Snow Surveys Program and Water Supply Forecasting

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January 23. 2015

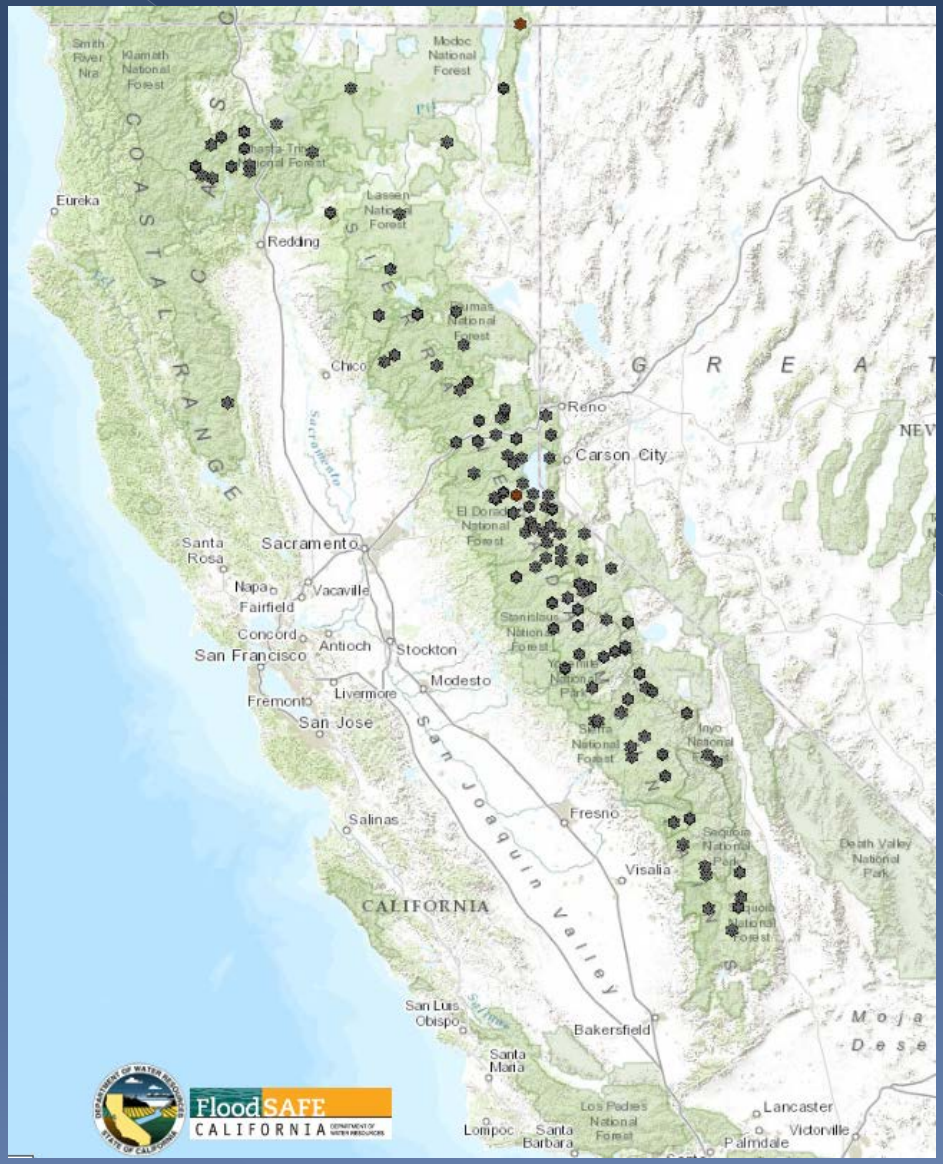
Central Valley Flood Protection Board

California Snow Courses and Snow Sensors

- Snow Course (oldest climate records)

- Snow Pillow / Sensor

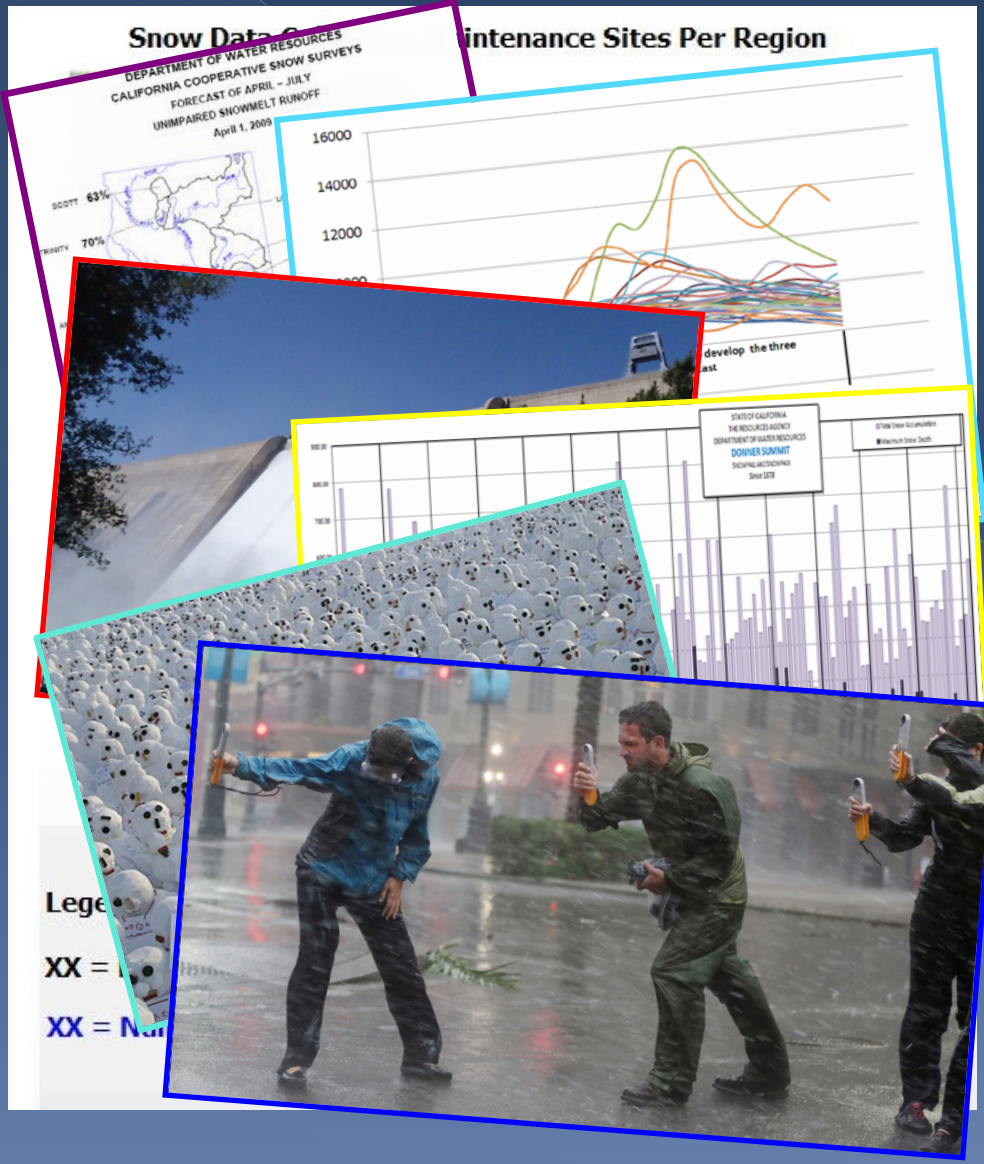
Snow Sensor Locations



Snow Pack is measured <u>from approximately:</u>

- 250 snow courses (measured monthly February thru May)
- 125 snow sensors (measured daily)

California Snow Courses and Snow Sensors



<u>Snow Data is used for:</u>

- Seasonal Runoff Determination (Water Supply)
- Snow Melt Runoff Forecasts (5-20 day outlook)
- **"Early Warning System" for Flood Emergency Response**
- Climate/Long term studies
- Recreation
- Giving PhD students something to do

So How Do We Produce DWR's Water Supply Forecasts?

Primary Forecasting Tool → Multiple Linear Regression Analysis

Dependent Variable → April-July Cumulative Unimpaired Runoff

Independent Variables

Three basic types of data

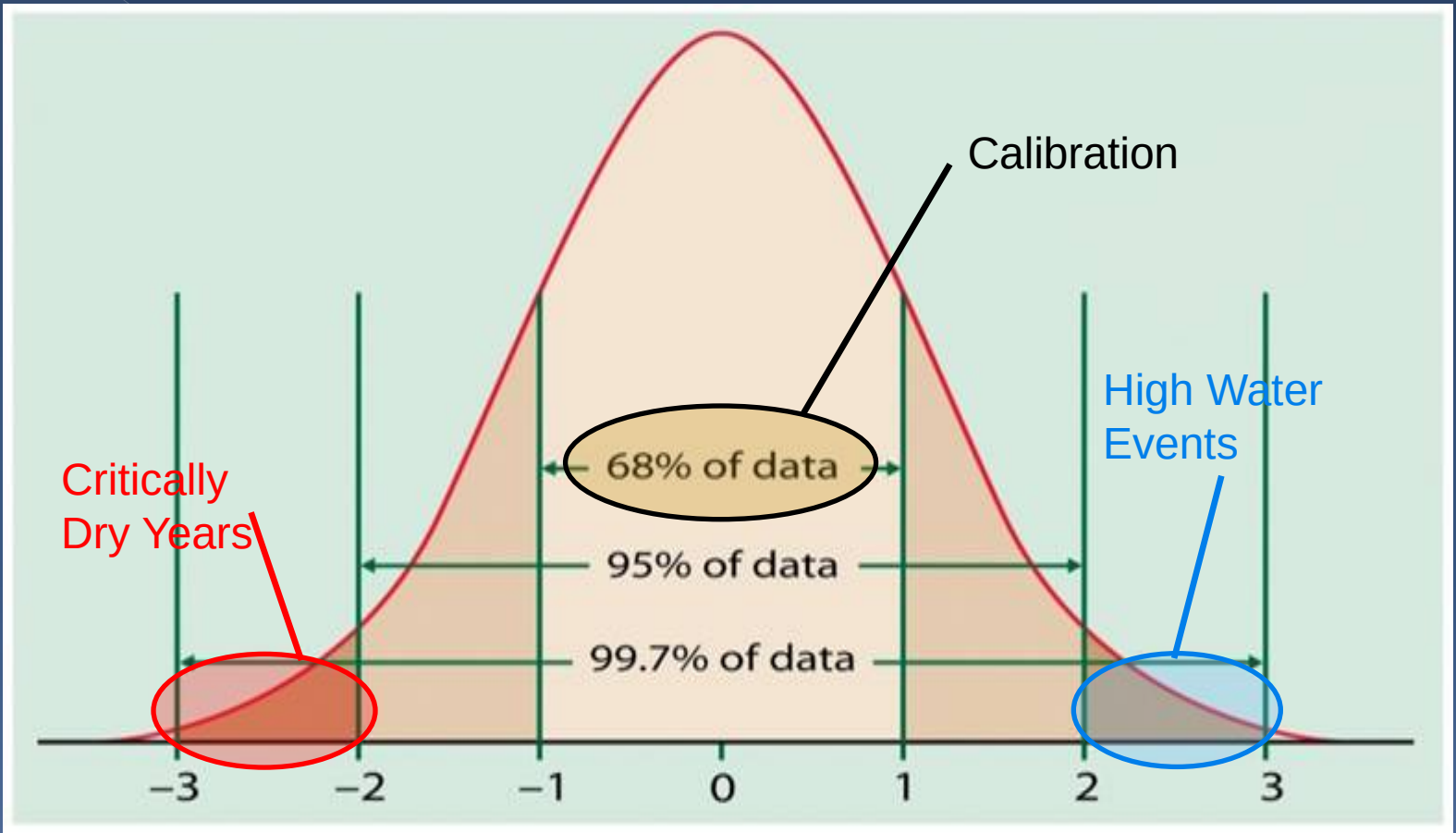
50-year averages

- → Prior Year April-July Cumulative Unimpaired Runoff
- → October-March Cumulative Unimpaired Runoff
- → Snow Index (High Elevation)
- → Snow Index (Low Elevation)
- → October-March Precipitation Index
- → April-June Precipitation Index

Ideal forecast accuracy: 5-10%*

i.e. – We use statistics from a long historical data record!!

The Statistical Anomaly of Using Statistics: Using Averages to Predict Extremes



- Based on…historical measurements
- Errors

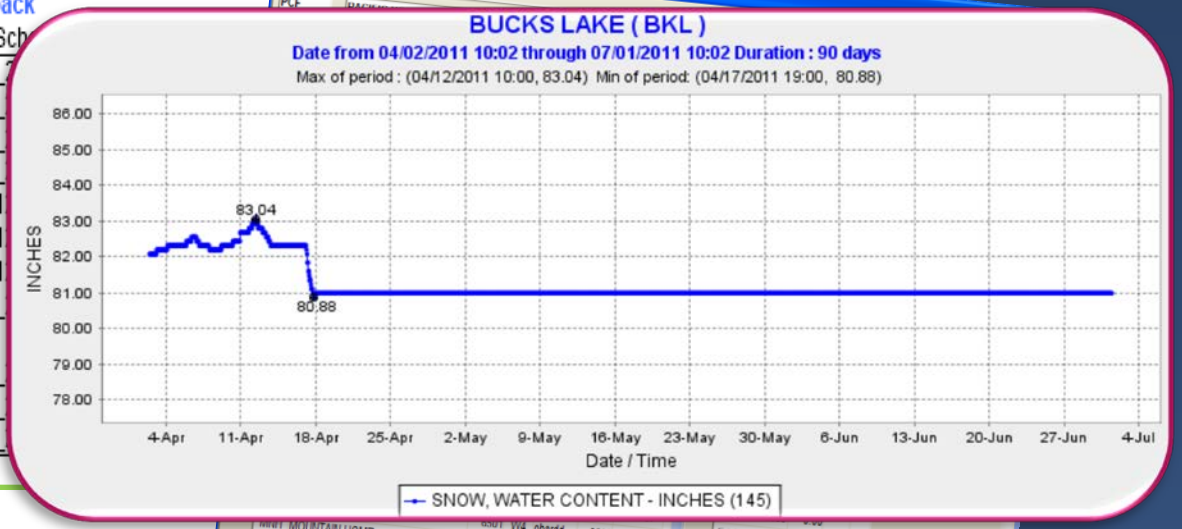
When Data Goes bad…

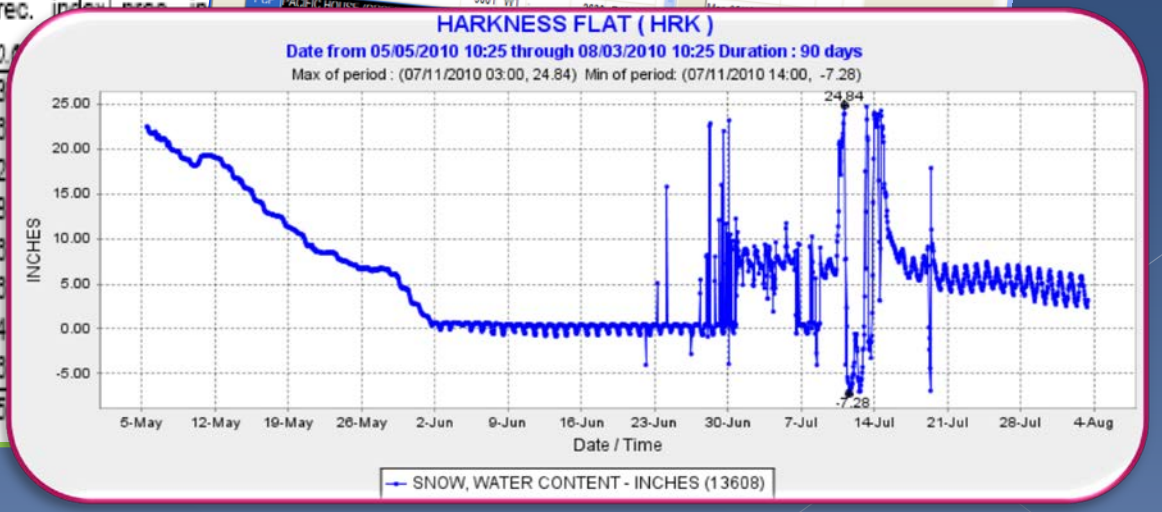
Feather River inflow to Lake Oroville — High Snowpack

#	ID	Name	Basin	Dir	Elev	4/1avg	Pr.st	Ratio	Sch
361	KTL	Kettle Rock	Feath	⇳	7300'	23.0	7	.7	
48	MDY	Mount Dyer	Feath	↑	7100'	25.5	6	1.0	
359	GRZ	Grizzly	Feath	⇳	6900'	30.3	7	1.1	
279	ERB	Eureka Bowl	Feath	↓	6800'	44.3	8	2.6	
280	RWL	Rowland Creek	Feath	→	6700'	17.8	7	.7	1
360	MHG	Mount Hough	Feath	⇳	6700'	29.5	7	1.1	1
75	CHU	Church Meadows	Feath	↓	6700'	32.1	8	1.9	1
74	YBP	Yuba Pass	Yuba	↘	6700'	30.9	8	.9	
45	SVR	Silver Lake Meado	Susan	↖	6450'	29.6	5	.9	
53	3LK	Three Lakes	Feath	←	6250'	39.9	7	1.5	
54	MLF	Mill Creek Flat	Feath	←	5900'	39.2	7	1.5	
49	LTT	Letterbox	Feath	←	5600'	49.9	7	1.9	
	Basin average:				6590'	32.7			

Feather River inflow to Lake Oroville

ID	Name	Dir	Elev [ft]	Oct-Mar avg	Oct prec.	Oct index	Nov prec.	Nov index
(8)	Scaling factor:				0.5		0.5	
SRR	Sierraville RS	↘	4975'	16.90	.88	2.6		
MNR	Mineral	↖	4875'	33.90	4.31	6.4		
PRT	Portola	→	4850'	13.30	.58	2.2		
CNY	Canyon Dam	↖	4560'	25.60	2.00	3.9		
BCR	Brush Creek RS	↙	3560'	47.00	4.25	4.5		
QNC	Quincy RS	⇳	3410'	26.70	2.28	4.3		
CBO	Caribou PH	⇳	2990'	27.50	1.95	3.5		
BUP	Bucks Creek PH	←	1760'	45.40	4.34	4.8		
Basin average:			3870'	29.54	2.57	4.0		

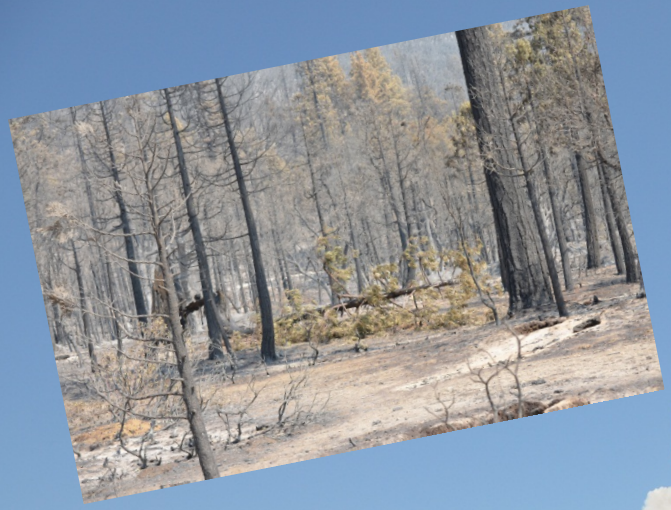




Source: DWR Snow Surveys Section and the California Data Exchange Center

When Landscapes Change…

Source: USFS



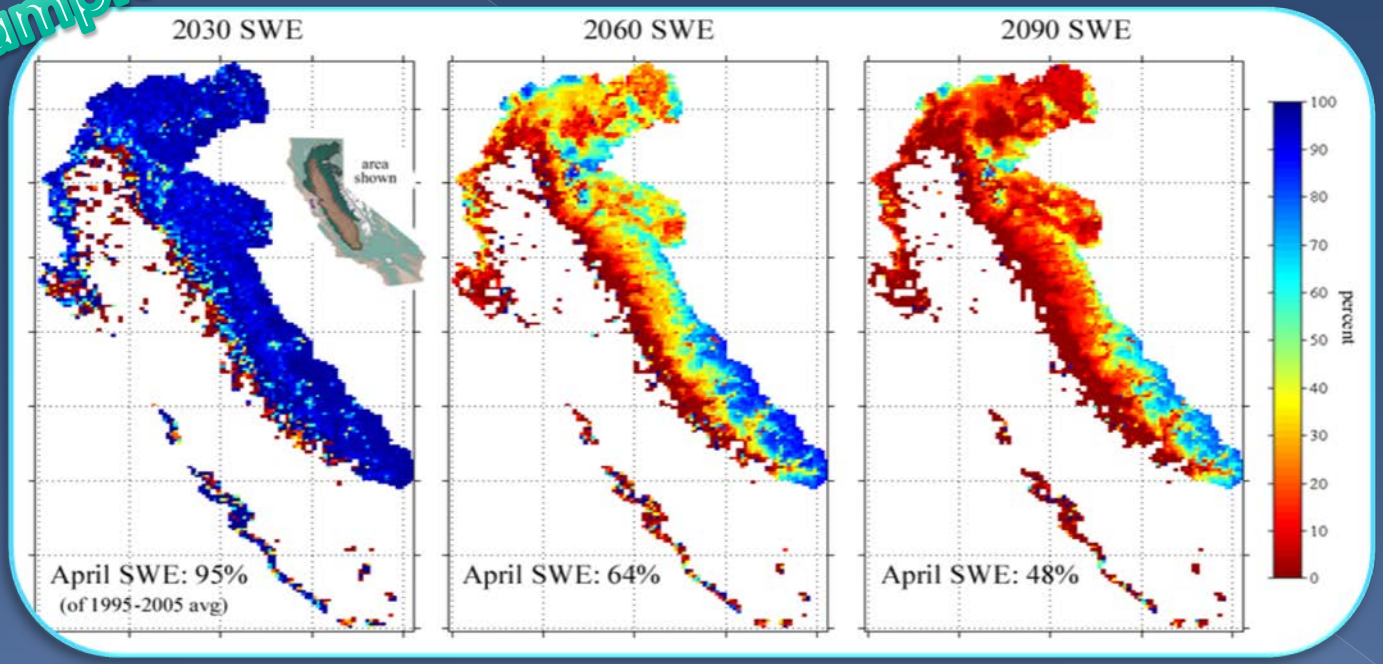
When Climate Changes…

"The Only Constant In Life Is Change"
-Heraclitus, c 535 BC

Warning! Climate Change Slide!

Example:

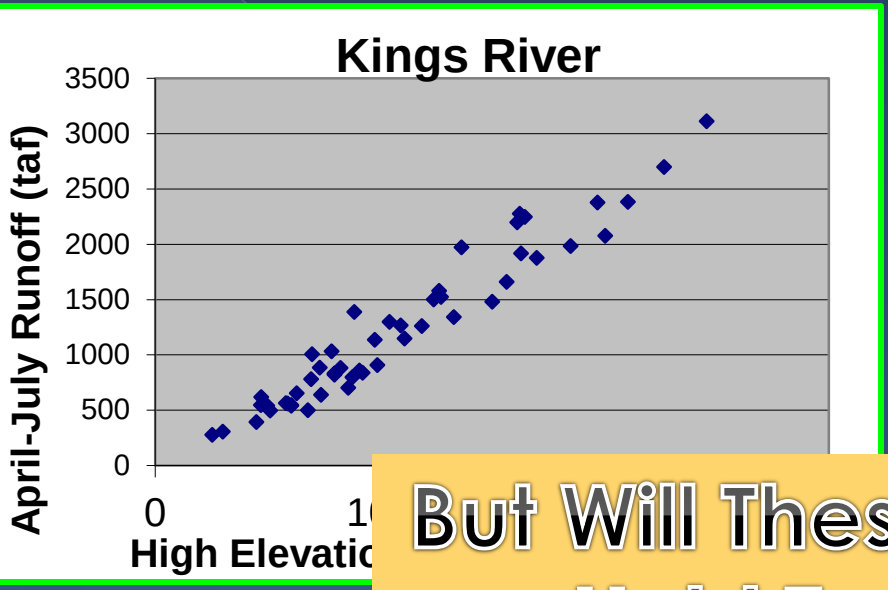
Springtime SWE Under Projected Temperature Increases

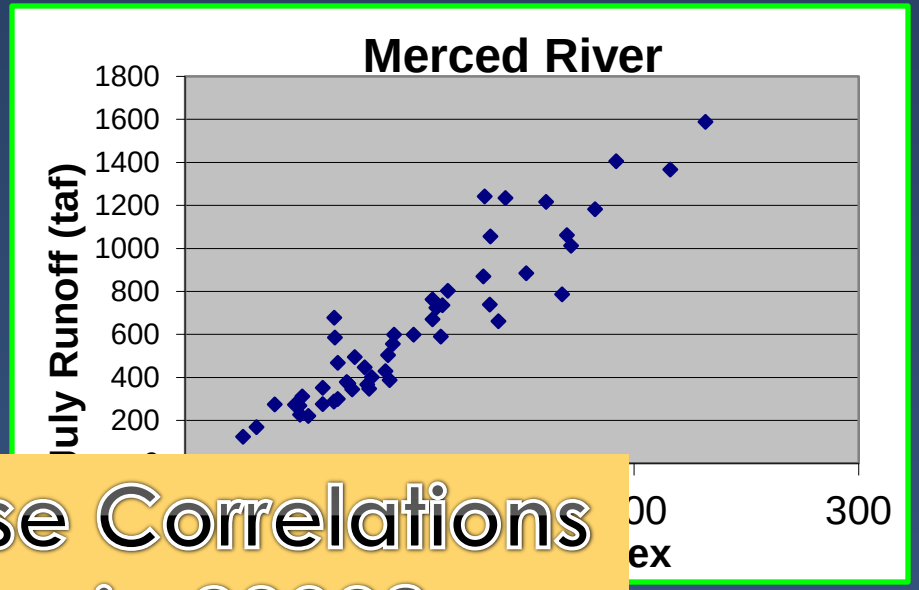


Source: Knowles and Cayan, 2002

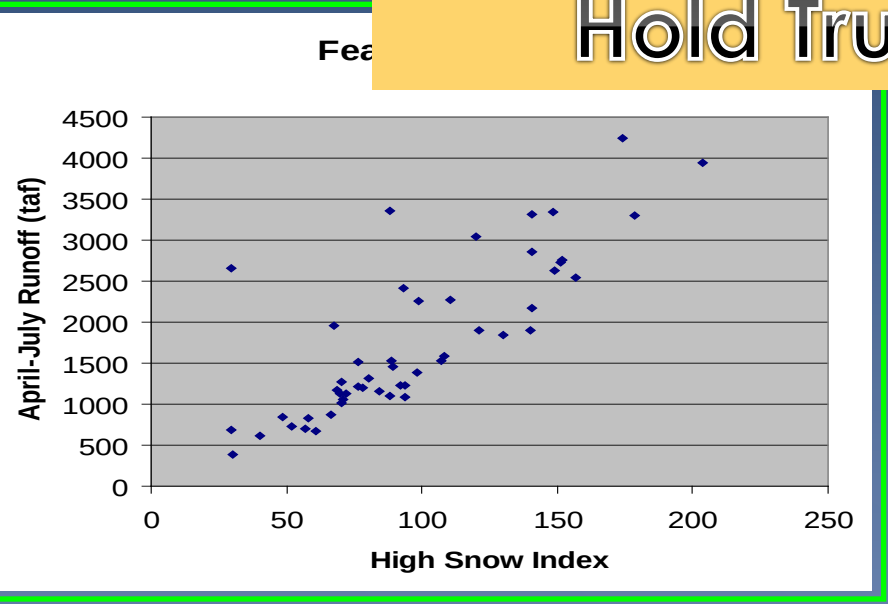
Notes: Projected temperature increases: 0.6C (2020-2039), 1.6C ((2050-2069), and 2.1C (2080-2099), expressed as a percentage of average present conditions

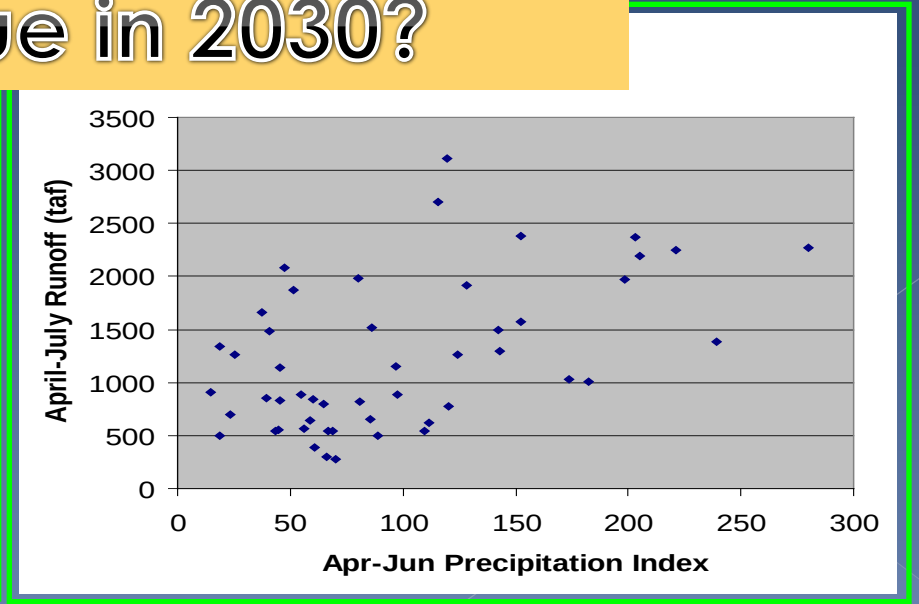
We Are Only As Good as Our Data





But Will These Correlations Hold True in 2030?





Good But Not Ideal

Primary Forecasting Tool → Multiple Linear Regression Analysis

Independent Variables

→ **Prior Year April-July Cumulative Unimpaired Runoff**

→ **October-March Cumulative Unimpaired Runoff**

→ **Snow Index (High Elevation)**

→ **Snow Index (Low Elevation)**

→ **October-March Precipitation Index**

→ **April-June Precipitation Index**

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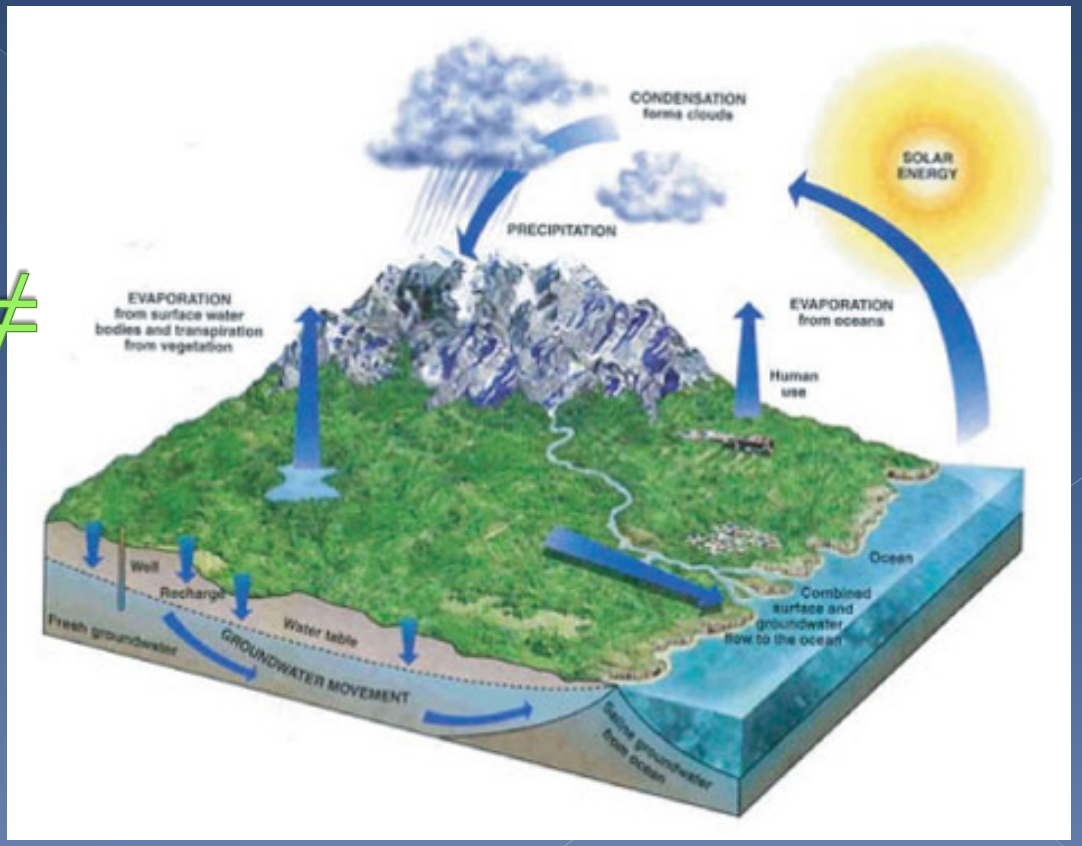
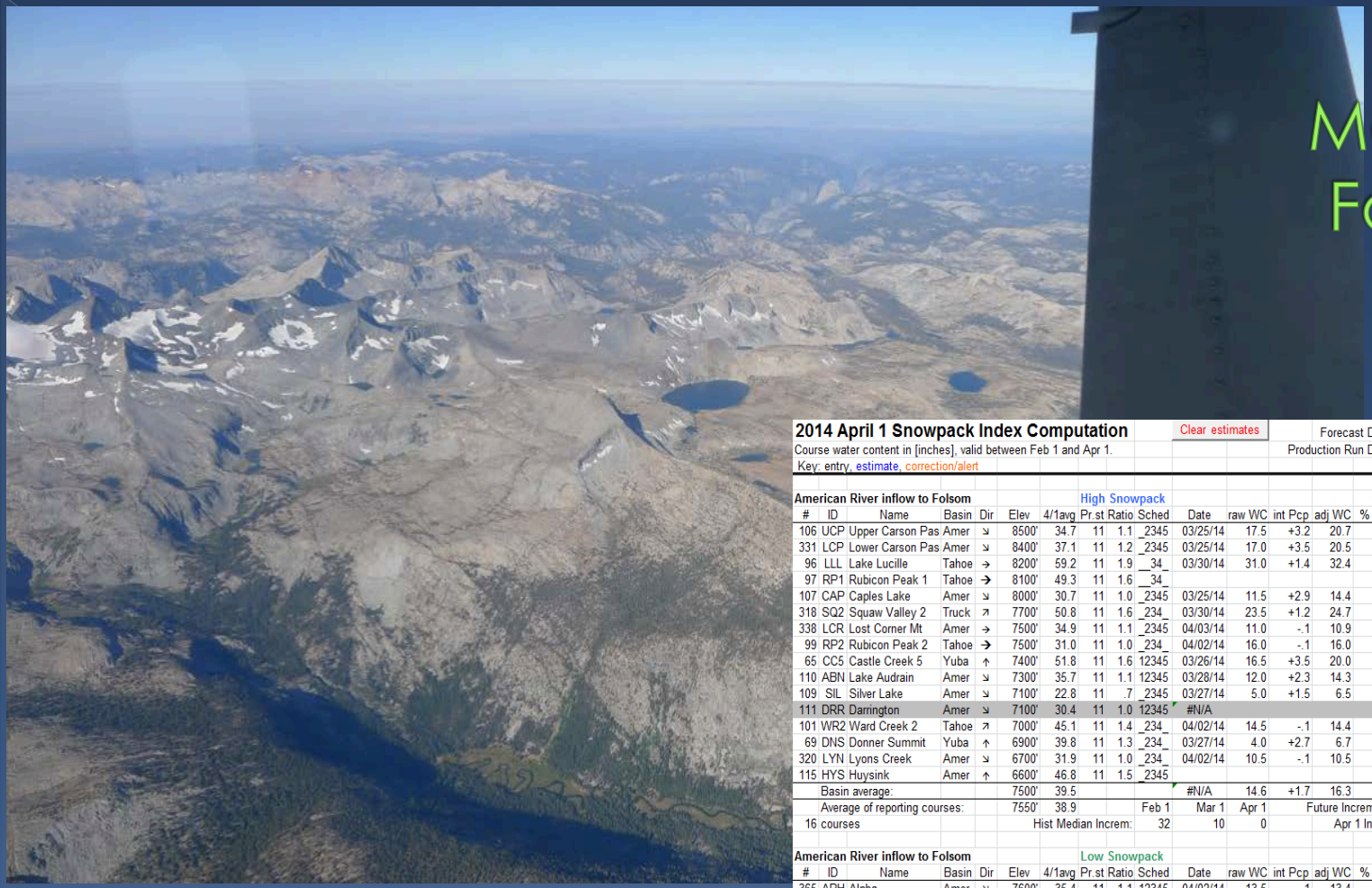




Modernizing Forecasting

2014 April 1 Snowpack Index Computation

Clear estimates

Forecast Date: 4/1/14 — 4/1 date for increment lookup

Course water content in [inches], valid between Feb 1 and Apr 1. — Production Run Date: 4/1/14 — 4 month

Key: entry, estimate, correction/alert — OK for dates >Apr 1

American River inflow to Folsom — High Snowpack

#	ID	Name	Basin	Dir	Elev	4/1avg	Pr.st	Ratio	Sched	Date	raw WC	int Pcp	adj WC	% avg	est %	adj %	rec'd?	altern.	note	Lat	Yr.Est
106	UCP	Upper Carson Pas	Amer	↘	8500'	34.7	11	1.1	_2345	03/25/14	17.5	+3.2	20.7	60		60	ok			38.70	1930
331	LCP	Lower Carson Pas	Amer	↘	8400'	37.1	11	1.2	_2345	03/25/14	17.0	+3.5	20.5	55		55	ok	Blue Lks c/s		38.69	1951
96	LLL	Lake Lucille	Tahoe	→	8200'	59.2	11	1.9	__34_	03/30/14	31.0	+1.4	32.4	55		55	ok	Echo Pk s		38.86	1913
97	RP1	Rubicon Peak 1	Tahoe	→	8100'	49.3	11	1.6	__34_								miss			38.99	1910
107	CAP	Caples Lake	Amer	↘	8000'	30.7	11	1.0	_2345	03/25/14	11.5	+2.9	14.4	47		47	ok	s		38.71	1951
318	SQ2	Squaw Valley 2	Truck	↗	7700'	50.8	11	1.6	_234_	03/30/14	23.5	+1.2	24.7	49		49	ok	SQV s		39.19	1954
338	LCR	Lost Corner Mt	Amer	→	7500'	34.9	11	1.1	_2345	04/03/14	11.0	-.1	10.9	31		31	ok			39.02	1959
99	RP2	Rubicon Peak 2	Tahoe	→	7500'	31.0	11	1.0	_234_	04/02/14	16.0	-.1	16.0	51		51	ok	s		39.00	1912
65	CC5	Castle Creek 5	Yuba	↑	7400'	51.8	11	1.6	12345	03/26/14	16.5	+3.5	20.0	39		39	ok	-		39.35	1946
110	ABN	Lake Audrain	Amer	↘	7300'	35.7	11	1.1	12345	03/28/14	12.0	+2.3	14.3	40		40	ok	Echo Sum c		38.82	1941
109	SIL	Silver Lake	Amer	↘	7100'	22.8	11	.7	_2345	03/27/14	5.0	+1.5	6.5	28		28	ok	s		38.68	1930
111	DRR	Darrington	Amer	↘	7100'	30.4	11	1.0	12345	#N/A							miss			38.83	1941
101	WR2	Ward Creek 2	Tahoe	↗	7000'	45.1	11	1.4	_234_	04/02/14	14.5	-.1	14.4	32		32	ok	Ward Cr 3 s		39.14	1913
69	DNS	Donner Summit	Yuba	↑	6900'	39.8	11	1.3	_234_	03/27/14	4.0	+2.7	6.7	17		17	ok	Snow Lab s		39.31	1910
320	LYN	Lyons Creek	Amer	↘	6700'	31.9	11	1.0	_234_	04/02/14	10.5	-.1	10.5	33		33	ok			38.81	1937
115	HYS	Huysink	Amer	↑	6600'	46.8	11	1.5	_2345						12	12	miss	s		39.28	1937
		Basin average:			7500'	39.5				#N/A	14.6	+1.7	16.3	41.3	39.2	39.2				38.96	
		Average of reporting courses:			7550'	38.9			Feb 1	Mar 1	Apr 1		Future Increment:		0.0					38.94	
16		courses				Hist Median Increm:			32	10	0		Apr 1 Index:		39.2					39.00	

American River inflow to Folsom — Low Snowpack

#	ID	Name	Basin	Dir	Elev	4/1avg	Pr.st	Ratio	Sched	Date	raw WC	int Pcp	adj WC	% avg	est %	adj %	rec'd?	altern.	note	Lat	Yr.Est
365	APH	Alpha	Amer	↘	7600'	35.4	11	1.1	12345	04/02/14	13.5	-.1	13.4	38		38	ok	s	too high	38.81	1965
316	WRG	Wrights Lake	Amer	↘	6900'	32.4	11	1.0	_2345	03/31/14	11.5	0	11.5	35		35	ok			38.85	1956
113	PHL	Phillips	Amer	↘	6800'	28.8	11	.9	_234_	04/01/14	8.0	-.0	8.0	28		28	ok			38.82	1941
289	TMF	Tamarack Flat	Amer	↘	6550'	28.7	11	1.1	_234_	04/01/14	14.5	-.1	14.4	50		50	ok			38.81	1939
114	WBM	Wabena Meadows	Amer	↑	6300'	42.3	11	1.3	_234_	03/28/14	6.5	+2.7	9.2	22		22	ok			39.23	1937
120	ONN	Onion Creek	Amer	↑	6100'	22.2	11	.7	_2345	03/26/14	1.0	+1.5	2.5	11		11	ok			39.28	1937
80	CCO	Cisco	Yuba	↑	5900'	26.3	11	.8	_234_	03/27/14	1.5	+1.7	3.2	12		12	ok			39.30	1918
123	SXV	Sixmile Valley	Amer	↖	5750'	23.5	11	.7	____	#N/A							-	Cisco c		39.32	1930
122	TBC	Talbot Camp	Amer	↑	5750'	20.7	11	.6	_234_	03/28/14	1.5	+1.3	2.8	13		13	ok			39.19	1940
124	STW	Strawberry	abandı	↘	5700'	8.4	11	.3	____	#N/A							-		TMF	38.79	1942
322	RBV	Robbs Valley	Amer	↔	5600'	21.3	11	1.5	_2345	03/31/14	3.0	0	3.0	14		14	ok	Robbs Sad s		38.92	1932
128	CPF	Carpenter Flat	Amer	↖	5300'	18.0	11	.6	____	#N/A							-	Blue Can s		39.30	1946
85	SPD	Lake Spaulding	Yuba	↖	5200'	24.4	11	.8	_234_	03/27/14	1.5	+1.7	3.2	13		13	ok	Blue Can s		39.32	1927
		Basin average:			6110'	25.6				#N/A	6.3	+.9	7.1	23.7	23.7	23.7				39.07	
		Average of reporting courses:			6270'	28.3			Feb 1	Mar 1	Apr 1		Future Increment:		0.0					39.05	
13-1		courses				Hist Median Increm:			17	-3	0		Apr 1 Index:		23.7					39.00	

What a Watershed looks like:

Lyell Fork of the Tuolumne River

Watersheds from An equation's point of view

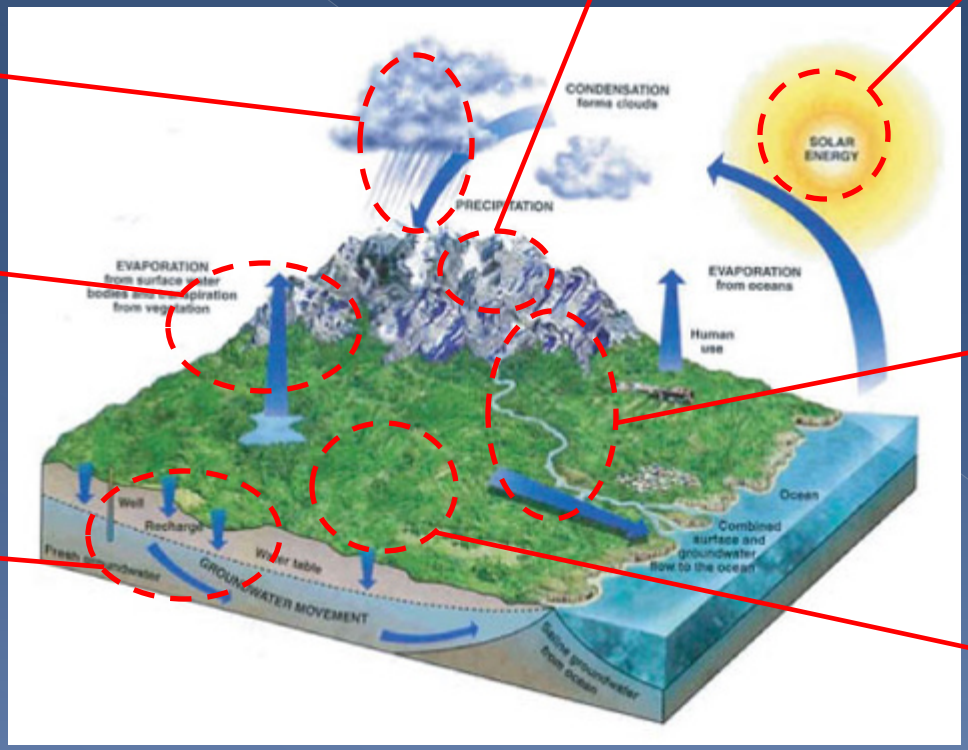
Feed Me!

"Healthy" Models Need Many Sources of Many Types of Good-Quality, Long-Term Data

Slope /
Aspect / Elev.

Solar
Radiation

Precip/Snow



Evapo-
transpiration

Full Natural Flow

Soil Moisture /
Groundwater

Soils / Vegetation
Properties

Conceptualized Physical Hydrology Model

Consider a 5% Error When…

Wet Year

- 5% Error on the A-J Inflow To Friant Dam in WY2011 was 112,153 AF (above and beyond our typical 5-10% error) or about 21% of Millerton's capacity.
- 5% Error on the A-J Inflow to Folsom Lake during WY2006 was 131,119 AF or about 13% of Folsom's capacity

Dry Year

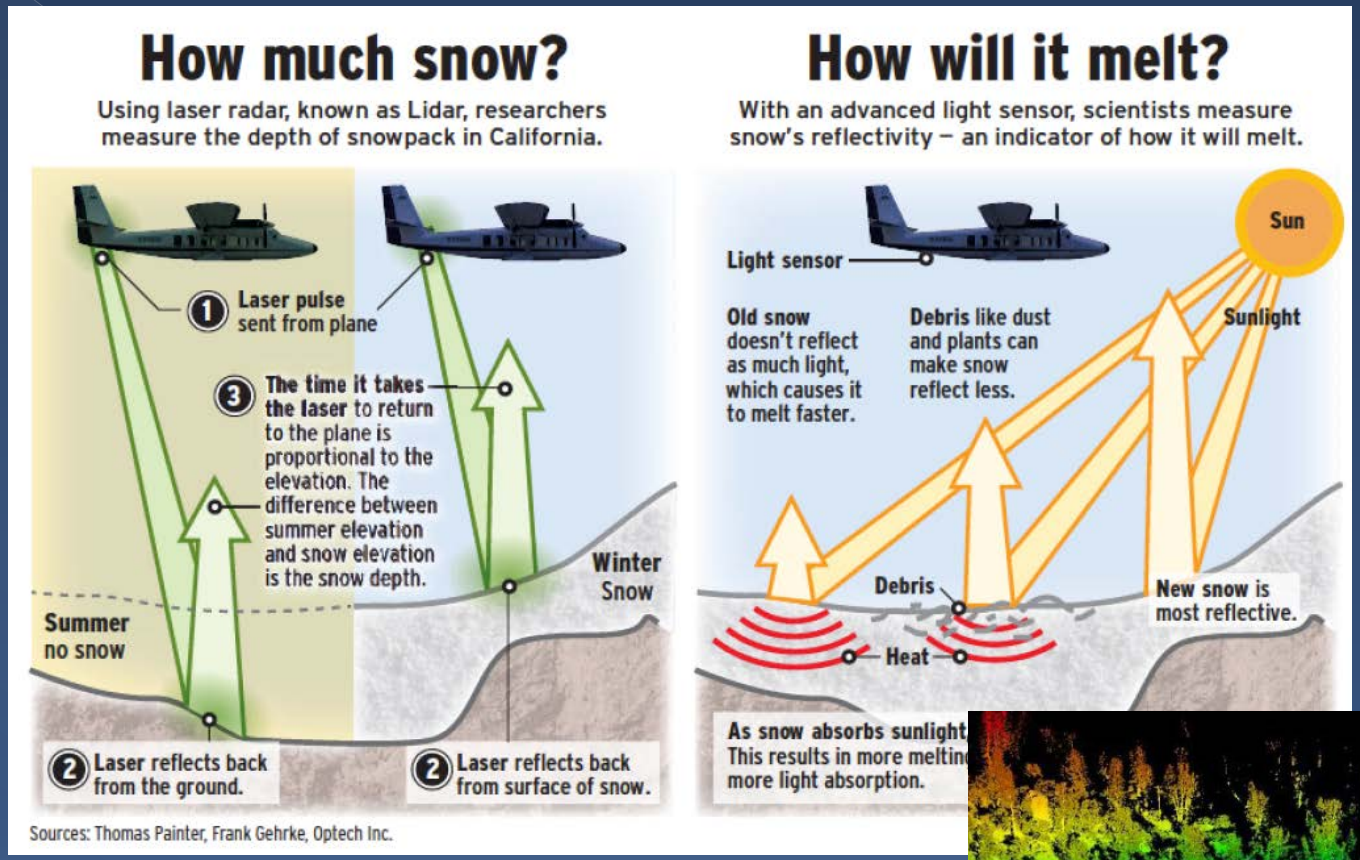
- 5% Error on the May 2012 A-J Inflow Forecast (175,000 AF) to Terminus Lake on the Kaweah is equal to 8,750 AF. An over-forecast means the A-J would have been less than 172,000 AF which is a Normal/Dry year trigger on the Kaweah River.

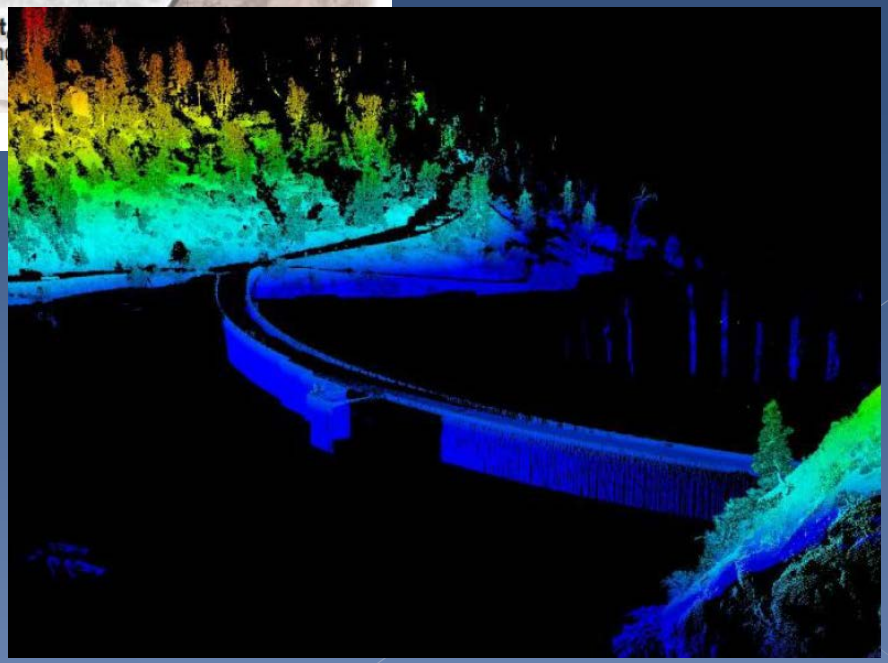
The Snapshot

- Current forecasting and data network is the backbone of our “early warning system” for Flood ER as well as responding to droughts
- Current Forecasting Methods do not take advantage of state-of-the-art ability to monitor and model physical parameters of watersheds
- Climate Change may limit regression correlations in the future leading to an increase in forecast error
- Advanced modeling capabilities have big appetites for data
- USFS and NPS limiting our access to Wilderness is a threat to remote data collection

Measuring Snow Into the Future!!

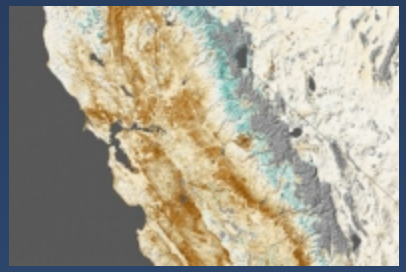
Using Airplane Based LiDAR

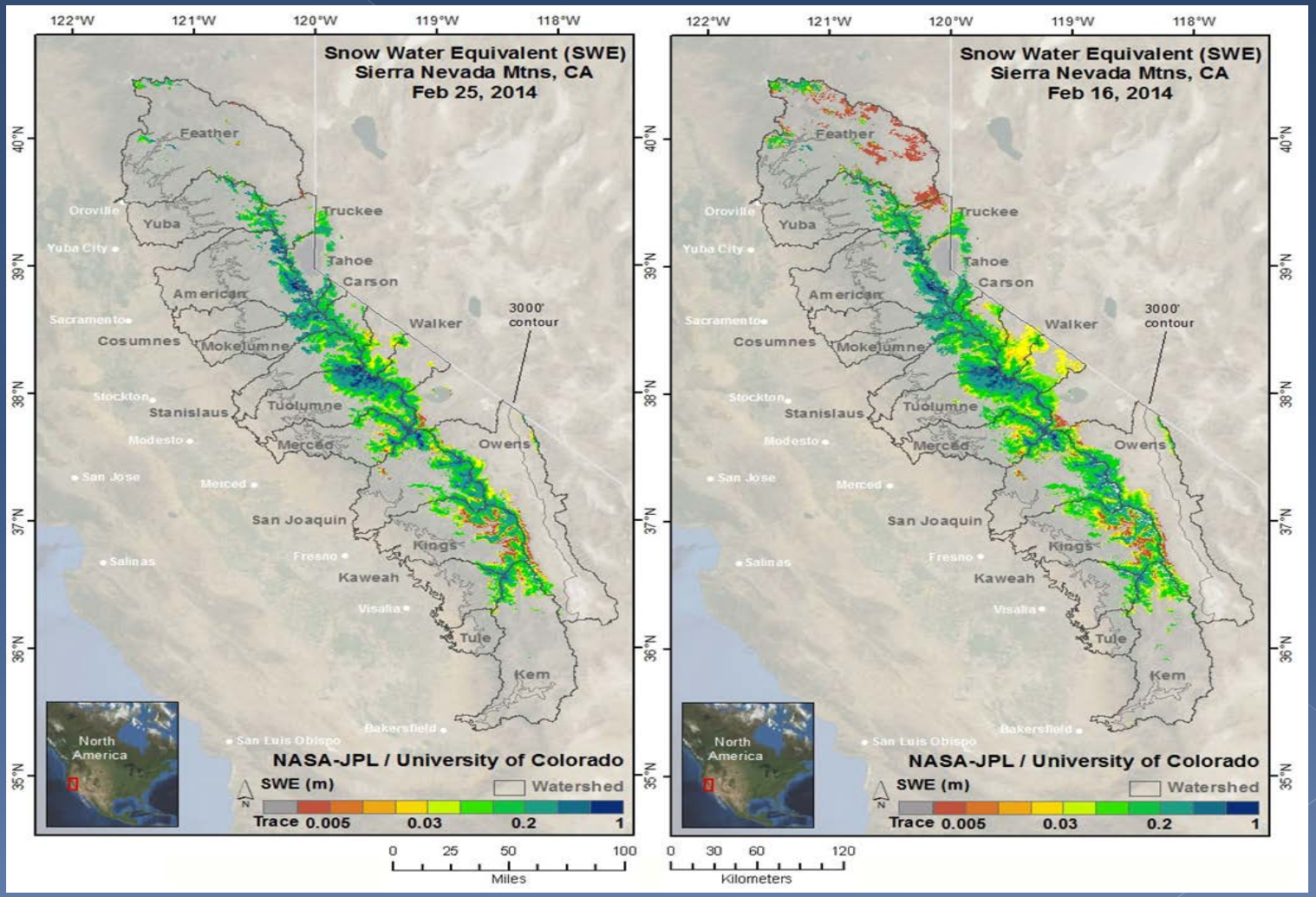




Hetch Hetchy Reservoir

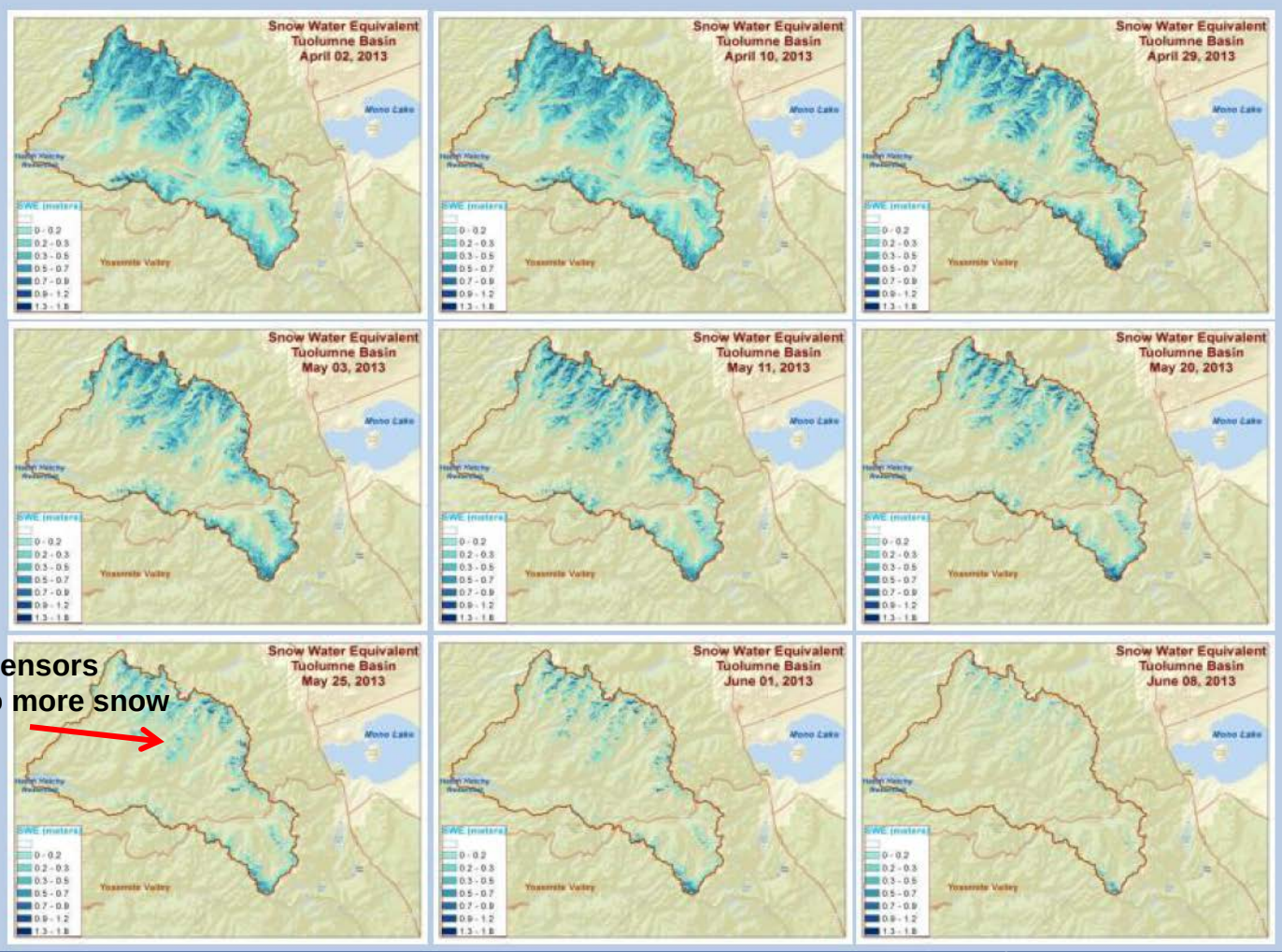
And Satellites!





Measuring Snow Into the Future!!

ASO time series of snow water equivalent Tuolumne Basin 2013



When snow sensors suggested no more snow

IT ALL STILL COMES BACK TO DATA COLLECTION

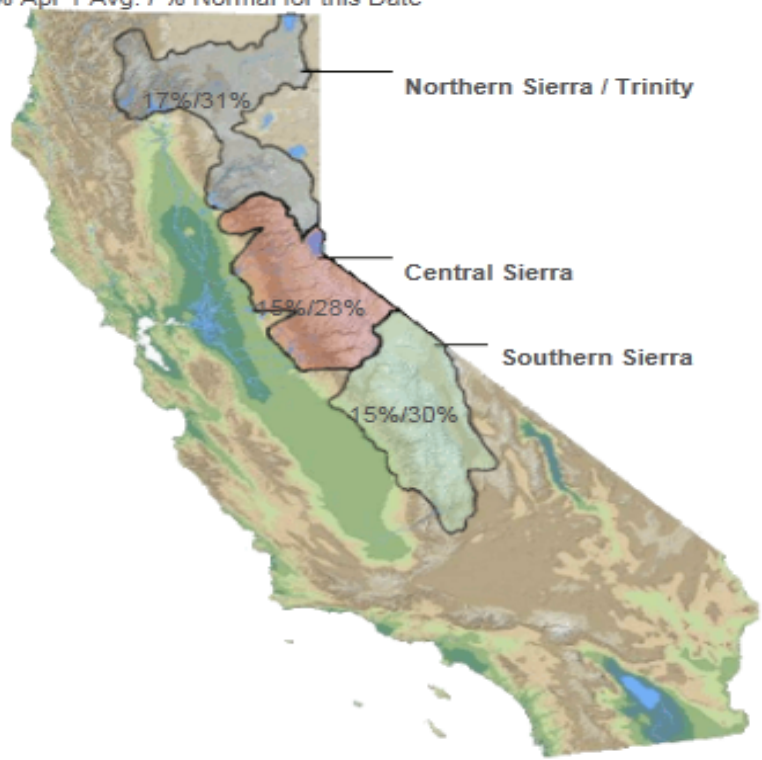
CURRENT SNOW PACK CONDITIONS

Snow Water Equivalents (inches)

Provided by the California Cooperative Snow Surveys

Data For: **22-Jan-2015**

% Apr 1 Avg. / % Normal for this Date



Change Date : 22-Jan-2015 Refresh Data

NORTH

Data For: 22-Jan-2015	
Number of Stations Reporting	31
Average snow water equivalent	5.0"
Percent of April 1 Average	17%
Percent of normal for this date	31%

CENTRAL

Data For: 22-Jan-2015	
Number of Stations Reporting	43
Average snow water equivalent	4.5"
Percent of April 1 Average	15%
Percent of normal for this date	28%

SOUTH

Data For: 22-Jan-2015	
Number of Stations Reporting	29
Average snow water equivalent	4.0"
Percent of April 1 Average	15%
Percent of normal for this date	30%

STATEWIDE SUMMARY

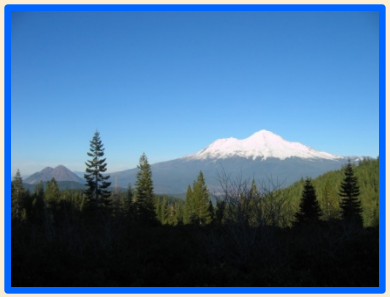
Data For: 22-Jan-2015	
Number of Stations Reporting	103
Average snow water equivalent	4.5"
Percent of April 1 Average	16%
Percent of normal for this date	30%

Thank You

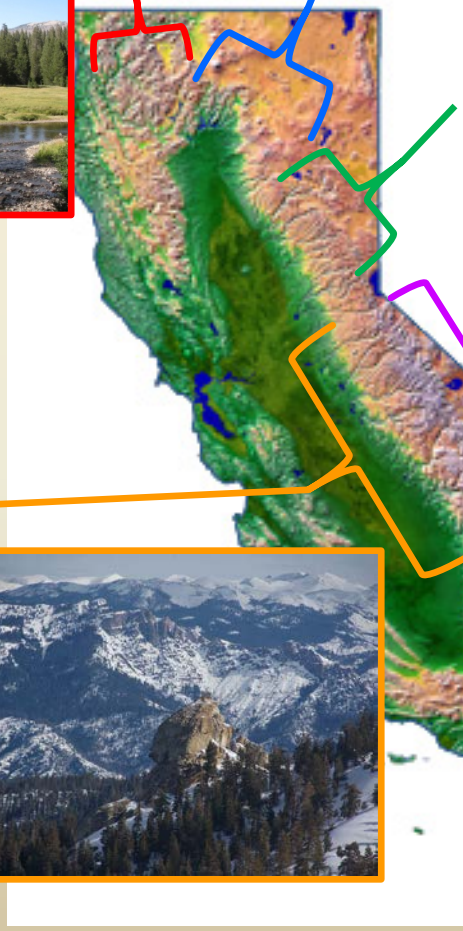
Regional Flood Threats

North Coast:
Mix of Snow fed and semi-arid regions. Wide range of mean annual precipitation, snow pack, and geology. Flooding is driven by heavy precipitation events.

Southern Cascades:
Mainly rainfall driven region with peak elevations around 10000 ft (other than Mt. Shasta and Mt. Lassen). Highly influenced by volcanic soils and some rain shadowed areas. Flood threats are driven by heavy precipitation events.



Northern Sierra:
Rainfall driven region. Peak elevations top out at 10000-11000 ft. Heavy rainfall/snowfall events possible. Large area of upper Feather watershed sits in rain shadowed plateau. 1986 and 1997 extreme precipitation storms caused flooding in this area.



Central/Southern Sierra: Snow melt driven basins. Large variety in size of watersheds. Characterized by high elevations (up to 14000 ft.), upper elevations consist of large areas of exposed granite batholiths. Susceptible to snow melt floods in heavy snow pack years. Limited data above 11000 ft which can account for up to 15% of watershed.

Eastern Sierra/Owens River:
High elevation, snow melt driven basins. Watersheds are in rain shadow from Sierra Nevada. Rivers drain to terminal sinks in Nevada desert. Gage data is extremely limited. Most susceptible to snow melt flood events.