

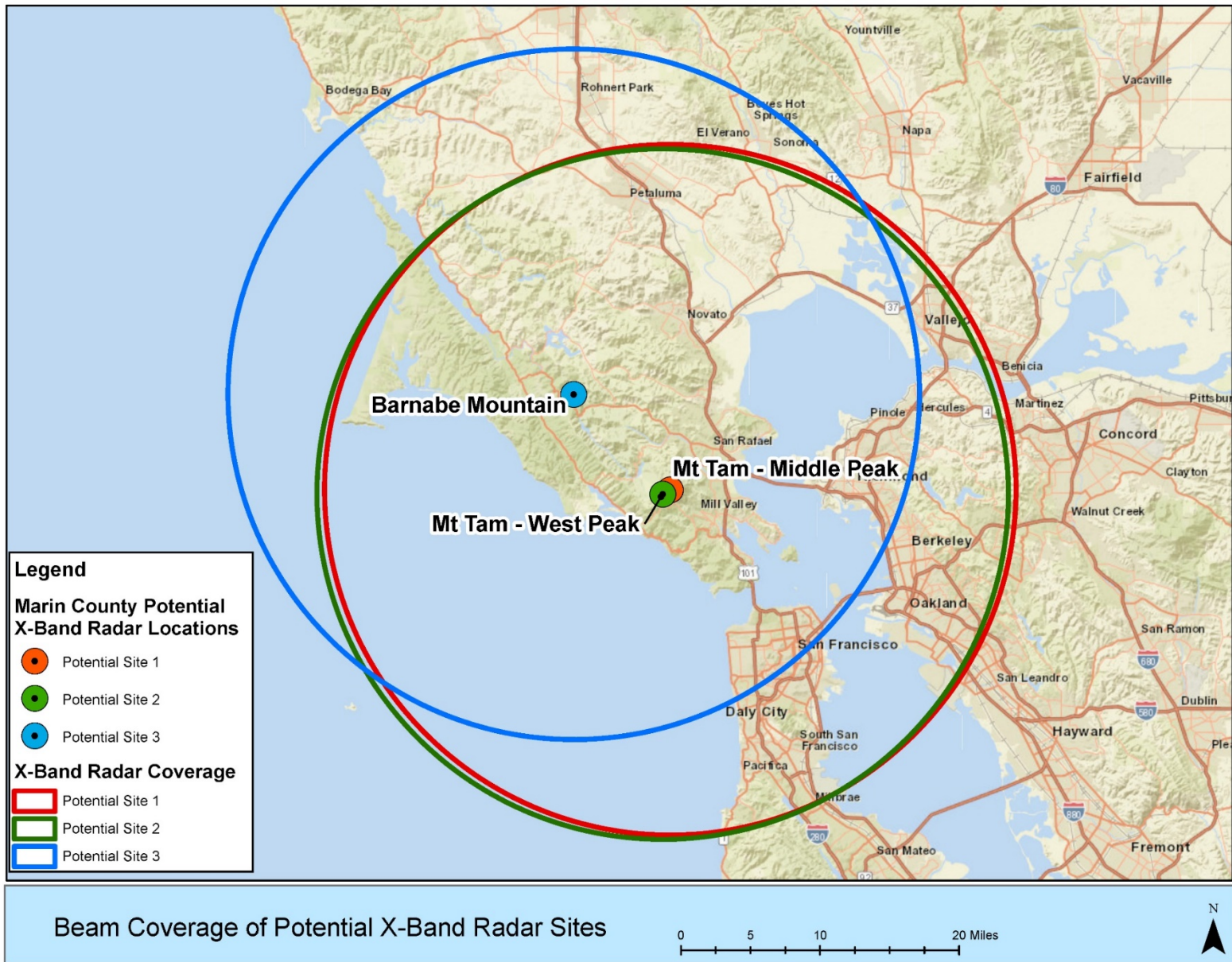
Rainfall Based Flash Flood Trigger Model - Based on Statistical Analysis of Historic Storm Events for Marin County, California



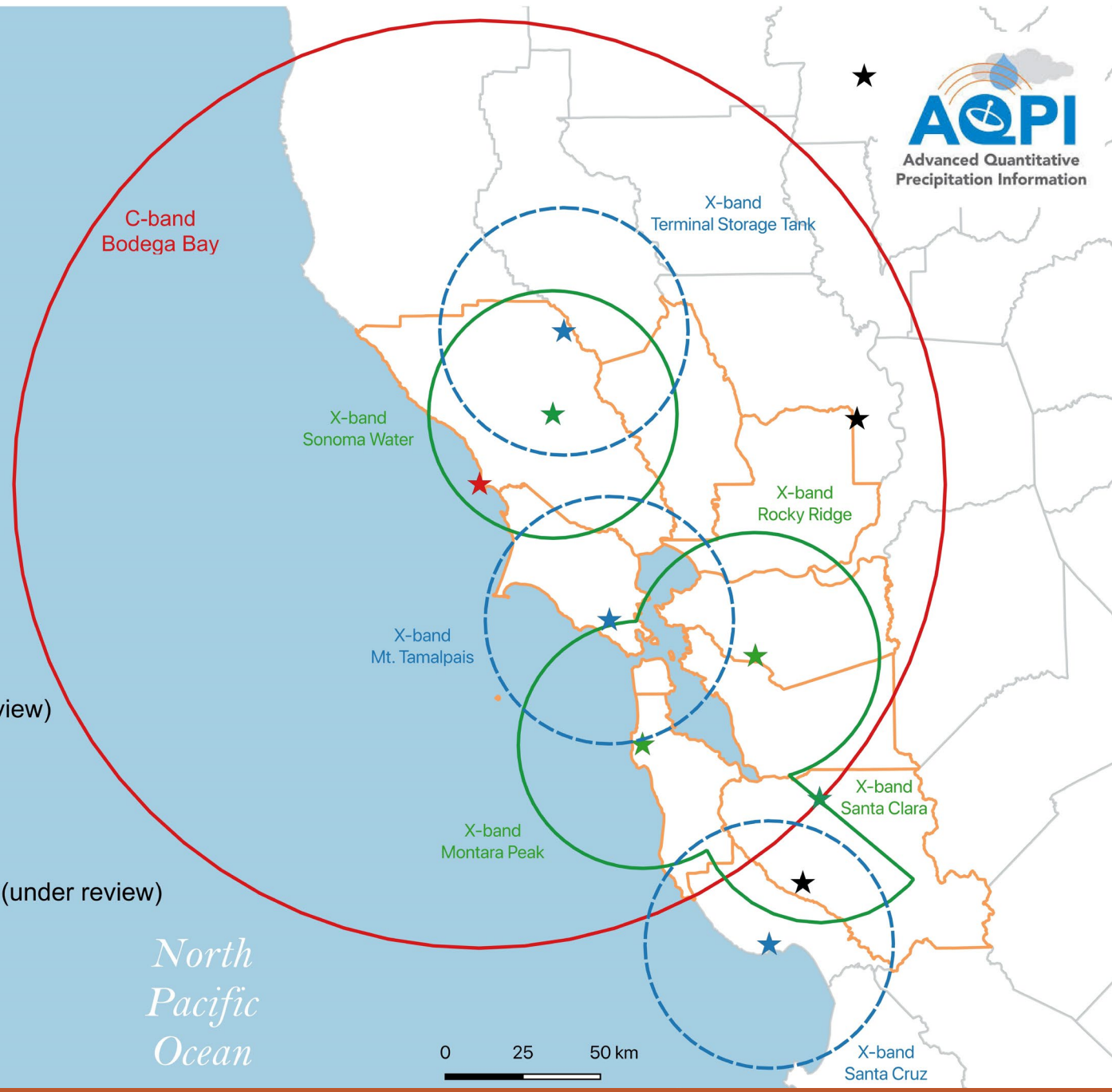
Roger Leventhal, P.E.
Senior Engineer
Marin County DPW

NBWA
November 6, 2020

Roadway flooding at "King" tides Dec 2012



Department of Public Works
 3501 Civic Center Drive, Suite 304
 San Rafael, CA 94903
 415.473.6528 T - 415.473.3232 TTY
marincounty.org/dpw



- ★ AQPI X-band radar (under review)
- ★ AQPI X-band radar
- ★ AQPI C-band radar
- ★ NEXRAD S-band radar
- ⬜ AQPI X-band radar coverage (under review)
- ⬜ AQPI X-band radar coverage
- ⬜ AQPI C-band radar coverage
- ⬜ AQPI 9 County boundary
- ⬜ US County

SF Bay Area AQPI System

Decision Support Tools - Integrate & disseminate observations & forecast information to...

- Emergency response & flood managers
- Water and wastewater managers
- Fire smoke detection capabilities (*new*)

For DPW - The next generation flooding models will use real time radar linked to hydraulic models...but until then...

Department of Public Works
3501 Civic Center Drive, Suite 304
San Rafael, CA 94903
415.473.6528 T - 415.473.3232 TTY
maincounty.org/dpw



X-band Radar



C-band Radar



Surface Met

The New Marin DPW Flash Flood Forecast Model (*beta*)

Need a reliable practical flood forecast tool to support efficient operation of flood responses

Marin's steep smaller watersheds, microclimate, geology – drive flash flooding

beta Solution – Uses statistical analysis of past events to predict flooding



Marin County, CA



Steep hills grading to river valleys and old marsh

Geologically active – high sediment loads

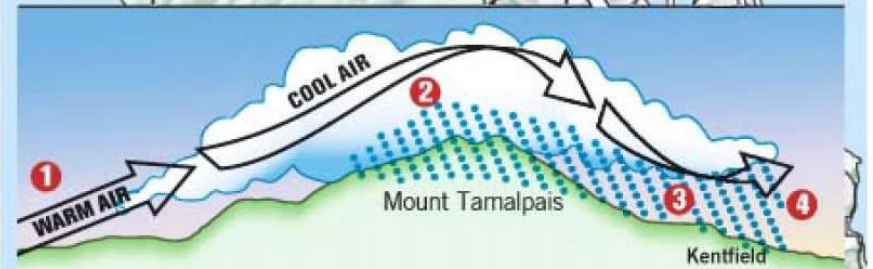
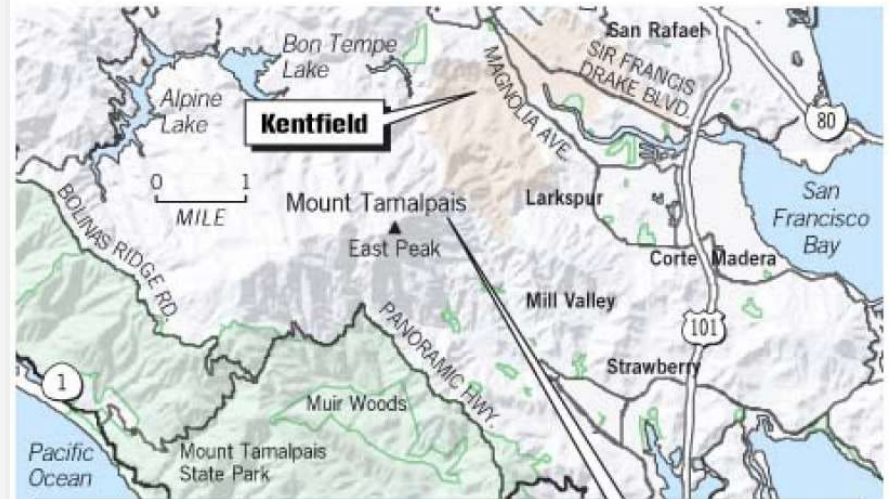
Vulnerable to SLR

Open to Pacific Ocean and Bay

Marin County Rainfall



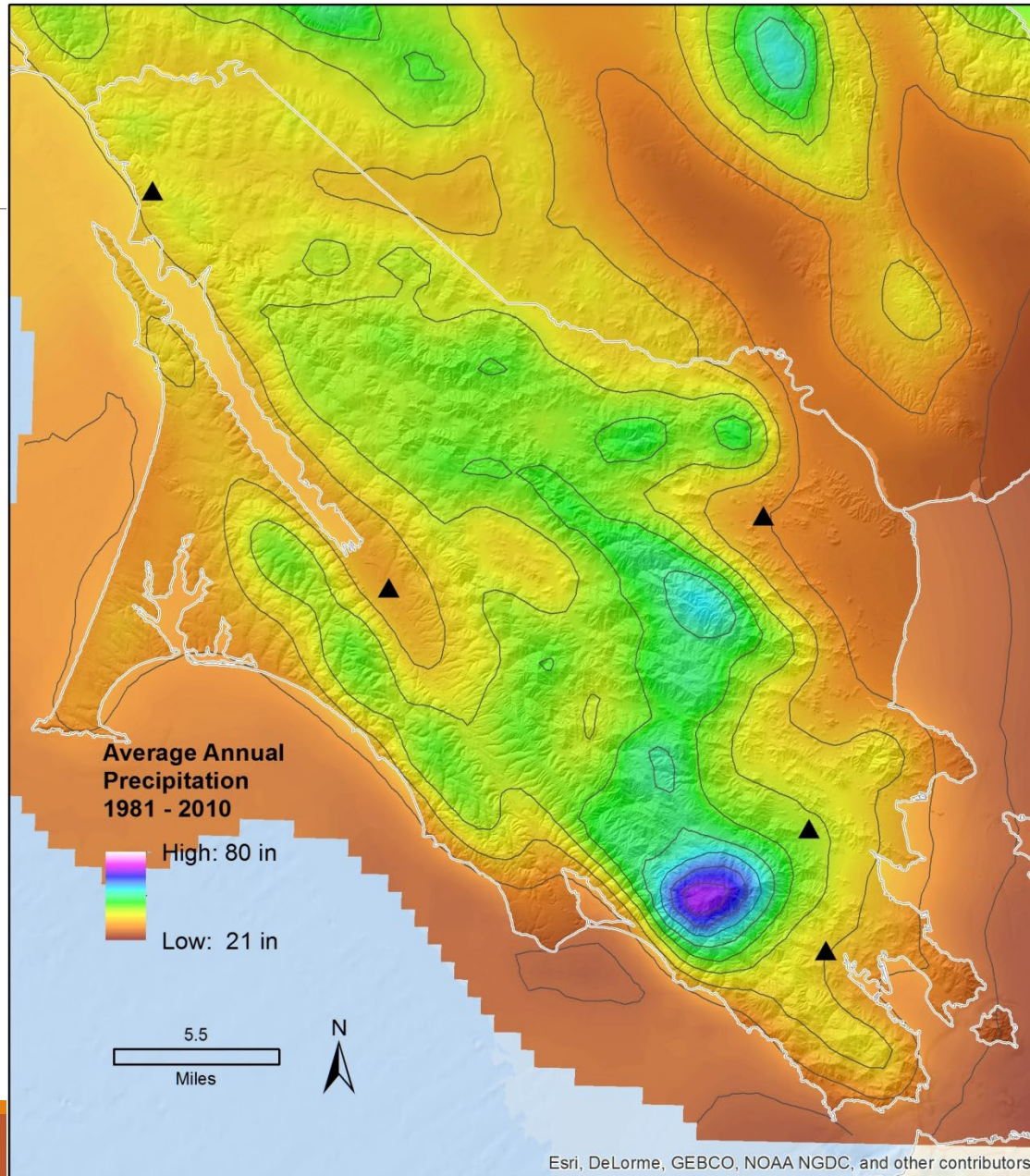
Orographic rainfall

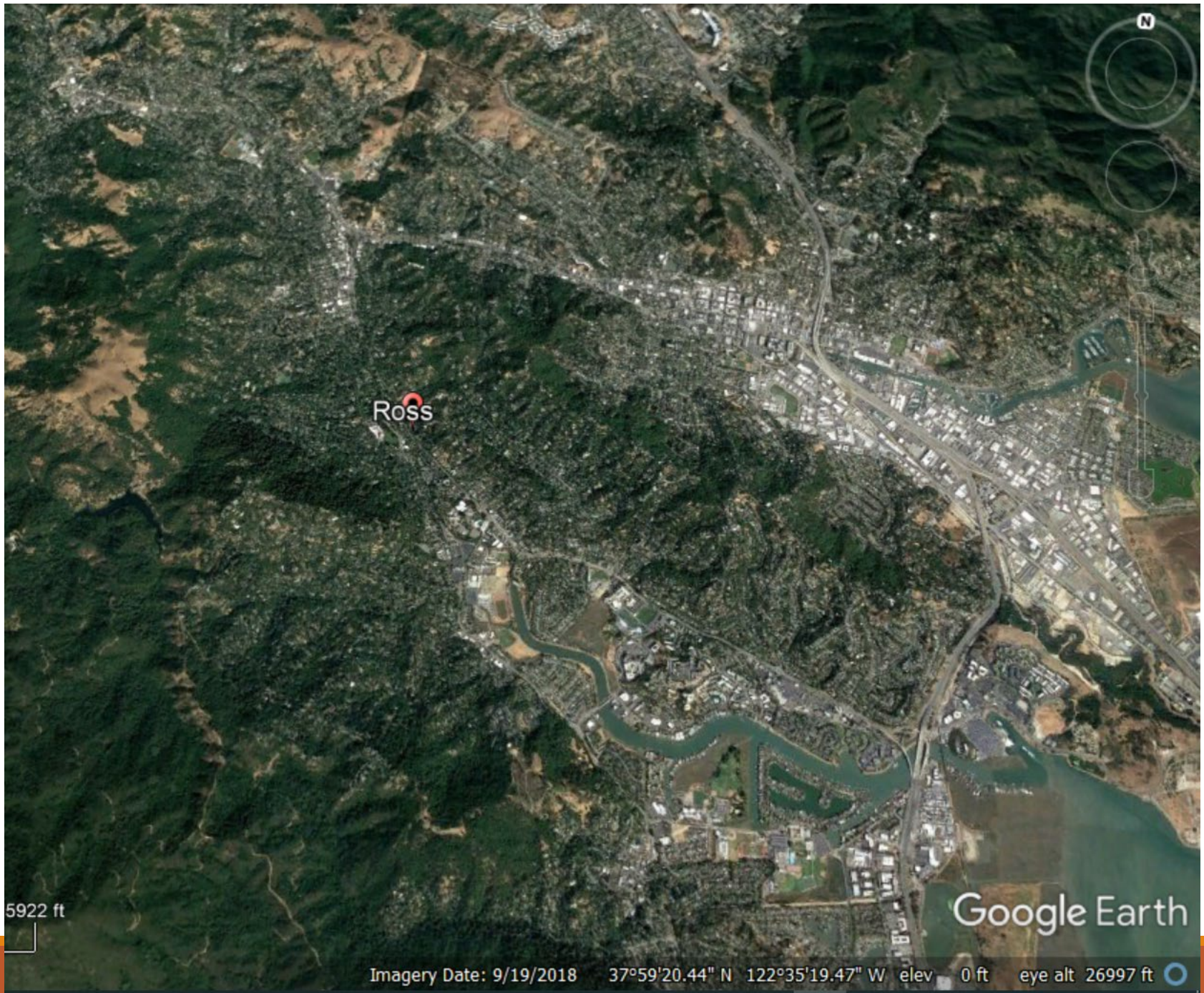


Kentfield receives more precipitation than many other areas in the Bay Area because air from the Pacific Ocean in the southwest is warmed by the ground **(1)**. As the warm air is forced up Mount Tamalpais, it

cools down and condenses, forming clouds **(2)**. These colder clouds can't hold water as well as warmer air, so they rain on the mountain and Kentfield **(3)**, then proceed eastward, warming up again **(4)**.

Rainfall MAP – Marin





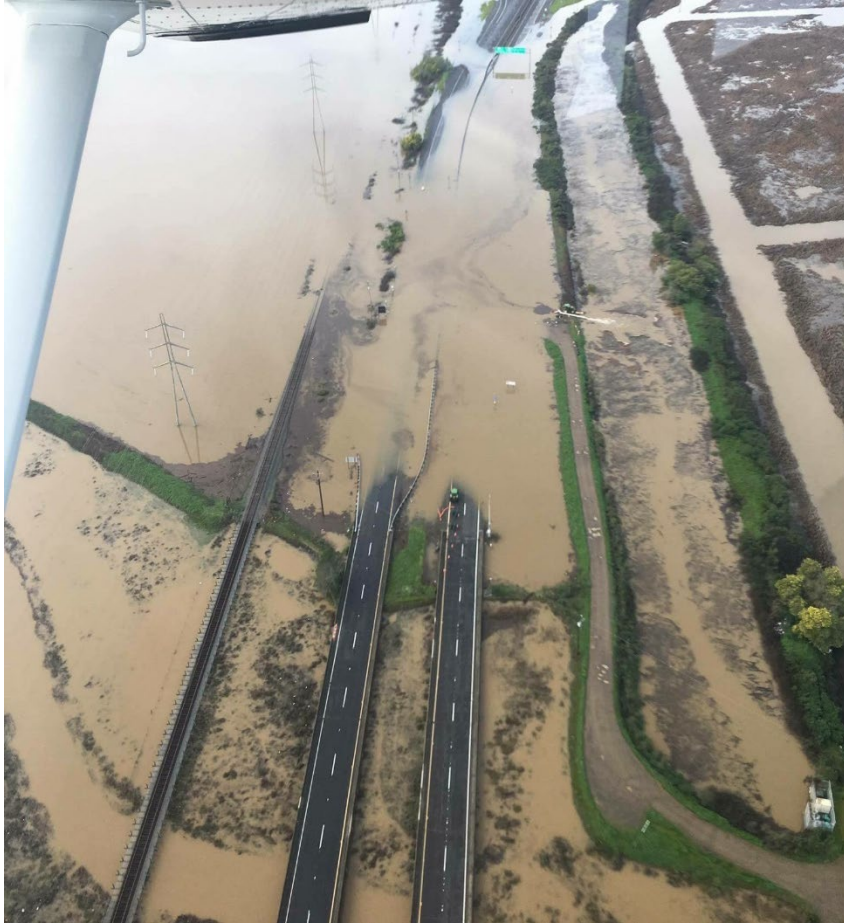
Ross

5922 ft

Google Earth

Imagery Date: 9/19/2018 37°59'20.44" N 122°35'19.47" W elev 0 ft eye alt 26997 ft

Historic Flooding



Highway 37 2017



Department Emergency Operations Center

Expensive to
open and staff
24/7

Overtime pay

Limited staff =
quick burnout
maybe 3 to 5
days realistically



Civic Center EOC

One solution...borrow a trigger from another County



Contra Costa County
Flood Control
& Water Conservation District

Flood Forecasting

CONDITIONS TO LOOK FOR

1. Compare the rainfall for the year and 24-hour forecast with the following criteria.
 - a. **7"** of rain for the season starting on July 1 (year).
 - b. **5"** of rain in the last 30 days (month).
3" of rain in the last 7 days (week).
 - c. **2"** of rainfall is forecast in the next 24 hours (day).
2. If these conditions are met, flooding may occur sometime in the next 24 hours. Warnings on TV and radio should be monitored. Your [Personal Evacuation Plan](#)



But didn't really work for Marin

- ✓ The CCC 7-5-3-2 (-1" for us)
 - Too conservative and doesn't account for Marin rainfall variability
 - Based on analysis of two or maybe events (so not statistically valid?)

Marin Storm Events – Spiky

Very early draft results for Novato...

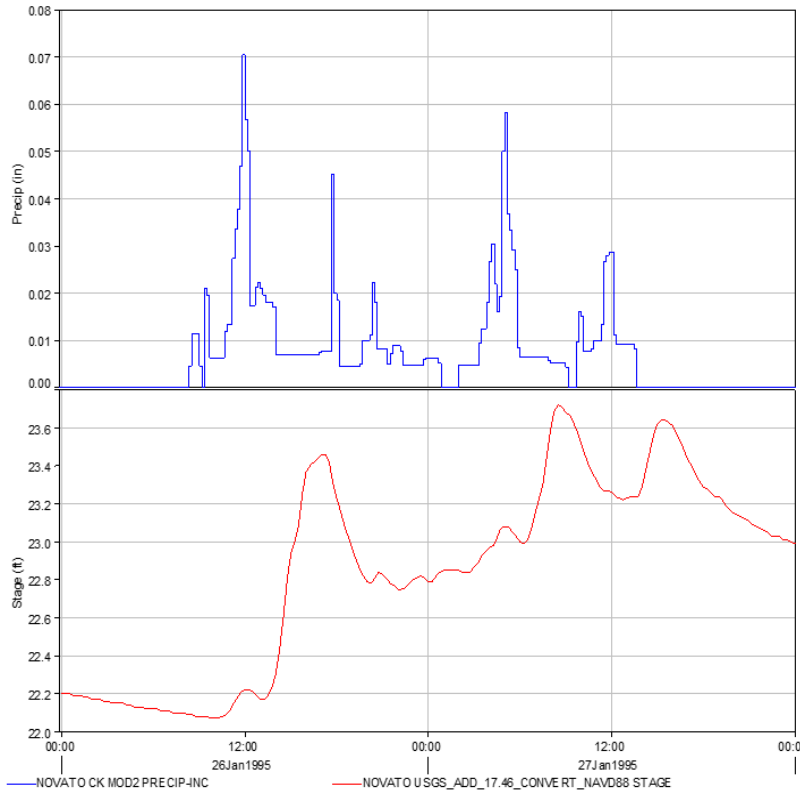


Figure 3: Event with multiple spikes - losing information only looking at one spike?

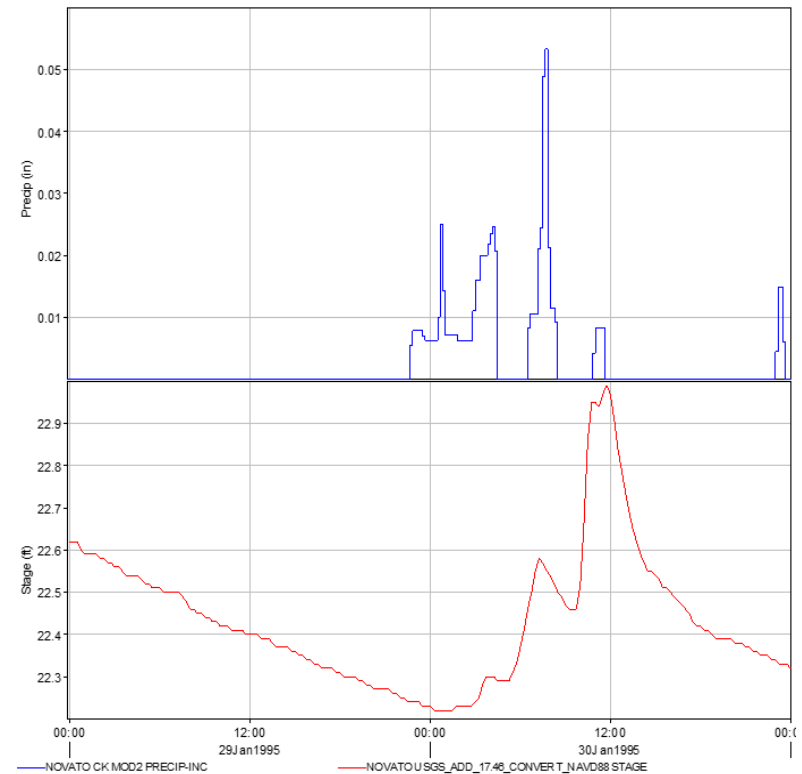


Figure 4: 10-minute peak intensity causes spike in stage. Does intensity matter more than antecedent rainfall?

So a 360 minute average forecast depths from NWS – maybe not all the useful?

Step 1- The Event Analyzer

Developed an event analyzer that works in DSS to divide into user specified “events”

User specifies the...

- interevent time
- minimum threshold values for storm depth and duration
- antecedent days
- event rainfall durations (10 min to 360 minutes typ)

Most work was cleaning up the data

Complete Output for Each “Event”

1. Event total rainfall
2. Antecedent rainfalls (6 user specified days)
3. Average and maximum depths for user specified durations (usually 10 to 360 minutes)
4. Calc'ed Parameter – (Max/Avg) for each user specified duration - peakiness
5. Tide at peak and at gauge
6. Wind speed and direction

Partial output table (25 year) - 290 events

Interstorm Duration (hr): 48											
Minimum Event Duration (min): 30											
Minimum Event Depth (in): 0.2											
Maximum Precipitation to Stage Lag (min): 180											
Stage Thresholds (ft): 26, 27, 28.5, 30											
		Antecedent Precipitation Depth (in)									
		<u>Duration</u>	<u>Total Storm</u>	30 day	20 day	10 day	7 day	3 day	1 day	WY to	
175	08Jun2005 18:00	09Jun2005 01:30	00:07:30	0.20	0.68	0.00	0.00	0.00	0.00	0.00	42.37
176	26Oct2005 08:30	28Oct2005 22:40	02:14:10	0.32	0.00	0.00	0.00	0.00	0.00	0.00	0.00
177	07Nov2005 11:50	08Nov2005 05:10	00:17:20	0.56	0.44	0.44	0.28	0.12	0.00	0.00	0.44
178	24Nov2005 22:30	25Nov2005 08:30	00:10:00	0.28	1.00	0.56	0.00	0.00	0.00	0.00	1.00
179	28Nov2005 17:00	01Dec2005 20:40	03:03:40	2.64	0.96	0.28	0.28	0.28	0.00	0.00	1.28
180	17Dec2005 09:00	04Jan2006 06:30	17:21:30	20.68	2.92	2.64	0.00	0.00	0.00	0.00	3.92
181	13Jan2006 18:30	14Jan2006 08:50	00:14:20	0.40	20.84	13.32	0.43	0.00	0.00	0.00	24.76
182	17Jan2006 18:00	21Jan2006 03:00	03:09:00	0.60	16.70	10.68	0.40	0.40	0.00	0.00	25.15
183	27Jan2006 00:00	04Feb2006 05:50	08:05:50	0.97	12.58	1.12	0.60	0.00	0.00	0.00	25.75

Sample Novato watershed event table – 48 hour IE

Partial output table (25 year record)

Average depths --->

Maximum depths (in) for durations (mins)							Peak Stage	Stage Thresholds Exceeded (Yes/No)		
10 minute	30 minute max	60 minute	120 minute	240 minute max	360 minute max	approach backwater		minor	major	
0.06	0.09	0.12	0.18	0.20	0.23	19.48	24Nov2005 22:20	No	No	No
0.12	0.28	0.46	0.62	0.92	1.15	20.83	01Dec2005 16:50	No	No	No
0.21	0.52	0.95	1.72	2.59	3.12	30.86	31Dec2005 06:20	Yes	Yes	Yes
0.03	0.06	0.09	0.11	0.18	0.22	20.42	14Jan2006 09:20	No	No	No
0.04	0.07	0.10	0.15	0.17	0.25	20.60	18Jan2006 10:35	No	No	No
0.04	0.08	0.14	0.18	0.20	0.21	20.70	30Jan2006 12:20	No	No	No
0.18	0.36	0.54	0.86	1.23	1.46	23.70	27Feb2006 19:05	No	No	No
0.11	0.21	0.32	0.48	0.76	0.97	22.94	05Mar2006 20:50	No	No	No
0.07	0.15	0.24	0.36	0.39	0.40	21.47	20Mar2006 10:05	No	No	No
0.04	0.09	0.15	0.25	0.37	0.40	21.13	25Mar2006 02:05	No	No	No

Sample Novato watershed event table – 48 hour IE (page 2)

Now goes into the Statistical Analyzer

User provides the event table in Excel

Plus whatever NWS forecast depth(s) for whatever intervals match the event table

Best statistical match (so far) was MLR on event table to predict flood peaks

Used tried NLR and machine learning – did worse but want to revisit all stats

Statistical Analyzer Input Table

Drop storm sizes less than inches

NY2006 Event Inputs

Export the full model to Excel

Storm Duration (hours)	<input type="text" value="429.000"/>
Total Storm Depth (in)	<input type="text" value="20.600"/>

30 Day Antecedent (in)	<input type="text" value="2.900"/>
20 Day Antecedent (in)	<input type="text" value="2.600"/>
10 Day Antecedent (in)	<input type="text" value="0."/>
7 Day Antecedent (in)	<input type="text" value="0."/>
3 Day Antecedent (in)	<input type="text" value="0."/>
1 Day Antecedent (in)	<input type="text" value="0."/>
Water Year To Date (in)	<input type="text" value="4.000"/>

7 known antecedent

10 Minute Max Depth (in)	<input type="text" value="0.200"/>
--------------------------	------------------------------------

Up to 14 NWS forecast values

30 Minute Max Depth (in)	<input type="text" value="0.500"/>
60 Minute Max Depth (in)	<input type="text" value="0.950"/>
120 Minute Max Depth (in)	<input type="text" value="1.700"/>
240 Minute Max Depth (in)	<input type="text" value="2.600"/>
360 Minute Max Depth (in)	<input type="text" value="3.100"/>
10 Minute Avg Depth (in)	<input type="text" value="0.020"/>
30 Minute Avg Depth (in)	<input type="text" value="0.020"/>
60 Minute Avg Depth (in)	<input type="text" value="0.050"/>
120 Minute Avg Depth (in)	<input type="text" value="0.100"/>
240 Minute Avg Depth (in)	<input type="text" value="0.200"/>
360 Minute Avg Depth (in)	<input type="text" value="0.300"/>

48 hours

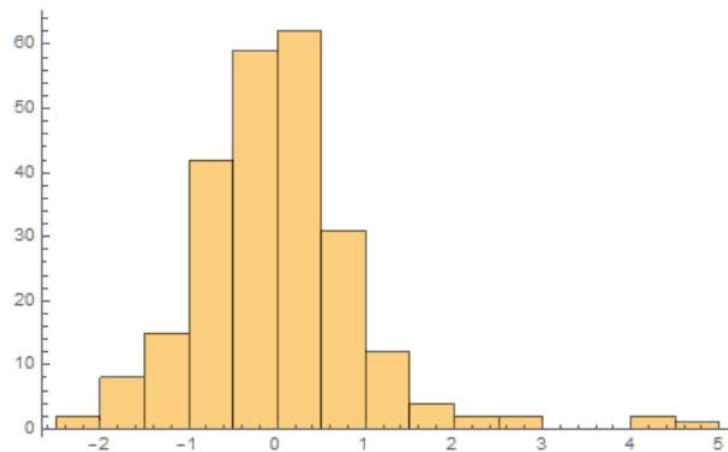
N: 242

$R^2 = 0.75$

$R^2: 0.754839$

Adjusted $R^2: 0.74086$

	Estimate	Standard Error	t-Statistic	P-Value
1	20.2735	0.151439	133.873	1.04271×10^{-218}
TotalStormDepth	0.719549	0.0889394	8.09034	3.52402×10^{-14}
Duration30Days	0.0416591	0.039921	1.04354	0.297804
Duration20Days	-0.00425979	0.0592081	-0.071946	0.942708
Duration10Days	0.276136	0.0770099	3.58572	0.000411184
Duration5Days	0.00822838	0.1215	0.067723	0.946065
Duration3Days	0.244058	0.246345	0.990717	0.322874
Ten	-0.044429	2.67811	-0.0165896	0.986778
Thirty	0.635959	2.76663	0.229868	0.818401
Sixty	-1.22964	2.33503	-0.526603	0.598982
OneHundredTwenty	2.81487	1.40244	2.00712	0.0459176
TwoHundredForty	-0.695829	1.24541	-0.558715	0.576904
ThreeHundredSixty	-0.472137	0.78319	-0.602839	0.547215
Duration	-0.0179768	0.0482394	-0.372657	0.70975



FittedModel1 [20.2735 - 0.0179768 Duration + 0.276136 Duration10Days - 0.00425979 Duration20Days + 0.0416591 Duration30Days + 0.244058 Duration3Days +
 <<1>> + <<1>> - <<19>> Sixty - 0.044429 Ten + 0.635959 Thirty - 0.472137 ThreeHundredSixty + 0.719549 TotalStormDepth - 0.695829 TwoHundredForty]

Statistical Analyzer Input Table – NY2006

NY2006 Event Inputs (not spiky)

Drop storm sizes less than inches

Export the full model to Excel

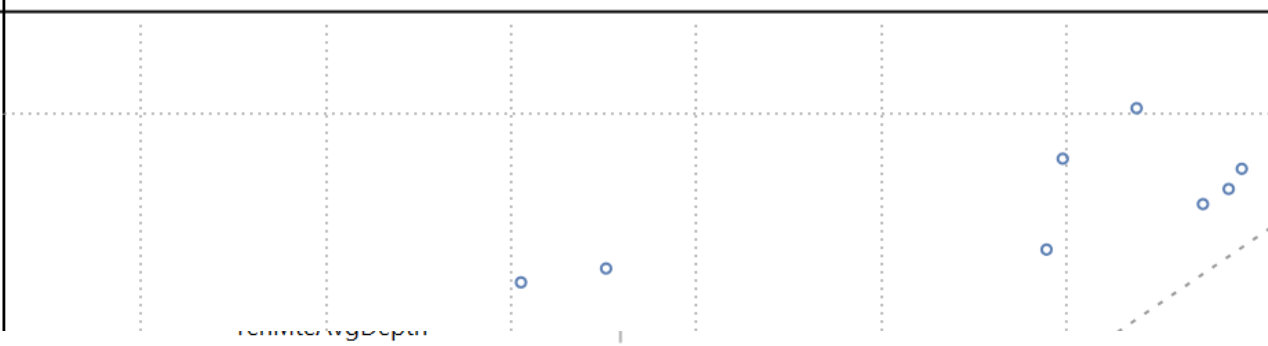
Storm Duration (hours)	<input type="text" value="429.000"/>
Total Storm Depth (in)	<input type="text" value="20.600"/>
30 Day Antecedent (in)	<input type="text" value="2.900"/>
20 Day Antecedent (in)	<input type="text" value="2.600"/>
10 Day Antecedent (in)	<input type="text" value="0."/>
7 Day Antecedent (in)	<input type="text" value="0."/>
3 Day Antecedent (in)	<input type="text" value="0."/>
1 Day Antecedent (in)	<input type="text" value="0."/>
Water Year To Date (in)	<input type="text" value="4.000"/>
10 Minute Max Depth (in)	<input type="text" value="0.200"/>

30 Minute Max Depth (in)	<input type="text" value="0.500"/>
60 Minute Max Depth (in)	<input type="text" value="0.950"/>
120 Minute Max Depth (in)	<input type="text" value="1.700"/>
240 Minute Max Depth (in)	<input type="text" value="2.600"/>
360 Minute Max Depth (in)	<input type="text" value="3.100"/>
10 Minute Avg Depth (in)	<input type="text" value="0.020"/>
30 Minute Avg Depth (in)	<input type="text" value="0.020"/>
60 Minute Avg Depth (in)	<input type="text" value="0.050"/>
120 Minute Avg Depth (in)	<input type="text" value="0.100"/>
240 Minute Avg Depth (in)	<input type="text" value="0.200"/>
360 Minute Avg Depth (in)	<input type="text" value="0.300"/>

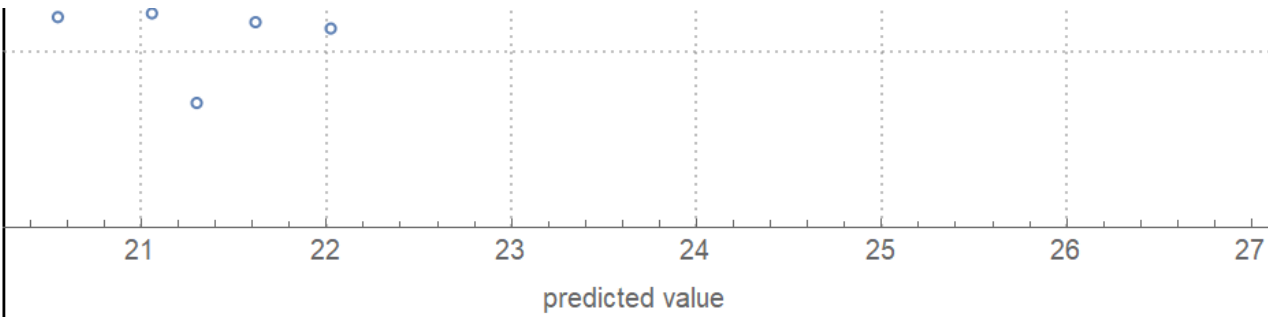
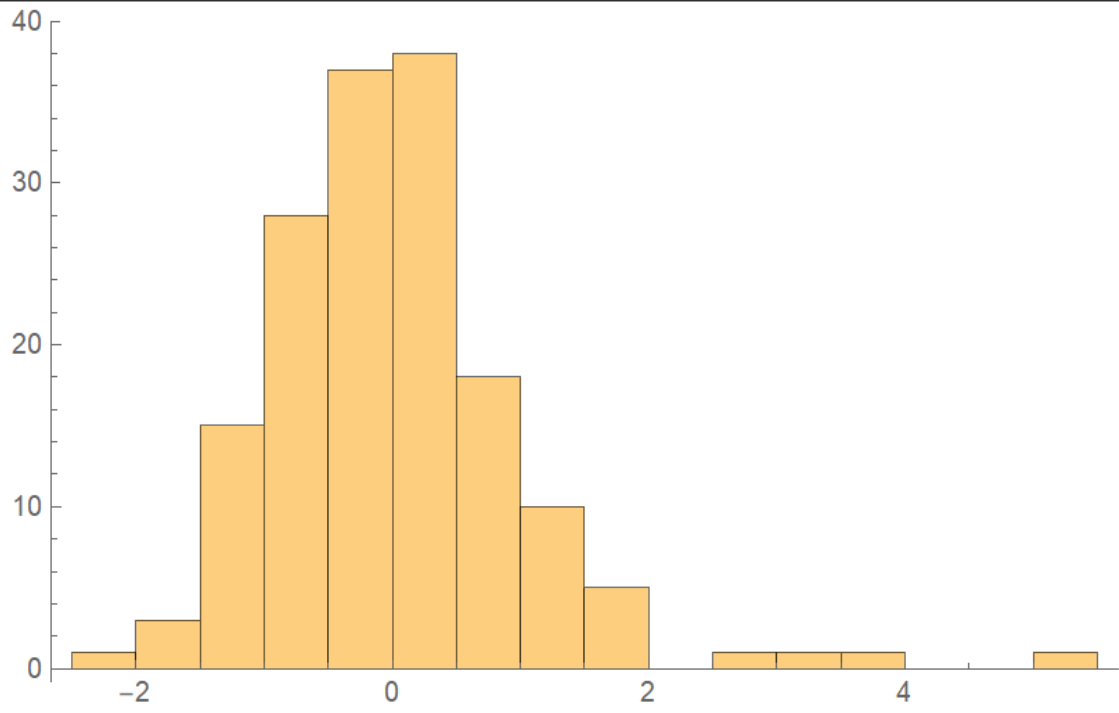
Model	Building a parsimonious model from StormDuration, TotalStormDepth, ThirtyDayAnt, TwentyDayAnt, TenDayAnt, SevenDayAnt, ThreeDayAnt, OneDayAnt, WYToDate, TenMteMaxDepth, ThirtyMteMaxDepth, SixtyMteMaxDepth, OneHundredTwentyMteMaxDepth, TwoHundredFortyMteMaxDepth, ThreeHundredSixtyMteMaxDepth, TenMteAvgDepth, ThirtyMteAvgDepth, SixtyMteAvgDepth, OneHundredTwentyMteAvgDepth, TwoHundredFortyMteAvgDepth, ThreeHundredSixtyMteAvgDepth, $\frac{\text{TenMteMaxDepth}}{\text{TenMteAvgDepth}}$, $\frac{\text{ThirtyMteMaxDepth}}{\text{ThirtyMteAvgDepth}}$, $\frac{\text{SixtyMteMaxDepth}}{\text{SixtyMteAvgDepth}}$, $\frac{\text{OneHundredTwentyMteMaxDepth}}{\text{OneHundredTwentyMteAvgDepth}}$, $\frac{\text{TwoHundredFortyMteMaxDepth}}{\text{TwoHundredFortyMteAvgDepth}}$, $\frac{\text{ThreeHundredSixtyMteMaxDepth}}{\text{ThreeHundredSixtyMteAvgDepth}}$				
Predicted value with 95% confidence interval	30.9215	31.9876	33.0538		
Number of events	159				
R²	0.764215				
Parameter table		Estimate	Standard Error	t-Statistic	P-Value
	1	20.1237	0.281513	71.4841	3.28091×10^{-117}
	StormDuration	-0.00436284	0.00209677	-2.08075	0.0391688
	TotalStormDepth	0.561086	0.0653067	8.59156	1.0701×10^{-14}
	TenDayAnt	0.279064	0.0503933	5.53772	1.34935×10^{-7}
	OneDayAnt	1.71543×10^{-11}	0.	∞	$0. \times 10^{-324}$
	TenMteMaxDepth	-10.0985	3.35793	-3.00735	0.00309426
	OneHundredTwentyMteMaxDepth	2.05736	0.573888	3.58494	0.000456253
	OneHundredTwentyMteAvgDepth	-22.5974	12.7499	-1.77236	0.0783786
	TwoHundredFortyMteAvgDepth	10.2349	5.56262	1.83995	0.0677655
	$\frac{\text{TenMteMaxDepth}}{\text{TenMteAvgDepth}}$	0.0912133	0.0303669	3.00371	0.0031294

Test Case Result

- ✓ NY 2006 Storm Event – predicted stage = 31.9 ft (CI - 30.9 – 33) actual is 30.86 ft NAVD88
- ✓ R2 values range from 0.6 to 0.88 – not bad for hydrology



Residuals



Need Custom NWS Forecast



NATIONAL WEATHER SERVICE
NATIONAL OCEANIC AND ATMOSPHERIC ADMINISTRATION

[Share](#)

San Francisco/Monterey Bay Area, CA
Weather Forecast Office

[Home](#) [Current Hazards](#) [Current Conditions](#) [Forecasts](#) [Hydrology](#) [Climate](#) [Weather Safety](#) [Additional Info](#) [Contact Us](#)



No Warnings or Advisories In Effect for this Point.
For warnings and/or advisories in effect for adjacent areas to this point, see [/mtr](#)

Change Table Font Size [Increase](#) [Decrease](#)

Forecast For Lat/Lon: 37.9550/-122.5440 (Elev. 197 ft)
Kentfield CA
Forecast Created at: 2pm PST Dec 14, 2018
Custom Weather Forecast Table

Weather	Fri Dec 14				Sat Dec 15				Sun Dec 16				Mon Dec 17				Tue Dec 18				Wed Dec 19		
	Rain Showers	Likely Rain Showers	Chance Rain		Rain Showers		Likely Rain	Rain	Rain Showers		Chance Rain Showers	Slight Chance Rain Showers											
Daily-Temp	High 59 Low --				High 59 Low 48				High 59 Low 52				High 58 Low 49				High 59 Low 44				High 60 Low 44		
Chance of Precip	--	75%	60%	30%	40%	35%	40%	40%	65%	85%	95%	80%	25%	15%	5%	5%	5%	5%	10%	10%	5%	5%	5%
Precip	0.15"	0.16"	0.04"	0.07"	0.05"	0.03"	0.04"	0.13"	0.42"	1.04"	0.12"	0.01"	0.01"	0.00"	0.00"	0.00"	0.00"	0.00"	0.00"	0.00"	0.00"	0.00"	0.00"
12-hr Snow Total	--	0"		0"		0"		0"		0"		0"		0"		0"							
6-Hour Temp	4am	10am	4pm	10pm	4am	10am	4pm	10pm	4am	10am	4pm	10pm	4am	10am	4pm	10pm	4am	10am	4pm	10pm	4am	10am	4pm
Temp	51	58	50	49	54	58	53	52	56	58	50	49	54	56	45	44	52	57	45	44	52	58	
Cloudiness	96%	80%	84%	91%	81%	71%	75%	91%	100%	100%	100%	61%	61%	47%	47%	49%	49%	35%	35%	44%	44%	36%	
Dewpoint	48	52	48	48	52	53	51	52	54	54	48	48	50	48	43	43	48	48	43	43	48	48	
Relative Humidity	91%	81%	95%	98%	92%	85%	95%	97%	92%	86%	95%	97%	86%	74%	92%	97%	84%	71%	92%	97%	84%	71%	
Wind	S 16	S 14	W 5	N 3	E 6	S 9	S 9	SE 15	S 22	S 23	S 13	NW 5	NE 3	E 2	NW 0	N 0	S 1	S 1	NE 1	NE 2	NE 2	E 2	
Snow Level (ft)	6671	6451	5621	6194	7023	7402	7370	7539	8158	7940	5996	5011	4967	5415	5433	6659	7350	7599	7861	7598	7723	7856	

Standard NWS forecast is 6 hour (360 minutes avg? depths)

Useful for other analysis

- ✓ Is there a CC signal in higher intensity events that drive a lot of Marin flooding?
- ✓ Allows us to develop future design storms – design life in flooded streets world
- ✓ More accurate coincident analysis of storm and tide events
- ✓ Help verify connected future H&H models with radar

Next Steps

First draft done last Nov – then it didn't rain all year so gathered dust

Unable to test last year – maybe this year?

Need to make many improvements to interface and model to be done w/ time and money

Hire a statistician evaluate methods and results