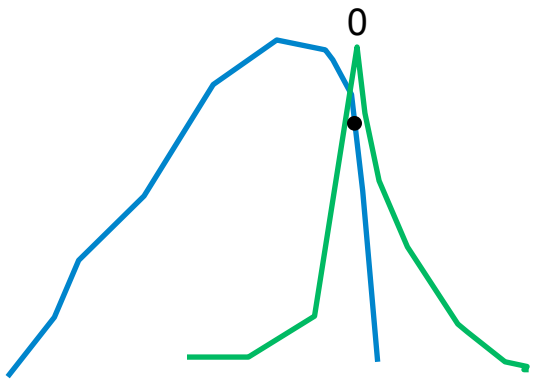
When snow is 30% gone, average time to peak was 6 days ago

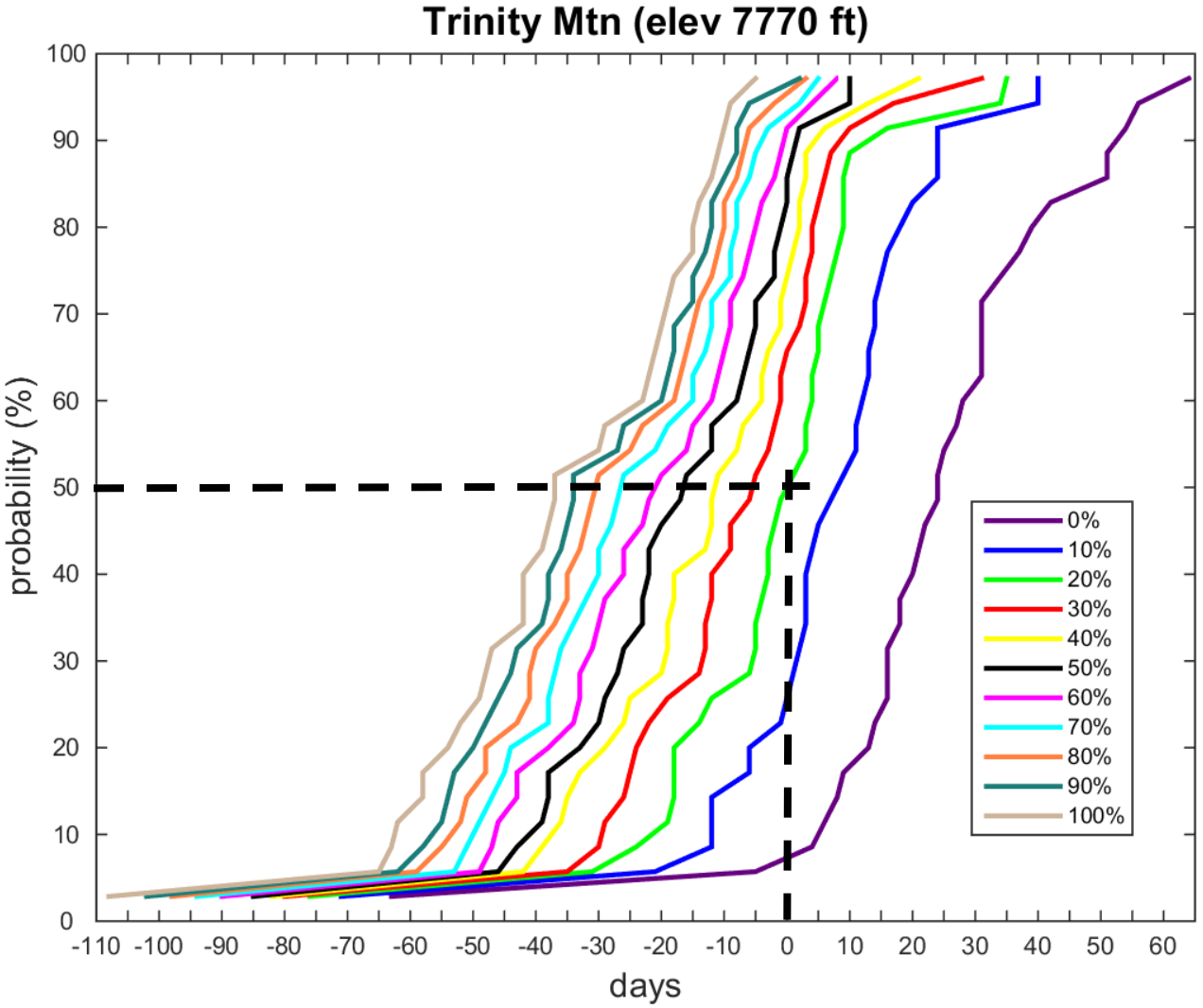




Trinity Mtn to Boise River at Twin Springs

Average melt out on day of peak flow is ~20%

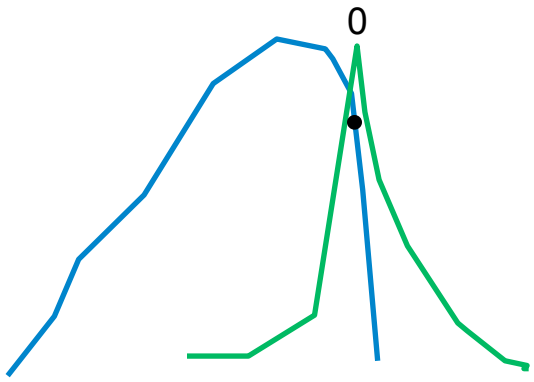


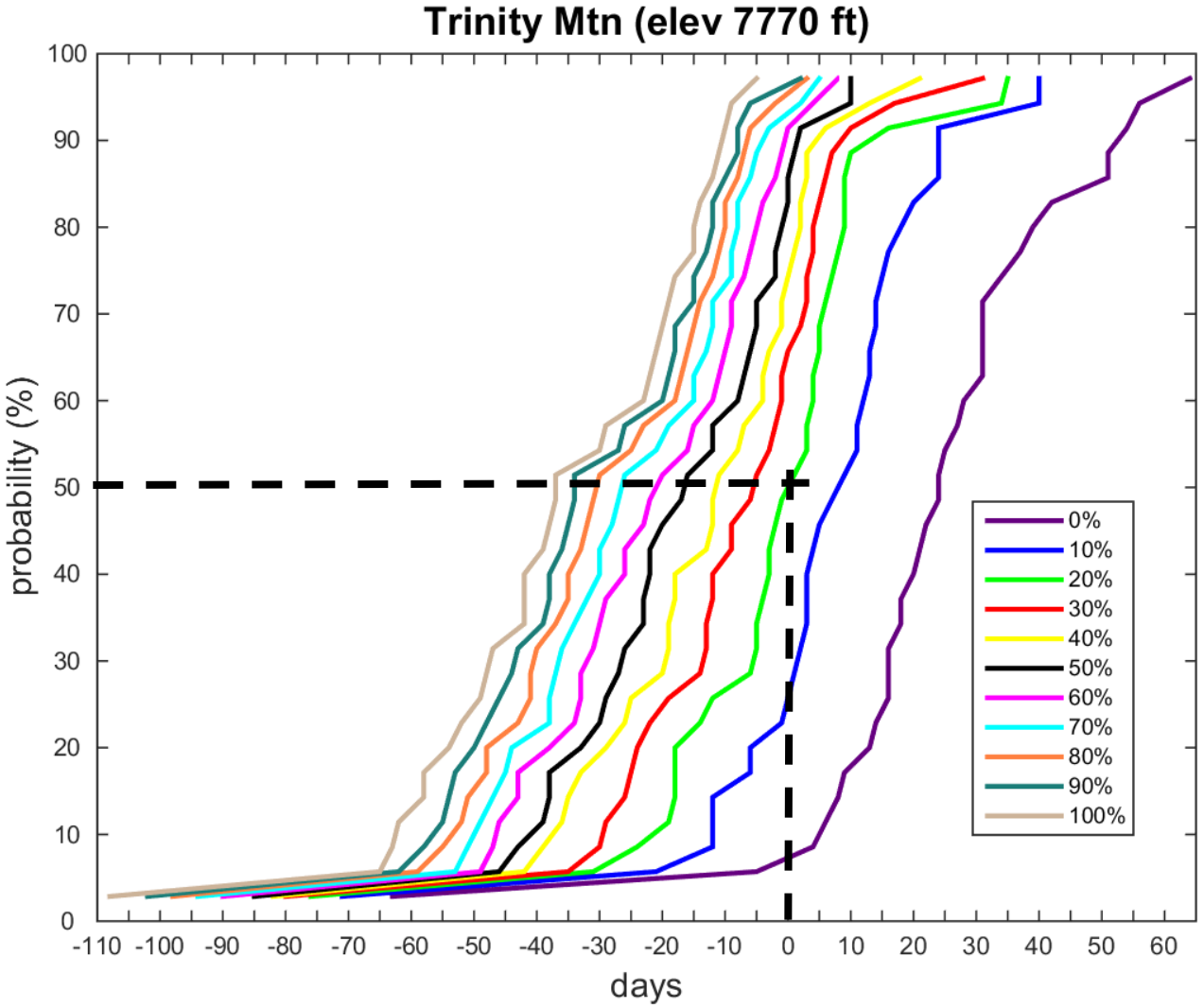


Trinity Mtn to Boise River at Twin Springs

"rule of thumb"

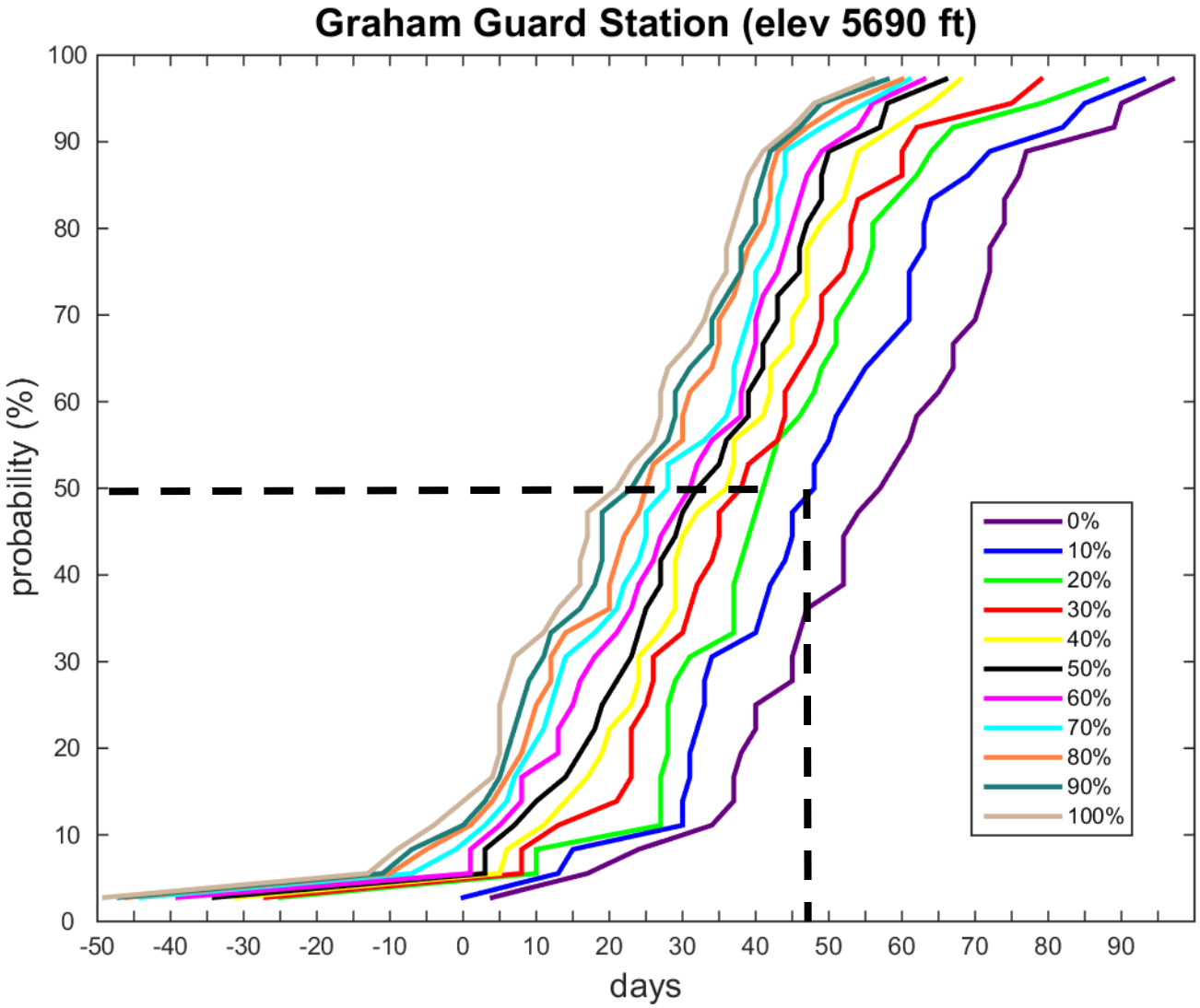
Peak flow happens on average when Trinity Mtn is 20% melted





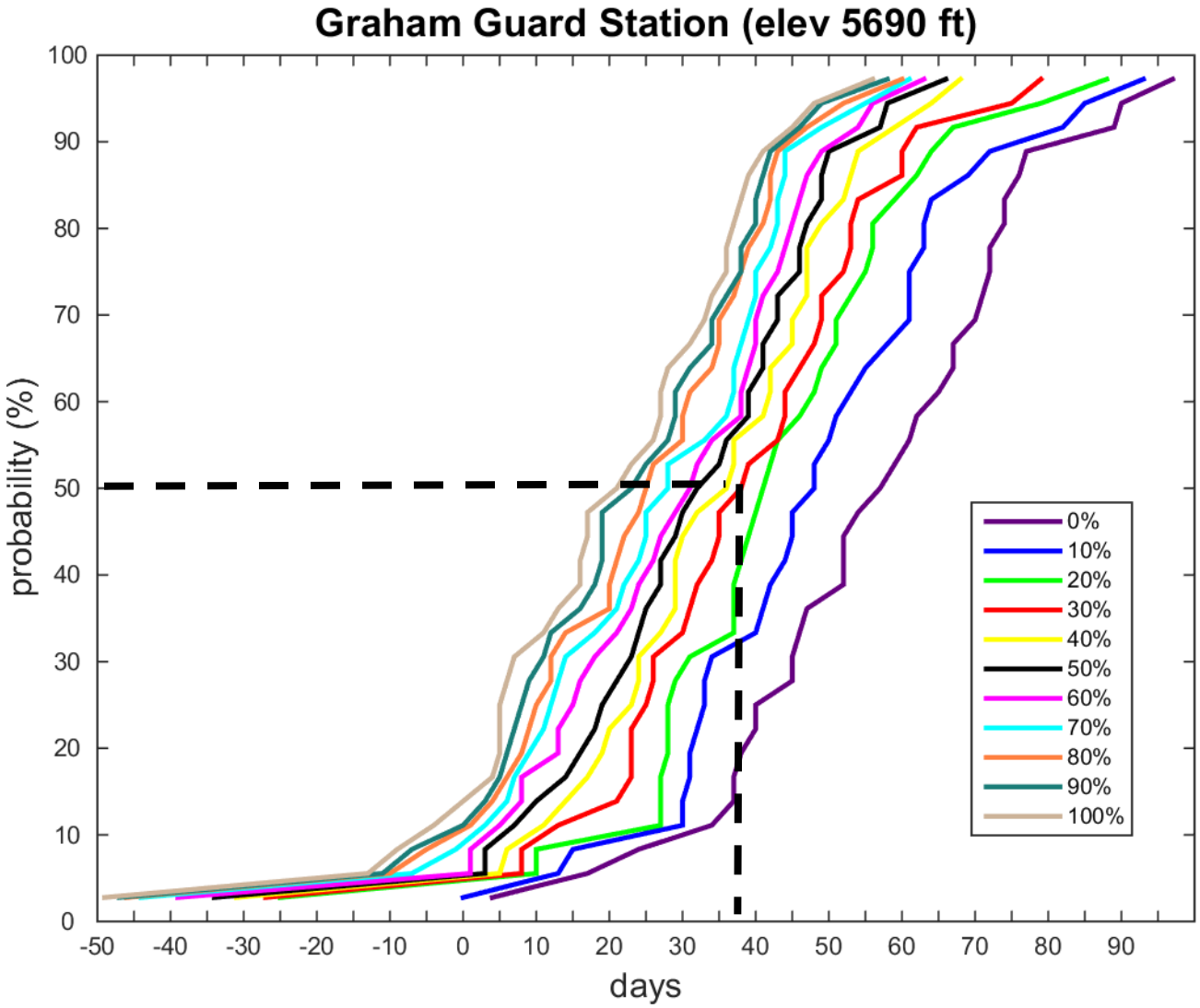
Graham Guard to Boise River at Twin Springs

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



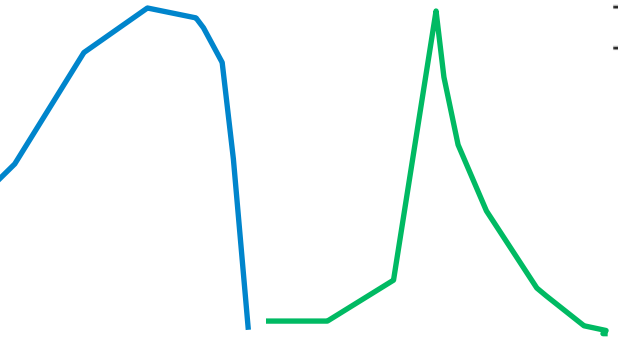
Graham Guard to Boise River at Twin Springs

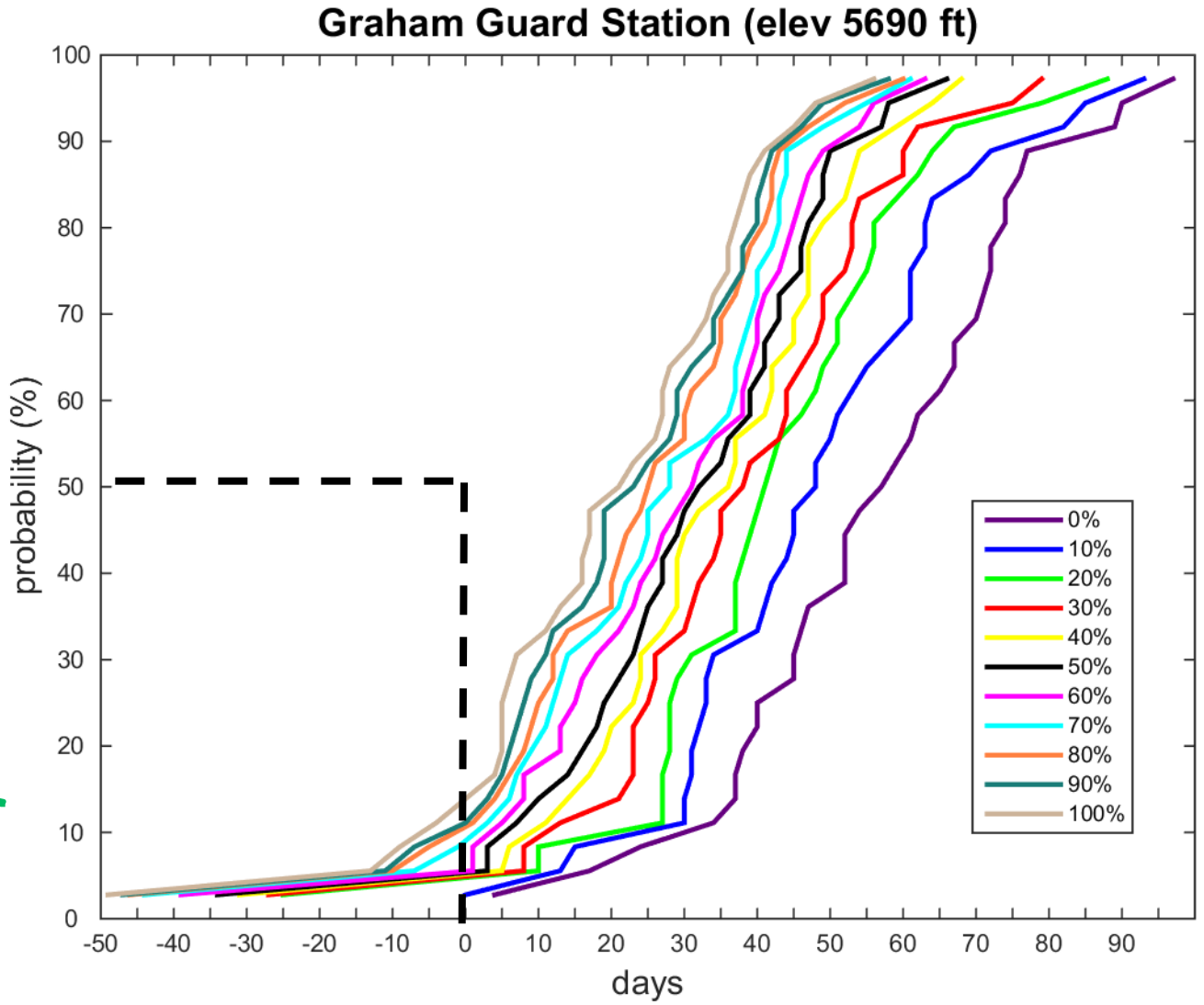
When snow is 30% gone, average time to peak is 38 days



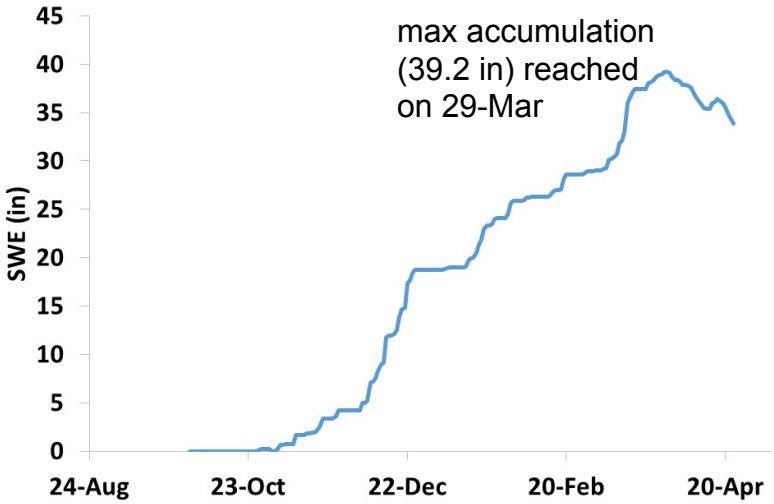
Graham Guard to Boise River at Twin Springs

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

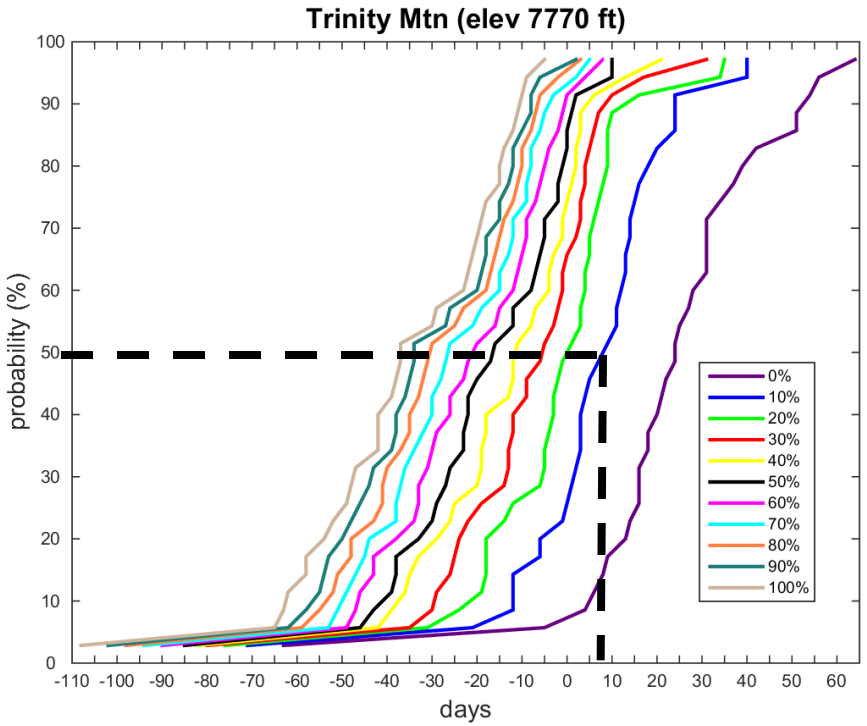




Real Time Analyses

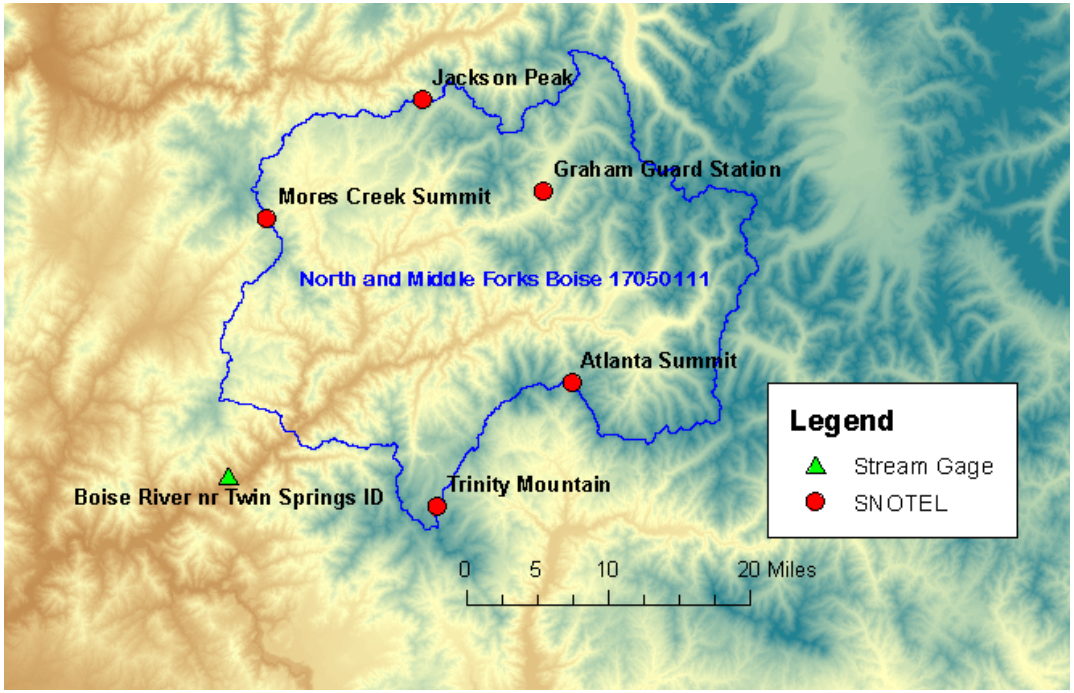


10% melt-out (35.3 in)
reached on 23-Apr



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

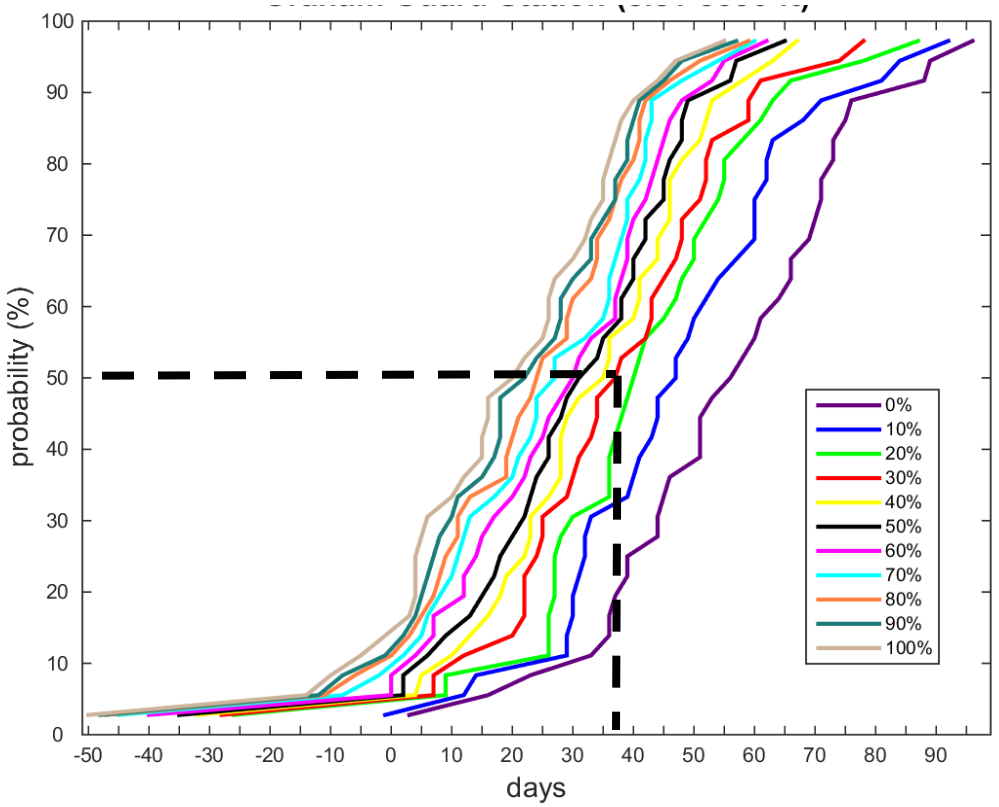
- **Are there environmental conditions that will tell us if the lag will be longer or shorter than average?**

Maximum snow depth?

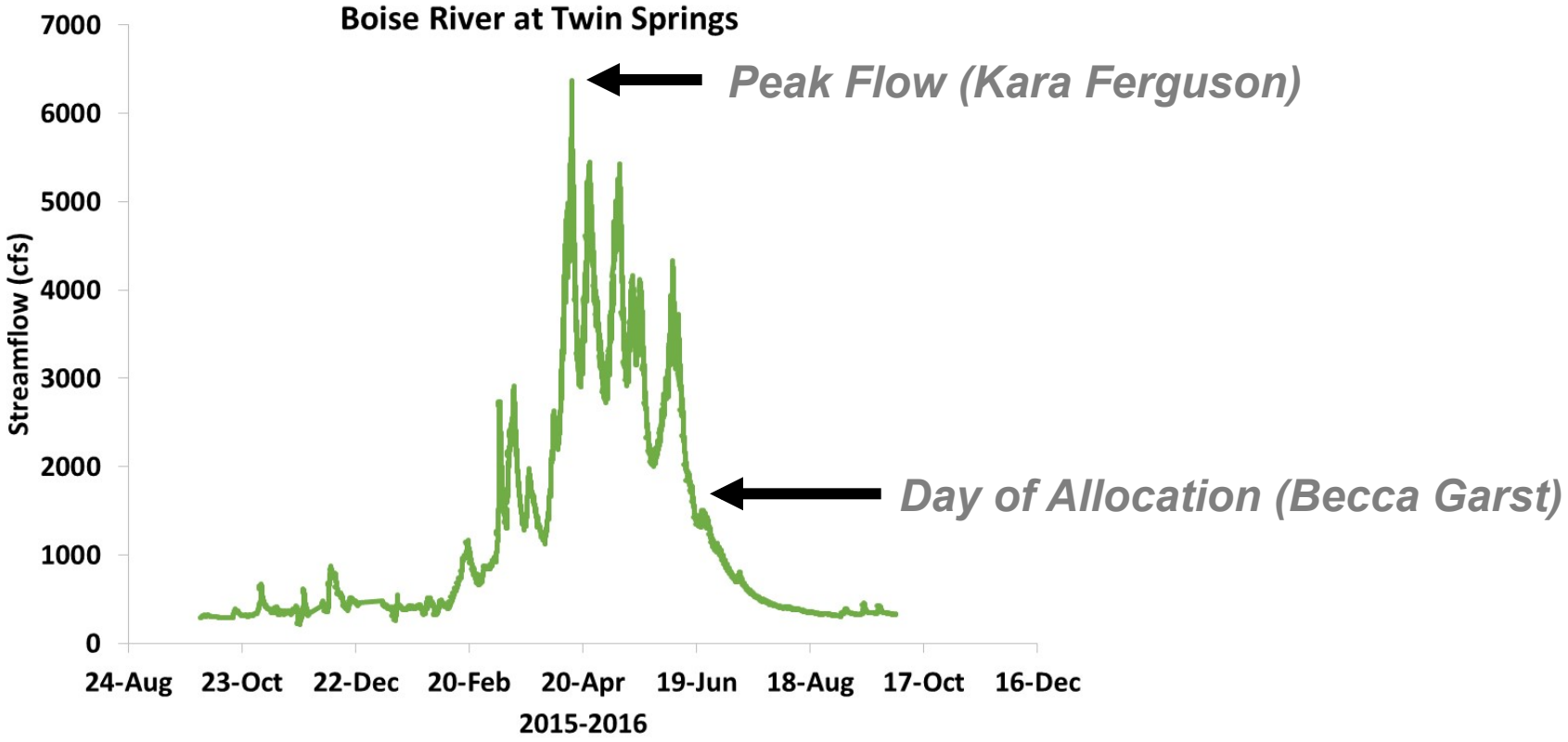
Date of melt?

Rate of melt?

Soil moisture?

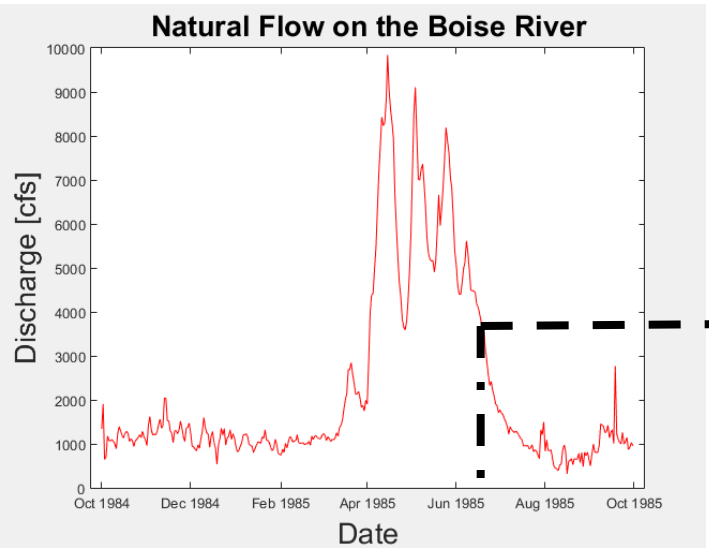


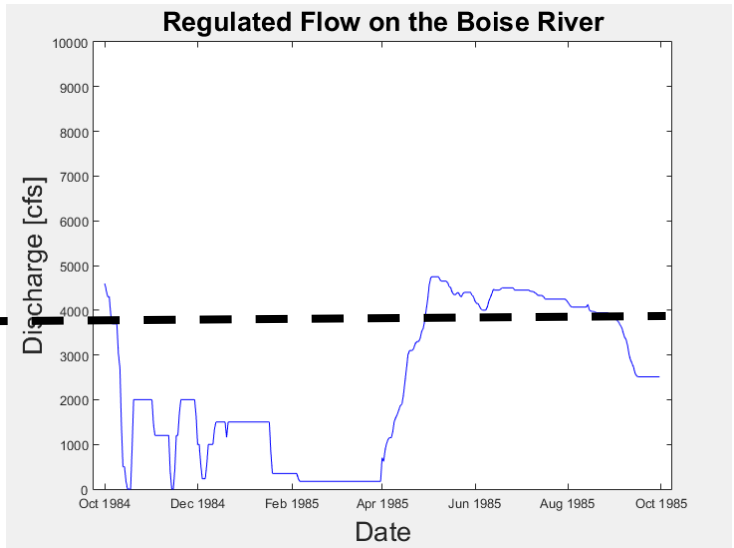
When Will Day of Allocation Occur?



Day of Allocation

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

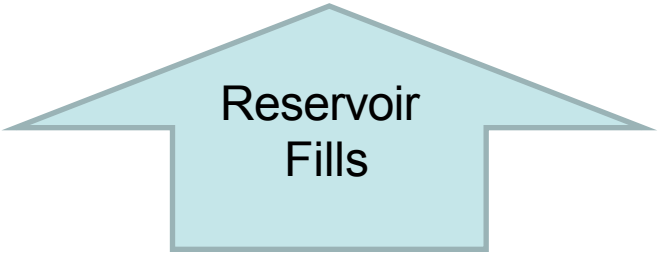




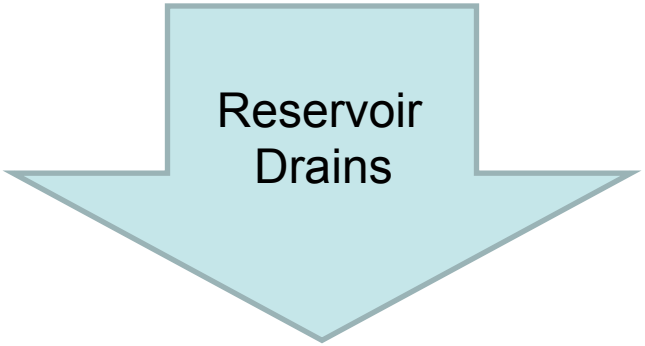
Natural Flow + **Reservoir (Δ Storage)** = **Regulated Flow**

Day of Allocation

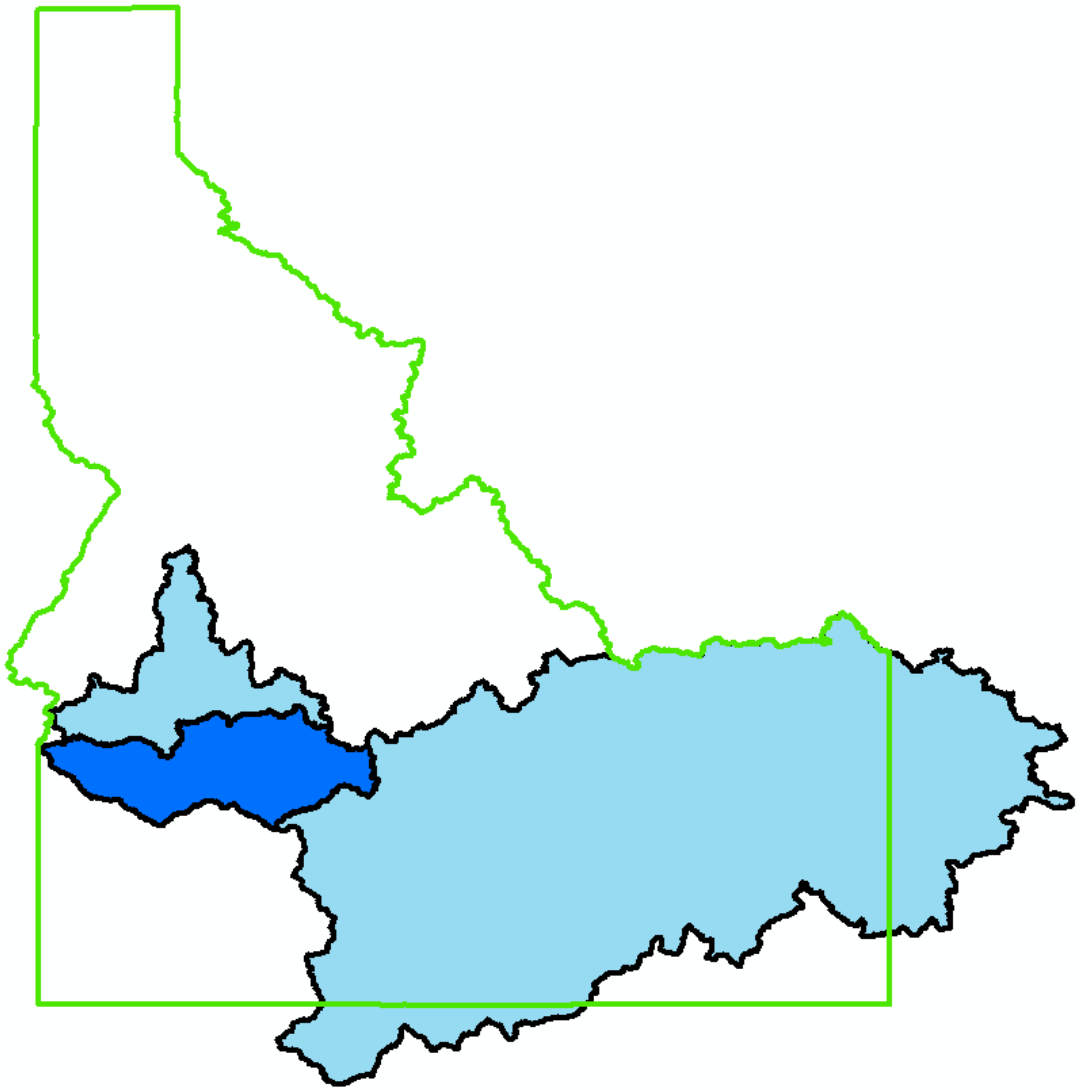
- **Before DOA**
  - Water demands are met by natural flow



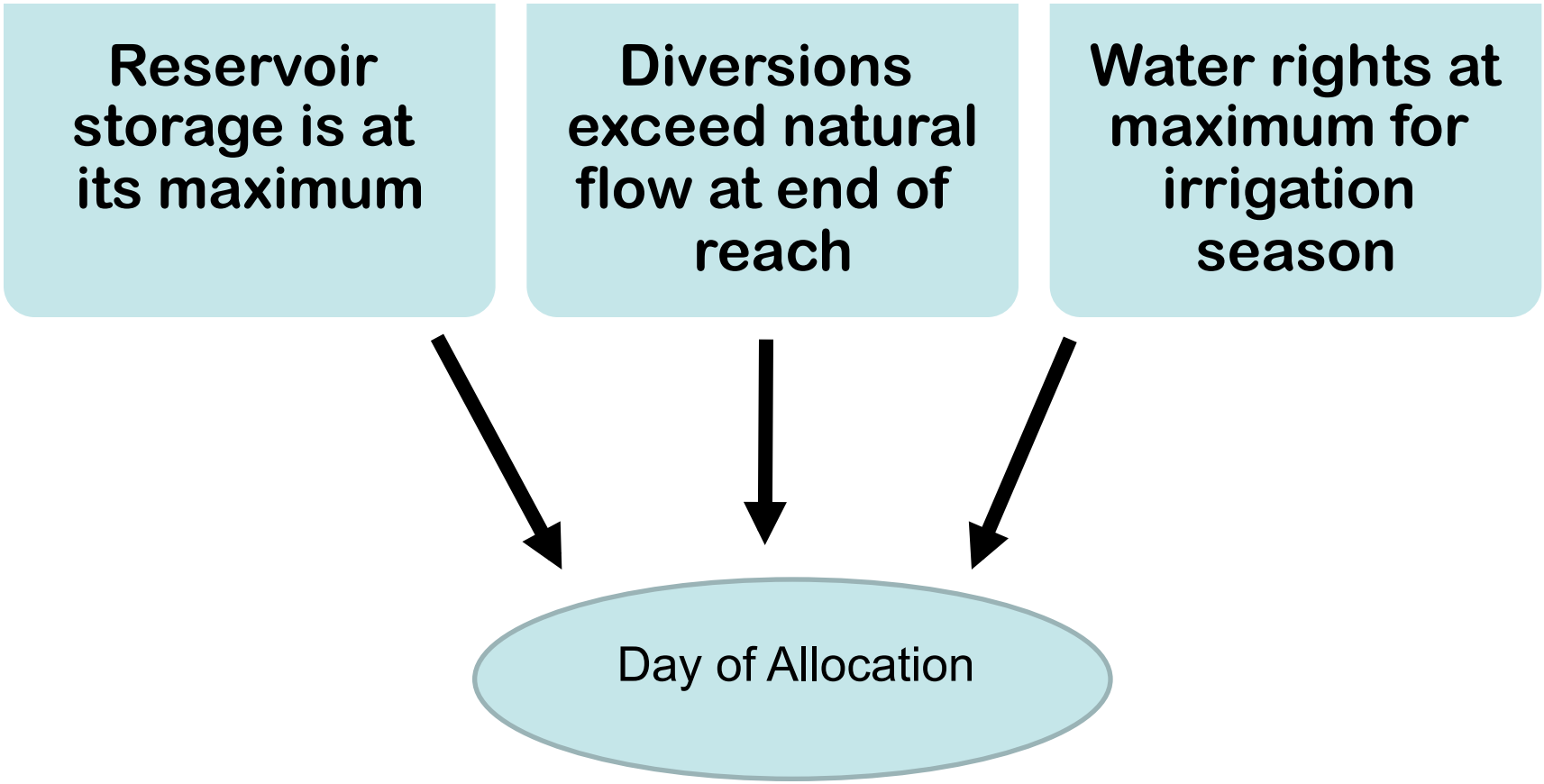
- **After DOA**
  - Water demands supplemented by storage
  - Water rights curtailments begin



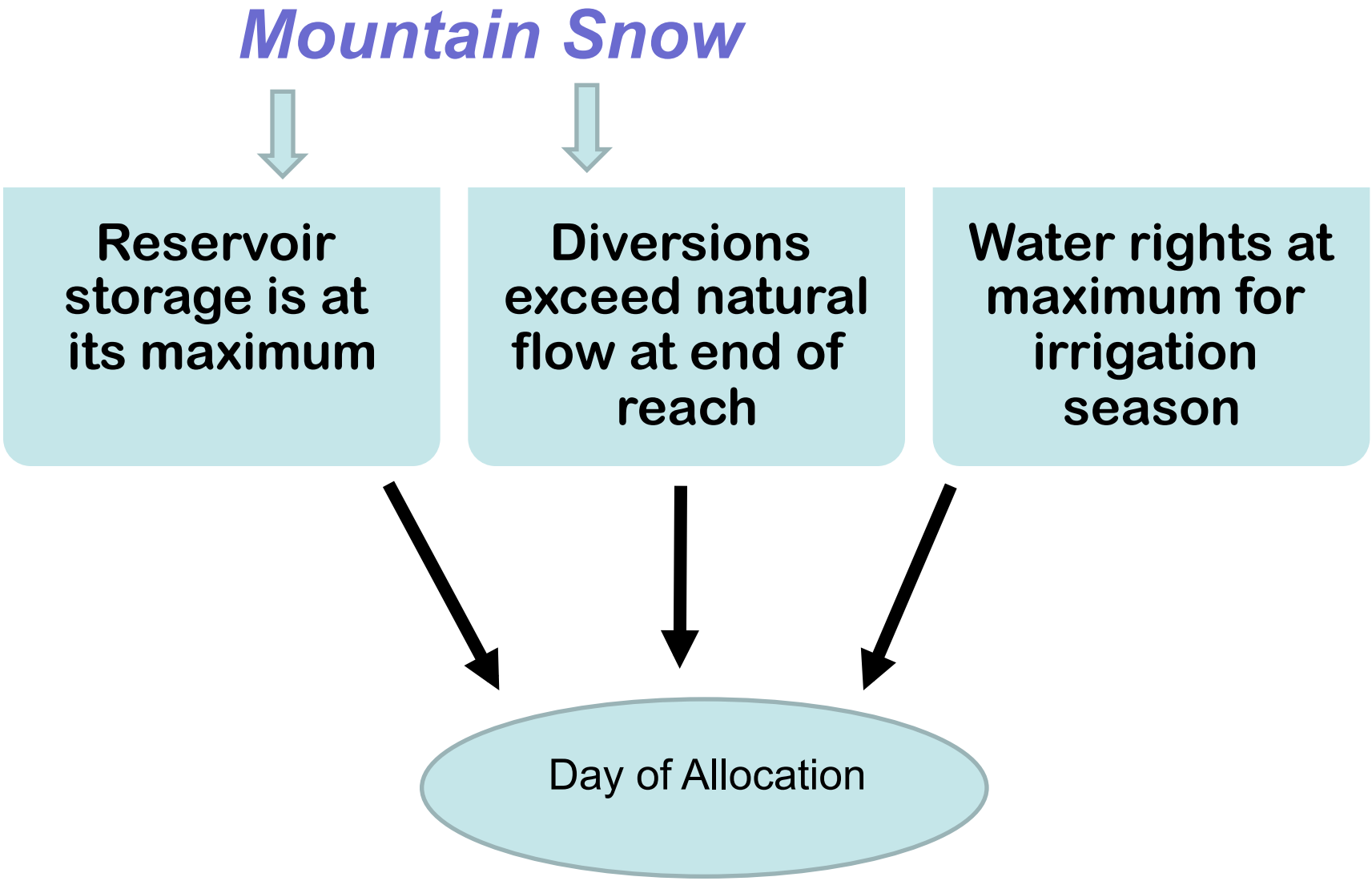
Can SNOTEL data improve DOA prediction?



Boise River DOA occurs when

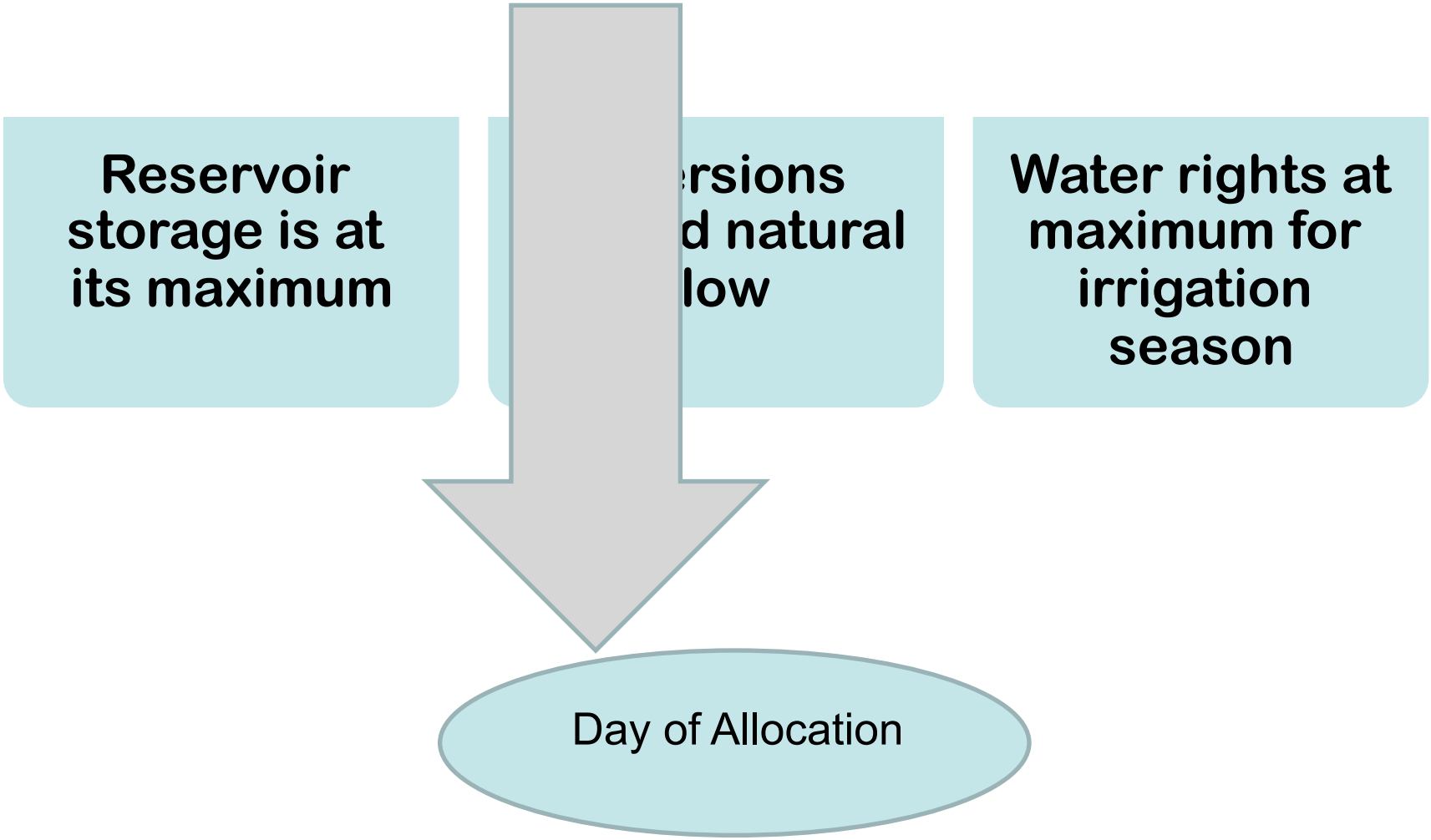


Boise River DOA occurs when

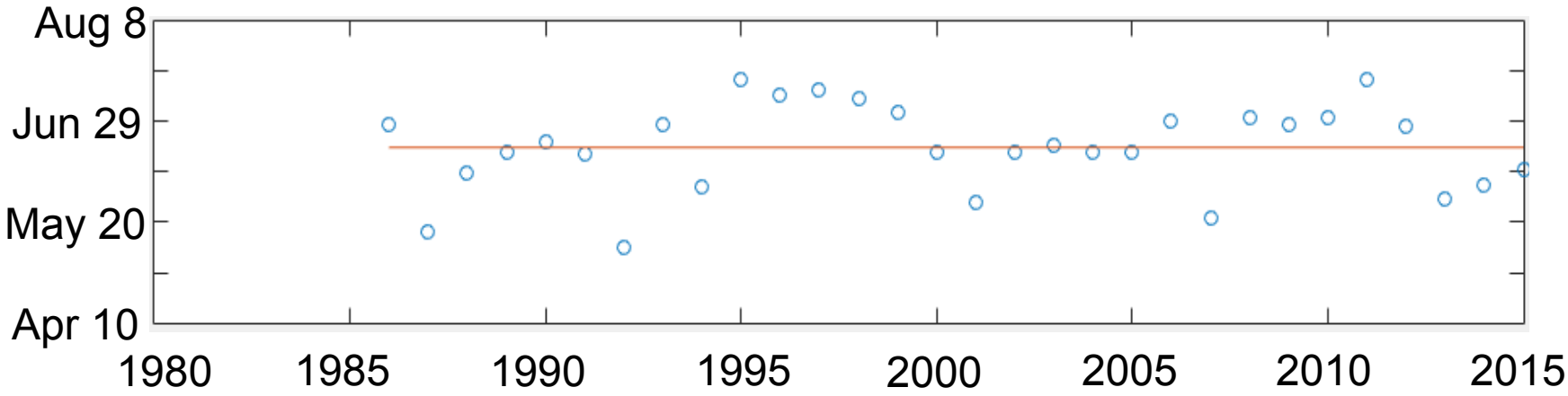


Boise River DOA occurs when

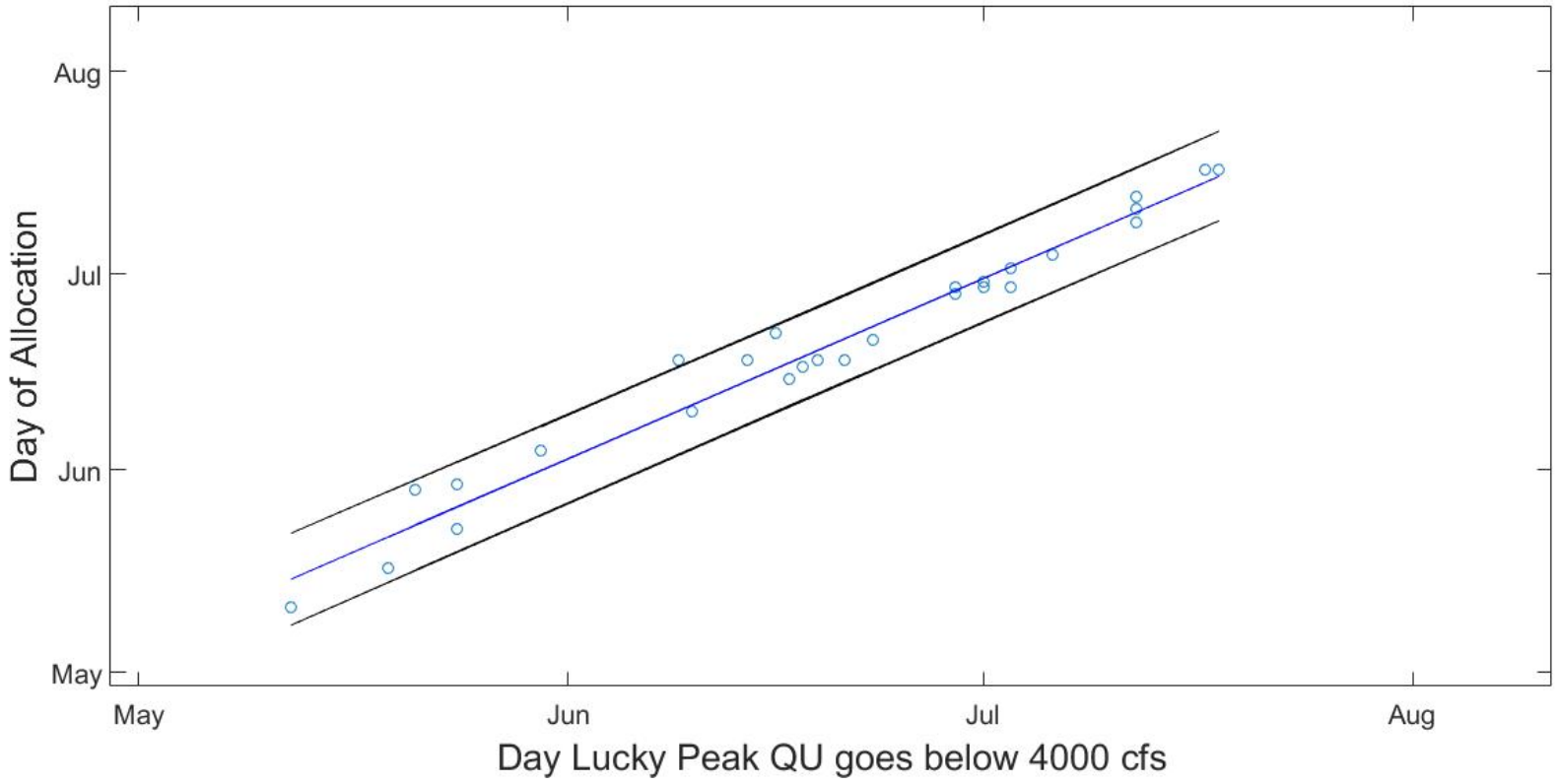
Mountain Snow



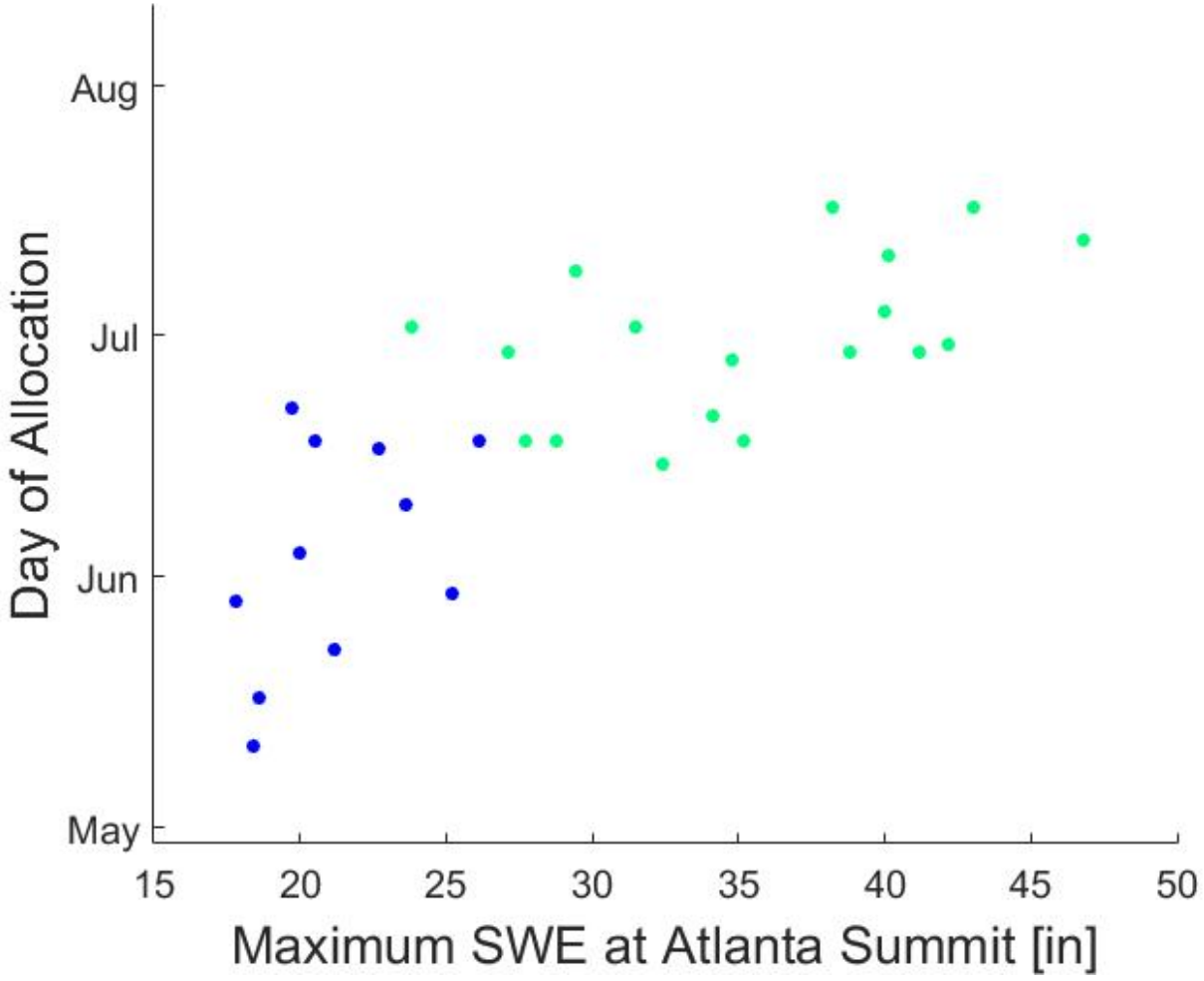
Boise River DOA Dates



DOA vs Natural Flow

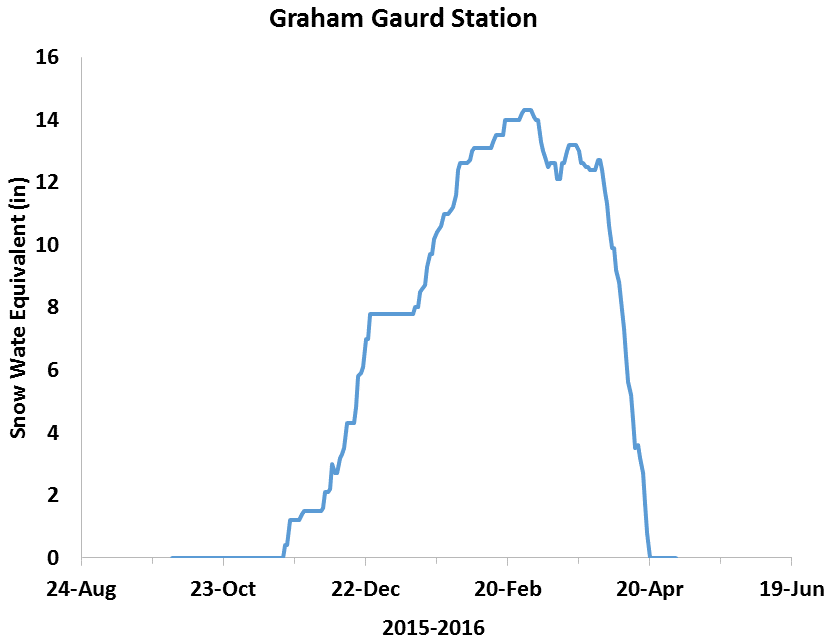


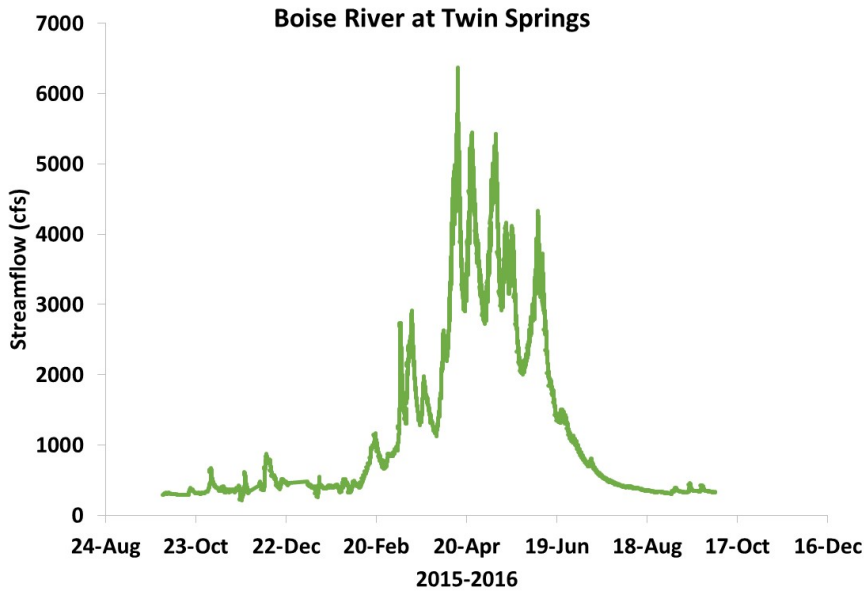
DOA vs Snow


Aug
Jul
Jun
May
Day of Allocation
15
20
25
30
35
40
45
50
Maximum SWE at Atlanta Summit [in]

How does snow control DOA?

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



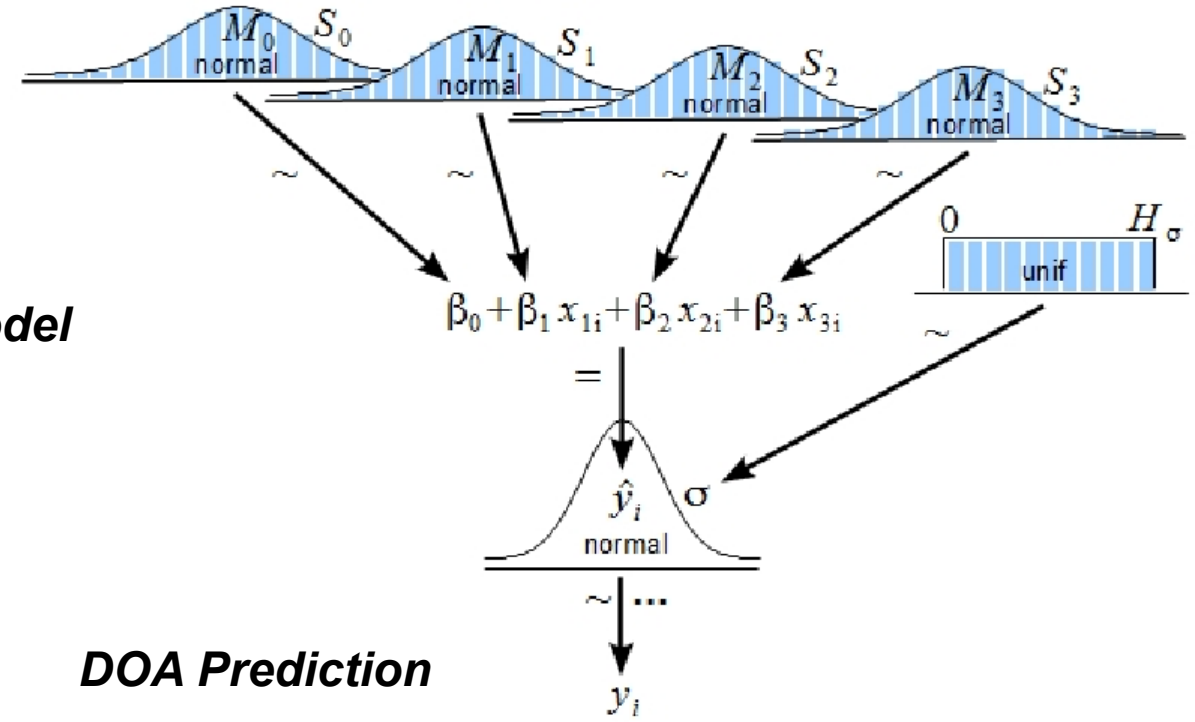


Multiple Linear Regression

Snow and DOA data

MLR Model

DOA Prediction

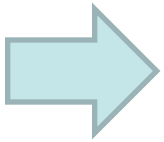


Multiple Linear Regression

Predictor Site

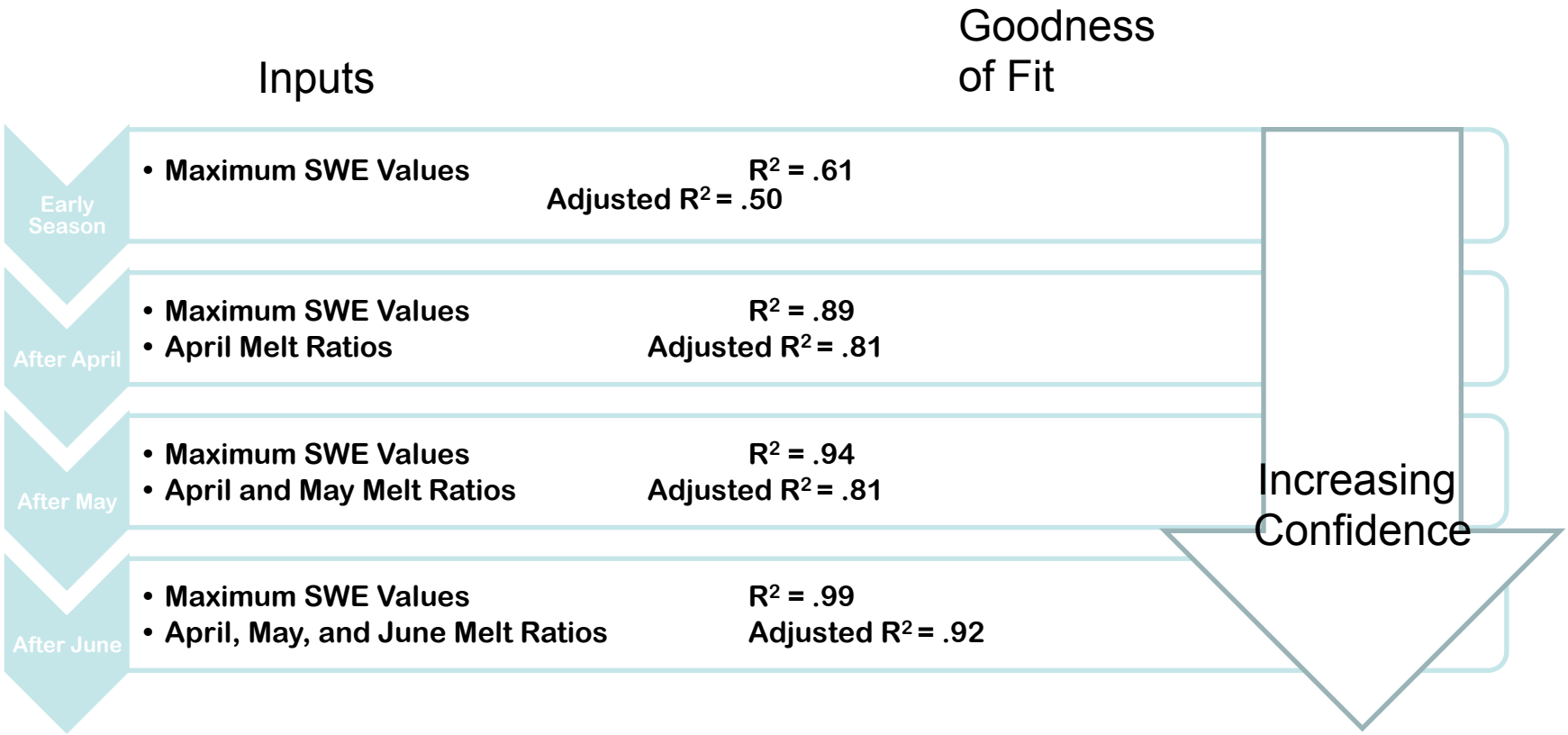
	Atlanta	Graham	Jackson	Mores	Trinity	Vienna
Max SWE	x1	x2	x3	x4	x5	x6
April Melt	x7	x8	x9	x10	x11	x12
May Melt	x13	x14	x15	x16	x17	x18
June Melt	x19	x20	x21	x22	x23	x24

Multiple Linear Regression Model



Day of Allocation Prediction

Boise River
Day of Allocation Prediction



2016 Predictions

2016 DOA
Observation
June 15

Period of Record Data

Predictor Site

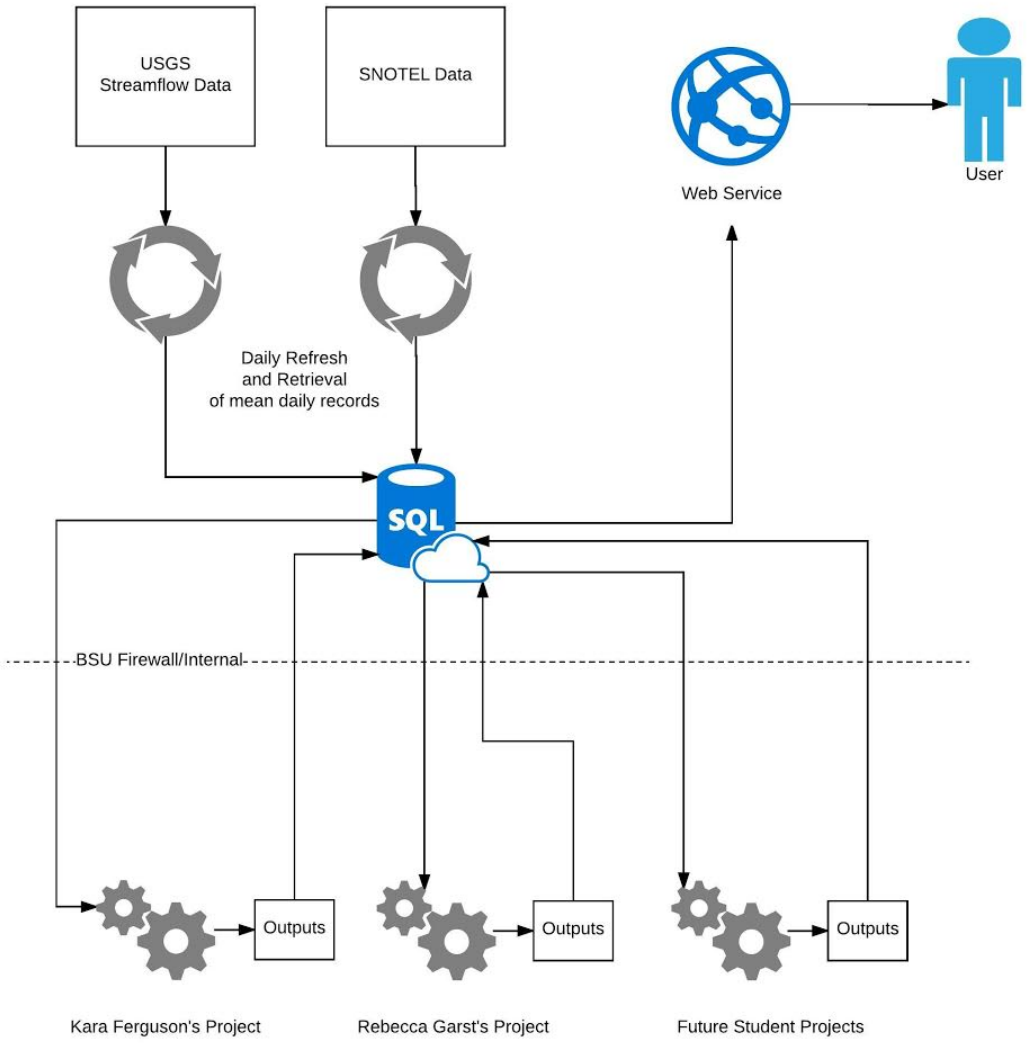
	Atlanta	Graham	Jackson	Mores	Trinity	Vienna
Max SWE	x1	x2	x3	x4	x5	x6
April Melt	x7	x8	x9	x10	x11	x12
May Melt	x13	x14	x15	x16	x17	x18
June Melt	x19	x20	x21	x22	x23	x24

Multiple Linear Regression Model

2016 DOA
Prediction
June 17

Making Research Useful

Ryan Dammrose



Snow to Flow

http://www.opb.org/