NATIONAL WATER MODEL RETROSPECTIVE SIMULATION ASSESSMENT

AQPI CASE STUDY – TRIBUTARY HYDROLOGIC MODEL

Abstract

A baseline verification of the National Water Model (NWM) using historical data for a retrospective simulation.

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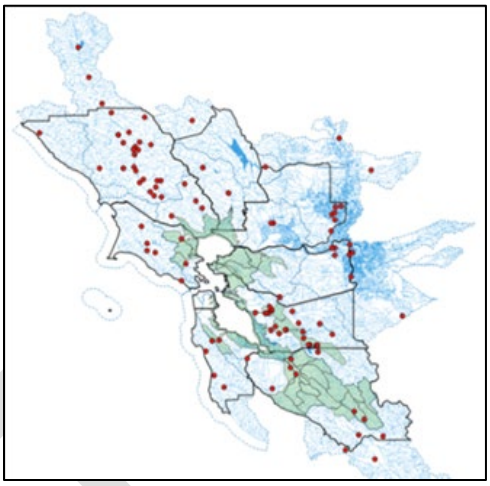
6 September 2019

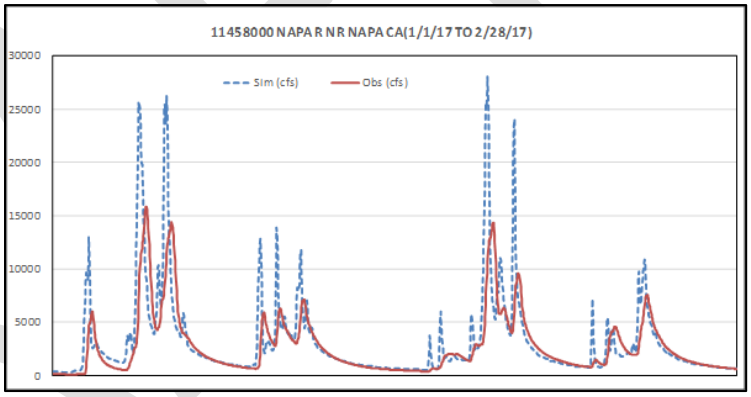
AQPI CASE STUDY – TRIBUTARY HYDROLOGIC MODEL NATIONAL WATER MODEL RETROSPECTIVE SIMULATION ASSESSMENT



SUMMARY

Background

APQI Hydro and NWM: The AQPI project is using the NOAA National Water Model (NWM, https://water.noaa.gov/) as the tributary hydrologic forecast tool. The NWM provides very high-resolution forecasts of flood runoff computed for a 1-km grid scale and for about 11,000 stream reaches in the AQPI region. It provides three forecast configurations (short- (0 to 18 hrs; 1-hr update), medium- (0 to 10 days; 6-hr update) and long-range (0 to 30 days; 1-day update)). The NWM simulates land surface response to precipitation and soil moisture dynamics but does not well represent reservoir operations or other water management activities.



Current Hydrologic Forecasting Practices and Needs

Flood mitigation and water managers in the SF Bay area use a mix of information sources and procedures to support their efforts to protect lives and reduce damages. Most use the CNRFC forecasts at some 24 stream gage forecast locations issued once per day with more frequent updates during storms. Monitoring of precipitation occurrence and forecasts is made using NWS QPE and QPF products, local ALERT rain gages and TV. Data downloads for local models is made by "scraping" various web sites, collating the data and formatting to input into their procedures. Flood and flash flood warnings are coordinated with the NWS WFOs and then through the county Emergency Operations Centers.

Baseline Verification

The intent of this report is to document NWM performance based on simulation using archived and quality checked precipitation data for the period 2013 to 2017. This verification is based on simulation results for the January – February 2017 which had several intense rainfall events resulting in significant flood flows. The NWM simulated flows are compared to USGS gaging station records to assess how well the simulation corresponds to the gaged flows. Various statistical measures are used to summarize this comparison. To help assure that the hydrologic forecasts are useful, the accuracy of the NWM needs to be characterized and then reviewed by the agencies who will use it. Time series graphics of the NWM and USGS gaged flows over plotted for the January-February 2017 period provide a visualization of the comparison between the two data sets.

Outcomes

Basin characteristics: There are 92 USGS stream gaging stations in the AQPI region; of these we identified 47 stations that have flow records that could be compared to the NWM. The basins average 133 sq. mi. in area and range from 1338 sq. mi. down to 5.5 sq. mi. The basins' rainfall averages 37 in. and ranges from 64 in. down to 21 in. Basin slopes average 21% and range from 30% down to 6%. Thirty-two (68%) of the basins can be considered to have little to no regulation by dams, the other 15 (32%) basins have significant regulation that influences downstream flows.

Verification Statistics: Various statistical metrics were computed in the comparison of simulated with gaged flows, including correlation coefficient (CC), percent bias (PBIAS) and Nash-Sutcliff Efficiency (NSE) coefficient. These were combined into a single metric called Score17 scaled from 0 to 5 which was used to compare across all stations and with basin characteristics; a Score 17 in the range 0 to 1 was rated Poor; a Score17 greater than 4 was rated Excellent.

Significant Findings:

Overall assessment of NWM performance is summarized by tabulating the frequency of Score17 values across all unregulated sites. To summarize:

- 79% of the sites were rated Moderate or better, 45% were rated Good or better, and 18% were rated Excellent. The regulated sites did not do as well but still some still showed useful performance; of the 15 regulated sites 7 (47%) showed Moderate performance, 8 (53%) were Poor or Mediocre.
- The Score17 performance metric was compared to various basin characteristics, including precipitation, drainage area, basin slope and impervious soils; in general, there was no strong correlation with any of these factors. There were two stations located in a large wetland area that the NWM performed poorly for; this was attributed to poor routing of flows which did not reproduce peak flow attenuation that occurs. There was some indication that the NWM did better for higher elevation basins.
- Comparison of the Score17 with basin storage confirmed that the NWM does poorly in heavily regulated basins, but several basins having moderate reservoir regulation performed at the Moderate level.
- For the unregulated basins the PBIAS metric for some sites, which measures total runoff volume, showed large positive and negative values. For these stations having low Score17 values, performance is attributed to poor rainfall mapping, either too much rain or too little. Stations with high positive or negative PBIAS are located mainly in Alameda and San Mateo counties, which have relatively lower elevations.
- Related assessment of precipitation mapping in the AQPI region (Chen at al 2018) has identified that the current NEXRAD radar coverage is too high in altitude, either because the radar is too high (e.g. KMUX) and/or the radar beam is blocked by mountainous terrain (KDAX). This may explain why there was some poor NWM performance for basins at lower altitude and better performance at higher altitude basins.

Review and Feedback:

Given this NWM baseline assessment and the (forthcoming) companion forecast assessment, it is intended that flood and other water management agencies review these to confirm that the data

presented is correct and that the performance characterization is appropriate. This could provide a foundation for “believability” by users.

What’s Next

Forecast Assessment: A follow on assessment will be conducted to determine how well the NWM does in forecast mode. Note the retrospective assessment was a comparative exercise and did not involve forecasts.

Real-Time Operations: The AQPI prototype will be deployed for real-time operations for the upcoming winter storm season 2019-2020. This will provide opportunity for users to access the hydrologic forecasts and consider how to incorporate these into their flood mitigation and water management operations. Some jurisdictions are requesting watershed-specific precipitation accumulation products to fit with their current flash flood alerting tools; this is being done.

AQPI CASE STUDY – TRIBUTARY HYDROLOGIC MODEL

NATIONAL WATER MODEL RETROSPECTIVE SIMULATION ASSESSMENT

BACKGROUND

AQPI staff have conducted a baseline verification of the National Water Model (NWM) using historical data for a retrospective simulation. The NWM 1-hour streamflow estimates were compared to USGS stream gage records to assess accuracy using various statistical metrics. Flow records for approximately 50 sites were examined in detail and factors were identified that impact simulation accuracy, including precipitation amount and location, watershed characteristics, soil moisture and water management. It is noted that the NWM retrospective simulation did not represent reservoir regulation, nor were USGS gage readings assimilated to establish initial conditions as is done with the real-time NWM forecast modeling. An overall summary is presented along with detailed assessment for each site.

NWM Retrospective Simulation

The NWM is a distributed hydrologic model which computes the hydrologic balance on a 250 m grid, aggregates excess precipitation to a 1 km grid, and routes these flood flows using the NHD-PlusV2 stream network. There are approximately 11,000 NWM stream reaches in the AQPI region. The system updates to include USGS gaged flows (-3 to 0 hrs), along with three forecast configurations (short- (0 to 18 hrs; 1-hr update), medium- (0 to 10 days; 6-hr update) and long-range (0 to 30 days; 1-day update). The NWM can provide a variety of flood forecast products, including hydrographs at any location (peak flow, time-to-peak, duration of high flow), and grid displays of streamflow and soil moisture.

The NOAA National Water Model Reanalysis dataset contains output from a 25-year retrospective simulation (January 1993 through December 2017) of version 1.2 of the National Water Model. We used data for the period 2013 to 2017, with emphasis placed on the January – February 2017 flood period. This simulation used observed rainfall as input and ingested other required meteorological input fields from a weather Reanalysis dataset. The output frequency and fields available in this historical NWM dataset differ from those contained in the real-time forecast model. One application of this dataset is to provide historical context to current real-time streamflow, soil moisture and snowpack NWM conditions. The Reanalysis data can be used to infer flow frequencies and perform temporal analyses with hourly streamflow output and 3-hourly land surface output. The long-term dataset can also be used in the development of end user applications which require a long baseline of data for system training or verification purposes. Access to these data can be found at: https://registry.opendata.aws/nwm-archive/.

NLDAS Precipitation Forcing

The North American Land Data Assimilation System (NLDAS, https://ldas.gsfc.nasa.gov/nldas/) is currently running operationally in near real-time (~4 day lag) on a 1/8th-degree grid with an hourly timestep over central North America (25-53 North). (Note: for the APQI region at approximately 38d N, -122d W, a 1/8th-degree grid has sides 8.6 mi x 6.8 mi, and area 59 sq. mi.) Retrospective hourly/monthly NLDAS datasets extend back to January 1979. NLDAS constructed a forcing dataset from a daily gauge-based precipitation analysis (temporally disaggregated to hourly using Stage II radar data), bias-corrected shortwave radiation, and surface meteorology re-analyses to drive the NWM.

ASSESSMENT OF NWM RETROSPECTIVE SIMULATION

Description of Assessment Approach

The NWM simulation results for the 2-month period January through February 2017 were examined in detail. This period was selected because there were several flood and high flow events which at several USGS gages produced the flood of record. In addition, the preceding December had several significant rainfall events which would have wet watershed soils so that rain abstractions during January-February would be minimized in comparison to dry conditions.

The assessment approach involved comparing the NWM simulation time series with the streamflow time series recorded at a USGS gage site. There were approximately 50 USGS gage sites where the comparison could be made (Figure X). The gage sites shown are those that are involved with the NWM and are active recording gages. In total there are 91 USGS gaging stations in the AQPI region, but not all of them are currently active or did not have records corresponding to the NWM retrospective simulation period 2012 to 2017. Also, some stations are located on streams or river reaches which are used strictly for water management and for which the NWM simulation did not apply. Note that the NWM simulation did not represent reservoir storage or other water management operations. For this NWM verification records for 46 USGS gaging stations were used.

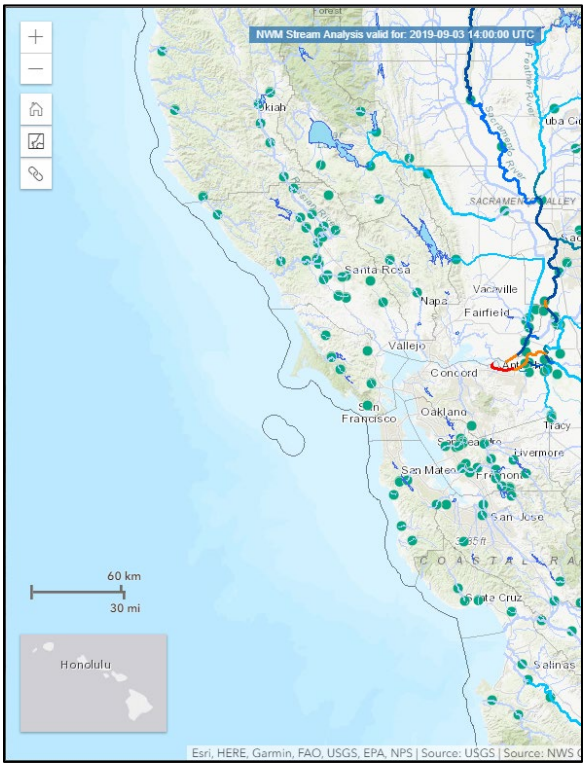


Figure 1 USGS stream gages in AQPI region.

USGS Gages-II Basin Characteristics

Basic information on watershed characteristics associated with each USGS gage site was obtained from the so-called Gages-II Basin Characteristics report and database (Falcone 2011,

https://water.usgs.gov/GIS/metadata/usgswrd/XML/gagesII_Sept2011.xml). This dataset, termed "GAGES II", an acronym for Geospatial Attributes of Gages for Evaluating Streamflow, version II, provides geospatial data and classifications for 9,322 stream gages maintained by the USGS. The GAGES II dataset consists of gages which have had either 20+ complete years (not necessarily continuous) of discharge record since 1950, or are currently active, as of water year 2009. The geospatial data include a number of watershed characteristics compiled from national data sources, including environmental features (e.g. climate – including historical precipitation, geology, soils, and topography) and anthropogenic influences (e.g. land use, road density, presence of dams, canals, or power plants). The dataset also includes comments from local USGS Water Science Centers, based on Annual Data Reports, pertinent to hydrologic modifications and influences. The general categories of basin data used here include: BASIN ID, BASIN_CLASSIFICATION, HYDROMOD_DAMS, CLIMATE, SOILS and TOPO. A complete listing of the variables is presented in Appendix A. Table 1 lists these stations along with selected basin characteristics taken from the Gages-II database.

Of interest is to examine whether there is any aspect of the basins that influences the accuracy of the NWM forecasts. For this purpose, the basin characteristics were generalized to five (5) categories: 1) Precipitation, 2) Orography, 3) Topography, 4) Soil, and 5) Water Management. Precipitation (1) is the mean annual precipitation for the basin, determined from the PRISM (Daly et al 2004, http://prism.oregonstate.edu/). A 1-5 index was generated by ranking the basin precipitation between the maximum and minimum of the AQPI region. Orography (2) was characterized as the ratio between the elevation of the basin divided by the elevation of the gage; this ratio was scaled between 1-5. A topography index (3) was determined using the BASIN SLOPE and scaling to 1-5 bounded by the maximum and minimum slopes for the AQPI region. The Soils (4) index was scales to 1-5 using the percentage of HSG4 (Hydrologic Soil Group 4) in the basin; HSG4 is the most impervious of four soil classifications. Water Management was scaled to 1-5 using the ratio Storage/Basin Area across all sites in the AQPI region. The example Site Summary presented above shows the basin factor indices and an annotation on its significance.

Table 1 Listing of USGS gaging station used for NWM verification.

STATION ID	STATION NAME	DRAINAGE AREA [mi^2]	COUNTY	PPTavg Basin [in]	BASIN_ELEV_FT	SLOPE [%]	HGD [%]	NDAMS_2009	STOR [KAF]	HDI score
11162500	PESCADERO C NR PESCADERO CA	45.9	San Mateo	36.4	1136	26.7	22.0	1	0.0	2.1
11162570	SAN GREGORIO C A SAN GREGORIO CA	51.0	San Mateo	35.0	1043	22.3	10.0	0	0.0	0.8
11162620	PILARCITOS C BL STONE DAM NR HILLSBOROUGH CA	6.7	San Mateo	41.0	1081	24.3	17.9	1	3.1	2.5
11162630	PILARCITOS C A HALF MOON BAY CA	26.9	San Mateo	35.3	780	25.0	18.6	2	3.1	2.3
11164500	SAN FRANCISQUITO C A STANFORD UNIVERSITY CA	37.7	Santa Clara	33.3	955	16.8	26.8	3	1.9	3.5
11169025	GUADALUPE R ABV HWY 101 A SAN JOSE CA	171.9	Santa Clara	30.4	879	16.1	55.3	12	44.2	5.0
11169500	SARATOGA C A SARATOGA CA	8.8	Santa Clara	42.0	1789	30.2	34.8	0	0.0	0.8
11169800	COYOTE C NR GILROY CA	109.2	Santa Clara	24.0	1981	25.6	72.1	2	0.3	0.6
11172945	ALAMEDA C AB DIV DAM NR SUNOL CA	33.6	Alameda	24.6	2671	26.7	65.0	0	0.0	0.2
11173200	ARROYO HONDO NR SAN JOSE CA	76.9	Santa Clara	24.5	2680	26.7	73.3	2	0.5	0.4
11173510	ALAMEDA C BL CALAVERAS C NR SUNOL CA	139.3	Alameda	24.5	2434	25.7	69.2	3	100.5	2.9
11173575	ALAMEDA C BL WELCH C NR SUNOL CA	148.8	Alameda	24.5	2357	25.8	68.8	3	100.5	2.9
11174000	SAN ANTONIO C NR SUNOL CA	39.1	Alameda	22.7	1617	21.9	68.7	1	50.5	4.0
11176400	ARROYO VALLE BL LANG CN NR LIVERMORE CA	130.7	Alameda	22.6	2473	23.4	78.0	0	0.0	0.2
11176900	ARROYO DE LA LAGUNA A VERONA CA	403.3	Alameda	21.0	1506	16.1	68.6	2	77.2	4.4
11179000	ALAMEDA C NR NILES CA	632.7	Alameda	22.0	1669	19.0	67.9	6	228.1	4.6
11180500	DRY C A UNION CITY CA	9.4	Alameda	26.5	928	19.4	58.0	0	0.0	0.6
11180825	SAN LORENZO C AB DON CASTRO RES NR CASTRO V CA	18.0	Alameda	26.9	920	21.4	58.0	0	0.0	0.8
11180900	CROW C NR HAYWARD CA	10.5	Alameda	26.4	847	20.8	58.0	0	0.0	0.6
11180960	CULL C AB CULL C RES NR CASTRO VALLEY CA	5.8	Alameda	26.7	847	23.3	58.0	0	0.0	0.8
11181000	SAN LORENZO C A HAYWARD CA	37.8	Alameda	26.4	846	20.9	58.0	2	0.7	3.1
11181040	SAN LORENZO C A SAN LORENZO CA	46.9	Alameda	25.7	740	18.0	57.4	4	0.9	3.5
11182500	SAN RAMON C A SAN RAMON CA	6.1	Contra Costa	26.5	1141	21.6	64.5	0	0.0	1.0
11456000	NAPA RIVER NEAR ST. HELENA CALIF	82.0	Napa	41.1	1001	20.9	40.1	4	3.4	2.7
11458000	NAPA R NR NAPA CA	218.7	Napa	37.8	907	18.6	38.3	17	40.1	2.5
11458433	SONOMA CREEK A KENWOOD CA	14.2	Sonoma	45.5	1352	22.2	43.0	0	0.0	1.7
11458500	SONOMA C A AGUA CALIENTE CA	58.1	Sonoma	42.5	988	17.6	59.6	3	0.9	2.5
11459500	NOVATO C A NOVATO CA	17.9	Marin	40.5	529	19.5	42.8	1	4.4	3.1
11460000	CORTE MADERA C A ROSS CA	18.3	Marin	42.7	514	21.4	49.2	1	0.6	3.5
11460400	LAGUNITAS C A SP TAYLOR STATE PK CA	34.3	Marin	46.1	919	25.4	34.0	4	46.4	4.4
11460600	LAGUNITAS C NR PT REYES STATION CA	81.7	Marin	42.5	729	23.1	34.3	6	68.9	3.5
11460750	WALKER C NR MARSHALL CA	31.3	Marin	41.4	616	20.8	34.5	3	10.8	2.5
11461000	RUSSIAN R NR UKIAH CA	100.2	Mendocino	46.7	1471	20.6	23.8	3	0.7	1.7
11461500	EF RUSSIAN R NR CALPELLA CA	92.2	Mendocino	45.1	1632	20.9	32.4	1	0.2	2.3
11462500	RUSSIAN R NR HOPLAND CA	362.4	Mendocino	45.5	1526	21.1	27.5	8	156.5	3.8
11463170	BIG SULPHUR C A G RESORT NR CLOVERDALE CA	13.1	Sonoma	58.6	2848	28.9	47.3	0	0.0	0.0
11464000	RUSSIAN R NR HEALDSBURG CA	793.9	Sonoma	45.6	1417	21.3	29.8	31	160.7	3.3
11465660	COPELAND C A ROHNERT PARK CA	5.5	Sonoma	43.5	921	10.0	84.3	0	0.0	2.3
11465680	LAGUNA DE SANTA ROSA A STONY PT RD NR COTATI CA	41.4	Sonoma	37.6	378	6.0	75.2	0	0.0	2.9
11466170	MATANZAS C A SANTA ROSA CA	21.6	Sonoma	41.7	724	12.2	73.4	3	2.3	3.8
11466200	SANTA ROSA C A SANTA ROSA CA	55.9	Sonoma	42.4	849	15.8	63.5	6	6.1	3.3
11466320	SANTA ROSA C A WILLOWSIDE RD NR SANTA ROSA CA	77.0	Sonoma	40.4	670	12.2	55.1	9	7.0	4.2
11466800	MARK WEST C NR MIRABEL HEIGHTS CA	251.8	Sonoma	39.6	509	9.2	52.1	21	12.8	5.0
11467000	RUSSIAN R NR GUERNEVILLE CA	1337.9	Sonoma	45.3	1110	18.8	31.5	60	624.3	4.2
11467200	AUSTIN C NR CAZADERO CA	62.8	Sonoma	64.0	1011	28.9	12.7	0	0.0	0.6
11467510	SF GUALALA R NR THE SEA RANCH CA	161.5	Sonoma	57.2	1024	26.2	6.1	3	0.8	1.5
	Count=	46		46	46	46	46	46	46	46
	Max =	1337.9		64.0	2848	30.2	84.3	60	624.3	5.0
	Min =	5.5		21.0	378	6.0	6.1	0	0.0	0.0
	Average =	133.3		36.6	1238	20.9	48.2	5	38.2	2.5

For each USGS gage site a summary description of the watershed was prepared to include:

- Watershed description – a general review of geography and characteristics
- Drainage area
- Comments – the USGS gage site descriptions notes factors which may influence flows, usually water management activities such are reservoir operations and diversions.
- USGS Gages-II watershed characteristics (see description below).
- Flood flow frequency levels – flood frequency levels (e.g. 100-year, 50-year, etc.) were derived for each site based on drainage area and precipitation characteristics (. These flow levels are intended

to be compared to simulated and observed flows to assess the relative magnitude or criticality, as illustrated in Figure 2.

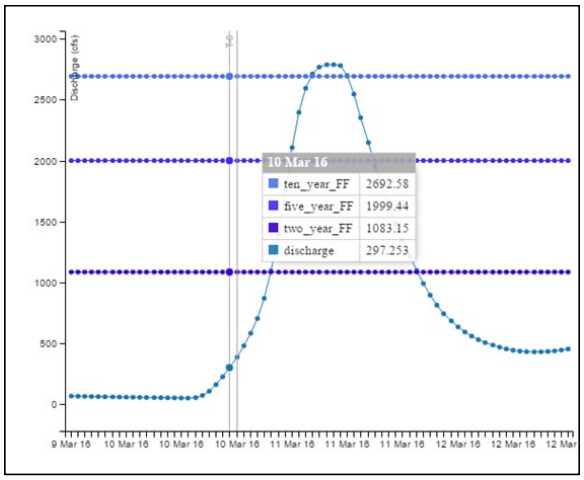


Figure 2 Overlay of flood frequency levels onto hydrograph indicates criticality.

- Performance metrics for the 2-month period 1 January to 28 February 2017:
  - Correlation coefficient (CC) – measures the strength and direction of a linear relationship between two variables on a scatterplot. The value of CC is always between +1 (perfect) and –1 (perfect opposite).
  - PBIAS – Percent bias, the difference in runoff volume between observed and simulated flow accumulation periods. Values near zero are good. This metric is considered a total period measure of rainfall.
  - Nash-Sutcliff Efficiency (NSE) coefficient - represents how well the simulated hydrograph matches the observed flows for all time steps. The closer the NSE is to 1, the more accurate the model is; values less than zero are meaningless. In contrast to CC, the NSE penalizes large differences.

Error Indices	Acronym	Equation
Correlation Coefficient	CC	$\frac{\sum(Q_{sim}-\overline{Q_{sim}})(Q_{obs}-\overline{Q_{obs}})}{\sqrt{\sum(Q_{sim}-\overline{Q_{sim}})^2}\sqrt{\sum(Q_{obs}-\overline{Q_{obs}})^2}}$
Nash-Sutcliffe Efficiency	NSE	$1-\frac{\sum(Q_{sim}-Q_{obs})^2}{\sum(Q_{obs}-\overline{Q_{obs}})^2}$
PBIAS	PBIAS	$\left(\sum(Q_{obs}-Q_{sim})\right) \div \sum(Q_{obs}+Q_{sim}) \times 100\ (\%)$

  - A composite performance index was computed as the weighted sum of the CC, PBIAS and NSE where each metric was scaled to a range 1 to 5. The matrix below illustrates the computation of the Score17 and Assess17 categorization.

Metric	Composite Score				
	Max	Min	5scale	Wt	5s*Wt
CC	1.0	0.0	4.4	0.1	0.4
Pbias	0%	100%	4.6	0.5	2.3
NSE	1.0	0.0	3.7	0.4	1.5
			Score17 =		4.2
			Assess17 =		Excellent

From	To	Assess17
0	1	Poor
1	2	Mediocre
2	3	Moderate
3	4	Good
4	5	Excellent

  - Another performance index, called the HAT (for Hydrologic Assessment Tool) was tabulated. The HAT used a combination of machine learning and clustering analysis to provide an assessment of NWM performance divided into 4 categories: unsatisfactory (US), satisfactory (S), good (G), and very good (VG). The HAT index used a 3-point scale. A more detailed description of the HAT procedure is presented in Appendix X.
- Time series graphic of the NWM and USGS gaged flows over plotted for the January-February 2017 period provides a visualization of the comparison between the two data sets.
- An example of a gage site report follows (Figure 3). Note that not all sites are excellent as this was rated.

The NWM performance statistics were tabulated for each USGS gaging station; results are presented in Table 2.

11456000 NAPA R NR ST HELENA CA

Site Description:

The Napa River rises in northwestern Napa County just south of the summit of Mt. St. Helena in the Mayacamas Mountains of the California Coast Ranges. It descends the southern slope of Mt. St. Helena to Kimball Canyon Dam. It flows south for 4 miles (6 km), entering the head of the slender Napa Valley north of Calistoga. In the valley, it flows southeast past Calistoga, St Helena and thence to Napa near SF Bay.

Remarks from USGS Site Report:

Some diversion for agriculture and regulation by Bell Canyon Res (2500 af). Small diversions upstream from station for irrigation of about 1,500 acres.

Watershed Factors:

Precipitation:	**Pavg [in] =**	41.1	**Prank =**	2.5
			Rainfall mapping seems good.	
Orography:	**ORO [%] =**	15%	**OROrank =**	2.0
			Rainfall location consistently good.	
Topography:	**SL [%] =**	20.9	**SLrank =**	3.3
			Moderate slopes.	
Soils:	**HGD [%] =**	40.1	**HGDrank =**	2.2
			Moderately impervious soils.	
Water management:	**STOR [kaf] =**	3.4	**DISTURB =**	2.5
	Some regulation, does not seem to impact peak flow simulation.			

Assessment of NWM Performance:

The NWM simulation showed generally very good results although most peak flows were slightly over-estimated. Perhaps the peaks are reduced when flows through Bell Canyon Reservoir. Water balance very good.

Gage #	11456000
Gage Name	NAPA R NR ST HELENA CA
County	Napa
Area [mi^2]	79
CNRFC	SHEC1
Qpeak [cfs]	18,300
Qpeak Year	2005
Q500 [cfs]	21228
Q200 [cfs]	18323
Q100 [cfs]	16169
Q50 [cfs]	13890
Q25 [cfs]	11671
Q10 [cfs]	8739
CC	0.89
PBias	8%
NSE	0.75
Score (1-5)	4.23
Assess17	Excellent
HAT (1-3)	1.29

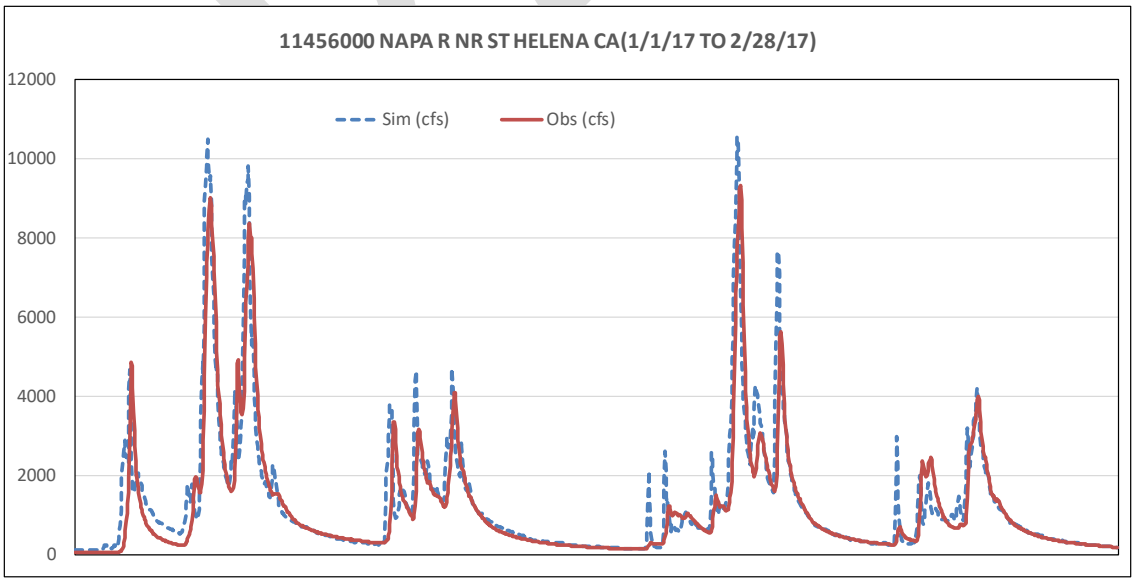


Figure 3 Example of NWM verification for a USGS gage site.

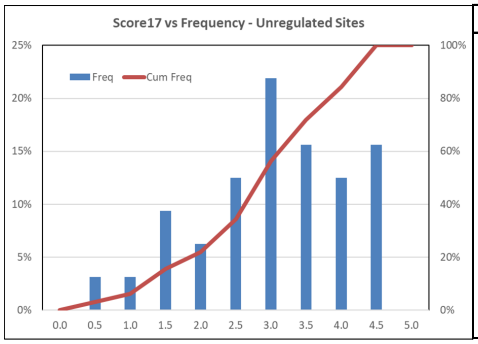
Table 2 Listing of NWM performance statistics.

STATION ID	STATION NAME	DRAINAGE AREA [mi^2]	CC	PBias	NSE	Score17 (1-5)	Assess	HAT (1-3)
11162500	PESCADERO C NR PESCADERO CA	45.9	0.87	54%	0.30	2.18	Moderate	2.22
11162570	SAN GREGORIO C A SAN GREGORIO CA	51.0	0.66	60%	-1.05	1.32	Mediocre	1.50
11162620	PILARCITOS C BL STONE DAM NR HILLSBOROUGH CA	6.7	0.27	-77%	-1.17	0.71	Poor	0.50
11162630	PILARCITOS C A HALF MOON BAY CA	26.9	0.52	-74%	-0.61	0.90	Poor	0.50
11164500	SAN FRANCISQUITO C A STANFORD UNIVERSITY CA	37.7	0.67	11%	0.44	3.44	Good	1.60
11169025	GUADALUPE R ABV HWY 101 A SAN JOSE CA	171.9	0.54	82%	-7.88	0.72	Poor	1.75
11169500	SARATOGA C A SARATOGA CA	8.8	0.56	7%	-0.04	2.60	Moderate	1.22
11169800	COYOTE C NR GILROY CA	109.2	0.88	31%	0.41	2.98	Moderate	2.22
11172945	ALAMEDA C AB DIV DAM NR SUNOL CA	33.6	0.88	-23%	0.75	3.87	Good	1.41
11173200	ARROYO HONDO NR SAN JOSE CA	76.9	0.90	-19%	0.79	4.07	Excellent	2.44
11173510	ALAMEDA C BL CALAVERAS C NR SUNOL CA	139.3	0.68	-24%	-1.99	2.25	Moderate	1.61
11173575	ALAMEDA C BL WELCH C NR SUNOL CA	148.8	0.72	-22%	-1.88	2.32	Moderate	1.48
11174000	SAN ANTONIO C NR SUNOL CA	39.1	0.09	-61%	-0.04	1.03	Mediocre	0.00
11176400	ARROYO VALLE BL LANG CN NR LIVERMORE CA	130.7	0.82	56%	0.04	1.59	Mediocre	1.04
11176900	ARROYO DE LA LAGUNA A VERONA CA	403.3	0.89	70%	-5.03	1.20	Mediocre	1.11
11179000	ALAMEDA C NR NILES CA	632.7	0.88	39%	-2.25	1.97	Mediocre	1.62
11180500	DRY C A UNION CITY CA	9.4	0.39	-57%	-0.08	1.26	Mediocre	0.50
11180825	SAN LORENZO C AB DON CASTRO RES NR CASTRO V CA	18.0	0.54	-55%	0.09	1.57	Mediocre	2.33
11180900	CROW C NR HAYWARD CA	10.5	0.81	-31%	0.61	3.35	Good	2.00
11180960	CULL C AB CULL C RES NR CASTRO VALLEY CA	5.8	0.79	-44%	0.53	2.87	Moderate	1.16
11181000	SAN LORENZO C A HAYWARD CA	37.8	0.78	-35%	0.56	3.15	Good	1.49
11181040	SAN LORENZO C A SAN LORENZO CA	46.9	0.86	-42%	0.62	3.12	Good	1.92
11182500	SAN RAMON C A SAN RAMON CA	6.1	0.77	25%	-0.31	2.25	Moderate	1.17
11456000	NAPA RIVER NEAR ST. HELENA CALIF	82.0	0.89	8%	0.75	4.23	Excellent	1.29
11458000	NAPA R NR NAPA CA	218.7	0.69	19%	-0.12	2.37	Moderate	0.87
11458433	SONOMA CREEK A KENWOOD CA	14.2	0.76	26%	0.35	2.94	Moderate	1.63
11458500	SONOMA C A AGUA CALIENTE CA	58.1	0.88	1%	0.78	4.46	Excellent	1.73
11459500	NOVATO C A NOVATO CA	17.9	0.69	81%	-2.32	0.82	Poor	0.87
11460000	CORTE MADERA C A ROSS CA	18.3	0.74	-36%	0.39	2.74	Moderate	0.71
11460400	LAGUNITAS C A SP TAYLOR STATE PK CA	34.3	0.76	-63%	0.01	1.32	Mediocre	0.19
11460600	LAGUNITAS C NR PT REYES STATION CA	81.7	0.66	-43%	0.27	2.28	Moderate	0.54
11460750	WALKER C NR MARSHALL CA	31.3	0.74	-36%	0.39	2.74	Moderate	0.95
11461000	RUSSIAN R NR UKIAH CA	100.2	0.86	16%	0.58	3.69	Good	1.17
11461500	EF RUSSIAN R NR CALPELLA CA	92.2	0.85	0%	0.71	4.34	Excellent	2.33
11462500	RUSSIAN R NR HOPLAND CA	362.4	0.63	-46%	-0.20	1.66	Mediocre	2.67
11463170	BIG SULPHUR C A G RESORT NR CLOVERDALE CA	13.1	0.73	-40%	0.46	2.79	Moderate	0.76
11464000	RUSSIAN R NR HEALDSBURG CA	793.9	0.91	-7%	0.70	4.19	Excellent	3.00
11465660	COPELAND C A ROHNERT PARK CA	5.5	0.77	-23%	0.56	3.42	Good	0.94
11465680	LAGUNA DE SANTA ROSA A STONY PT RD NR COTATI CA	41.4	0.74	104%	-1.33	0.26	Poor	1.02
11466170	MATANZAS C A SANTA ROSA CA	21.6	0.77	54%	0.38	2.31	Moderate	1.38
11466200	SANTA ROSA C A SANTA ROSA CA	55.9	0.90	12%	0.69	4.03	Excellent	1.98
11466320	SANTA ROSA C A WILLOWSIDE RD NR SANTA ROSA CA	77.0	0.87	17%	0.52	3.56	Good	1.74
11466800	MARK WEST C NR MIRABEL HEIGHTS CA	251.8	0.75	30%	-1.99	2.12	Mediocre	0.93
11467000	RUSSIAN R NR GUERNEVILLE CA	1337.9	0.78	-5%	0.05	2.88	Moderate	1.83
11467200	AUSTIN C NR CAZADERO CA	62.8	0.74	-24%	0.28	2.82	Moderate	1.18
11467510	SF GUALALA R NR THE SEA RANCH CA	161.5	0.86	-13%	0.69	3.99	Good	1.73
	Count=	46	46	46	46	46		46
	Max =	1337.9	0.9	1.0	0.8	4.5		3.0
	Min =	5.5	0.1	-0.8	-7.9	0.3		0.0
	Average =	133.3	0.7	0.0	-0.3	2.5		1.4

Review of NWM Performance Statistics

Overall Assessment

Overall assessment of NWM performance is summarized by tabulating the frequency of Score17 values across all unregulated sites; Figure 4 illustrates this. To summarize, 78% of the unregulated sites were rated Moderate or better, 50% were rated Good or better, and 16% were rated Excellent. The regulated sites did not do as well but some still showed useful performance; of the 15 regulated sites 7 (47%) showed Moderate performance, 8 (53%) were Poor or Mediocre.



SC17	All	Unreg
0.0	0%	0%
0.5	2%	3%
1.0	11%	6%
1.5	22%	16%
2.0	30%	22%
2.5	48%	34%
3.0	67%	56%
3.5	78%	72%
4.0	87%	84%
4.5	100%	100%
5.0	100%	100%

Figure 4 Frequency of Score17 values for all sites.

Basin Characteristics

Exploration of the potential relationships between NWM performance as Score17 and basin characteristics was conducted. Figure 5 illustrates results for Precipitation, Orography, Slope, Soils and Basin Storage (i.e. reservoirs). The lack of correspondence of NWM performance to these basin characteristics indicates that these NWM basin parameters do not systematically influence performance.

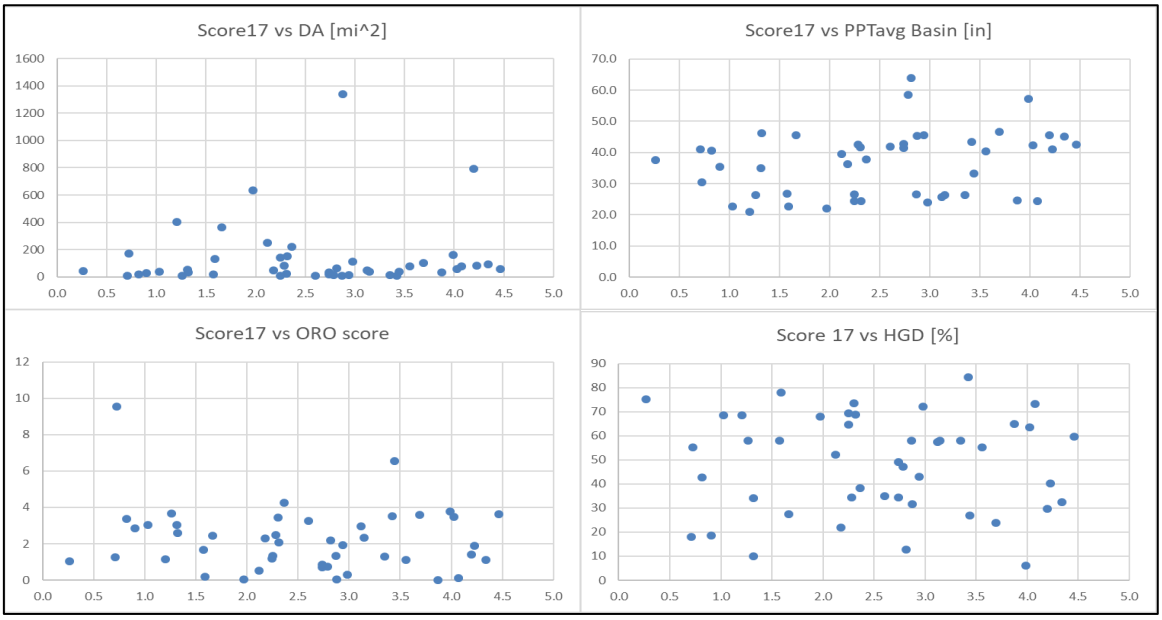


Figure 5 Score17 plotted against a) drainage area, b) PPTavg, c) ORO score, d) HGD soils. No relationship for any of these basin variables is evident.

Of interest is how much the regulated basins influenced overall performance. Note that some stations were not included because of complete regulation (e.g. Dry Creek below Lake Sonoma in Sonoma County). An indication of reservoir storage is illustrated in Figure 6 which shows that stations having a high basin storage ratio also exhibit Mediocre or Poor performance per Score 17 (i.e. below 2.5). If these stations are removed from the summary tabulation (Figure 4) the NWM performance improves to 78% of the sites were rated Moderate or better, 44% were rated Good or better, and 16% were rated Excellent. There was no evident relationship shown when comparing Score17 against the HDI (Hydrologic Disturbance Index; not shown). Figure 7 illustrates and example of the influence of regulation of the flow time series.

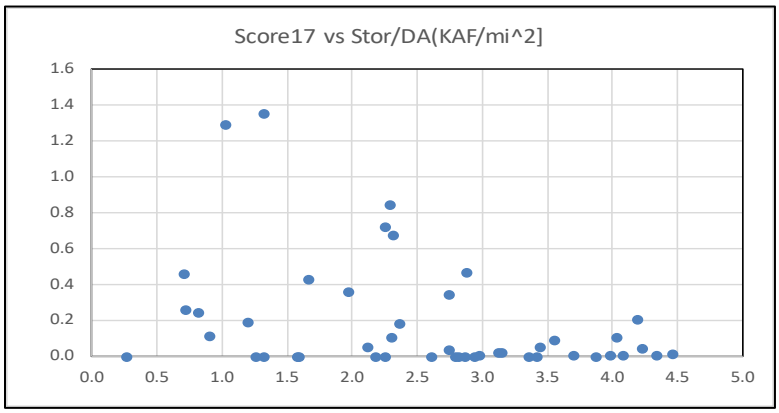


Figure 6 Score17 plotted against the ratio of basin storage per drainage area [KAF/sq. mi.]

Figure 5 shows an example of the influence of reservoir operations on the observed hydrograph.

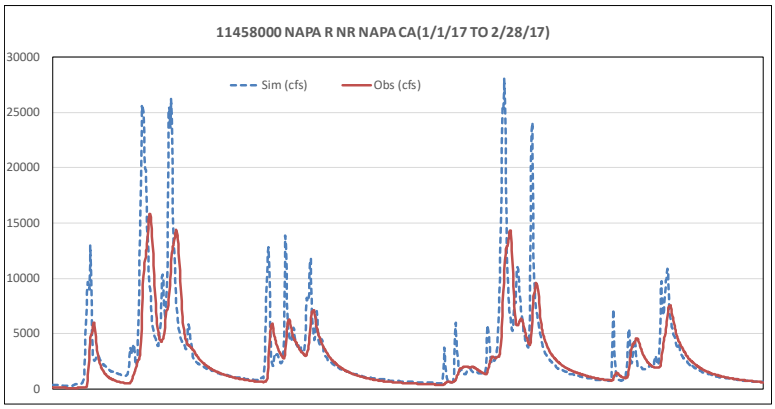


Figure 7 Example of reservoir operations on observed hydrograph.

Runoff Volume

The correspondence of NWM simulated runoff volume is measured by the PBIAS metric. It turns out that PBIAS can be negative or positive depending on whether the NWM simulated volume exceeds or is less than the gaged volume. Figure 8 shows two examples of basins having little regulation that exhibit a) large positive PBIAS, and b) large negative PBIAS.

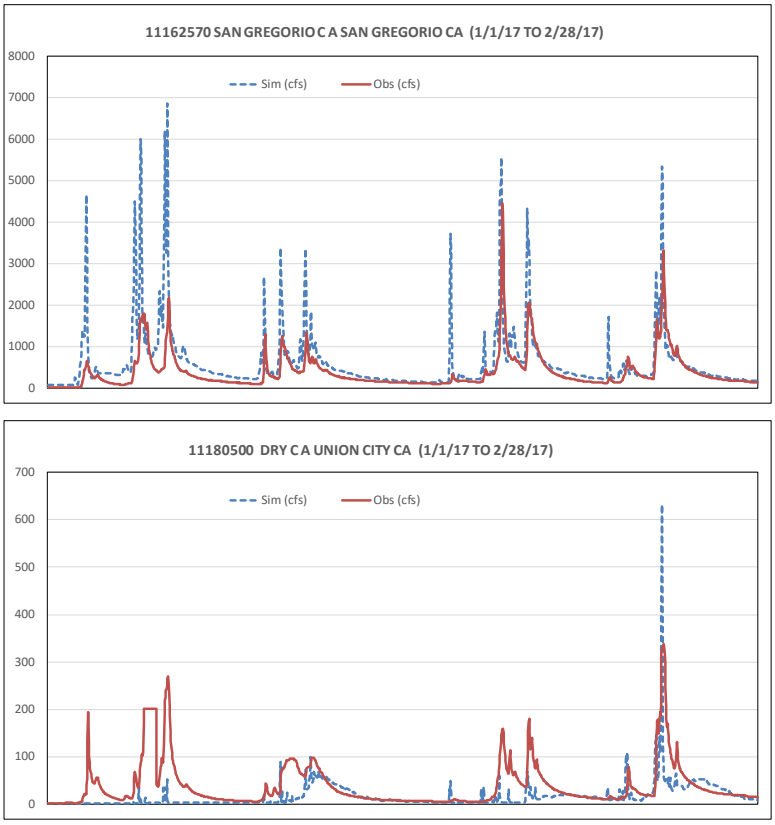


Figure 8 Examples of stations having large PBIAS, a) positive, and b) negative. Neither station has significant regulation.

Many of the positive PBIAS are due to reservoir operations; if these stations are removed from the list, leaving 33 stations having no or low regulation, then there remain a number of stations that exhibit a range of positive or negative PBIAS (Figure 8, Table 3). For these stations having low Score17 values, performance is attributed to poor rainfall mapping, either too much rain or too little. Stations with high positive or negative PBIAS are located mainly in Alameda and San Mateo counties, which have relatively lower elevations.

Table 3 Unregulated stations ranked by PBIAS.

STA_ID	STA_NAME	DA [mi^2]	COUNTY NAME	Score17 (1-5)	PBias
11465680	LAGUNA DE SANTA ROSA A STONY PT RD NR COTATI CA	41.4	Sonoma	0.26	1.04
11176900	ARROYO DE LA LAGUNA A VERONA CA	403.3	Alameda	1.20	0.70
11162570	SAN GREGORIO C A SAN GREGORIO CA	51.0	San Mateo	1.32	0.60
11176400	ARROYO VALLE BL LANG CN NR LIVERMORE CA	130.7	Alameda	1.59	0.56
11162500	PESCADERO C NR PESCADERO CA	45.9	San Mateo	2.18	0.54
11466170	MATANZAS C A SANTA ROSA CA	21.6	Sonoma	2.31	0.54
11169800	COYOTE C NR GILROY CA	109.2	Santa Clara	2.98	0.31
11466800	MARK WEST C NR MIRABEL HEIGHTS CA	251.8	Sonoma	2.12	0.30
11458433	SONOMA CREEK A KENWOOD CA	14.2	Sonoma	2.94	0.26
11182500	SAN RAMON C A SAN RAMON CA	6.1	Contra Costa	2.25	0.25
11466320	SANTA ROSA C A WILLOWSIDE RD NR SANTA ROSA CA	77.0	Sonoma	3.56	0.17
11461000	RUSSIAN R NR UKIAH CA	100.2	Mendocino	3.69	0.16
11466200	SANTA ROSA C A SANTA ROSA CA	55.9	Sonoma	4.03	0.12
11164500	SAN FRANCISQUITO C A STANFORD UNIVERSITY CA	37.7	Santa Clara	3.44	0.11
11456000	NAPA RIVER NEAR ST. HELENA CALIF	82.0	Napa	4.23	0.08
11174600	ALAMO CN NR PLEASANTON CA	39.5	Alameda	4.21	0.07
11169500	SARATOGA C A SARATOGA CA	8.8	Santa Clara	2.60	0.07
11458500	SONOMA C A AGUA CALIENTE CA	58.1	Sonoma	4.46	0.01
11461500	EF RUSSIAN R NR CALPELLA CA	92.2	Mendocino	4.34	0.00
11467510	SF GUALALA R NR THE SEA RANCH CA	161.5	Sonoma	3.99	-0.13
11173200	ARROYO HONDO NR SAN JOSE CA	76.9	Santa Clara	4.07	-0.19
11172945	ALAMEDA C AB DIV DAM NR SUNOL CA	33.6	Alameda	3.87	-0.23
11465660	COPELAND C A ROHNERT PARK CA	5.5	Sonoma	3.42	-0.23
11467200	AUSTIN C NR CAZADERO CA	62.8	Sonoma	2.82	-0.24
11180900	CROW C NR HAYWARD CA	10.5	Alameda	3.35	-0.31
11181000	SAN LORENZO C A HAYWARD CA	37.8	Alameda	3.15	-0.35
11460000	CORTE MADERA C A ROSS CA	18.3	Marin	2.74	-0.36
11463170	BIG SULPHUR C A G RESORT NR CLOVERDALE CA	13.1	Sonoma	2.79	-0.40
11181040	SAN LORENZO C A SAN LORENZO CA	46.9	Alameda	3.12	-0.42
11180960	CULL C AB CULL C RES NR CASTRO VALLEY CA	5.8	Alameda	2.87	-0.44
11180825	SAN LORENZO C AB DON CASTRO RES NR CASTRO V CA	18.0	Alameda	1.57	-0.55
11180500	DRY C A UNION CITY CA	9.4	Alameda	1.26	-0.57
11162630	PILARCITOS C A HALF MOON BAY CA	26.9	San Mateo	0.90	-0.74

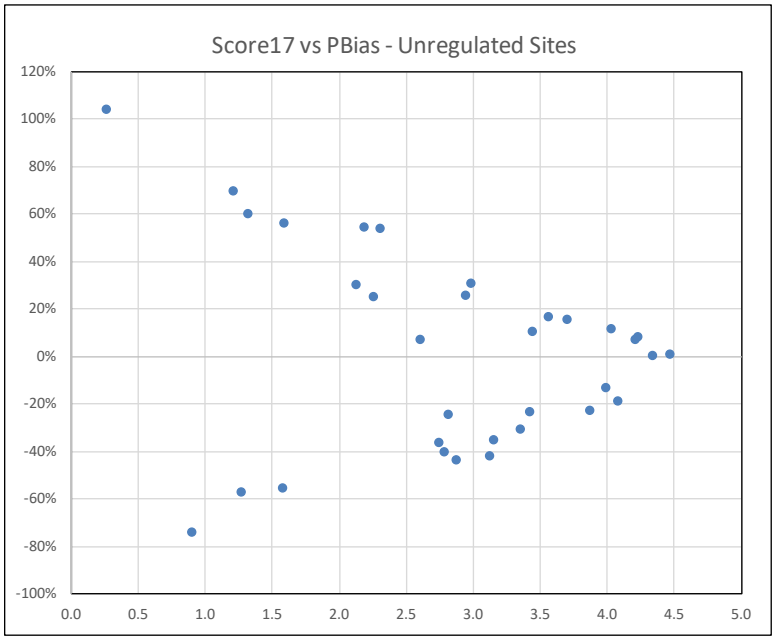


Figure 8 Score17 vs PBIAS for unregulated stations.

NWM Parameters – Wetland Routing

The lack of correspondence of NWM performance to a number of basin characteristics (Figure 3) indicates that the NWM basin parameters do not systematically influence performance. However, there are two stations in Sonoma county that seem to have issues with performance, even though they have little regulation by upstream reservoirs. The two stations gage flows in the Laguna de Santa Rosa which has the lowest basin slopes in the AQPI region; the high positive PBIAS is evident in the hydrographs (Figure 9). The Laguna de Santa Rosa is an ancestral lakebed and currently a large wetland. It seems that NWM flow routing in this area is poor, and that inflows and local runoff in the wetland tend to be delayed and attenuated. It is noteworthy that the Mark West station has the highest HDI rating by the Gages-II database. Additional investigation of the NWM flow routing seems warranted for this area, and perhaps also for the low slope reaches along the SF Bay coast.

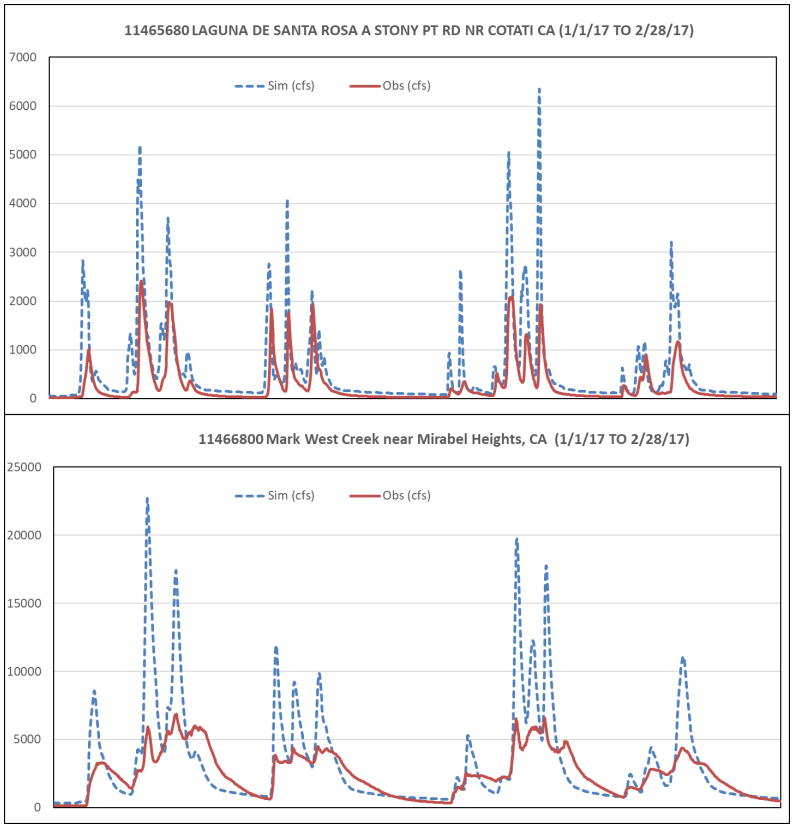
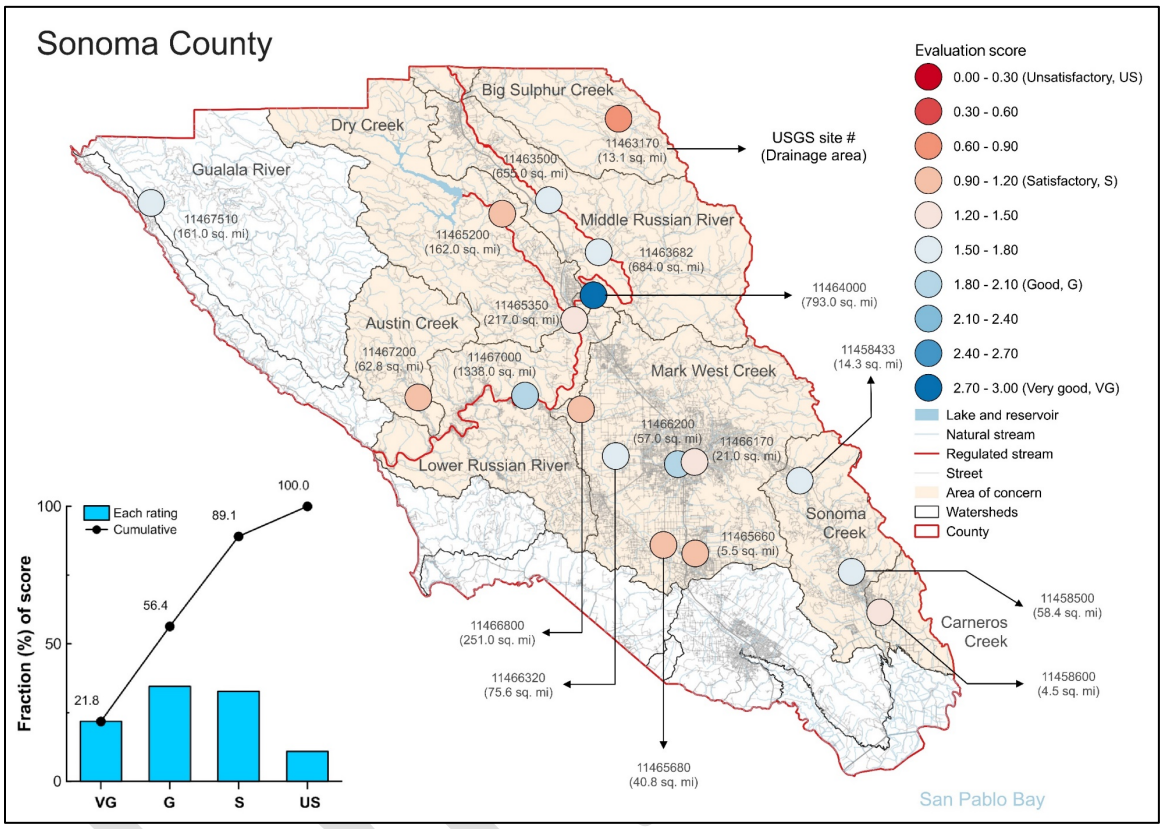


Figure 9 Two stations located in the low slope Laguna de Santa Rosa seem to have NWM flow routing issues.

HAT Assessment Overview

The HAT procedure was applied for USGS stream gage sites in Sonoma County. Figure 1 summarizes the results. The map shows the HAT ratings as color codes for each USGS age site. There seems no evident spatial pattern to the HAT performance ratings. The inserted graphic summarizes performance statistics. Cumulatively across all sites and flood events it can be said that 90% of the NWM simulations were Satisfactory or better, 20% were Very Good, and 10% were Unsatisfactory.



Comparison of Score17 to HAT

The use of composite indices or metrics to assess NWM simulation accuracy involves collapsing several metrics into a single number. For this project, there were two composite indices used, the Score17 and the HAT indices. The Score17 index involved weighting the CC, PBIAS and NSE statistics for the 2-month period January-February 2017 as detailed above. The HAT index was generated using an automated machine learning approach applied to the entire 5-year period as described in Appendix B. Comparison of the two indices is illustrated in Figure 9. As indicated, there is weak correspondence between the two indices. In discussion with the HAT developers it was learned that that index varies from year to year (e.g dry to wet) and season to season. This suggests that basic hydrological processes vary depending on season and moisture conditions (e.g. soil moisture). The 2-month period January – February 2017 was a notably wet period with significant rain during the preceding December. Additional research is on-going to examine this topic.

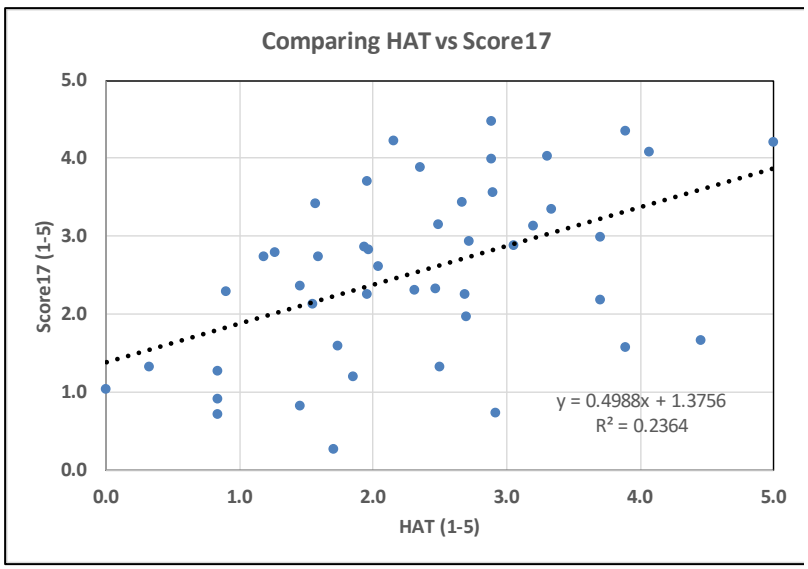


Figure 9 Score17 vs HAT index.

Discussion

The NWM baseline verification presented here has identified several issues, including a) precipitation mapping, b) reservoir operations, and c) NWM channel routing.

a) Precipitation Mapping

Precipitation intensity, duration and location are primary drivers for flood runoff. This NWM baseline verification has identified a number of basins where precipitation mapping is apparently suspect as the streamflow volumes differ greatly from observations. Improvements in precipitation mapping therefore hold promise for improvements in flood runoff prediction which is a primary goal of the AQPI project.

Tracking precipitation occurrence as it develops using radar and surface observations is called Quantitative Precipitation Estimation (QPE). QPE products are important for flash flood alerting and provide the basis for short-term nowcasting out to 6 hours. The main NWS QPE product is the Multi-Radar Multi-Sensor (MRMS, https://mrms.nssl.noaa.gov/) project which utilizes an automated system that rapidly and intelligently integrates data from multiple radars and radar networks, surface observations, numerical weather prediction (NWP) models, and climatology to generate seamless, high spatio-temporal resolution mosaics. AQPI project local x-band radars are intended to improve QPE mapping and are to be incorporated into the NWM MRMS products. Chen et al (2018) described improvements of QPE for the SF Bay area associated with operation of an x-band radar located in Santa Clara County.

Forecasting of precipitation out to longer lead times is called Quantitative Precipitation Forecasting (QPF) which involves numerical predictions modeling (NWP) of the atmosphere. The main NWP model for AQPI is the so-called High Resolution Rapid Refresh (HRRR, https://rapidrefresh.noaa.gov/hrrr/)

model. The HRRR is a NOAA real-time 3-km resolution, hourly updated, cloud-resolving, convection-allowing atmospheric model, initialized by 3km grids with 3km radar assimilation. Radar data is assimilated in the HRRR every 15 min over a 1-h period adding further detail to that provided by the hourly data assimilation from the 13km radar-enhanced Rapid Refresh. Recent development of an ensemble version of the HRRR, called HRRRE, seeks to improve 0-12 hr high-resolution forecasts through ensemble-based, multi-scale data assimilation; there continues testing of ensemble-design concepts for 0-36 hr forecasts. English et al (2018) described HRRR development for the SF Bay area.

b) Reservoir operations

Reservoir capture of flood flows and other water management actions have been identified as a significant factor in the accuracy of the NWM. The NWM does not represent reservoir operations, except for some reservoirs it performs a level pool routing procedure. The NWM does not represent diversions of other water management actions. As shown herein, a large amount of reservoir storage in a basin will greatly influence model performance. Lesser amounts of storage have corresponding lesser effects so that there is useful value in the NWM forecasts downstream from reservoir in these basins. Given the generally good to excellent performance of the NWM for unregulated basins, then the NWM forecasts of tributary inflows into reservoirs should have value to reservoir operators. To represent reservoir operations requires supplementary modeling of the reservoir. Kim et al (2019) demonstrated linkage of NWM generated flows with the ResSim model of Lake Mendota in the upper Russian River basin. A case study involving interfacing of NWM forecasts with the Santa Clara County Coyote and Guadalupe Rivers operations model is on-going.

Review and Feedback:

Given this NWM baseline assessment and the (forthcoming) companion forecast assessment, it is intended that flood and other water management agencies review these to confirm that the data presented is correct and that the performance characterization is appropriate. This could provide a foundation for “believability” by users.

Previous activities directed to review of the distributed hydrologic modeling approach were conducted to guide design of the AQPI tributary hydrologic modeling (Johnson et al 2016, Herdman et al 2018). Simulation of the watersheds allowed portrayal of forecast flood hydrographs, peak flows and their frequency equivalent (e.g. 1 % or 100-year recurrence level), soil moisture levels, and built facilities at risk (e.g. bridge crossings) for any location. All of these products were rated Very Useful by survey respondents. However, some asked about river stage and inundation mapping; inundation mapping for tributaries is not expected for initial rollout of the AQPI system. Inundation mapping is the emphasis for the coastal hydrodynamic model of the SF Bay and the tributary estuaries.

What’s Next

Forecast Assessment: A follow on assessment will be conducted to determine how well the NWM does in forecast mode. Note the retrospective assessment was a comparative exercise and did not involve forecasts.

Real-Time Operations: The AQPI prototype will be deployed for real-time operations for the upcoming winter storm season 2019-2020. This will provide opportunity for users to access the hydrologic forecasts and consider how to incorporate these into their flood mitigation and water management operations. Some jurisdictions are requesting watershed-specific precipitation accumulation products to fit with their current flash flood alerting tools; this is being done.

Collaboration for AQPI Hydrologic Assessment

This report is intended to support reflective assessment with prospective users of the NWM products to determine its usability and believability. Involved staff are associated with the various county-level flood and water management agencies; detailed listing of these staff is listed in Appendix B. Reflective assessment involves polling users' opinions about the various NWM performance.

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AGU & AMS papers and posters.

APPENDIX A: USGS GAGES-II BASIN CHARACTERISTICS

BASIN ID:

- BasinID STAID Gage ID
- BasinID STANAME Station Name
- BasinID DRAIN_SQKM Watershed drainage area, sq km, as delineated in our basin boundary
- BasinID HUC02 NHDPlus Water Resources Region (HUC2; 01 = New England, 02 = Mid-Atlantic, etc.) in which the basin is contained.
- BasinID LAT_GAGE Latitude at gage, decimal degrees
- BasinID LNG_GAGE Longitude at gage, decimal degrees
- BasinID STATE State at gage location
- BasinID COUNTYNAME_SITE Name of the county at gage location

BASIN_CLASSIFICATION:

- Bas_Classif HYDRO_DISTURB_INDX Hydrologic "disturbance index" score, based on 7 variables: 1) MAJ_DDENS_2009, 2) WATER_WITHDR, 3) change in dam storage 1950-2009, 4) CANALS_PCT, 5) RAW_DIS_NEAREST_MAJ_NPDES, 6) ROADS_KM_SQ_KM, and 7) FRAGUN_BASIN. Low values = low anthropogenic hydrologic modification in the watershed, high values = high anthropogenic hydologic modification

HYDROMOD_DAMS:

- HydroMod_Dams NDAMS_2009 Number of dams in watershed, from our enhanced version of the 2009 National Inventory of Dams (NID), created in December 2010. See note.
- HydroMod_Dams STOR_NID_2009 Dam storage in watershed ("NID_STORAGE"); megaliters total storage per sq km (1 megaliters = 1,000,000 liters = 1,000 cubic meters). Also see note to the right.
- HydroMod_Dams MAJ_NDAMS_2009 Number of "major" dams in watershed. Major dams defined as being >= 50 feet in height (15m) or having storage >= 5,000 acre feet (National Atlas definition)

CLIMATE:

- Climate PPTAVG_BASIN Mean annual precip (cm) for the watershed, from 800m PRISM data. 30 years period of record 1971-2000.

SOILS:

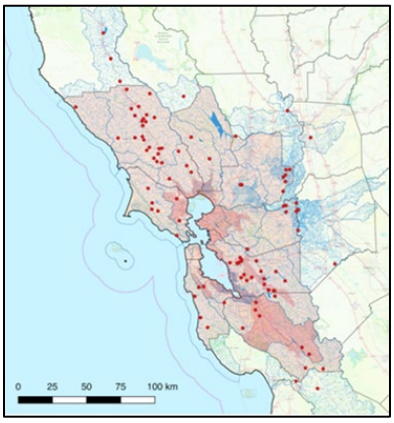
- Soils HGA Percentage of soils in hydrologic group A. Hydrologic group A soils have high infiltration rates. Soils are deep and well drained and, typically, have high sand and gravel content.
- Soils HGB Percentage of soils in hydrologic group B. Hydrologic group B soils have moderate infiltration rates. Soils are moderately deep, moderately well drained, and moderately coarse in texture.
- Soils HGC Percentage of soils in hydrologic group C. Hydrologic group C soils have slow soil inflitration rates. The soil profiles include layers impeding downward movement of water and, typically, have moderately fine or fine texture.
- Soils HGD Percentage of soils in hydrologic group D. Hydrologic group D soils have very slow infiltration rates. Soils are clayey, have a high water table, or have a shallow impervious layer.

TOPO:

- Topo ELEV_MEAN_M_BASIN Mean watershed elevation (meters) from 100m National Elevation Dataset

- Topo ELEV_SITE_M Elevation at gage location (meters) from 100m National Elevation Dataset
- Topo SLOPE_PCT Mean watershed slope, percent. Derived from 100m resolution National Elevation Dataset, so slope values may differ from those calculated from data of other resolutions.

APPENDIX B – SUMMARY OF HAT PERFORMANCE RANKNG PROCEDURE



Background

Hydrologic models can be used for both planning and operational purposes. In order to establish confidence in a hydrologic model, it is important to know how the model performs in the regions of concern to the user. The hydrologic model being used for the AQPI project is the National Water Model (NWM, https://water.noaa.gov/). There are many ways to evaluate a hydrologic model, depending on the user needs (e.g., peak flow, time to peak). A variety of performance metrics can be generated to quantify overall skill. The metrics are designed to assess a particular aspects of model performance and interpretation of the results can be confusing for people who are not experts in hydrologic analysis. To facilitate interpretation of results and minimize confusion, NOAA has developed the Hydrologic Assessment Tool (HAT) to help evaluate NWM performance. The HAT uses a combination of machine learning and clustering analysis to provide an assessment of NWM performance divided into 4 categories: unsatisfactory (US), satisfactory (S), good (G), and very good (VG).

Objectives

- Develop a hydrological assessment tool (HAT) to rate performance of the NWM with understandable terms.
- Assess the NWM retrospective simulations for flood events using the HAT and summarize the results.

Motivation of AQPI-HAT for Flood Mitigation and Water Management Programs in the SF Bay Area

San Francisco Bay is a highly urbanized estuary and the surrounding communities are susceptible to flooding in inland rivers and creeks that drain to the Bay, and along the Bay shoreline. The AQPI integrated forecast system is intended to forecast flooding in the SF Bay tributaries and estuaries. Flood mitigation and water management agencies require stream flow forecasts to support decisions on emergency resource deployments and infrastructure management.

AQPI HAT Application

To provide forecasters, water managers, and other stakeholders with information on the NWM assessment in understandable terms, the NOAA AQPI Team has developed the HAT and its application in the SF Bay area. This case study focuses on the NWM retrospective simulation which is based on observed precipitation data for the period October 2013 to January 2017. The HAT employs a hybrid machine learning framework based on a combination of clustering and classification techniques and a composite of error metrics. Details are provided in the reference cited below. To train the HAT procedure, NWM simulated flows are compared to observed flows at selected USGS gage sites for tributaries in the SF Bay area. The performance of the HAT is then validated against NWM simulated streamflow data for storm events during February 2017.

Assessment of AQPI NWM Performance

The NWM is a distributed hydrologic model which computes the hydrologic balance on a 250 m grid, aggregates excess precipitation to a 1 km grid, and routes these flood flows using the NHD-PlusV2 stream network. The system updates to include USGS gaged flows (-3 to 0 hrs), along with three forecast configurations (short- (0 to 18 hrs; 1-hr update), medium- (0 to 10 days; 6-hr update) and long-range (0 to 30 days; 1-day update). The NWM can provide a variety of flood forecast products, including hydrographs at any location (peak flow, time-to-peak, duration of high flow), and grid displays of streamflow and soil moisture.

Application of the HAT procedure involves two main themes for a) refinement of the HAT framework and b) assessment of the NWM retrospective simulations in 2017. Results of the NWM performance assessment will be presented for selected tributaries in each of the SF Bay counties. These results will be provided to flood and water management agency staff in each county so they can judge the NWM performance assessment and consider how the model can be used to support their flood mitigation operations.

57 USGS gages were selected in this study, excluding those that observed low-quality streamflow data associated with reservoir operations and diversions. The watershed for these 57 gages varies from 11.5 to 3,425.3 km2.

This study used the NWM v.1.2 to conduct a retrospective streamflow simulation and train the HAT from October 2013 to January 2017 (total 1440 storm events were identified at the 57 USGS gages). The performance of HAT and NWM for the SF Bay area is assessed against the USGS streamflow data and an independent NWM retrospective simulation for February 2017 (total 280 storm events were identified at the 57 USGS gages).

To illustrate the HAT procedure the following figures show the various types of NWM simulation performance in comparison to USGS gage readings. Figure 1 shows a typical hydrograph with the segments highlighted for the a) rising limb, b) falling limb (or recession) and c) total hydrograph.

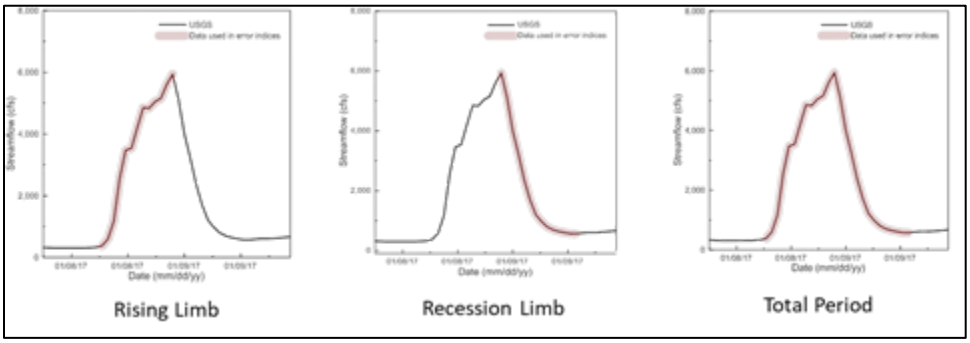


Figure 1 Illustration of hydrograph segments used for HAT procedure

Figure 2 illustrates the HAT ratings for various hydrographs. The figure represents total hydrograph and it has four rows representing each rating. Red and blue lines are the simulated and observed hydrographs respectively.

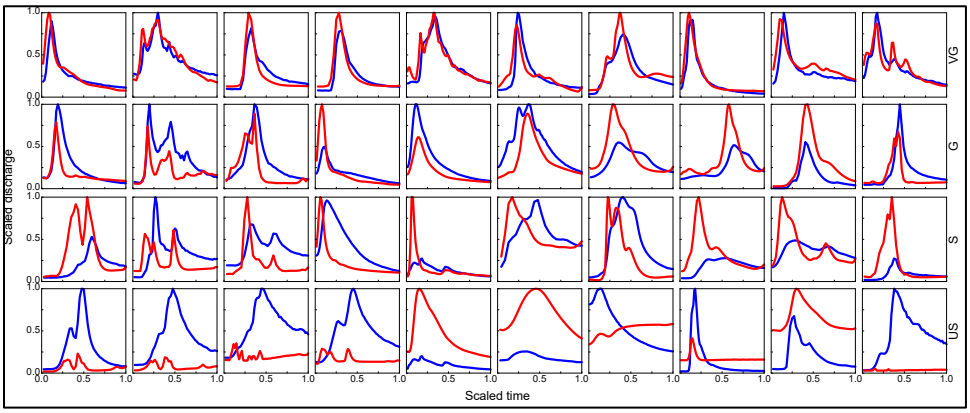


Figure 2 Illustration of hydrograph shapes characterized as a) Very Good (VG), b) Good (G), c) Satisfactory (S) and d) Unsatisfactory (US).

Figure 3 shows two examples of NWM performance per the HAT procedure for February 2017.

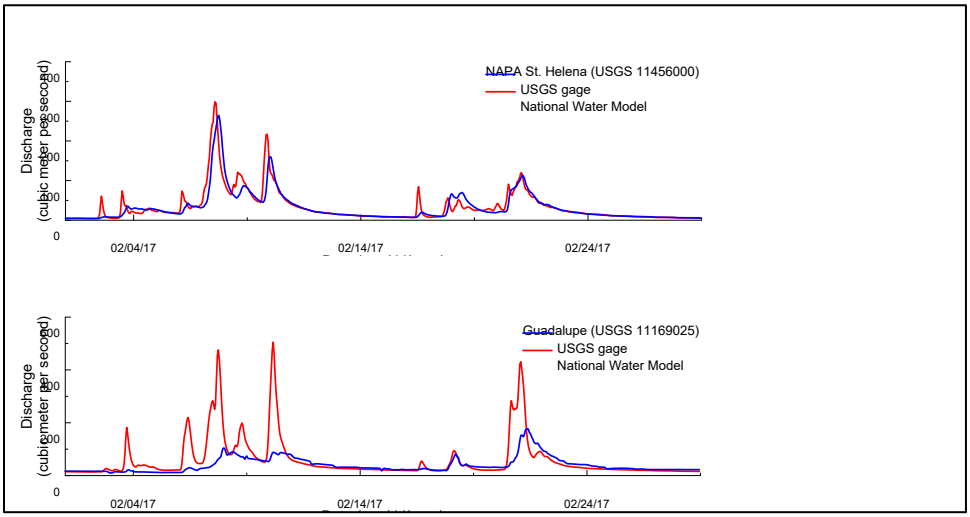


Figure 3 Two examples of NWM performance per the HAT procedure.

Figure 4 illustrates the HAT ratings for USGS gages in the AQPI region. The inserted graphs for the 6 counties show the frequency of assignment t the four categories, VG, G, S, NS.

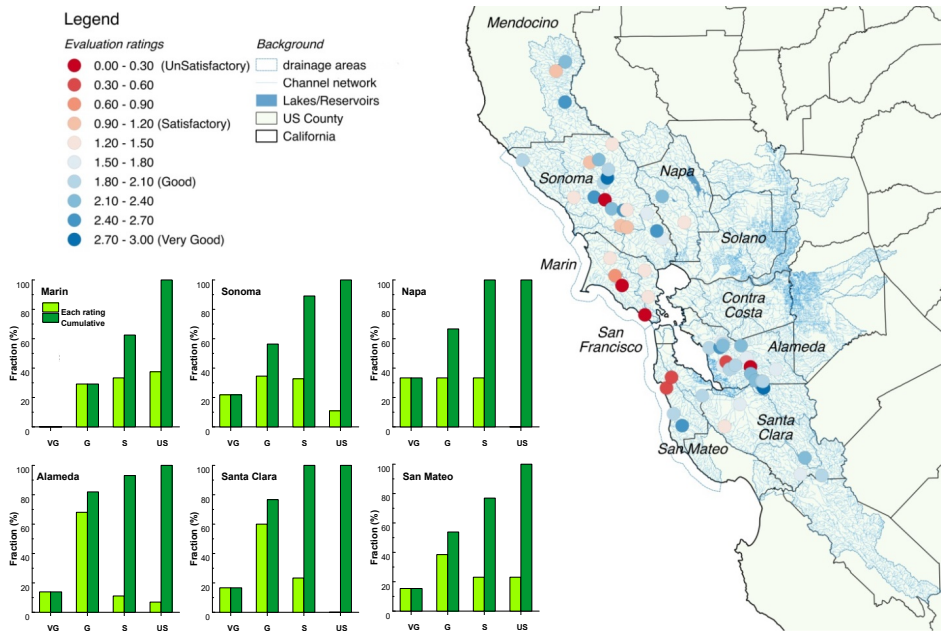


Figure 3 Two examples of NWM performance per the HAT procedure.

Detailed reporting on the NWM performance for each USGS gage are linked to this report, summarized by county.

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APPENDIX C – NWM GAGE STATION ASSESSMENT REPORTS

11162500 PESCADERO C NR PESCADERO CA

Site Description:

Pescadero Creek is a major stream in Santa Cruz and San Mateo counties in California. At 26.6 miles (42.8 km), it is the longest stream in San Mateo County and flows all year from springs in the Santa Cruz Mountains. Its source is at 1,880 feet (570 m) above sea level. It enters Pescadero Marsh Natural Preserve at Pescadero State Beach and thence to the Pacific Ocean 14.4 miles (23 km) south of Half Moon Bay.

Remarks from USGS Site Report:

Small diversions upstream from station by pumping.

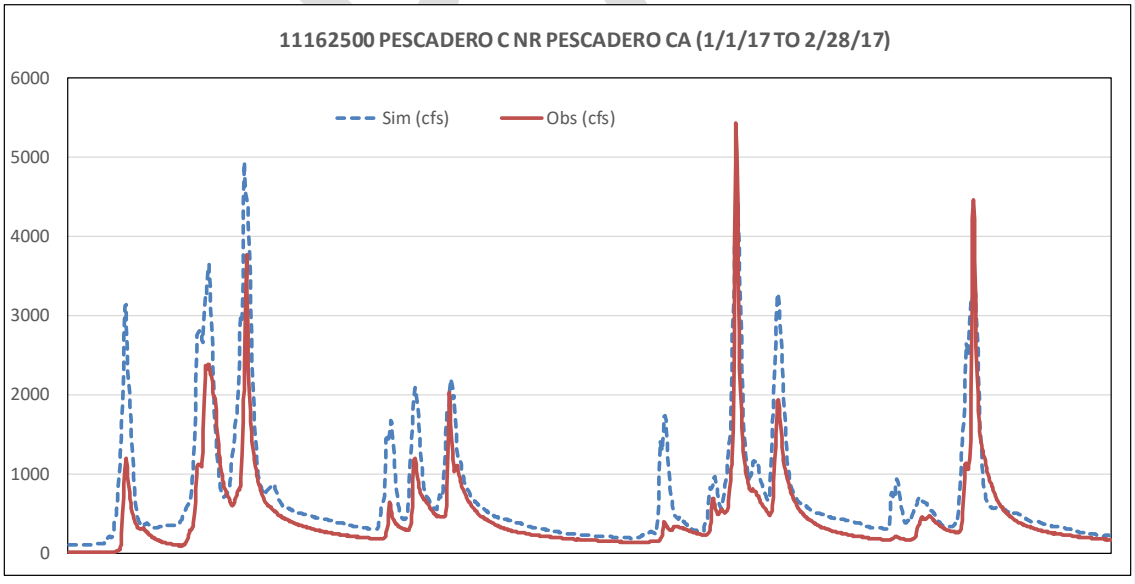
Watershed Factors:

Precipitation:	**Pavg [in] =**	36.4	**Prank =**	1.8
			NWM rainfall seems OK.	
Orography:	**ORO [%] =**	20%	**OROrank =**	2.3
		Moderate coastal orographic influence within watershed.		
Topography:	**SL [%] =**	26.7	**SLrank =**	4.3
			Steep slopes speed runoff.	
Soils:	**HGD [%] =**	22.0	**HGDrank =**	1.0
			Moderate percentage pervious soils.	
Water management:	**STOR [kaf] =**	0.0	**DISTURB =**	2.1
		No regulation, except for some small diversions.		

Assessment of NWM Performance:

The NWM simulation captures flood peaks relatively well, but over-estimates most peak flows and has relatively high bias (over-estiamted total volume).

Gage #	11162500
Gage Name	PESCADERO C NR PESCADERO CA
County	San Mateo
Area [mi^2]	45.9
CNRFC	No
Qpeak [cfs]	10600
Qpeak Year	1998
Q500 [cfs]	24892
Q200 [cfs]	21525
Q100 [cfs]	19027
Q50 [cfs]	16381
Q25 [cfs]	13799
Q10 [cfs]	10376
CC	0.87
PBias	54%
NSE	0.30
Score (1-5)	2.18
Assess	Moderate
HAT (1-3)	2.22



11162570 SAN GREGORIO C A SAN GREGORIO CA

Site Description:

The San Gregorio Creek mainstem begins at the confluence of Alpine and La Honda Creeks, whence it flows 12 miles (19 km) through rolling grasslands and pasturelands until it meets the Pacific Ocean at San Gregorio State Beach. Its tributaries originate on the western ridges of the Santa Cruz Mountains whence it courses southwest through steep forested canyons.

Remarks from USGS Site Report:

No regulation or known diversion upstream from station. Low flow affected by domestic use.

Watershed Factors:

Precipitation: **Pavg [in] =** 35.0 **Prank =** 1.6
NWM overprediction indicates less actual rain.

Orography: **ORO [%] =** 28% **OROrank =** 3.0
Moderate orographohic influence within watershed.

Topography: **SL [%] =** 22.3 **SLrank =** 3.4
Moderate slopes.

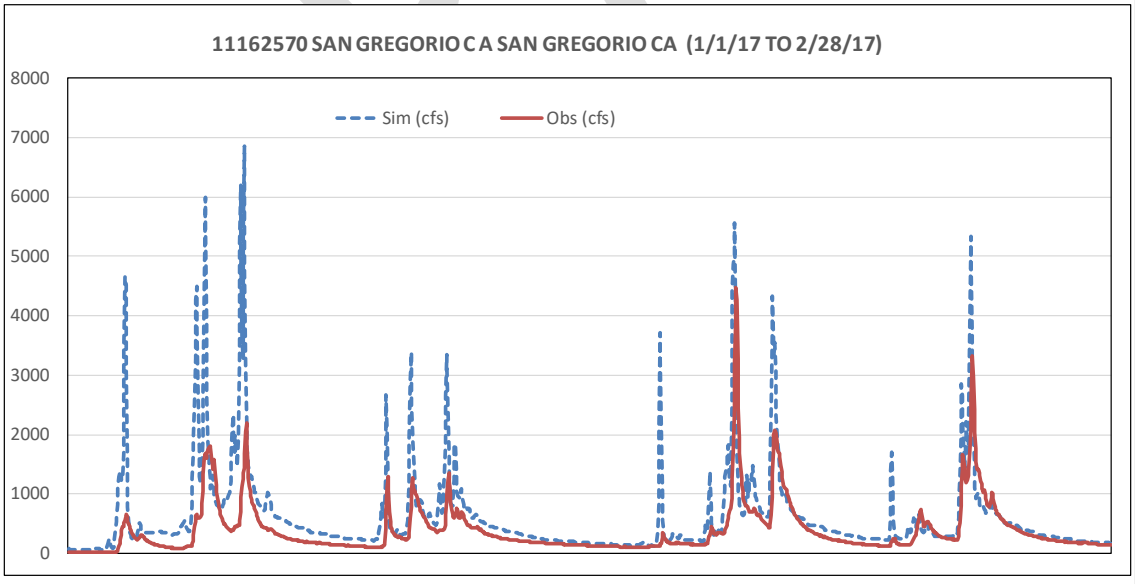
Soils: **HGD [%] =** 10.0 **HGDrank =** 0.2
Large percentage pervious soils.

Water management: **STOR [kaf] =** 0.0 **DISTURB =** 0.8
No regulation and lttle disturbance.

Assessment of NWM Performance:

The NWM simulation overpredicts flod peaks and runoff volume, perhaps due to poor rainfall (too much) and/or soil infiltration (too little).

Gage #	11162570
Gage Name	SAN GREGORIO C A SAN GREGORIO CA
County	San Mateo
Area [mi^2]	51
CNRFC	No
Qpeak [cfs]	7910
Qpeak Year	1982
Q500 [cfs]	12345
Q200 [cfs]	10544
Q100 [cfs]	9216
Q50 [cfs]	7817
Q25 [cfs]	6473
Q10 [cfs]	4727
CC	0.66
PBias	60%
NSE	-1.05
Score (1-5)	1.32
Assess	Mediocre
HAT (1-3)	1.50



11162620 PILARCITOS C BL STONE DAM NR HILLSBOROUGH CA

Site Description:

Pilarcitos Creek (Spanish for: Little Pillars or Pillaries Creek) is a 13.5-mile-long (21.7 km) coastal stream in San Mateo County, that rises on the western slopes of the Santa Cruz Mountains and descends through Pilarcitos Canyon to discharge into the Pacific Ocean Half Moon Bay State Beach.

Remarks from USGS Site Report:

Flow regulated by storage in Pilarcitos Lake, 2.6 mi upstream, capacity, 2,900 acre-ft. Water is diverted by city of San Francisco water system at Pilarcitos Lake and Stone Dam.

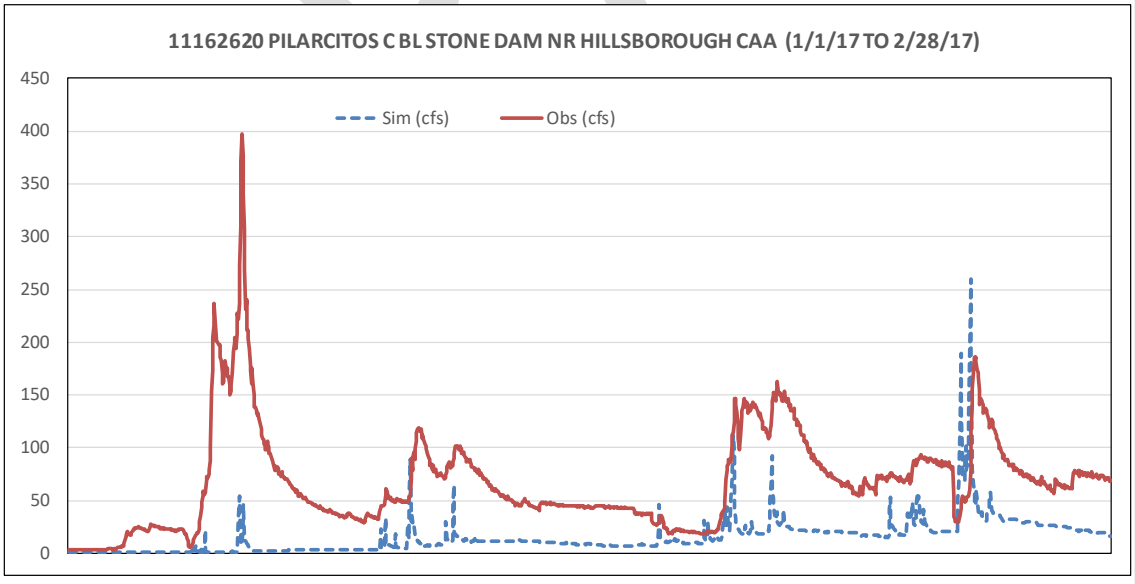
Watershed Factors:

Precipitation:	**Pavg [in] =**	41.0	**Prank =**	2.3
				NWM rainfall seems OK.
Orography:	**ORO [%] =**	8%	**ORORank =**	1.2
				Low orographic influence within watershed.
Topography:	**SL [%] =**	24.3	**SLrank =**	3.8
				Moderate slopes.
Soils:	**HGD [%] =**	17.9	**HGDrank =**	0.8
				Moderate percentage pervious soils.
Water management:	**STOR [kaf] =**	3.1	**DISTURB =**	2.5
				Reservoir regulation and out-of-basin diversions.

Assessment of NWM Performance:

The NWM simulation was poor, with a high negative Pbias. There must be something way off with the precipitation forcing for this basin, and/or the NWM representation.

Gage #	11162620
Gage Name	PILARCITOS C BL STONE DAM NR HILLSBOROUGH CA
County	San Mateo
Area [mi^2]	6.54
CNRFC	No
Qpeak [cfs]	408
Qpeak Year	2017
Q500 [cfs]	1701
Q200 [cfs]	1430
Q100 [cfs]	1232
Q50 [cfs]	1025
Q25 [cfs]	831
Q10 [cfs]	585
CC	0.27
PBias	-77%
NSE	-1.17
Score (1-5)	0.71
Assess	Poor
HAT (1-3)	0.50



11162630 PILARCITOS C A HALF MOON BAY CA

Site Description:

Pilarcitos Creek (Spanish for: Little Pillars or Pillaries Creek) is a 13.5-mile-long (21.7 km) coastal stream in San Mateo County, that rises on the western slopes of the Santa Cruz Mountains and descends through Pilarcitos Canyon to discharge into the Pacific Ocean Half Moon Bay State Beach.

Remarks from USGS Site Report:

Flow slightly regulated by storage in Pilarcitos Lake 10 mi upstream

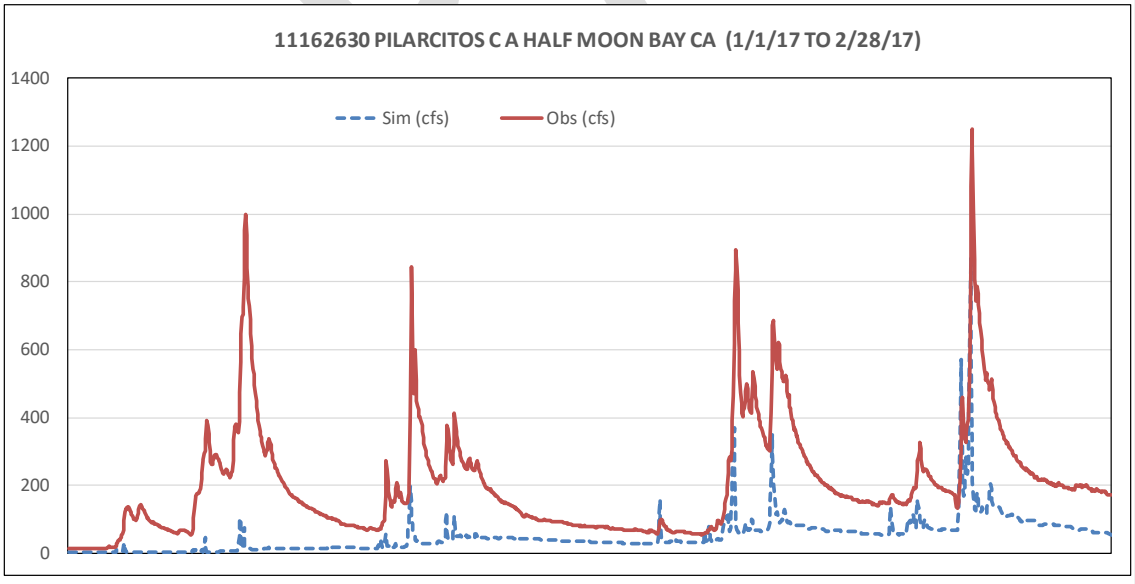
Watershed Factors:

Precipitation:	**Pavg [in] =**	45.1	**Prank =**	2.8
			NWM rainfall seems OK.	
Orography:	**ORO [%] =**	7%	**OROrank =**	1.1
		Low orographic influence within watershed.		
Topography:	**SL [%] =**	20.9	**SLrank =**	3.1
			Moderate slopes.	
Soils:	**HGD [%] =**	32.4	**HGDrank =**	1.7
			Moderate percentage pervious soils.	
Water management:	**STOR [kaf] =**	0.2	**DISTURB =**	2.3
		No regulation, except for some irrigation.		

Assessment of NWM Performance:

The NWM simulation was poor, with a high negative Pbias. There must be something way off with the precipitation forcing for this basin, and/or the NWM model representation.

Gage #	11162630
Gage Name	PILARCITOS C A HALF MOON BAY CA
County	San Mateo
Area [mi^2]	26.9
CNRFC	No
Qpeak [cfs]	4750
Qpeak Year	1982
Q500 [cfs]	6943
Q200 [cfs]	5908
Q100 [cfs]	5146
Q50 [cfs]	4344
Q25 [cfs]	3579
Q10 [cfs]	2592
CC	0.52
PBias	-74%
NSE	-0.61
Score (1-5)	0.90
Assess	1
HAT (1-3)	0.50



11164500 SAN FRANCISQUITO C A STANFORD UNIVERSITY CA

Site Description:

San Francisquito Creek is a creek that flows into southwest San Francisco Bay. San Francisquito Creek courses through the towns of Portola Valley and Woodside, as well as the cities of Menlo Park, Palo Alto, and East Palo Alto. The creek and its Los Trancos Creek tributary define the boundary between San Mateo and Santa Clara counties.

Remarks from USGS Site Report:

Flow slightly regulated by Searsville Lake, capacity, 952 acre-ft. Diversions upstream from station to Los Trancos and Lagunita Canals for irrigation on Stanford University Campus downstream from station.

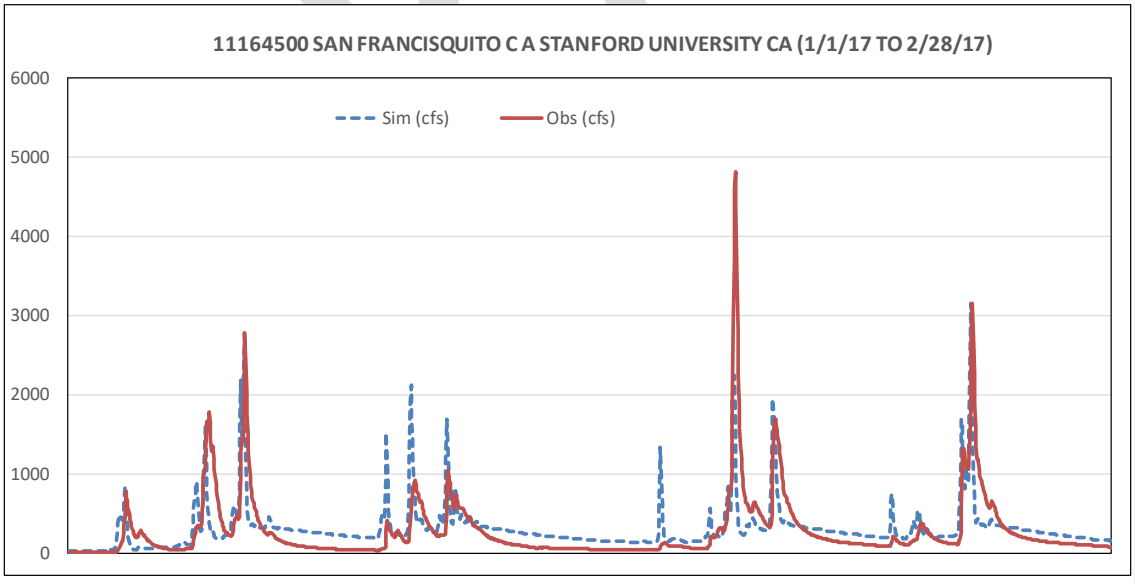
Watershed Factors:

Precipitation:	**Pavg [in] =**	33.3	**Prank =**	1.4
			Low rainfall relative to region.	
Orography:	**ORO [%] =**	68%	**OROrank =**	6.6
			High orographic influence.	
Topography:	**SL [%] =**	26.8	**SLrank =**	2.2
			Very steep slopes.	
Soils:	**HGD [%] =**	26.8	**HGDrank =**	1.3
			Low percentage impervious soils.	
Water management:	**STOR [kaf] =**	1.9	**DISTURB =**	3.5
	Low level of reservoir regulation and high disturbance (i.e. urbanization).			

Assessment of NWM Performance:

The NWM simulation tracked observed flows well overall; some smaller peaks over-estimated (storage capture).

Gage #	11164500
Gage Name	SAN FRANCISQUITO C A STANFORD UNIVERSITY CA
County	San Mateo
Area [mi^2]	37.4
CNRFC	SFCC1
Qpeak [cfs]	7200
Qpeak Year	1998
Q500 [cfs]	9334
Q200 [cfs]	7958
Q100 [cfs]	6944
Q50 [cfs]	5878
Q25 [cfs]	4856
Q10 [cfs]	3532
CC	0.67
PBias	11%
NSE	0.44
Score (1-5)	3.44
Assess	Good
HAT (1-3)	1.60



11169025 GUADALUPE R ABV HWY 101 A SAN JOSE CA

Site Description:

The Guadalupe River mainstem is an urban, northward flowing 14 miles (23 km) river in California whose much longer headwater creeks originate in the Santa Cruz Mountains. The Guadalupe River empties into south San Francisco Bay at the Alviso Slough. he Guadalupe River is the southernmost major U.S. river with a Chinook salmon run.

Remarks from USGS Site Report:

Flow regulated by Lexington Reservoir 12 mi upstream and by Calero, Almaden, and Guadalupe Reservoirs, and Lake Elsman (combined usable capacity, about 42,000 acre-ft

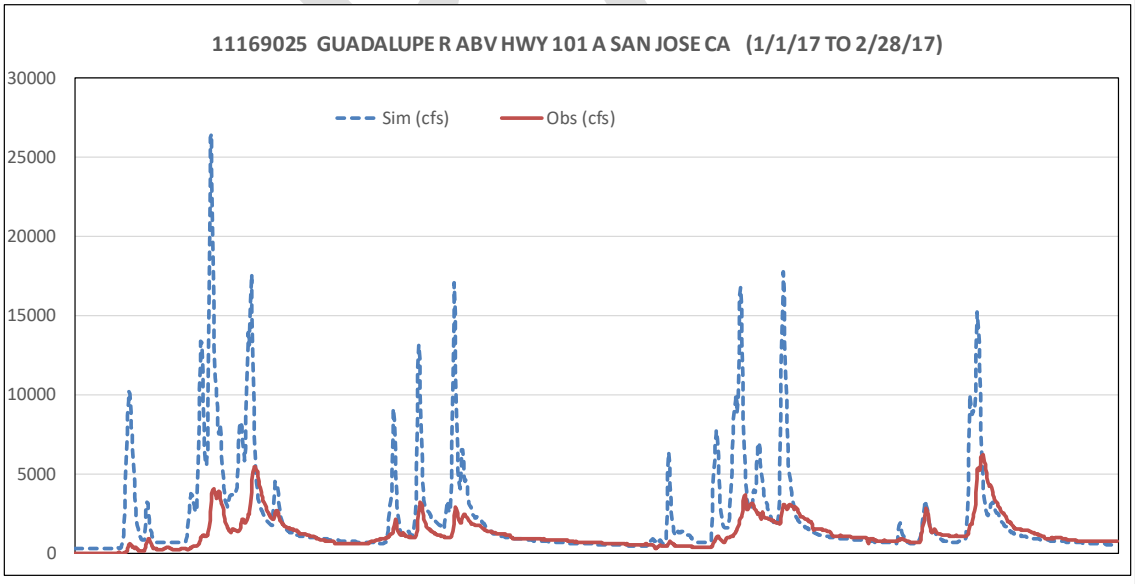
Watershed Factors:

Precipitation:	**Pavg [in] =**	30.4	**Prank =**	1.1
			Low rainfall relative to region.	
Orography:	**ORO [%] =**	101%	**OROrank =**	9.5
			Very high orographic influence.	
Topography:	**SL [%] =**	16.1	**SLrank =**	2.1
			Very steep slopes.	
Soils:	**HGD [%] =**	55.3	**HGDrank =**	3.1
			Moderate percentage impervious soils.	
Water management:	**STOR [kaf] =**	44.2	**DISTURB =**	5.0
		High level of reservoir regulation evident in observed flows.		

Assessment of NWM Performance:

The NWM simulation peak flows exceed observed flows throughout; this due to reservoir operations for flood control and water supply.

Gage #	11169500
Gage Name	GUADALUPE R ABV HWY 101 A SAN JOSE CA
County	Santa Clara
Area [mi^2]	160
CNRFC	GSJC1
Qpeak [cfs]	6070
Qpeak Year	2002
Q500 [cfs]	42304
Q200 [cfs]	36757
Q100 [cfs]	32636
Q50 [cfs]	28264
Q25 [cfs]	23966
Q10 [cfs]	18219
CC	0.54
PBias	82%
NSE	-7.88
Score (1-5)	0.72
Assess	Poor
HAT (1-3)	1.75



11169500 SARATOGA C A SARATOGA CA

Site Description:

Coyote Creek is a river draining 320 square miles (830 km2) and running 63.6 miles (102.4 km)[4] from the confluence of its East Fork and Middle Fork to southeast San Francisco Bay. The Gilroy gage site is 5.0 mi upstream from Coyote Creek Dam at the base of the Diablo Range.

Remarks from USGS Site Report:

Water is diverted for municipal use by San Jose Water Works at diversion dam 0.7 mi upstream.

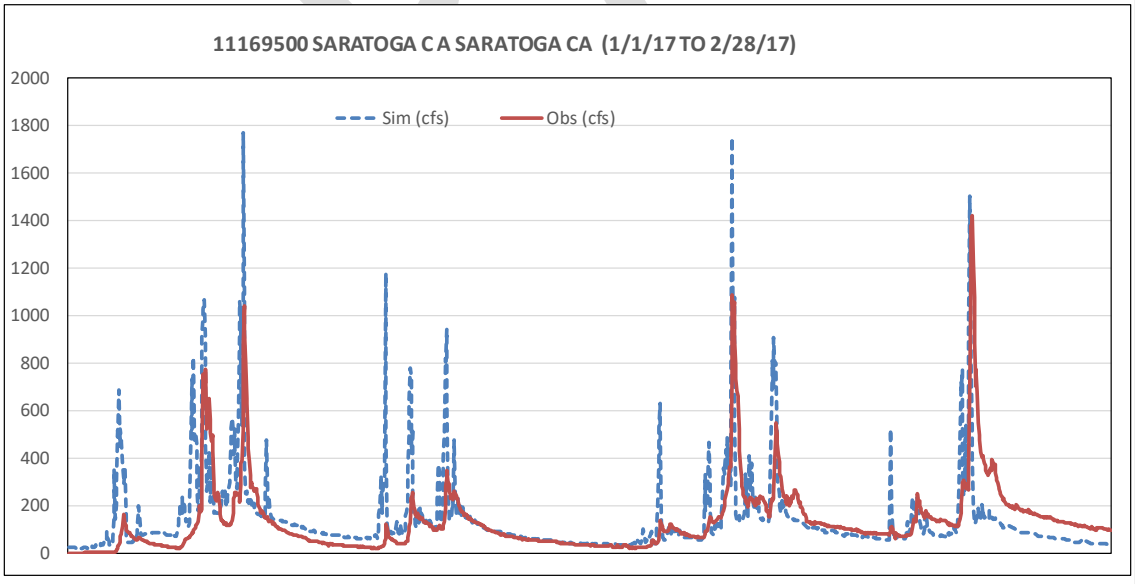
Watershed Factors:

Precipitation:	**Pavg [in] =**	42.0	**Prank =**	2.4
			Low rainfall relative to region.	
Orography:	**ORO [%] =**	30%	**OROrank =**	3.2
			Basin rain is less than at stream gage.	
Topography:	**SL [%] =**	30.2	**SLrank =**	5.0
			Steep slopes.	
Soils:	**HGD [%] =**	34.8	**HGDrank =**	1.8
			Large percentage impervious soils.	
Water management:	**STOR [kaf] =**	0.0	**DISTURB =**	0.8
Diversions evident in observed flows, not in NWM simulation nor the DISTURB index.				

Assessment of NWM Performance:

The NWM simulation peak flows exceed observed flows throughout; this due to diversions for water supply.

Gage #	11169500
Gage Name	SARATOGA C A SARATOGA CA
County	Santa Clara
Area [mi^2]	9.22
CNRFC	No
Qpeak [cfs]	2730
Qpeak Year	1955
Q500 [cfs]	2629
Q200 [cfs]	2224
Q100 [cfs]	1926
Q50 [cfs]	1615
Q25 [cfs]	1320
Q10 [cfs]	944
CC	0.56
PBias	7%
NSE	-0.04
Score (1-5)	2.60
Assess	Moderate
HAT (1-3)	1.22



11169800 COYOTE C NR GILROY CA

Site Description:

Coyote Creek is a river draining 320 square miles (830 km2) and running 63.6 miles (102.4 km)[4] from the confluence of its East Fork and Middle Fork to southeast San Francisco Bay. The Gilroy gage site is 5.0 mi upstream from Coyote Creek Dam at the base of the Diablo Range.

Remarks from USGS Site Report:

No storage or diversion upstream from station.

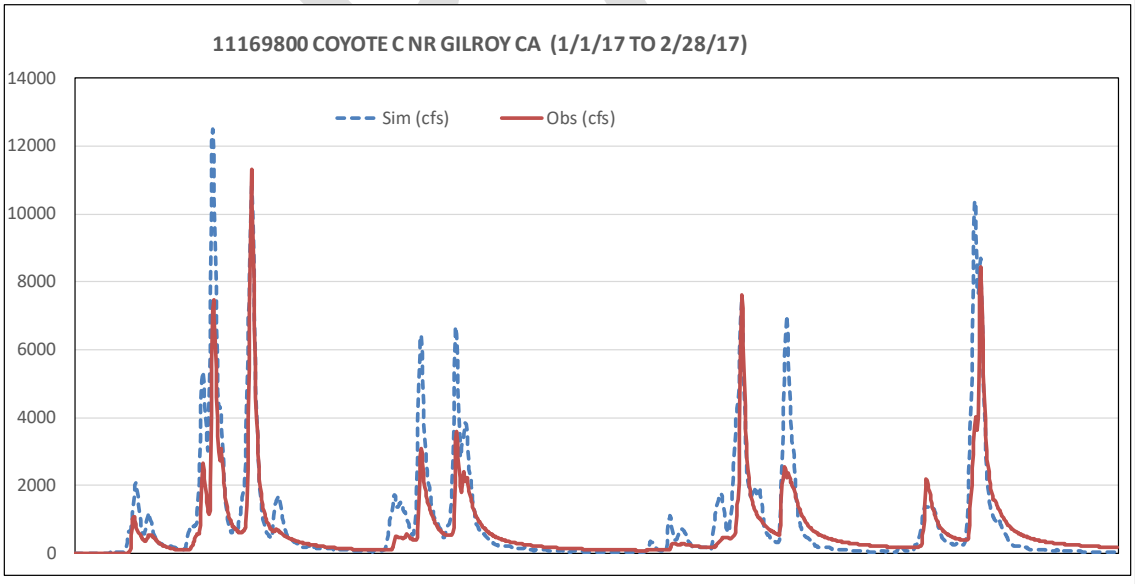
Watershed Factors:

Precipitation:	**Pavg [in] =**	24.0	**Prank =**	0.3
				Low rainfall relative to region.
Orography:	**ORO [%] =**	-3%	**OROrank =**	0.3
				Basin rain is less than at stream gage.
Topography:	**SL [%] =**	25.6	**SLrank =**	4.1
				Steep slopes.
Soils:	**HGD [%] =**	72.1	**HGDrank =**	4.2
				Large percentage impervious soils.
Water management:	**STOR [kaf] =**	0.3	**DISTURB =**	0.6
				No regulation and lttle disturbance.

Assessment of NWM Performance:

The NWM simulation moderately well with observed flows. Most peaks are over-estimated as is the total runoff volumes (Pbias). Better rainfall tracking could resolve the overprediction.

Gage #	11169800
Gage Name	COYOTE C NR GILROY CA
County	Santa Clara
Area [mi^2]	109.2
CNRFC	No
Qpeak [cfs]	11500
Qpeak Year	2017
Q500 [cfs]	20660
Q200 [cfs]	17549
Q100 [cfs]	15267
Q50 [cfs]	12871
Q25 [cfs]	10575
Q10 [cfs]	7613
CC	0.88
PBias	31%
NSE	0.41
Score (1-5)	2.98
Assess	Moderate
HAT (1-3)	2.22



11172945 ALAMEDA C AB DIV DAM NR SUNOL CA

Site Description:

Alameda Creek is the largest watershed within the southern San Francisco Bay, draining 700 square miles (1,813 square kilometers), or about 20% of the total drainage area for the south Bay. The watershed includes three man-made reservoirs: Lake Del Valle, San Antonio Reservoir and Calaveras Reservoir. This site is just above a diversion dam into Calaveras Reservoir.

Remarks from USGS Site Report:

No regulation or diversion upstream from gage

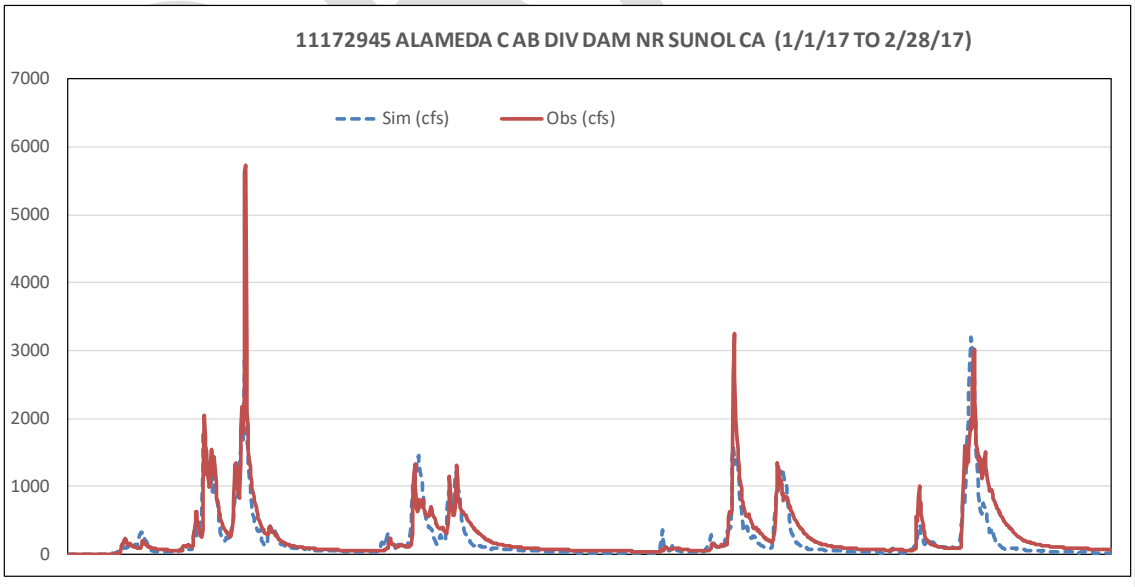
Watershed Factors:

Precipitation:	**Pavg [in] =**	24.6	**Prank =**	0.4
			Low rainfall relative to region.	
Orography:	**ORO [%] =**	-6%	**OROrank =**	0.0
			Moderate orographic influence.	
Topography:	**SL [%] =**	26.7	**SLrank =**	4.3
			Steep slopes.	
Soils:	**HGD [%] =**	65.0	**HGDrank =**	3.8
			Moderate percentage impervious soils.	
Water management:	**STOR [kaf] =**	0.0	**DISTURB =**	0.2
			No regulation.	

Assessment of NWM Performance:

The NWM simulation was rated good and almost excellent.

Gage #	11172945
Gage Name	ALAMEDA C AB DIV DAM NR SUNOL CA
County	Alameda
Area [mi^2]	33.3
CNRFC	No
Qpeak [cfs]	5730
Qpeak Year	2017
Q500 [cfs]	7089
Q200 [cfs]	5984
Q100 [cfs]	5174
Q50 [cfs]	4328
Q25 [cfs]	3525
Q10 [cfs]	2503
CC	0.88
PBias	-23%
NSE	0.75
Score (1-5)	3.87
Assess	Good
HAT (1-3)	1.41



11162570 ARROYO HONDO NR SAN JOSE CA

Site Description:

Arroyo Hondo is a northwestward-flowing 13.0-mile-long (20.9 km) river in Santa Clara County, California. The area is privately owned by the San Francisco Water Department and is closed to public access because of its usage as drinking water. Bounded to the east by Oak Ridge and to the west by Poverty Ridge, Arroyo Hondo empties into the Calaveras Reservoir where it joins Calaveras Creek.

Remarks from USGS Site Report:

No regulation or diversion upstream from station.

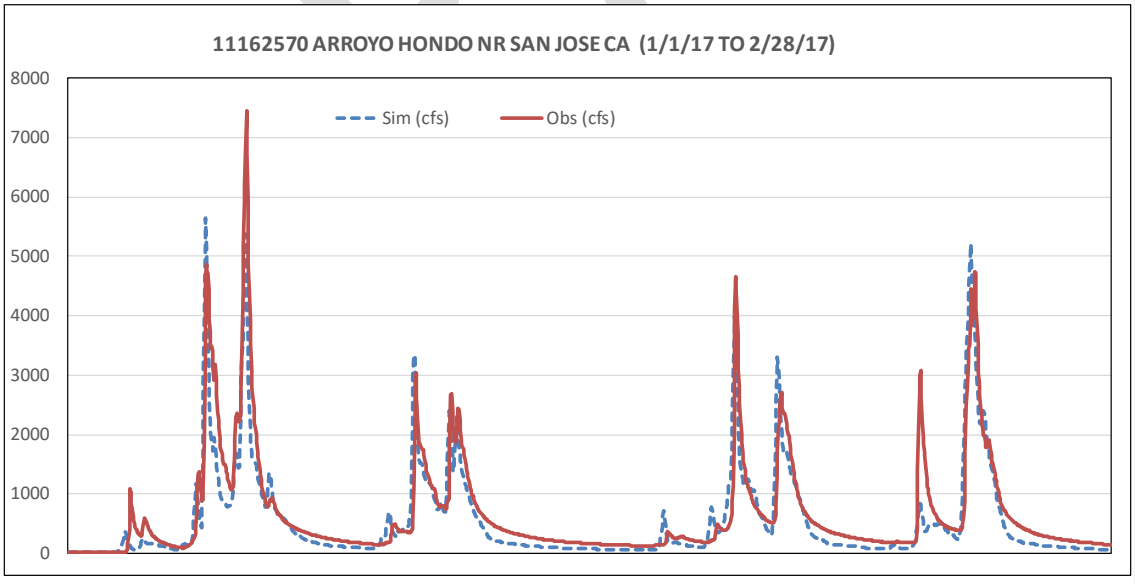
Watershed Factors:

Precipitation:	**Pavg [in] =**	24.5	**Prank =**	0.4
			Low rainfall relative to region.	
Orography:	**ORO [%] =**	-5%	**OROrank =**	0.1
			Basin rain is less than at stream gage.	
Topography:	**SL [%] =**	26.7	**SLrank =**	4.3
			Moderate to high slopes.	
Soils:	**HGD [%] =**	73.3	**HGDrank =**	4.3
			Large percentage impervious soils.	
Water management:	**STOR [kaf] =**	0.5	**DISTURB =**	0.4
			No regulation and lttle disturbance.	

Assessment of NWM Performance:

The NWM simulation ocompars closely with observations; lower Pbias indicated less rain.

Gage #	11173200
Gage Name	ARROYO HONDO NR SAN JOSE CA
County	Santa Clara
Area [mi^2]	76.9
CNRFC	No
Qpeak [cfs]	7,480
Qpeak Year	2017
Q500 [cfs]	16656
Q200 [cfs]	14197
Q100 [cfs]	12388
Q50 [cfs]	10486
Q25 [cfs]	8658
Q10 [cfs]	6288
CC	0.90
PBias	-19%
NSE	0.79
Score (1-5)	4.07
Assess	Excellent
HAT (1-3)	2.44



11173510 ALAMEDA C BL CALAVERAS C NR SUNOL CA

Site Description:

Alameda Creek is the largest watershed within the southern San Francisco Bay, draining 700 square miles (1,813 square kilometers), or about 20% of the total drainage area for the south Bay. Two-thirds of the watershed is in Alameda County including the reach through the Sunol Valley, the rest is in Santa Clara County. The watershed includes three man-made reservoirs: Lake Del Valle, San Antonio Reservoir and Calaveras Reservoir.

Remarks from USGS Site Report:

Flow regulated by Calaveras Reservoir, usable capacity, 96,800 acre-ft, 1.1 mi upstream from gage and by diversion dam on Alameda Creek, 2.9 mi upstream. Dead storage, 3,200 acre-ft. Flow is diverted out of basin from Calaveras Reservoir by city and county of San Francisco for domestic use.

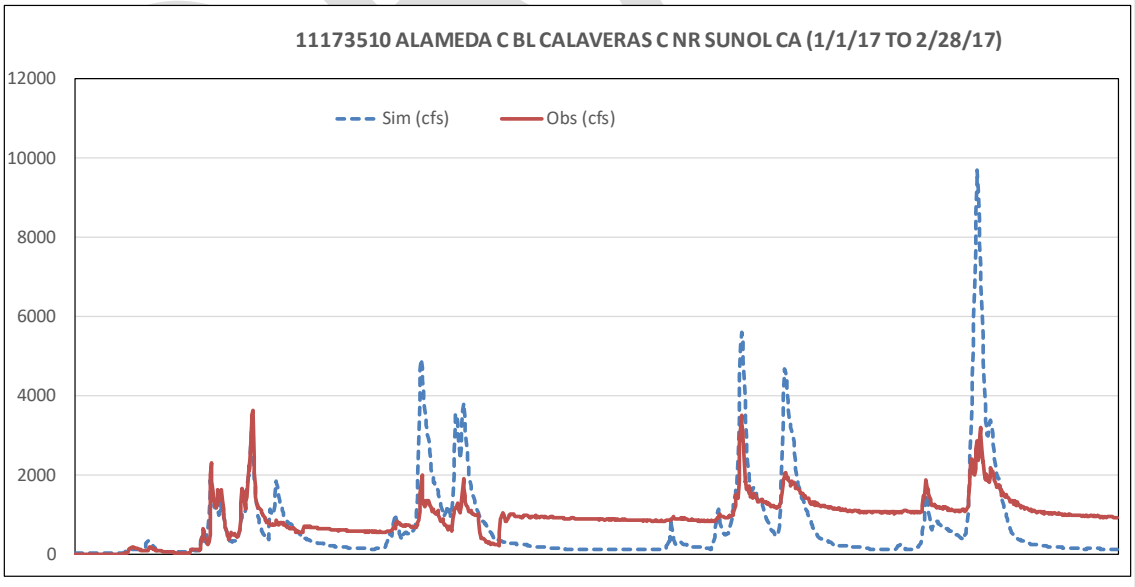
Watershed Factors:

Precipitation:	**Pavg [in] =**	24.5	**Prank =**	0.4
				Low rainfall relative to region.
Orography:	**ORO [%] =**	9%	**ORORank =**	1.3
				Moderate orographic influence.
Topography:	**SL [%] =**	25.7	**SLrank =**	4.1
				Steep slopes.
Soils:	**HGD [%] =**	69.2	**HGDrank =**	4.0
				Moderate percentage impervious soils.
Water management:	**STOR [kaf] =**	100.5	**DISTURB =**	2.9
				Reservoir regulation and diversions.

Assessment of NWM Performance:

The NWM simulation was rated moderate, but reservoir regu;lation is evident with observed peak flows lower than NWM and low flows higher.

Gage #	11173510
Gage Name	ALAMEDA C BL CALAVERAS C NR SUNOL CA
County	Alameda
Area [mi^2]	139.0
CNRFC	No
Qpeak [cfs]	5220
Qpeak Year	2017
Q500 [cfs]	37483
Q200 [cfs]	32554
Q100 [cfs]	28892
Q50 [cfs]	25008
Q25 [cfs]	21193
Q10 [cfs]	16097
CC	0.68
PBias	-24%
NSE	-1.99
Score (1-5)	2.25
Assess	Moderate
HAT (1-3)	1.61



11173575 ALAMEDA C BL WELCH C NR SUNOL CA

Site Description:

Alameda Creek is the largest watershed within the southern San Francisco Bay, draining 700 square miles (1,813 square kilometers), or about 20% of the total drainage area for the south Bay. Two-thirds of the watershed is in Alameda County including the reach through the Sunol Valley, the rest is in Santa Clara County. The watershed includes three man-made reservoirs: Lake Del Valle, San Antonio Reservoir and Calaveras Reservoir.

Remarks from USGS Site Report:

Flow regulated by Calaveras Reservoir, usable capacity, 96,800 acre-ft, 3.7 mi upstream from gage and by diversion dam on Alameda Creek, 5.5 mi upstream. Flow is diverted out of basin from Calaveras Reservoir by city and county of San Francisco for domestic use.

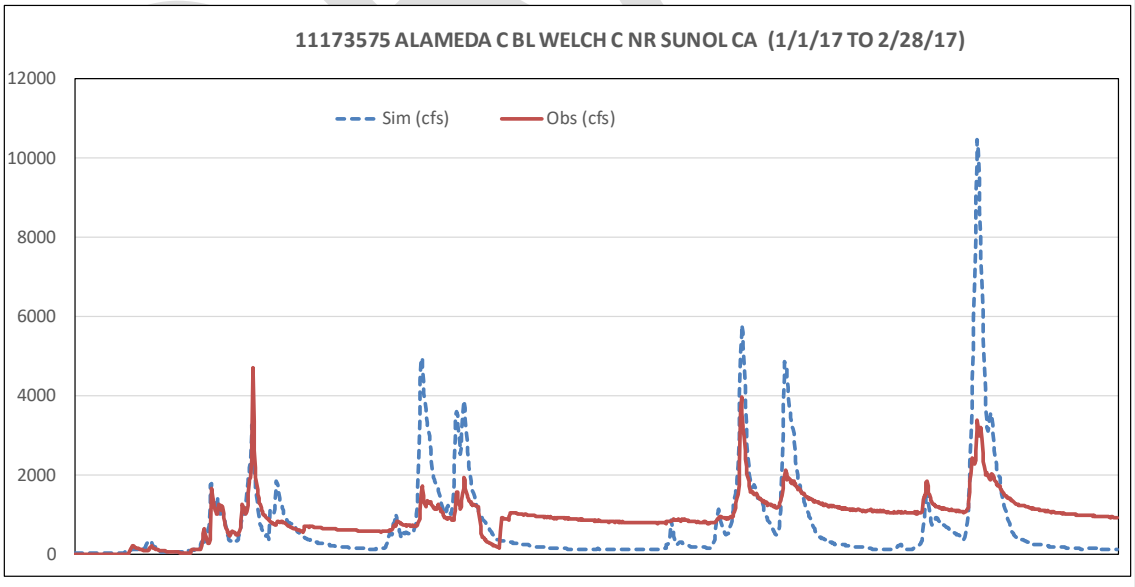
Watershed Factors:

Precipitation:	**Pavg [in] =**	24.5	**Prank =**	0.4
				Low rainfall relative to region.
Orography:	**ORO [%] =**	17%	**ORORank =**	2.1
				Moderate orographic influence.
Topography:	**SL [%] =**	25.8	**SLrank =**	4.1
				Steep slopes.
Soils:	**HGD [%] =**	68.8	**HGDrank =**	4.0
				Moderate percentage impervious soils.
Water management:	**STOR [kaf] =**	100.5	**DISTURB =**	2.9
				Reservoir regulation and diversions.

Assessment of NWM Performance:

The NWM simulation was rated moderate, but reservoir regu;lation is evident with observed peak flows lower than NWM and low flows higher.

Gage #	11173575
Gage Name	ALAMEDA C BL WELCH C NR SUNOL CA
County	Alameda
Area [mi^2]	149.0
CNRFC	No
Qpeak [cfs]	5750
Qpeak Year	2002
Q500 [cfs]	39790
Q200 [cfs]	34566
Q100 [cfs]	30684
Q50 [cfs]	26566
Q25 [cfs]	22519
Q10 [cfs]	17112
CC	0.72
PBias	-22%
NSE	-1.88
Score (1-5)	2.32
Assess	Moderate
HAT (1-3)	1.48



11174000 SAN ANTONIO C NR SUNOL CA

Site Description:

San Antonio Creek is a 24.4-kilometre-long (15.2 mi)northwesterly-flowing stream originating on the eastern edge of Santa Clara County just west of its border with Stanislaus County. It arises at 3,177 feet (968 m) on the southwest slopes of Mount Stakes and descends into the San Antonio Valley. Its confluence with Arroyo Bayo[6] forms the source of Arroyo Valle. Arroyo Valle proceeds through Lake Del Valle to join Arroyo de la Laguna thence to Alameda Creek and finally terminates in San Francisco Bay.

Remarks from USGS Site Report:

Flows regulated by Lake San Antonio located 0.6 mi upstream of gage.

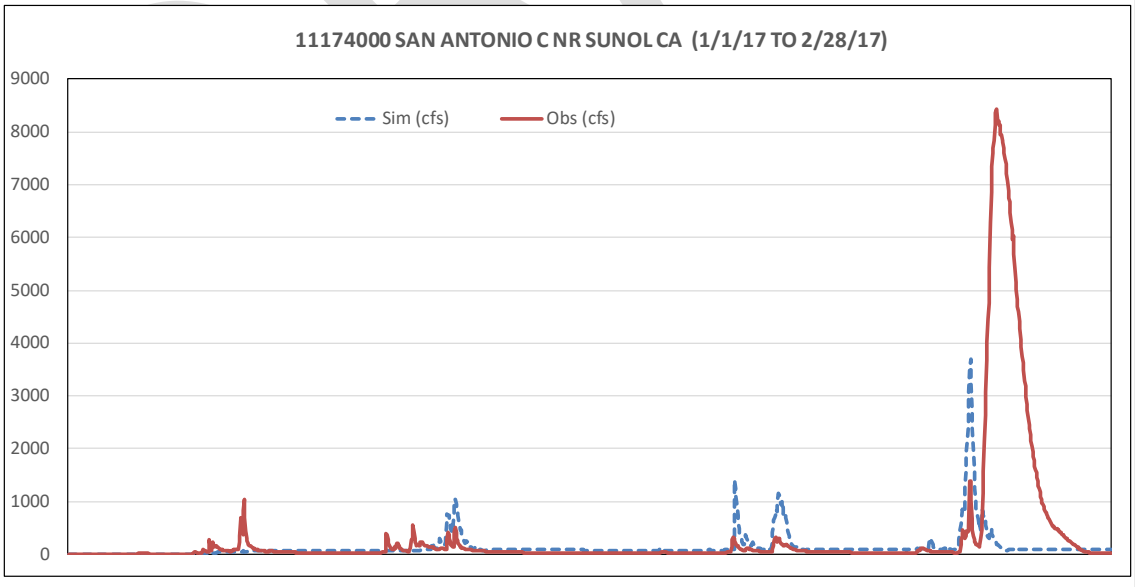
Watershed Factors:

Precipitation:	**Pavg [in] =**	22.7	**Prank =**	0.2
			Low rainfall relative to region.	
Orography:	**ORO [%] =**	28%	**OROrank =**	3.0
			Moderate orographic influence.	
Topography:	**SL [%] =**	21.9	**SLrank =**	3.3
			Moderate slopes.	
Soils:	**HGD [%] =**	68.7	**HGDrank =**	4.0
			Moderate percentage impervious soils.	
Water management:	**STOR [kaf] =**	50.5	**DISTURB =**	4.0
			No regulation and little disturbance.	

Assessment of NWM Performance:

The NWM simulation was mediocre with very poor NSE and Pbias; undoubtedly due to reservoir regulation and other water management.

Gage #	11174000
Gage Name	SAN ANTONIO C NR SUNOL CA
County	Alameda
Area [mi^2]	37.0
CNRFC	ACSC1
Qpeak [cfs]	624
Qpeak Year	2017
Q500 [cfs]	12009
Q200 [cfs]	10388
Q100 [cfs]	9183
Q50 [cfs]	7907
Q25 [cfs]	6665
Q10 [cfs]	5022
CC	0.09
PBias	-61%
NSE	-0.04
Score (1-5)	1.03
Assess	Mediocre
HAT (1-3)	0.00



AQPI
Advanced Quantitative Precipitation Information

11174600 ALAMO CN NR PLEASANTON CA

Site Description:

Alamo Canal is located .3 mi upstream from confluence with Arroyo Mocho, and 3.3 mi northwest of Pleasanton. It channels drainage from Alamo Creek through urbanized area. Arroyo Mocho is a tributary to Alameda Creek, the reach extending upstream from the confluence with Arroyo de la Laguna through the Livermore-Amador Valley and into unincorporated ranch and agricultural lands.

Remarks from USGS Site Report:

No regulation or large diversions upstream.

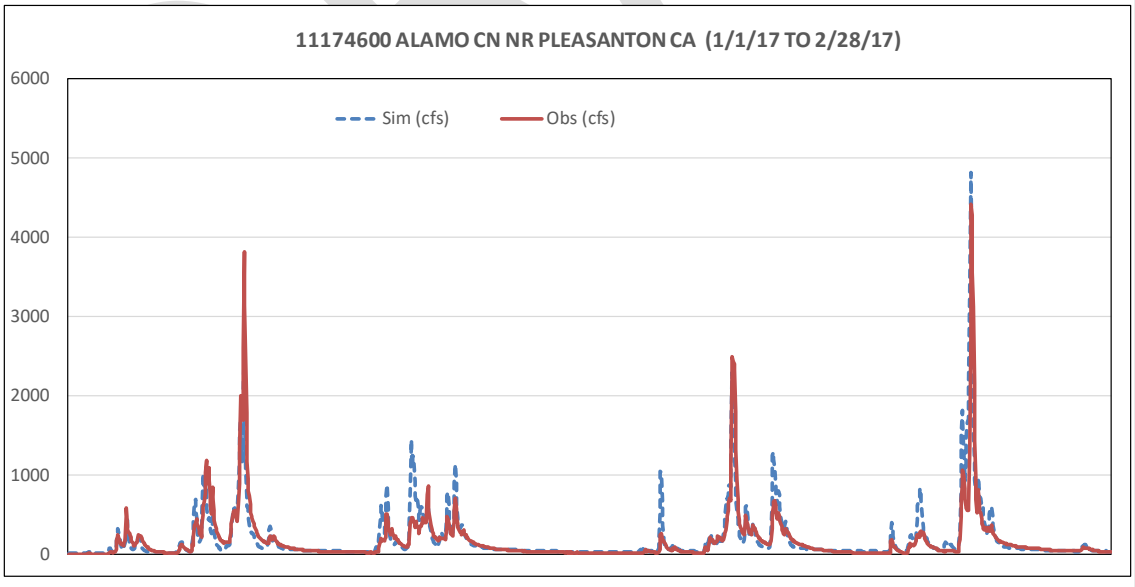
Watershed Factors:

Precipitation:	**Pavg [in] =**	22.6	**Prank =**	0.2
			Low rainfall relative to region.	
Orography:	**ORO [%] =**	28%	**OROrank =**	3.0
			Moderate orographic influence.	
Topography:	**SL [%] =**	21.9	**SLrank =**	3.3
			Moderate slopes.	
Soils:	**HGD [%] =**	68.7	**HGDrank =**	4.0
			Moderate percentage impervious soils.	
Water management:	**STOR [kaf] =**	0.0	**DISTURB =**	0.2
			No regulation and little disturbance.	

Assessment of NWM Performance:

The NWM simulation was excellent with high CC and NSE, and low Pbias.

Gage #	11174600
Gage Name	ALAMO CN NR PLEASANTON CA
County	Alameda
Area [mi^2]	39.5
CNRFC	No
Qpeak [cfs]	4480
Qpeak Year	2017
Q500 [cfs]	8381
Q200 [cfs]	7086
Q100 [cfs]	6137
Q50 [cfs]	5143
Q25 [cfs]	4199
Q10 [cfs]	2992
CC	0.86
PBias	7%
NSE	0.73
Score (1-5)	4.21
Assess	Excellent
HAT (1-3)	2.02



11176500 ARROYO VALLE NR LIVERMORE CA

Site Description:

Remarks from USGS Site Report:

Flows regulated by Lake San Antonio located 0.6 mi upstream of gage

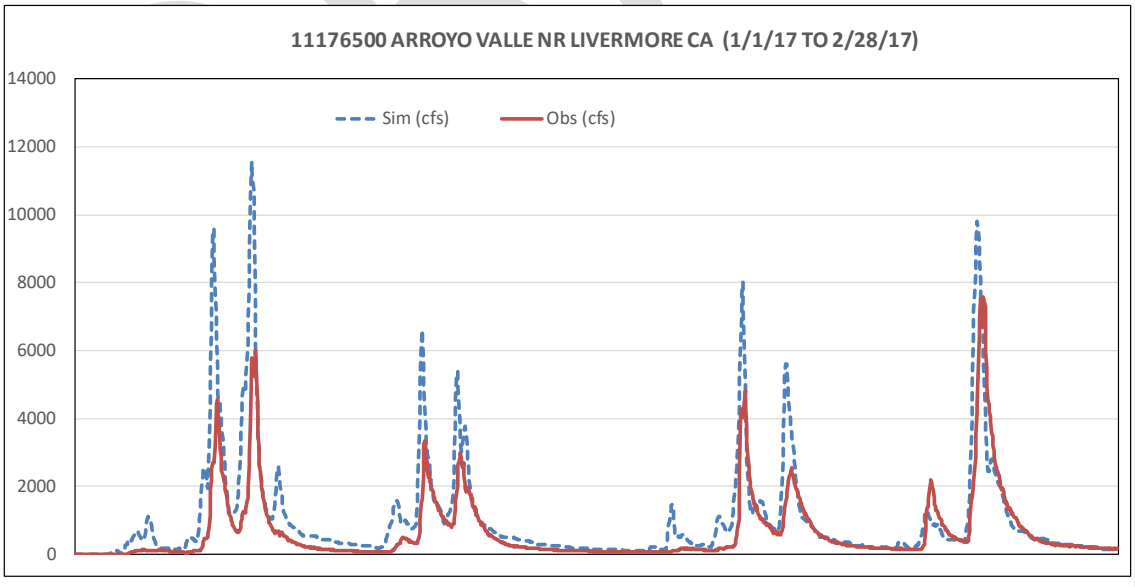
Watershed Factors:

Precipitation:	**Pavg [in] =**	22.0	**Prank =**	0.1
			Low rainfall relative to region.	
Orography:	**ORO [%] =**	-6%	**OROrank =**	0.0
			Low orographic influence.	
Topography:	**SL [%] =**	19.0	**SLrank =**	2.7
			Moderate slopes.	
Soils:	**HGD [%] =**	67.9	**HGDrank =**	4.0
			Moderate percentage impervious soils.	
Water management:	**STOR [kaf] =**	228.0	**DISTURB =**	4.6
			High level of regulation at lower end of watershed.	

Assessment of NWM Performance:

The NWM simulation was mediocre with very poor NSE and Pbias; undoubtedly due to reservoir regulation and other water management.

Gage #	11176500
Gage Name	ARROYO VALLE NR LIVERMORE CA
County	Alameda
Area [mi^2]	147.0
CNRFC	No
Qpeak [cfs]	12200
Qpeak Year	1958
Q500 [cfs]	39331
Q200 [cfs]	34165
Q100 [cfs]	30327
Q50 [cfs]	26255
Q25 [cfs]	22255
Q10 [cfs]	16910
CC	0.82
PBias	56%
NSE	0.04
Score (1-5)	1.59
Assess	Mediocre
HAT (1-3)	1.04



11176900 ARROYO DE LA LAGUNA A VERONA CA

Site Description:

Arroyo de la Laguna is a 7.5-mile-long (12.1 km) southward-flowing stream in Alameda County, which originates at the confluences of South San Ramon Creek and Arroyo Mocho. The Arroyo de la Laguna is fed by tributaries in the Amador Valley and certain eastern slope drainages of the Diablo Range; these tributaries include Arroyo Valle and Sinbad Creek. Arroyo del la Laguna is the major tributary to Alameda Creek which in turn flows into the San Francisco Bay.

Remarks from USGS Site Report:

Flow partly regulated by Del Valle Reservoir 14 mi upstream, beginning in September 1968, capacity, 77,100 acre-ft. Water imported from Sacramento-San Joaquin Delta.

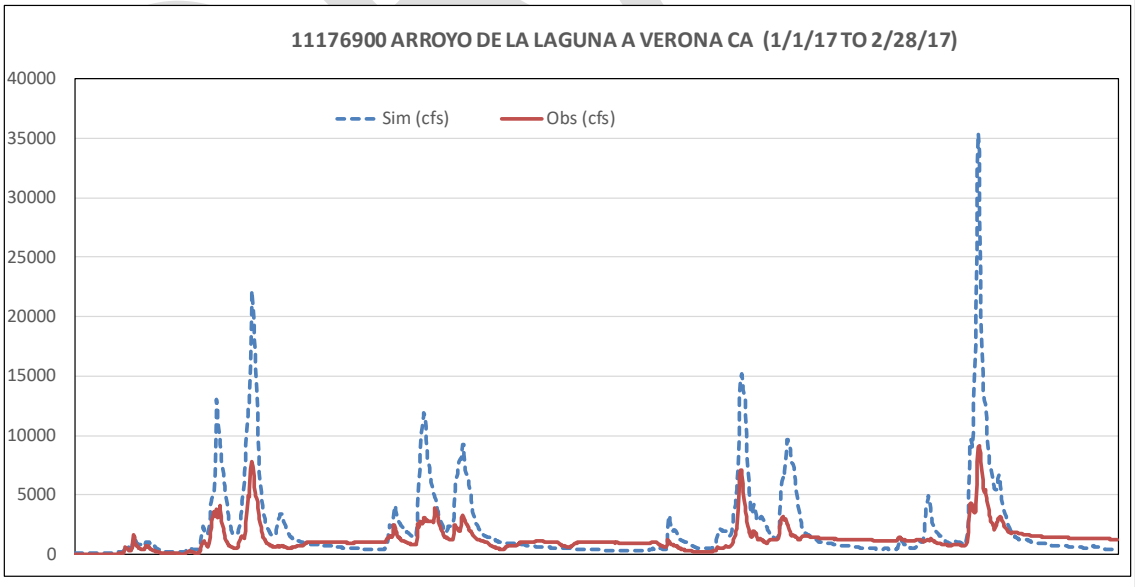
Watershed Factors:

Precipitation:	**Pavg [in] =**	22.6	**Prank =**	0.2
			Low rainfall relative to region.	
Orography:	**ORO [%] =**	-4%	**OROrank =**	0.2
			Low orographic influence.	
Topography:	**SL [%] =**	23.4	**SLrank =**	3.6
			Moderate slopes.	
Soils:	**HGD [%] =**	78.0	**HGDrank =**	4.6
			Moderate percentage impervious soils.	
Water management:	**STOR [kaf] =**	228.0	**DISTURB =**	4.6
			High level of regulation at lower end of watershed.	

Assessment of NWM Performance:

The NWM simulation was mediocre with very poor NSE and Pbias; undoubtedly due to reservoir regulation and other water management.

Gage #	11176900
Gage Name	ARROYO DE LA LAGUNA A VERONA CA
County	Alameda
Area [mi^2]	403.0
CNRFC	ADLC1
Qpeak [cfs]	11400
Qpeak Year	1982
Q500 [cfs]	93627
Q200 [cfs]	81576
Q100 [cfs]	72631
Q50 [cfs]	63134
Q25 [cfs]	53731
Q10 [cfs]	41074
CC	0.89
PBias	70%
NSE	-5.03
Score (1-5)	1.20
Assess	Mediocre
HAT (1-3)	1.11



11179000 ALAMEDA C NR NILES CA

Site Description:

Alameda Creek (Spanish: Arroyo de la Alameda) is the largest watershed within the southern San Francisco Bay, draining 700 square miles (1,813 square kilometers), or about 20% of the total drainage area for the south Bay.The creek runs for 45 miles (72 km) from a lake northeast of Packard Ridge to the eastern shore of San Francisco Bay by way of Niles Canyon and a flood control channel.

Remarks from USGS Site Report:

Flow partly regulated by Del Valle Reservoir 14 mi upstream

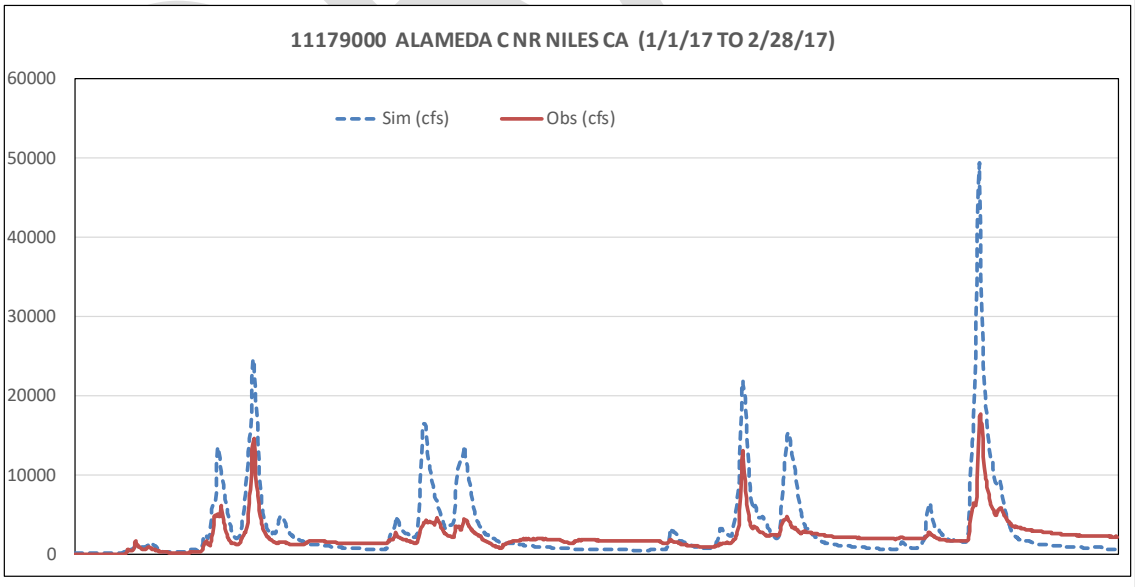
Watershed Factors:

Precipitation:	**Pavg [in] =**	21.0	**Prank =**	0.0	Low rainfall relative to region.
Orography:	**ORO [%] =**	7%	**OROrank =**	1.2	Low orographic influence.
Topography:	**SL [%] =**	16.1	**SLrank =**	2.1	Moderate slopes.
Soils:	**HGD [%] =**	68.6	**HGDrank =**	4.0	Moderate percentage impervious soils.
Water management:	**STOR [kaf] =**	77.2	**DISTURB =**	4.4	High level of regulation at lower end of watershed.

Assessment of NWM Performance:

The NWM simulation was mediocre with very poor NSE and high Pbias; undoubtedly due to reservoir regulation and other water management.

Gage #	11179000
Gage Name	ALAMEDA C NR NILES CA
County	Alameda
Area [mi^2]	633.0
CNRFC	No
Qpeak [cfs]	12200
Qpeak Year	1958
Q500 [cfs]	39331
Q200 [cfs]	34165
Q100 [cfs]	30327
Q50 [cfs]	26255
Q25 [cfs]	22255
Q10 [cfs]	16910
CC	0.88
PBias	39%
NSE	-2.25
Score (1-5)	1.97
Assess	Mediocre
HAT (1-3)	1.62



AQPI
Advanced Quantitative Precipitation Information

11180500 DRY C A UNION CITY CA

Site Description:

Dry Creek is a small tributary to Alameda Creek. The gage is 900 ft downstream from bridge on State Highway 238 in Decoto District in Union City, and 1.7 mi upstream from mouth.

Remarks from USGS Site Report:

No regulation or diversion upstream from station

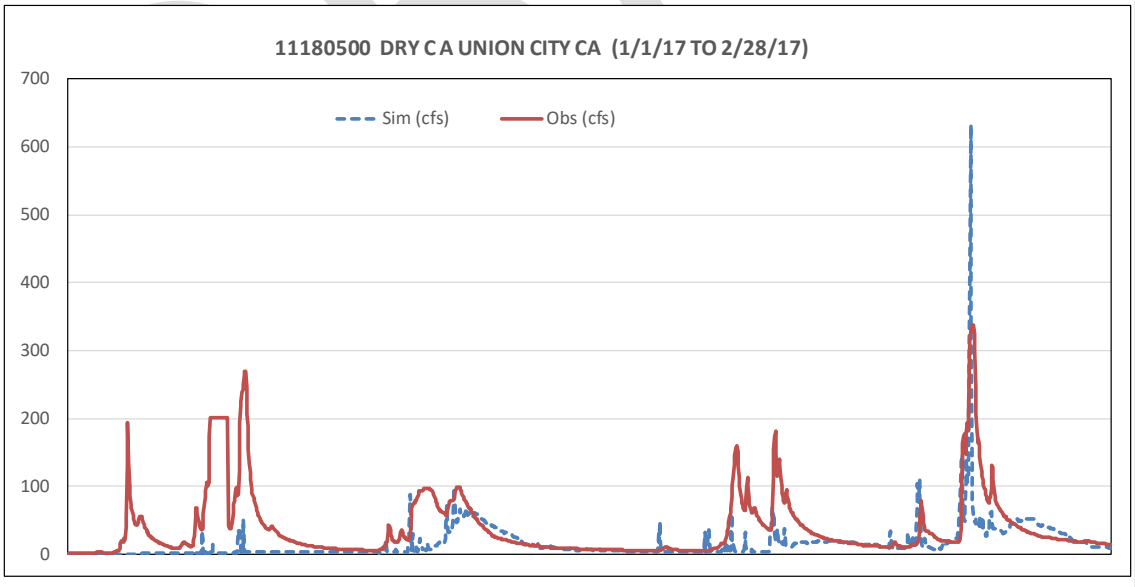
Watershed Factors:

Precipitation:	**Pavg [in] =**	26.5	**Prank =**	0.6
				Low rainfall relative to region.
Orography:	**ORO [%] =**	35%	**OROrank =**	3.7
				Low orographic influence.
Topography:	**SL [%] =**	19.4	**SLrank =**	2.8
				Moderate slopes.
Soils:	**HGD [%] =**	58.0	**HGDrank =**	2.3
				Moderate percentage impervious soils.
Water management:	**STOR [kaf] =**	0.0	**DISTURB =**	0.6
				No regulation or diversion upstream from station

Assessment of NWM Performance:

The NWM simulation was mediocre with very poor NSE and Pbias. Poor rainfall mapping likely cause of performance.

Gage #	11180500
Gage Name	DRY C A UNION CITY CA
County	Alameda
Area [mi^2]	9.4
CNRFC	No
Qpeak [cfs]	1680
Qpeak Year	1959
Q500 [cfs]	2387
Q200 [cfs]	2007
Q100 [cfs]	1729
Q50 [cfs]	1439
Q25 [cfs]	1166
Q10 [cfs]	821
CC	0.39
PBias	-57%
NSE	-0.08
Score (1-5)	1.26
Assess	Mediocre
HAT (1-3)	0.50



11180700 ALAMEDA C FLOOD CHANNEL A UNION CITY CA

Site Description:

The Alameda Flood Control Channel was built in the 1950's to 1960's. This channel prevented Alameda Creek from flooding Niles, Fremont, and Union City.

Remarks from USGS Site Report:

This stream is a distributary of Alameda Creek, a diversion by Alameda County Water District to percolation ponds between station 11179000 and this station; additional percolation to ground water by placing check dams in channel.

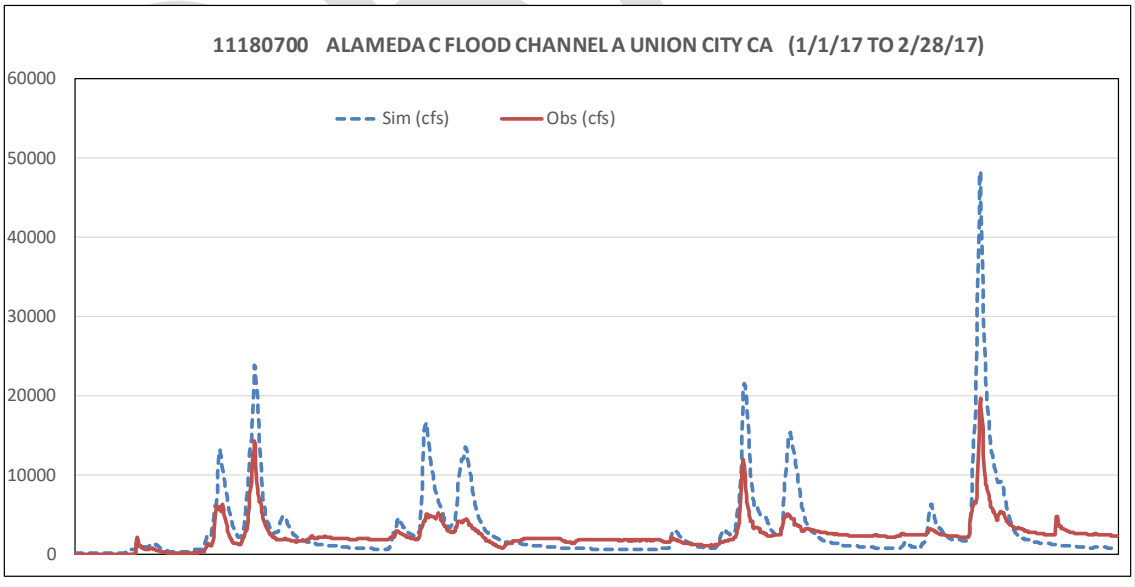
Watershed Factors:

Precipitation:	**Pavg [in] =**	22.0	**Prank =**	0.1
			Low rainfall relative to region.	
Orography:	**ORO [%] =**	29%	**OROrank =**	3.1
			Low orographic influence.	
Topography:	**SL [%] =**	18.8	**SLrank =**	2.6
			Moderate slopes.	
Soils:	**HGD [%] =**	67.1	**HGDrank =**	3.9
			Moderate percentage impervious soils.	
Water management:	**STOR [kaf] =**	232.5	**DISTURB =**	4.4
			High level of regulation and disturbance.	

Assessment of NWM Performance:

This site so regulated it doesn't make much sense to include it in NWM assessment.

Gage #	11180700
Gage Name	ALAMEDA C FLOOD CHANNEL A UNION CITY CA
County	Alameda
Area [mi^2]	???
CNRFC	No
Qpeak [cfs]	25500
Qpeak Year	1998
Q500 [cfs]	--
Q200 [cfs]	--
Q100 [cfs]	--
Q50 [cfs]	--
Q25 [cfs]	--
Q10 [cfs]	--
CC	0.89
PBias	30%
NSE	-1.99
Score (1-5)	2.20
Assess	Moderate
HAT (1-3)	1.75



11180825 SAN LORENZO C AB DON CASTRO RES NR CASTRO V CA

Site Description:

Crow Creek is a small tributary to San Lorenzo Creek in the Castro Valley, Alameda County.

Remarks from USGS Site Report:

Some regulation of low flow by ponds upstream from station.

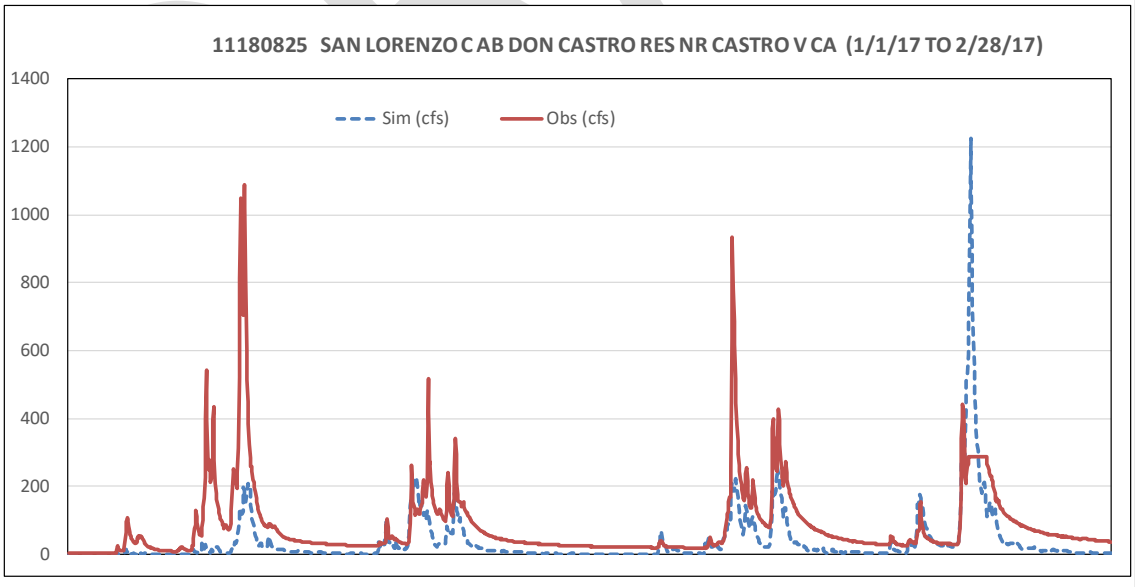
Watershed Factors:

Precipitation:	**Pavg [in] =**	26.9	**Prank =**	0.7
			Low rainfall relative to region.	
Orography:	**ORO [%] =**	13%	**ORORank =**	1.7
			Low orographic influence.	
Topography:	**SL [%] =**	21.4	**SLrank =**	3.2
			Moderate slopes.	
Soils:	**HGD [%] =**	58.0	**HGDrank =**	3.3
			Moderate percentage impervious soils.	
Water management:	**STOR [kaf] =**	0.0	**DISTURB =**	0.8
			Low level of regulation and disturbance.	

Assessment of NWM Performance:

The NWM simulation has good correlation and NSE, but the high negative bias indicates overall runoff volume is low. Perhaps this is due to poor rainfall mapping.

Gage #	11180825
Gage Name	SAN LORENZO C AB DON CASTRO RES NR CASTRO V CA
County	Alameda
Area [mi^2]	18.0
CNRFC	No
Qpeak [cfs]	1990
Qpeak Year	1998
Q500 [cfs]	2627
Q200 [cfs]	2210
Q100 [cfs]	1904
Q50 [cfs]	1585
Q25 [cfs]	1286
Q10 [cfs]	906
CC	0.54
PBias	-55%
NSE	0.09
Score (1-5)	1.57
Assess	Mediocre
HAT (1-3)	2.33



11180900 CROW C NR HAYWARD CA

Site Description:

Crow Creek is a small tributary to San Lorenzo Creek in the Castro Valley, Alameda County.

Remarks from USGS Site Report:

No regulation or diversion upstream from station.

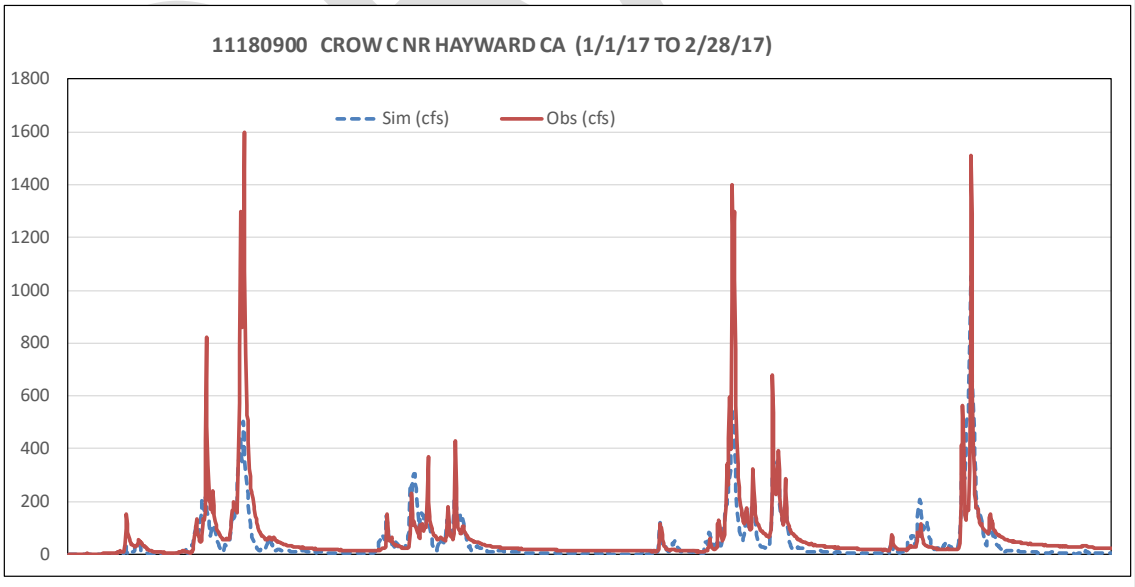
Watershed Factors:

Precipitation:	**Pavg [in] =**	26.4	**Prank =**	0.6
			Low rainfall relative to region.	
Orography:	**ORO [%] =**	8%	**OROrank =**	1.3
			Low orographic influence.	
Topography:	**SL [%] =**	20.8	**SLrank =**	3.6
			Moderate slopes.	
Soils:	**HGD [%] =**	58.0	**HGDrank =**	3.3
			Moderate percentage impervious soils.	
Water management:	**STOR [kaf] =**	0.0	**DISTURB =**	0.6
			Low level of reservoir regulation and disturbance.	

Assessment of NWM Performance:

The NWM simulation has good correlation and NSE, but the high negative bias indicates overall runoff volume is low. Perhaps this is due to poor rainfall mapping.

Gage #	11180900
Gage Name	CROW C NR HAYWARD CA
County	Alameda
Area [mi^2]	10.5
CNRFC	No
Qpeak [cfs]	1990
Qpeak Year	1998
Q500 [cfs]	2627
Q200 [cfs]	2210
Q100 [cfs]	1904
Q50 [cfs]	1585
Q25 [cfs]	1286
Q10 [cfs]	906
CC	0.81
PBias	-31%
NSE	0.61
Score (1-5)	3.35
Assess	Good
HAT (1-3)	2.00



11180960 CULL C AB CULL C RES NR CASTRO VALLEY CA

Site Description:

Cull Creek is a small tributary to San Lorenzo Creek in the Castro Valley, Alemeda County. There have been sedimentation issues with the Cull Creek Reservoir which has filled most of the storage capacity and has been a continuing maintenance issue.

Remarks from USGS Site Report:

Flow partly regulated by Cull Creek Reservoir, capacity, 310 acre-ft, and by Don Castro Reservoir, capacity, 380 acre-ft, 7 mi upstream.

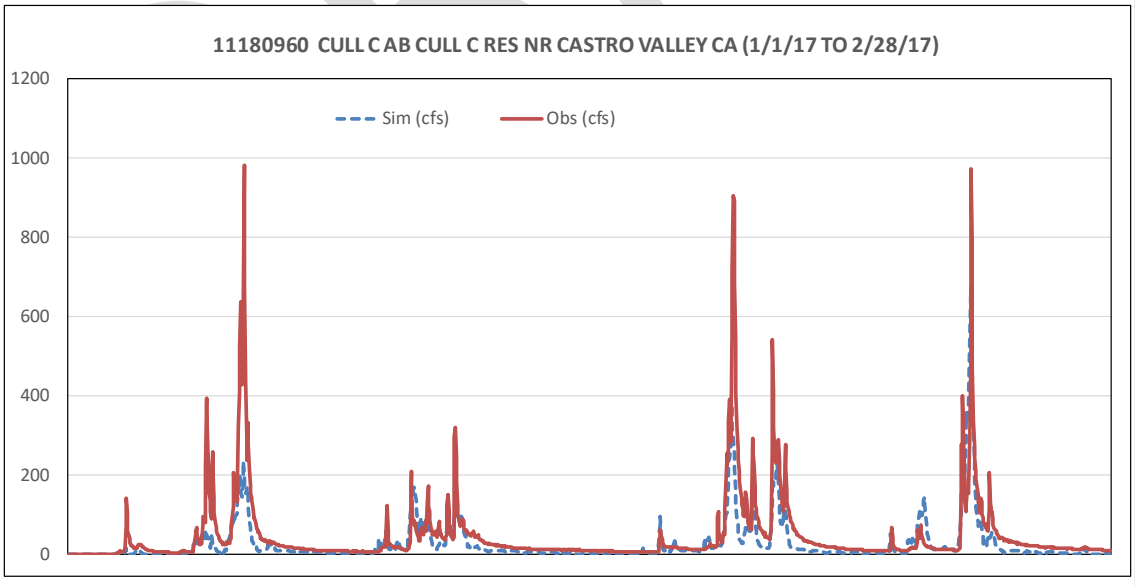
Watershed Factors:

Precipitation:	**Pavg [in] =**	26.7	**Prank =**	0.7
				Low rainfall relative to region.
Orography:	**ORO [%] =**	9%	**OROrank =**	1.3
				Low orographic influence.
Topography:	**SL [%] =**	20.9	**SLrank =**	3.6
				Moderate slopes.
Soils:	**HGD [%] =**	58.0	**HGDrank =**	3.3
				Moderate percentage impervious soils.
Water management:	**STOR [kaf] =**	0.0	**DISTURB =**	0.8
				Low level of reservoir regulation and disturbance.

Assessment of NWM Performance:

The NWM simulation has good correlation and NSE, but the high negative bias indicates overall runoff volume is low. Perhaps this is due to poor rainfall mapping.

Gage #	11180960
Gage Name	CULL C AB CULL C RES NR CASTRO VALLEY CA
County	Alameda
Area [mi^2]	5.8
CNRFC	No
Qpeak [cfs]	1690
Qpeak Year	1982
Q500 [cfs]	1575
Q200 [cfs]	1322
Q100 [cfs]	1137
Q50 [cfs]	945
Q25 [cfs]	764
Q10 [cfs]	537
CC	0.79
PBias	-44%
NSE	0.53
Score (1-5)	2.87
Assess	Moderate
HAT (1-3)	1.16



11181000 SAN LORENZO C A HAYWARD CA

Site Description:

San Lorenzo Creek is a 10.7-mile-long (17.2 km) year-round natural stream flowing through Hayward, California, into San Francisco Bay at the Hayward Regional Shoreline. The creek begins in Castro Valley, and is the main tributary within the San Lorenzo Watershed, including the formerly independent Sulpher Creek, which had most of its flow diverted into San Lorenzo Creek in the 1960s to reduce the risk of flooding in downtown Hayward. Only in large flow events does some of the creek flow follow its old course into the Bay.

Remarks from USGS Site Report:

Flow partly regulated by Cull Creek Reservoir, capacity, 310 acre-ft, and by Don Castro Reservoir, capacity, 380 acre-ft, 7 mi upstream.

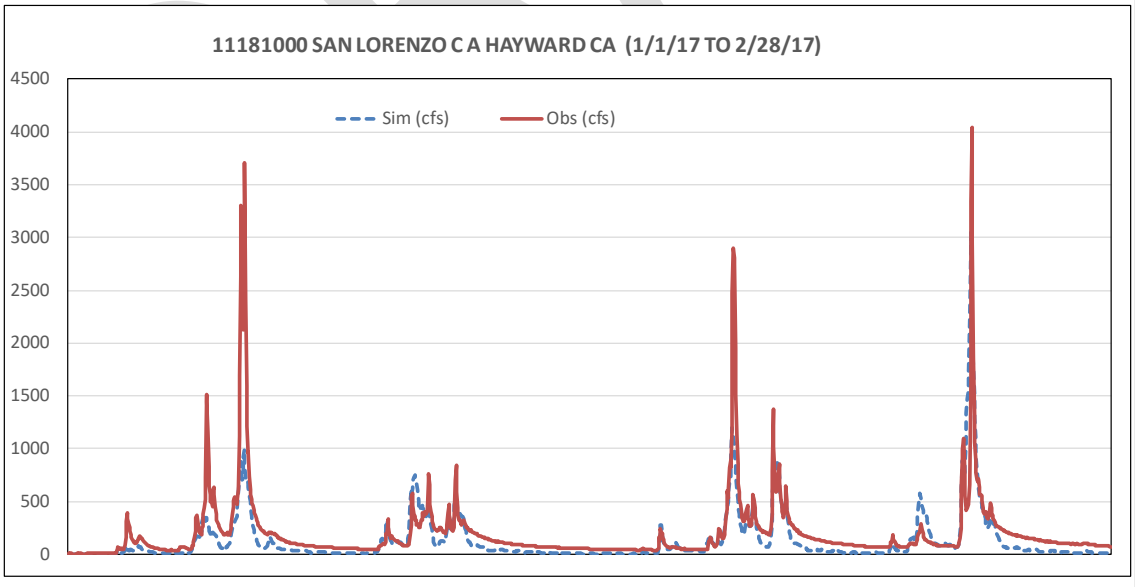
Watershed Factors:

Precipitation:	**Pavg [in] =**	26.4	**Prank =**	0.6
			Low rainfall relative to region.	
Orography:	**ORO [%] =**	20%	**OROrank =**	2.4
			Moderate orographic influence.	
Topography:	**SL [%] =**	20.9	**SLrank =**	3.1
			Moderate slopes.	
Soils:	**HGD [%] =**	58.0	**HGDrank =**	3.3
			Moderate percentage impervious soils.	
Water management:	**STOR [kaf] =**	0.7	**DISTURB =**	3.1
	Low level of reservoir regulation and moderate disturbance (i.e. urbanization).			

Assessment of NWM Performance:

The NWM simulation has good correlation and NSE, but the high negative bias indicates overall runoff volume is low. Perhaps this is due to the Sulphur Creek not represented in NWM.

Gage #	11181000
Gage Name	SAN LORENZO C A HAYWARD CA
County	Alameda
Area [mi^2]	37.5
CNRFC	LRZC1
Qpeak [cfs]	8140
Qpeak Year	1998
Q500 [cfs]	7852
Q200 [cfs]	6630
Q100 [cfs]	5735
Q50 [cfs]	4799
Q25 [cfs]	3911
Q10 [cfs]	2778
CC	0.78
PBias	-35%
NSE	0.56
Score (1-5)	3.15
Assess	Good
HAT (1-3)	1.49



11181040 SAN LORENZO C A SAN LORENZO CA

Site Description:

San Lorenzo Creek is a 10.7-mile-long (17.2 km) year-round natural stream flowing through Hayward, California, into San Francisco Bay at the Hayward Regional Shoreline. The creek begins in Castro Valley, and is the main tributary within the San Lorenzo Watershed, including the formerly independent Sulpher Creek, which had most of its flow diverted into San Lorenzo Creek in the 1960s to reduce the risk of flooding in downtown Hayward. Only in large flow events does some of the creek flow follow its old course into the Bay.

Remarks from USGS Site Report:

Flow partly regulated by Cull Creek Reservoir, capacity, 310 acre-ft, and by Don Castro Reservoir, capacity, 380 acre-ft, 7 mi upstream.

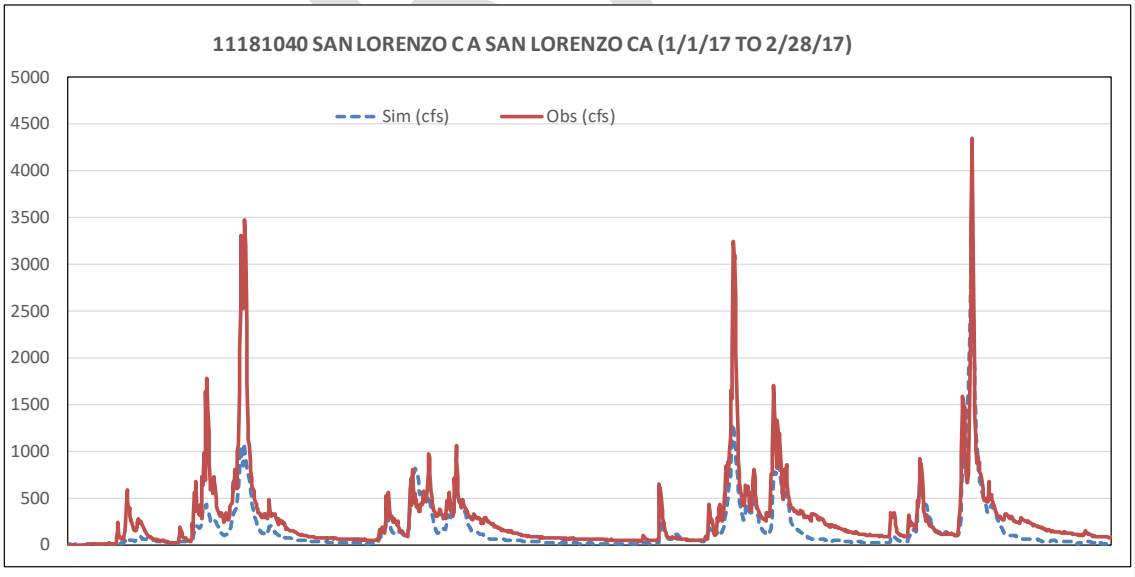
Watershed Factors:

Precipitation:	**Pavg [in] =**	25.7	**Prank =**	0.6
			Low rainfall relative to region.	
Orography:	**ORO [%] =**	27%	**OROrank =**	2.9
			Moderate orographic influence.	
Topography:	**SL [%] =**	18.0	**SLrank =**	2.5
			Moderate slopes.	
Soils:	**HGD [%] =**	57.4	**HGDrank =**	3.3
			Moderate percentage impervious soils.	
Water management:	**STOR [kaf] =**	0.9	**DISTURB =**	3.5
			Low level of reservoir regulation and moderate disturbance (i.e. urbanization).	

Assessment of NWM Performance:

The NWM simulation has good correlation and NSE, but the high negative bias indicates overall runoff volume is low. Perhaps this is due to the Sulphur Creek not represented in NWM.

Gage #	11181040
Gage Name	SAN LORENZO C A SAN LORENZO CA
County	Alameda
Area [mi^2]	44.6
CNRFC	No
Qpeak [cfs]	10300
Qpeak Year	1998
Q500 [cfs]	9115
Q200 [cfs]	7700
Q100 [cfs]	6664
Q50 [cfs]	5580
Q25 [cfs]	4551
Q10 [cfs]	3236
CC	0.86
PBias	-42%
NSE	0.62
Score (1-5)	3.12
Assess	Good
HAT (1-3)	1.92



11182500 SAN RAMON C A SAN RAMON CA

Site Description:

San Ramon Creek is a north flowing small headwater tributary to Walnut Creek in Contra Costa County.

Remarks from USGS Site Report:

No regulation or diversion upstream from station

Watershed Factors:

Precipitation: **Pavg [in] =** 26.5 **Prank =** 0.8
Rainfall mapping seems good.

Orography: **ORO [%] =** 7% **OROrank =** 1.3
Relatively high bias indicates better rain mapping needed.

Topography: **SL [%] =** 21.6 **SLrank =** 3.4
Moderate slopes.

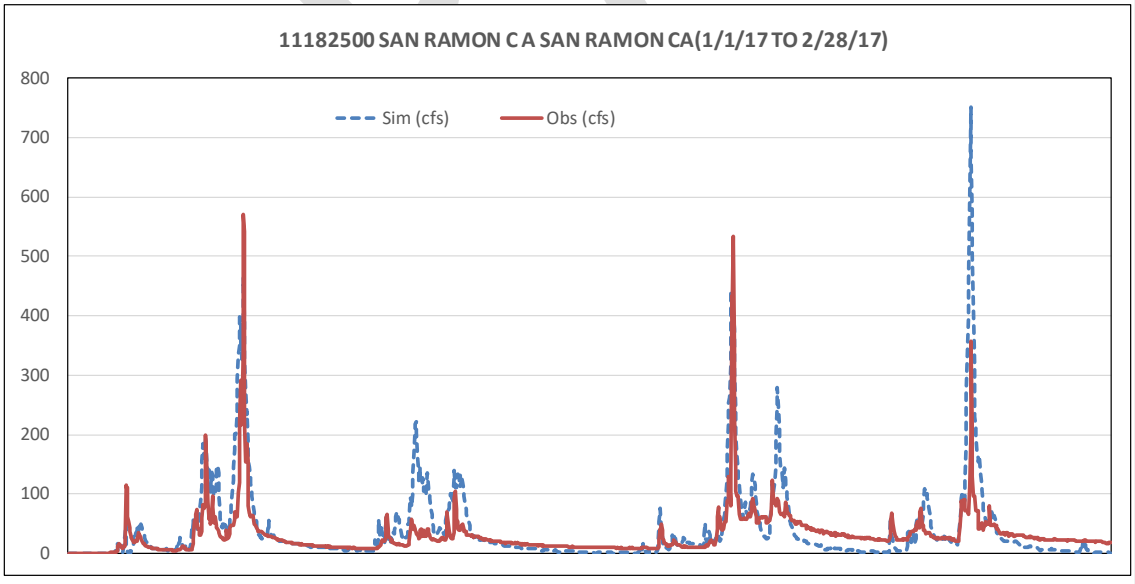
Soils: **HGD [%] =** 64.5 **HGDrank =** 3.7
High percentage impervious soils.

Water management: **STOR [kaf] =** 0.0 **DISTURB =** 1.0
No regulation, but urbanization alters natural regime.

Assessment of NWM Performance:

The NWM simulation rated as moderate; high PBias and poor NSE indicate better rainfall mapping needed. Several of the large peak flows tracked OK.

Gage #	11182500
Gage Name	SAN RAMON C A SAN RAMON CA
County	Santa Clara
Area [mi^2]	5.89
CNRFC	No
Qpeak [cfs]	1600
Qpeak Year	1962
Q500 [cfs]	1847
Q200 [cfs]	1563
Q100 [cfs]	1355
Q50 [cfs]	1136
Q25 [cfs]	929
Q10 [cfs]	666
CC	0.77
PBias	25%
NSE	-0.31
Score (1-5)	2.25
Assess	Moderate
HAT (1-3)	1.17



11456000 NAPA R NR ST HELENA CA

Site Description:

The Napa River rises in northwestern Napa County just south of the summit of Mt. St. Helena in the Mayacamas Mountains of the California Coast Ranges. It descends the southern slope of Mt. St. Helena to Kimball Canyon Dam. It flows south for 4 miles (6 km), entering the head of the slender Napa Valley north of Calistoga. In the valley, it flows southeast past Calistoga, St Helena and thence to Napa near SF Bay.

Remarks from USGS Site Report:

Some diversion for agriculture and regulation by Bell Canyon Res (2500 af). Small diversions upstream from station for irrigation of about 1,500 acres.

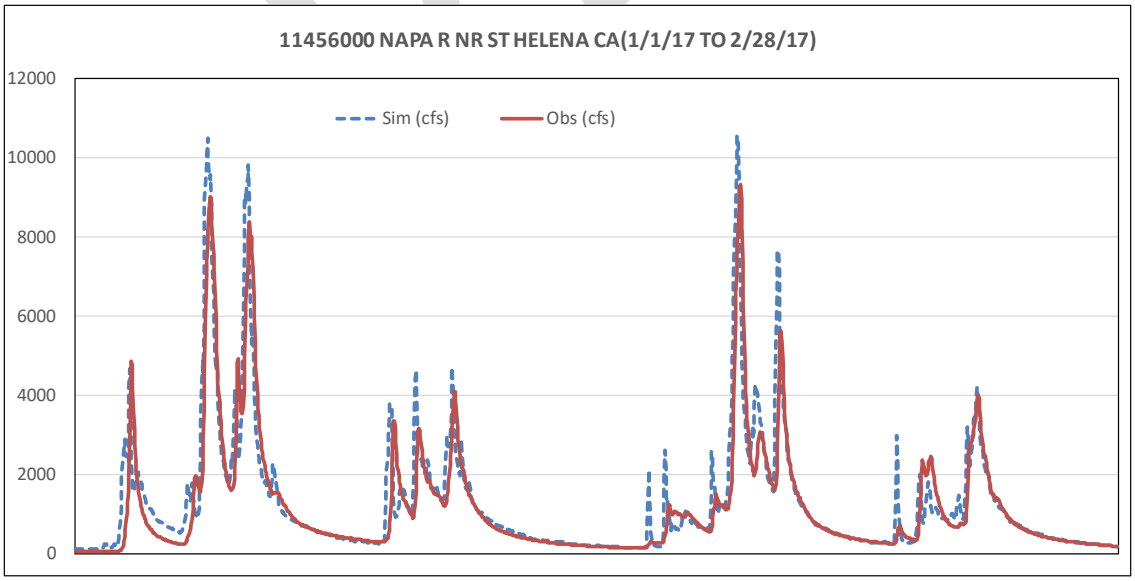
Watershed Factors:

Precipitation:	**Pavg [in] =**	41.1	**Prank =**	2.5
			Rainfall mapping seems good.	
Orography:	**ORO [%] =**	15%	**OROrank =**	2.0
			Rainfall location consistently good.	
Topography:	**SL [%] =**	20.9	**SLrank =**	3.3
			Moderate slopes.	
Soils:	**HGD [%] =**	40.1	**HGDrank =**	2.2
			Moderately impervious soils.	
Water management:	**STOR [kaf] =**	3.4	**DISTURB =**	2.5
	Some regulation, does not seem to impact peak flow simulation.			

Assessment of NWM Performance:

The NWM simulation showed generally very good results although most peak flows were slightly over-estimated. Perhaps the peaks are reduced when flows through Bell Canyon Reservoir. Water balance very good.

Gage #	11456000
Gage Name	NAPA R NR ST HELENA CA
County	Napa
Area [mi^2]	79
CNRFC	SHEC1
Qpeak [cfs]	18,300
Qpeak Year	2005
Q500 [cfs]	21228
Q200 [cfs]	18323
Q100 [cfs]	16169
Q50 [cfs]	13890
Q25 [cfs]	11671
Q10 [cfs]	8739
CC	0.89
PBias	8%
NSE	0.75
Score (1-5)	4.23
Assess17	Excellent
HAT (1-3)	1.29



11458000 NAPA R NR NAPA CA

Site Description:

The Napa River rises in northwestern Napa County in the Mayacamas Mountains of the California Coast Ranges. It descends the southern slope of Mt. St. Helena Calistoga, St Helena and thence to Napa near SF Bay. Several water supply dams regulate flow, esp. Lake Hennessey which has flood control function. The mouth is at Vallejo where the inter-tidal zone of fresh and salt waters flow into the Carquinez Straits on San Pablo Bay.

Remarks from USGS Site Report:

Regulated by Lake Hennessey (31kaf, 58 sq. mi.)

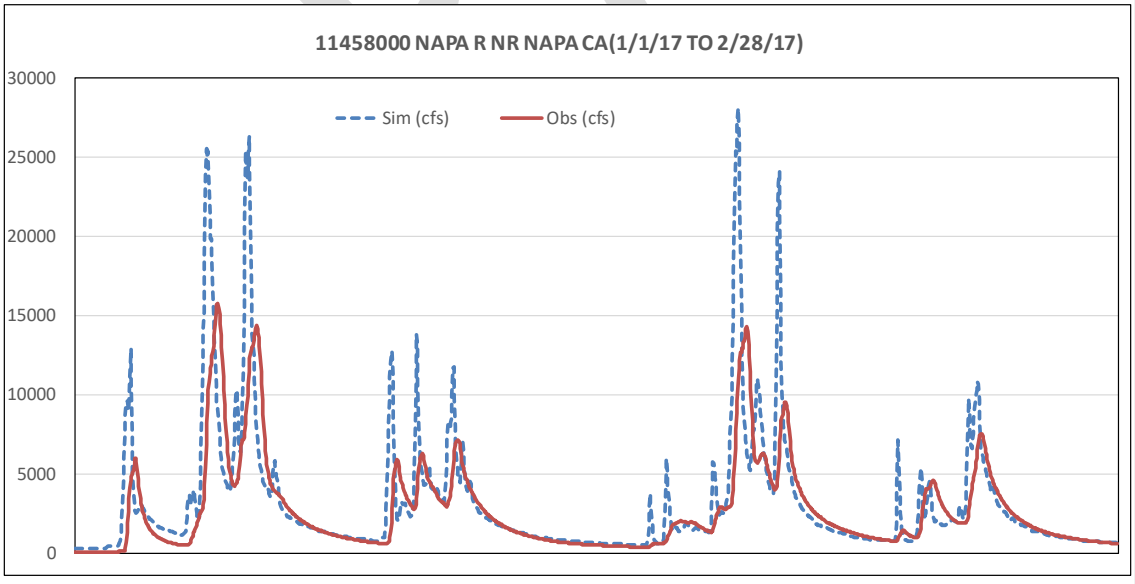
Watershed Factors:

Precipitation:	**Pavg [in] =**	37.8	**Prank =**	2.1
			Rainfall mapping seems good.	
Orography:	**ORO [%] =**	42%	**OROrank =**	4.3
			Rainfall location consistently good.	
Topography:	**SL [%] =**	18.6	**SLrank =**	2.9
			Moderate slopes.	
Soils:	**HGD [%] =**	38.3	**HGDrank =**	2.1
			Moderately impervious soils.	
Water management:	**STOR [kaf] =**	40.1	**DISTURB =**	2.3
	Reservoir regulation effects evidenced by peak reductions and time lags.			

Assessment of NWM Performance:

The NWM simulation was not a good as for St. Helena due to the influence of various dams, esp. Lake Hennessey. NWM flood peaks consistently exceed observed given dam regulation.

Gage #	11458000
Gage Name	NAPA R NR NAPA CA
County	Napa
Area [mi^2]	218
CNRFC	APCC1
Qpeak [cfs]	37100
Qpeak Year	1986
Q500 [cfs]	48116
Q200 [cfs]	41528
Q100 [cfs]	36655
Q50 [cfs]	31499
Q25 [cfs]	26459
Q10 [cfs]	19781
CC	0.69
PBias	19%
NSE	-0.12
Score (1-5)	2.37
Assess	Moderate
HAT (1-3)	0.87



AQPI
Advanced Quantitative Precipitation Information

11458433 SONOMA CREEK A KENWOOD CA

Site Description:

Sonoma Creek drains south to SF Bay through Sonoma. Peak flows are a concern for urban and local flooding in this increasing dense suburban watershed.

Remarks from USGS Site Report:

No regulation above station. Diversions for irrigation of about 1,500 acres upstream.

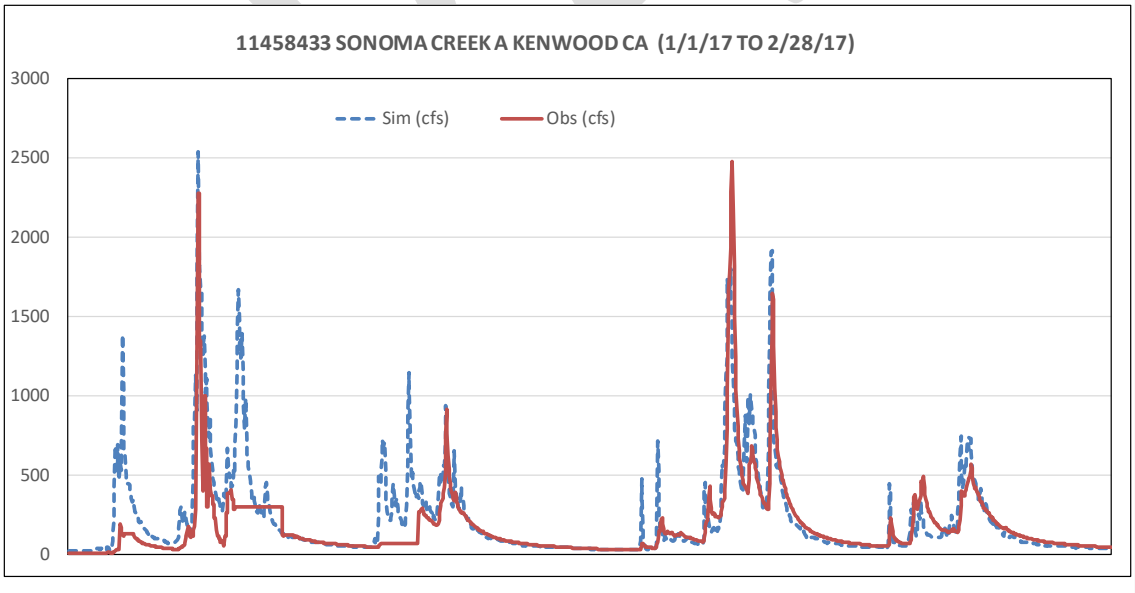
Watershed Factors:

Precipitation:	**Pavg [in] =**	45.5	**Prank =**	2.9
		Rainfall on east side of Coast Range varies widely.		
Orography:	**ORO [%] =**	15%	**OROrank =**	2.0
		Strong orographic influence.		
Topography:	**SL [%] =**	22	**SLrank =**	3.5
		Steep slopes speed runoff.		
Soils:	**HGD [%] =**	43.0	**HGDrank =**	2.4
		Moderately pervious soils.		
Water management:	**STOR [kaf] =**	0.0	**DISTURB =**	1.5
		No reservoir regulation.		

Assessment of NWM Performance:

For the assessment period the NWM gernerally mimicked gaged flows, but has several peaks not represented by the gage. Several the largest peaks were matched closely. Diversions for irrigation may explain these discrepancies.

Gage #	11458433
Gage Name	SONOMA CREEK A KENWOOD CA
County	Sonoma
Area [mi^2]	14.3
CNRFC	No
Qpeak [cfs]	2531
Qpeak Year	2017
Q500 [cfs]	4324
Q200 [cfs]	3688
Q100 [cfs]	3218
Q50 [cfs]	2723
Q25 [cfs]	2251
Q10 [cfs]	1641
CC	0.76
PBias	26%
NSE	0.35
Score (1-5)	2.94
Assess	Moderate
HAT (1-3)	1.63



AQPI
Advanced Quantitative Precipitation Information

11458500 SONOMA C A AGUA CALIENTE CA

Site Description:

Sonoma Creek drains south to SF Bay through Sonoma. Peak flows are a concern for urban and local flooding in this increasing dense suburban watershed.

Remarks from USGS Site Report:

Records good. No regulation; some diversion above station for irrigation of about 2,000 acres.

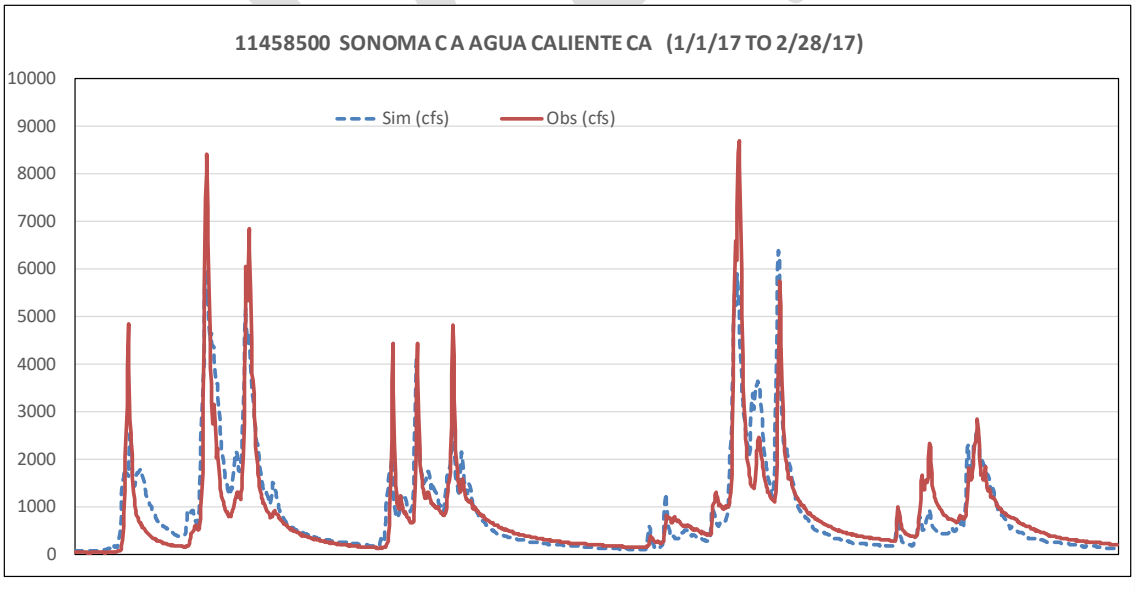
Watershed Factors:

Precipitation:	**Pavg [in] =**	42.5	**Prank =**	2.6
			Mid-range for precipiation in region.	
Orography:	**ORO [%] =**	35%	**OROrank =**	3.7
			Strong orographic influence.	
Topography:	**SL [%] =**	17.6	**SLrank =**	2.7
			Steep slopes speed runoff.	
Soils:	**HGD [%] =**	59.6	**HGDrank =**	3.4
			Moderately impervious soils.	
Water management:	**STOR [kaf] =**	0.9	**DISTURB =**	2.3
			No reservoir regulation.	

Assessment of NWM Performance:

For the assessment period the NWM closely tracked observed flows; high scores for CC and NSE and very low Pbias rates an "Excellent" rating.

Gage #	11458500
Gage Name	SONOMA C A AGUA CALIENTE CA
County	Sonoma
Area [mi^2]	58.4
CNRFC	No
Qpeak [cfs]	20300
Qpeak Year	2005
Q500 [cfs]	14481
Q200 [cfs]	12402
Q100 [cfs]	10867
Q50 [cfs]	9248
Q25 [cfs]	7687
Q10 [cfs]	5649
CC	0.88
PBias	1%
NSE	0.78
Score (1-5)	4.46
Assess	Excellent
HAT (1-3)	1.73



11459500 NOVATO C A NOVATO CA

Site Description:

Novato Creek is a stream in eastern Marin County, CA. It originates in highlands between Red Hill and Mount Burdell above the city of Novato, California, and flows 17 miles (27 km) before emptying into San Pablo Bay south of Petaluma Point. Approximately 20% of Novato's water supply comes from Stafford Lake.

Remarks from USGS Site Report:

Flow regulated by Stafford Lake, 4,500 acre-ft.

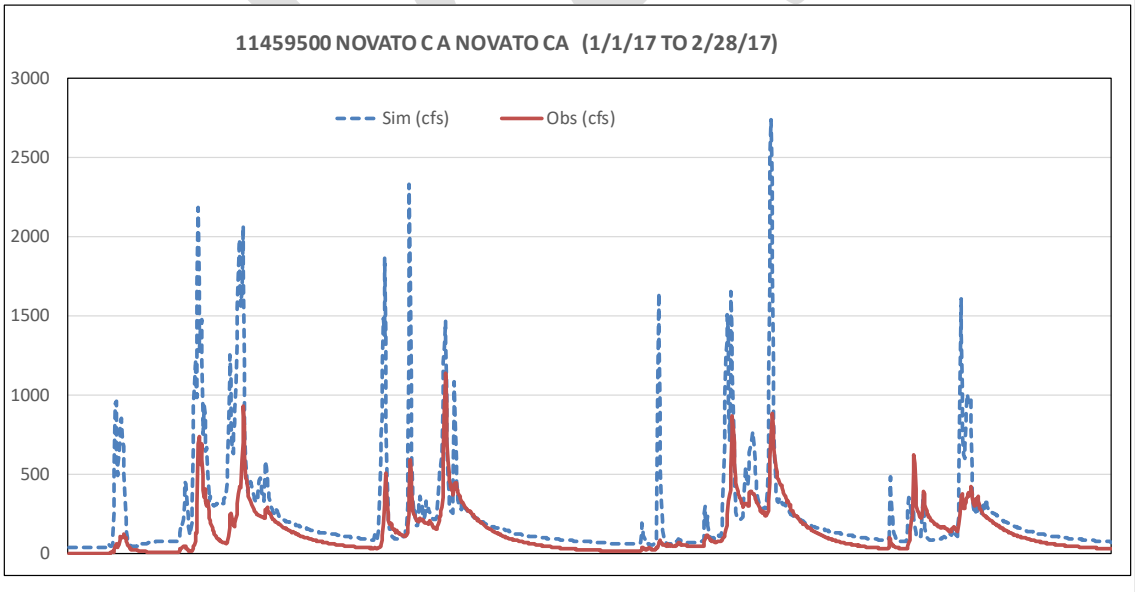
Watershed Factors:

Precipitation:	**Pavg [in] =**	40.5	**Prank =**	2.4
				Mid-range for region.
Orography:	**ORO [%] =**	32%	**OROrank =**	3.4
				Moderate orographic influence.
Topography:	**SL [%] =**	19.5	**SLrank =**	3.0
				Moderately steep slopes speed runoff.
Soils:	**HGD [%] =**	42.8	**HGDrank =**	2.3
				Moderately impervious soils.
Water management:	**STOR [kaf] =**	4.4	**DISTURB =**	2.9
				Reservoirs regulation and water supply diversions.

Assessment of NWM Performance:

The NWM simulation showed considerably more runoff than observed, with regard to flood peaks and total runoff volume. This is in contract to Corte Madera Creek which showed the opposite. The difference is ascribed to regulation by Stafford Lake, but rainfall mapping also relevant.

Gage #	11459500
Gage Name	NOVATO C A NOVATO CA
County	Marin
Area [mi^2]	17.6
CNRFC	No
Qpeak [cfs]	5000
Qpeak Year	1983
Q500 [cfs]	5720
Q200 [cfs]	4909
Q100 [cfs]	4308
Q50 [cfs]	3673
Q25 [cfs]	3063
Q10 [cfs]	2266
CC	0.69
PBias	81%
NSE	-2.32
Score (1-5)	0.82
Assess	Poor
HAT (1-3)	0.87



11460000 CORTE MADERA C A ROSS CA

Site Description:

Corte Madera Creek is a short stream which flows southeast for 4.5 miles (7.2 km) in Marin County, CA. It formed by the confluence of San Anselmo Creek and Ross Creek, and entering a tidal marsh at Kentfield before connecting to SF Bay. Watershed ranges in elevation from sea level to 2,571 feet (784 m) at the East Peak of Mount Tamalpais.

Remarks from USGS Site Report:

Flow slightly regulated by Phoenix Lake, capacity 612 acre-ft. Upsrteam diversion by MMWD.

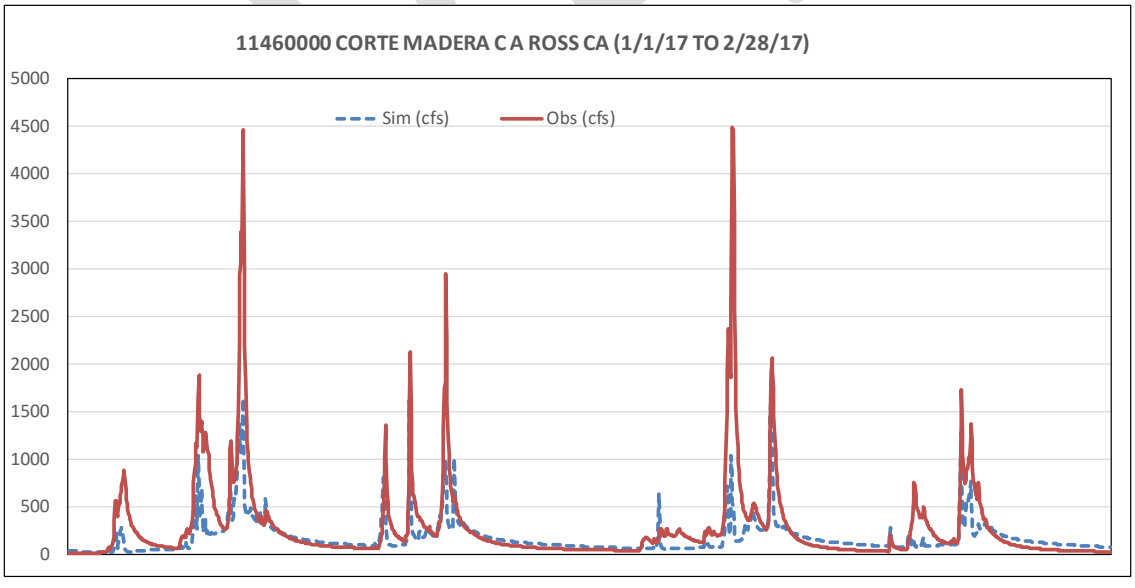
Watershed Factors:

Precipitation:	**Pavg [in] =**	42.7	**Prank =**	2.6
			Mid-range for region.	
Orography:	**ORO [%] =**	3%	**OROrank =**	0.9
			Moderate orographic influence.	
Topography:	**SL [%] =**	21.4	**SLrank =**	3.4
			Moderately steep slopes speed runoff.	
Soils:	**HGD [%] =**	49.2	**HGDrank =**	2.8
			Moderately impervious soils.	
Water management:	**STOR [kaf] =**	0.6	**DISTURB =**	3.3
			Some reservoir regulation and water supply diversions.	

Assessment of NWM Performance:

The NWM simulation showed less runoff than observed, with regard to flood peaks and total runoff volume. Locals note that rain gage data show large variability in rain amounts from peak to the SF Bay.

Gage #	11460000
Gage Name	CORTE MADERA C A ROSS CA
County	Marin
Area [mi^2]	18.1
CNRFC	No
Qpeak [cfs]	7200
Qpeak Year	1983
Q500 [cfs]	6071
Q200 [cfs]	5221
Q100 [cfs]	4590
Q50 [cfs]	3923
Q25 [cfs]	3281
Q10 [cfs]	2439
CC	0.74
PBias	-36%
NSE	0.39
Score (1-5)	2.74
Assess	Moderate
HAT (1-3)	0.71



1460400 LAGUNITAS C A SAMUEL P TAYLOR STATE PARK CA

Site Description:

Lagunitas Creek begins on Mt. Tamalpais, and the creek and its tributaries feed into MMWD's reservoirs. Downstream of the reservoirs, the creek is a spawning and rearing ground for coho salmon and steelhead trout, both of which are on the endangered species list.

Remarks from USGS Site Report:

Flow regulated by Kent Lake, capacity, 32,900 acre-ft, Alpine Lake, capacity, 8,890 acre-ft, and Bon Tempe Lake, capacity, 4,300 acre-ft

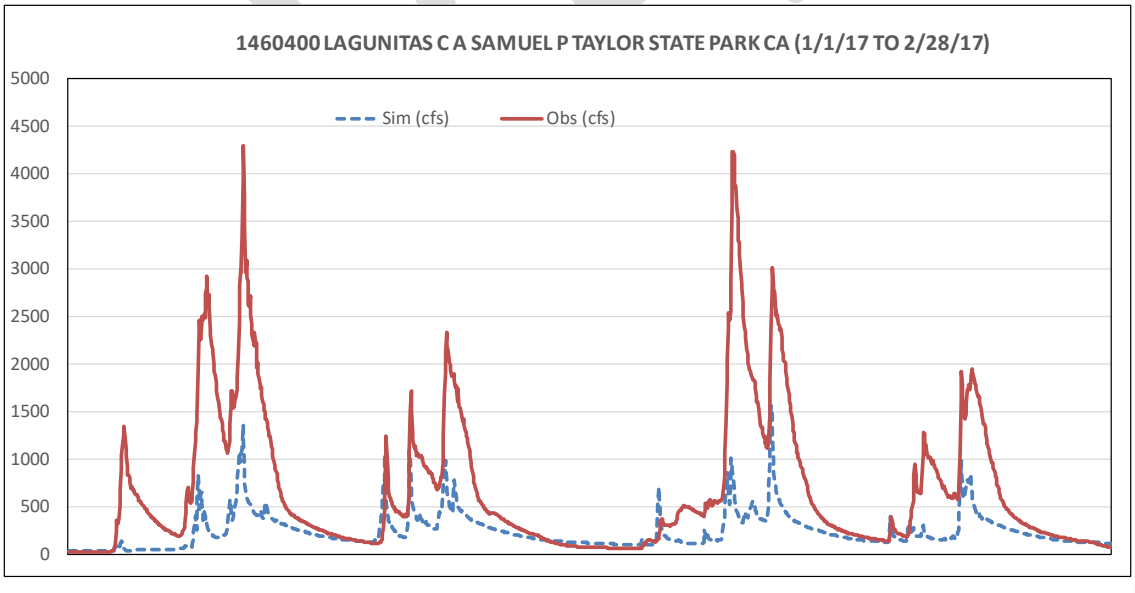
Watershed Factors:

Precipitation:	**Pavg [in] =**	46.1	**Prank =**	3.0
			Mid-range for region.	
Orography:	**ORO [%] =**	23%	**OROrank =**	2.6
			Strong orographic influence.	
Topography:	**SL [%] =**	25.4	**SLrank =**	4.1
			Steep slopes speed runoff.	
Soils:	**HGD [%] =**	34.0	**HGDrank =**	1.8
			NWM soil moisture seems OK,	
Water management:	**STOR [kaf] =**	46.4	**DISTURB =**	4.0
			Reservoirs regulation and water supply diversions.	

Assessment of NWM Performance:

The NWM simulation rated mediocre; showed less runoff than observed, with regard to flood peaks and total runoff volume. All this due to water supply reservoir capture and diversions.

Gage #	11460400
Gage Name	LAGUNITAS C A SAMUEL P TAYLOR STATE PARK CA
County	Marin
Area [mi^2]	34.3
CNRFC	No
Qpeak [cfs]	10200
Qpeak Year	2005
Q500 [cfs]	11474
Q200 [cfs]	9932
Q100 [cfs]	8784
Q50 [cfs]	7568
Q25 [cfs]	6385
Q10 [cfs]	4818
CC	0.76
PBias	-63%
NSE	0.01
Score (1-5)	1.32
Assess	Mediocre
HAT (1-3)	0.19



11460600 LAGUNITAS C NR PT REYES STATION CA

Site Description:

Lagunitas Creek begins on Mt. Tamalpais, and the creek and its tributaries feed into MMWD's reservoirs. Downstream of the reservoirs, the creek is a spawning and rearing ground for coho salmon and steelhead trout, both of which are on the endangered species list.

Remarks from USGS Site Report:

Flow regulated by Nicasio Reservoir, capacity, 22,450 acre-ft, Kent Lake, capacity, 16,680 acre-ft, Alpine Lake, capacity, 8,890 acre-ft, and Bon Tempe Lake, capacity 4,296 acre-ft, all of which divert water for domestic and industrial use in Marin County.

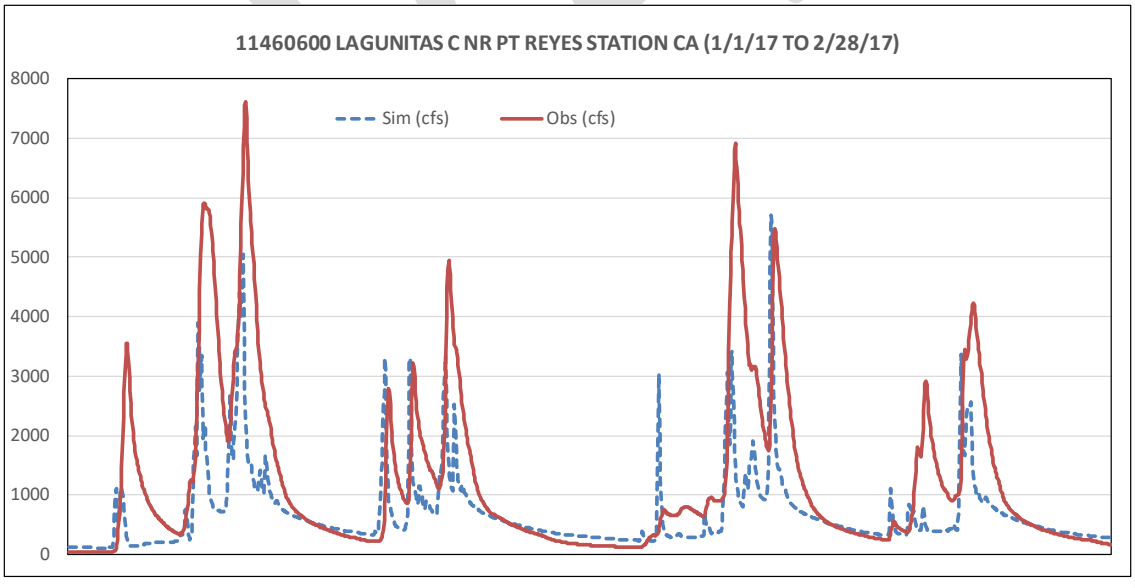
Watershed Factors:

Precipitation:	**Pavg [in] =**	42.5	**Prank =**	2.6
	Mid-range for region. Rainfall on east side of Coast Range varies widely.			
Orography:	**ORO [%] =**	22%	**OROrank =**	2.6
	Strong orographic influence.			
Topography:	**SL [%] =**	23	**SLrank =**	3.7
	Steep slopes speed runoff.			
Soils:	**HGD [%] =**	34.3	**HGDrank =**	1.8
	NWM soil moisture seems OK,			
Water management:	**STOR [kaf] =**	68.9	**DISTURB =**	3.3
	Reservoirs regulation and water supply diversions.			

Assessment of NWM Performance:

The NWM simulation rated moderate; showed less runoff than observed, with regard to flood peaks and total runoff volume. Performance for bias (i.e. total volume) is poor. All this due to water supply reservoir capture and diversions.

Gage #	11460600
Gage Name	LAGUNITAS C NR PT REYES STATION CA
County	Marin
Area [mi^2]	81.7
CNRFC	No
Qpeak [cfs]	22100
Qpeak Year	1982
Q500 [cfs]	23390
Q200 [cfs]	20248
Q100 [cfs]	17914
Q50 [cfs]	15442
Q25 [cfs]	13027
Q10 [cfs]	9823
CC	0.66
PBias	-43%
NSE	0.27
Score (1-5)	2.28
Assess	Moderate
HAT (1-3)	0.54



11460750 WALKER CREEK NEAR MARSHALL, CA

Site Description:

Walker Creek is a tributary to Tomales Bay in western Marin County. It is regulated by Soulajule Reservoir, but flows are maintained in efforts to establish sustainable coho salmon habitat.both of which are on the endangered species list.

Remarks from USGS Site Report:

Regulated by Soulajule Reservoir on Arroyo Sausal; reservoir capacity, 10,570 acre-ft.

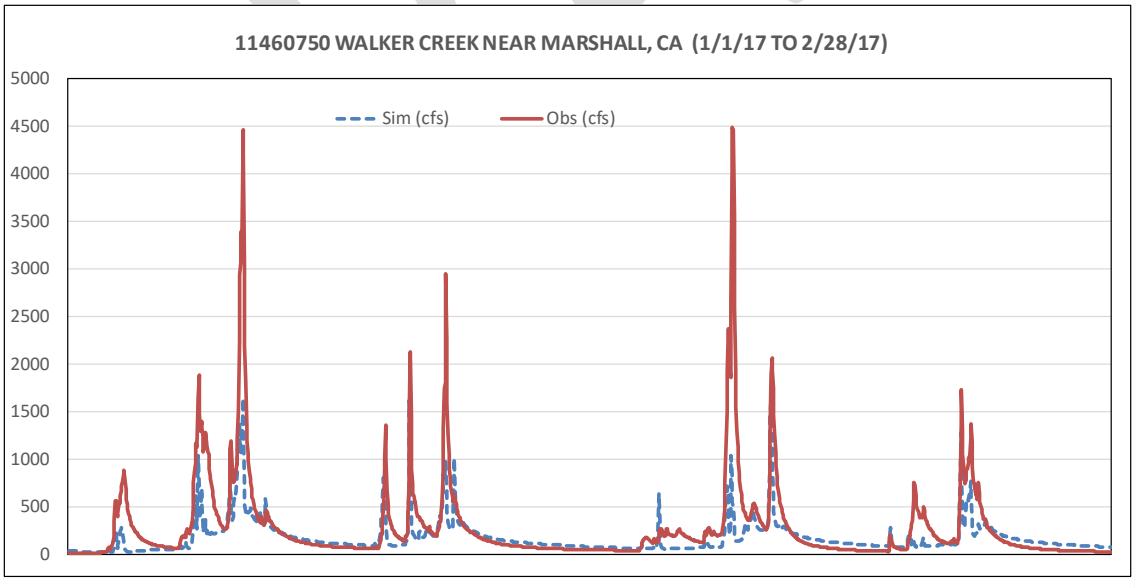
Watershed Factors:

Precipitation:	**Pavg [in] =**	42.5	**Prank =**	2.6
	Rainfall on east side of Coast Range varies widely.			
Orography:	**ORO [%] =**	22%	**OROrank =**	2.6
	Strong orographic influence.			
Topography:	**SL [%] =**	23	**SLrank =**	3.7
	Steep slopes speed runoff.			
Soils:	**HGD [%] =**	34.3	**HGDrank =**	1.8
	Moderately pervious soils.			
Water management:	**STOR [kaf] =**	68.9	**DISTURB =**	3.3
	Reservoirs regulation and water supply diversions.			

Assessment of NWM Performance:

The NWM simulation rated moderate; showed less runoff than observed, with regard to flood peaks and total runoff volume. All this due to water supply reservoir capture and diversions.

Gage #	11460750
Gage Name	WALKER CREEK NEAR MARSHALL, CA
County	Marin
Area [mi^2]	31.1
CNRFC	No
Qpeak [cfs]	10500
Qpeak Year	1998
Q500 [cfs]	9353
Q200 [cfs]	8042
Q100 [cfs]	7070
Q50 [cfs]	6043
Q25 [cfs]	5051
Q10 [cfs]	3751
CC	0.74
PBias	-36%
NSE	0.39
Score (1-5)	2.74
Assess	Moderate
HAT (1-3)	0.95



11461000 RUSSIAN R NR UKIAH CA

Site Description:

Sometimes referred to as the West Fork of the Russian River, this watershed springs from the Laughlin Range about 5 mi (8 km) east of Willits in Mendocino County. It flows generally southward to Redwood Valley, then past Calpella, where it is bordered by U.S. Route 101, to join the East Fork Russian River just below Lake Mendocino.

Remarks from USGS Site Report:

No regulation. Diversions upstream for irrigation of about 1,000 acres.

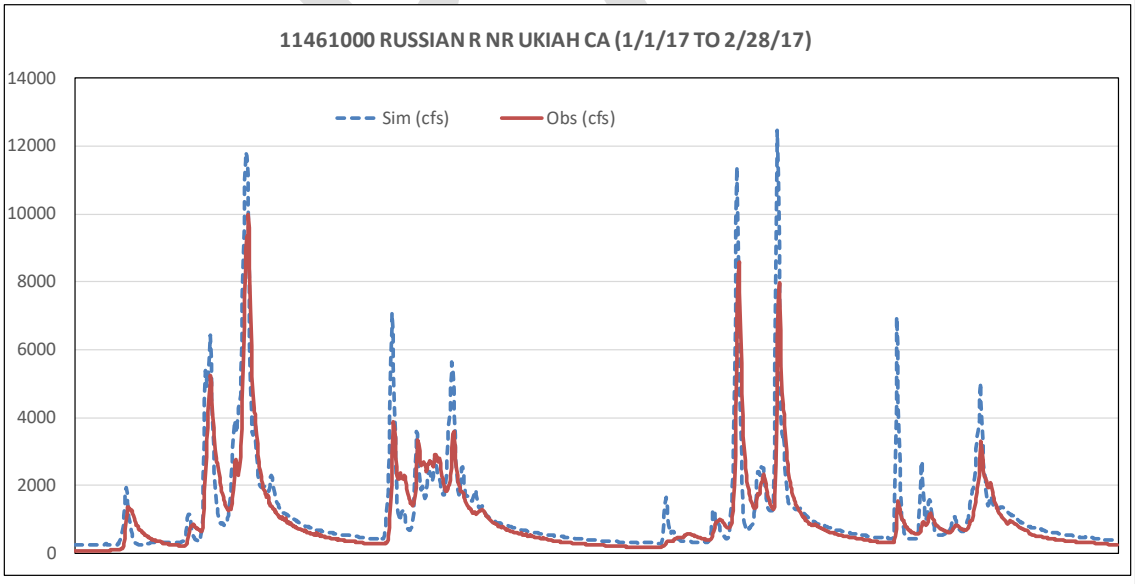
Watershed Factors:

Precipitation:	**Pavg [in] =**	46.7	**Prank =**	3.0
		NWM rainfall intensity may be too high.		
Orography:	**ORO [%] =**	34%	**OROrank =**	3.6
		Moderate bias indicates better rain mapping needed.		
Topography:	**SL [%] =**	20.6	**SLrank =**	3.0
				Moderate slopes.
Soils:	**HGD [%] =**	23.8	**HGDrank =**	1.1
				Moderate percentage pervious soils.
Water management:	**STOR [kaf] =**	0.7	**DISTURB =**	1.7
				No regulation, except for some irrigation.

Assessment of NWM Performance:

NWM simulation tends to over-estimate flood peaks, but otherwise corresponds well to observed flows.

Gage #	11461000
Gage Name	RUSSIAN R NR UKIAH CA
County	Mendocino
Area [mi^2]	100
CNRFC	UKAC1
Qpeak [cfs]	22600
Qpeak Year	2005
Q500 [cfs]	26242
Q200 [cfs]	22677
Q100 [cfs]	20033
Q50 [cfs]	17233
Q25 [cfs]	14503
Q10 [cfs]	10885
CC	0.86
PBias	16%
NSE	0.58
Score (1-5)	3.69
Assess	Good
HAT (1-3)	1.17



11461500 EF RUSSIAN R NR CALPELLA CA

Site Description:

E. Fk. Russian supplies Lake Mendocino, a water supply reservoir for Sonoma County. The Potter Valley Project delivers additional water from the Eel River, which flows into the Russian River here via a controversial hydroelectric plant. Potter Valley is a rich agricultural region, with excellent soils, planted mostly in irrigated pasture, wine grapes, and pears.

Remarks from USGS Site Report:

Diversions into Efk from Eel River through Potter Valley Powerplant used for irrigation.

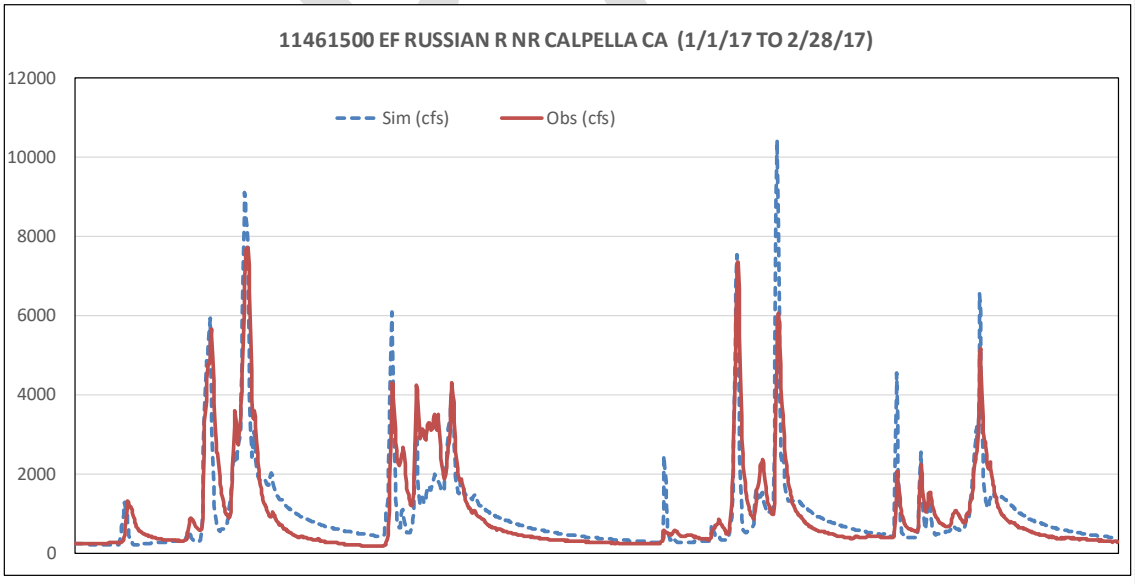
Watershed Factors:

Precipitation:	**Pavg [in] =**	45.1	**Prank =**	2.8
			NWM rainfall seems OK.	
Orography:	**ORO [%] =**	7%	**OROrank =**	1.1
		Low orographohic influence within watershed.		
Topography:	**SL [%] =**	20.9	**SLrank =**	3.1
			Moderate slopes.	
Soils:	**HGD [%] =**	32.4	**HGDrank =**	1.7
			Moderate percentage pervious soils.	
Water management:	**STOR [kaf] =**	0.2	**DISTURB =**	2.3
		No regulation, except for some irrigation.		

Assessment of NWM Performance:

The NWM simulation captures flood peaks relatively well, but over-estimates flows on the recession. Bias is small but this may result from augmented flows beng offset by irrigation losses.

Gage #	11461000
Gage Name	RUSSIAN R NR UKIAH CA
County	Mendocino
Area [mi^2]	100
CNRFC	LAMC1
Qpeak [cfs]	18700
Qpeak Year	1964
Q500 [cfs]	24892
Q200 [cfs]	21525
Q100 [cfs]	19027
Q50 [cfs]	16381
Q25 [cfs]	13799
Q10 [cfs]	10376
CC	0.85
PBias	0%
NSE	0.71
Score (1-5)	4.34
Assess	Excellent
HAT (1-3)	2.33



11462500 RUSSIAN R NR HOPLAND CA

Site Description:

The Russian River springs from the Laughlin Range about 5 mi (8 km) east of Willits in Mendocino County. Joined by the E. Fk. below Lake Mendocino near Ukiah, it flows south past vineyards to Hopland and then crosses into Sonoma County near Cloverdale. Russian River nr Hopland gage is important control point to guide Lake Mendocino reservoir operations.

Remarks from USGS Site Report:

Flow regulated by Lake Mendocino 15.2 mi upstream. Diversions for irrigation of ~11,800 acres upstream.

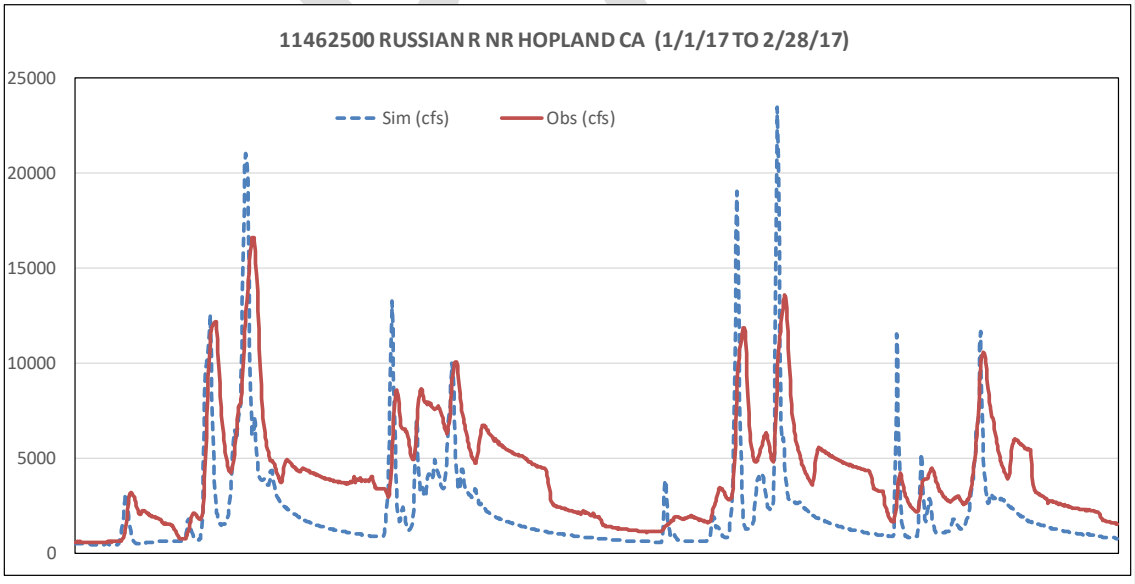
Watershed Factors:

Precipitation:	**Pavg [in] =**	45.5	**Prank =**	2.9
			NWM rainfall seems OK.	
Orography:	**ORO [%] =**	21%	**ORQrank =**	2.5
			Low orographic influence within watershed.	
Topography:	**SL [%] =**	21.1	**SLrank =**	3.1
			Moderate slopes.	
Soils:	**HGD [%] =**	27.5	**HGDrank =**	1.4
			Moderate percentage pervious soils.	
Water management:	**STOR [kaf] =**	156.2	**DISTURB =**	3.8
			No regulation, except for some irrigation.	

Assessment of NWM Performance:

NWM simulation over-estimated flood peaks because Lake Mendocino reservoir operations not reflected. Large negative bias for overall water volume indicates that reservoir releases exceed Jan-Feb runoff.

Gage #	11462500
Gage Name	Russian River near Hopland, CA
County	Mendocino
Area [mi^2]	362
CNRFC	HOPC1
Qpeak [cfs]	45000
Qpeak Year	1955
Q500 [cfs]	85375
Q200 [cfs]	74362
Q100 [cfs]	66187
Q50 [cfs]	57508
Q25 [cfs]	48922
Q10 [cfs]	37373
CC	0.63
PBias	-46%
NSE	-0.20
Score (1-5)	1.66
Assess	Mediocre
HAT (1-3)	2.67



AQPI
Advanced Quantitative Precipitation Information

11463170 BIG SULPHUR C A G RESORT NR CLOVERDALE CA

Site Description:

This gage is located in the headwaters of Big Sulphur Creek near to peaks of the Mayacama mtns. The small drainage area may be missed by intesense rain cells associated with orographic influences.

Remarks from USGS Site Report:

Diversion for industry upstream when above 10 ft³/s. Records fair except above 200 ft³/s, which are poor.

Watershed Factors:

Precipitation: **Pavg [in] =** 58.6 **Prank =** 4.4
High rainfall on mountain east of Russian River valley.

Orography: **ORO [%] =** 2% **OROrank =** 0.8
Located near top of mountain; storng orography from below.

Topography: **SL [%] =** 28.9 **SLrank =** 4.8
Very steep slopes speed runoff.

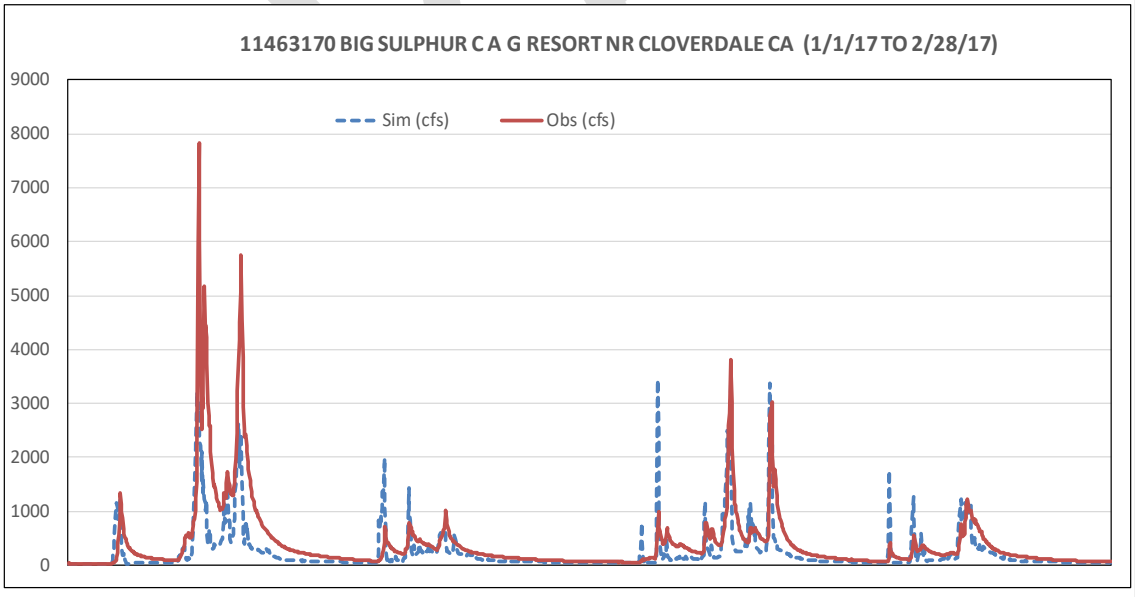
Soils: **HGD [%] =** 47.3 **HGDrank =** 2.6
Moderately impervious soils.

Water management: **STOR [kaf] =** 0.0 **DISTURB =** 0.0
No reservoir regulation.

Assessment of NWM Performance:

For the assessment period the NWM showed variable performance with high negative Pbias. This is attributed to poor tracking of rainfall patterns at the high mountain elevations.

Gage #	11463170
Gage Name	BIG SULPHUR C A G RESORT NR CLOVERDALE CA
County	Sonoma
Area [mi^2]	13.1
CNRFC	No
Qpeak [cfs]	8010
Qpeak Year	1997
Q500 [cfs]	4971
Q200 [cfs]	4289
Q100 [cfs]	3782
Q50 [cfs]	3245
Q25 [cfs]	2726
Q10 [cfs]	2045
CC	0.73
PBias	-40%
NSE	0.46
Score (1-5)	2.79
Assess	Moderate
HAT (1-3)	0.76



11464000 RUSSIAN R NR HEALDSBURG CA

Site Description:

Located on the main stem Russian River, this gage serves as a reference for tracking flood and low flows by water managers. River flows are influenced by operation of Lake Mendocino which captures flood flows and makes releases for water supply and fishery habitat.

Remarks from USGS Site Report:

Flow regulated by Lake Mendocino 63 mi upstream, beginning November 1958. Many diversions for irrigation.

Watershed Factors:

Precipitation: **Pavg [in] =** 45.6 **Prank =** 3.0
High rainfall on mountain east of Russian River valley.

Orography: **ORO [%] =** 10% **OROrank =** 1.5
Located near top of mountain; storng orography from below.

Topography: **SL [%] =** 21.3 **SLrank =** 3.4
Very steep slopes speed runoff.

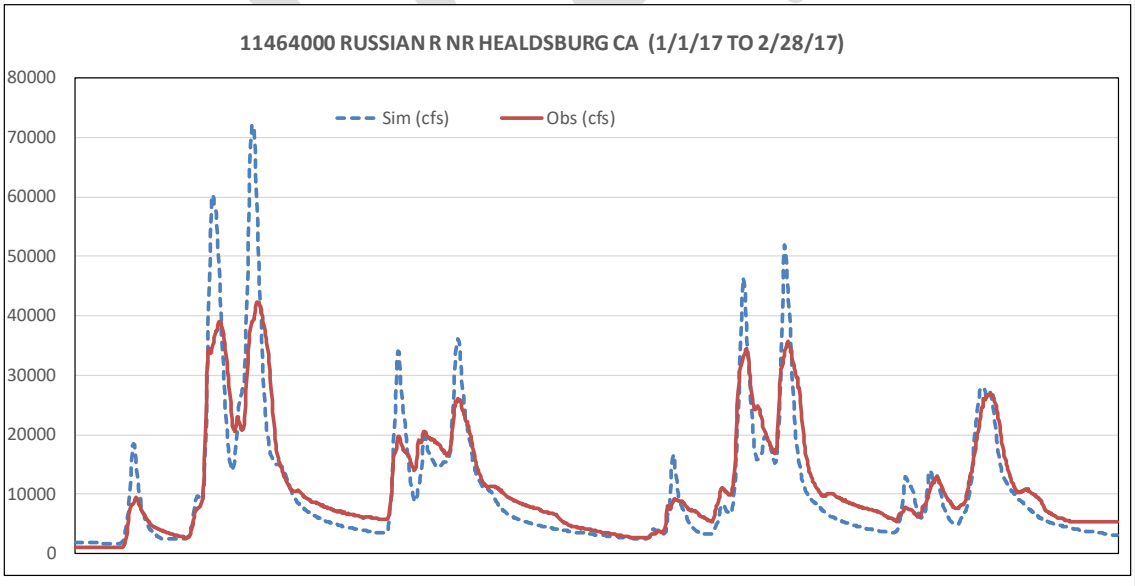
Soils: **HGD [%] =** 29.8 **HGDrank =** 1.5
Moderately pervious soils.

Water management: **STOR [kaf] =** 160.7 **DISTURB =** 3.1
Peak flows regulated by Lake Mendocino.

Assessment of NWM Performance:

In spite of all the water management influences, the NWM gets high marks with statistics. But influence of Lake Mendocino operations for flood control are evident as the observed peaks are consistently lower than simulated.

Gage #	11464000
Gage Name	RUSSIAN R NR HEALDSBURG CA
County	Sonoma
Area [mi^2]	793
CNRFC	HEAC1
Qpeak [cfs]	73000
Qpeak Year	1993
Q500 [cfs]	167577
Q200 [cfs]	146305
Q100 [cfs]	130526
Q50 [cfs]	113767
Q25 [cfs]	97086
Q10 [cfs]	74517
CC	0.91
PBias	-7%
NSE	0.70
Score (1-5)	4.19
Assess	Excellent
HAT (1-3)	3.0



AQPI
Advanced Quantitative Precipitation Information

11465660 COPELAND C A ROHNERT PARK CA

Site Description:

Copeland Creek is a very small watershed draining the west slope of Sonoma Mountain and then through a suburbanized area of Rohnert Park, CA.

Remarks from USGS Site Report:

No regulation or diversion upstream of station

Watershed Factors:

Precipitation: **Pavg [in] =** 43.5 **Prank =** 2.7
Moderate rainfall on mountain east of Russian River valley.

Orography: **ORO [%] =** 33% **OROrank =** 3.5
Located on west slope of mountain; strong orographic influence.

Topography: **SL [%] =** 10.0 **SLrank =** 1.3
Small drainage area with low slope.

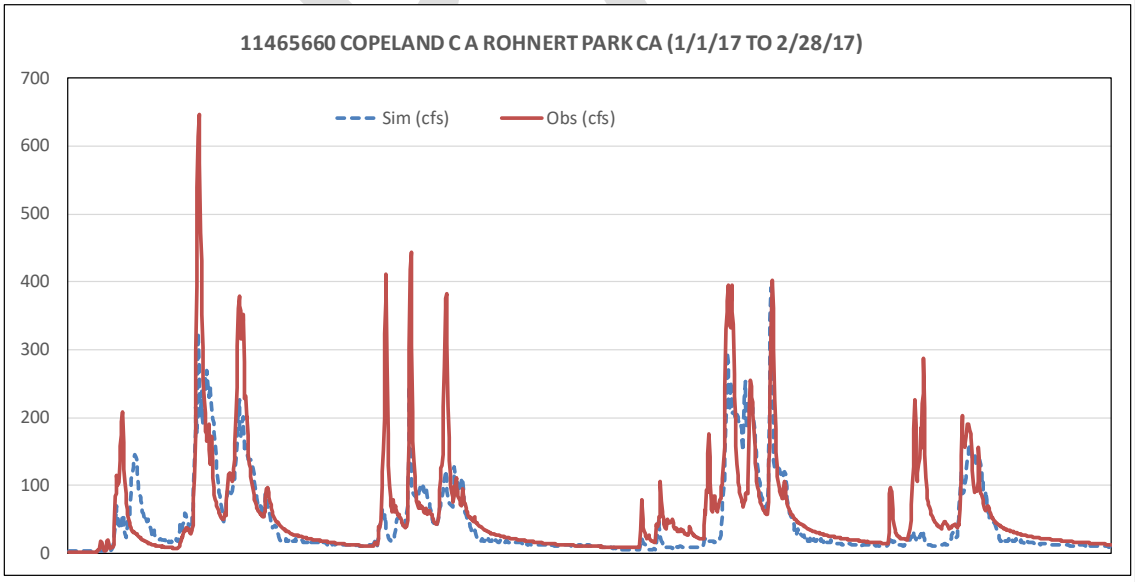
Soils: **HGD [%] =** 84.3 **HGDrank =** 5.0
Very high percentage impervious soils.

Water management: **STOR [kaf] =** 0.0 **DISTURB =** 2.1
No reservoir regulation.

Assessment of NWM Performance:

For the assessment period the NWM mimicked gaged flows, but consistently under-predicted peak flows. There seems under-prediction of rainfall and/or over-prediction of abstractions. This may be attributed to poor representation of rain spatial distribution and tight soils. Also, storm runoff from the suburban impervious areas of Rohnert Park.

Gage #	11465660
Gage Name	COPELAND C A ROHNERT PARK CA
County	Sonoma
Area [mi^2]	6.23
CNRFC	No
Qpeak [cfs]	672
Qpeak Year	2016
Q500 [cfs]	2624
Q200 [cfs]	2259
Q100 [cfs]	1988
Q50 [cfs]	1701
Q25 [cfs]	1425
Q10 [cfs]	1064
CC	0.77
PBias	-23%
NSE	0.56
Score (1-5)	3.42
Assess	Good
HAT (1-3)	0.94



11465680 LAGUNA DE SANTA ROSA A STONY PT RD NR COTATI CA

Site Description:

The Laguna de Santa Rosa near Cotati feeds into a wetland complex tencompassing most of the Santa Rosa Plain in Sonoma County. The sinuous watercourse and associated wetlands form a significant floodplain, capable of storing over 80,000 acre feet of stormwater.

Remarks from USGS Site Report:

No regulation or diversion upstream from station

Watershed Factors:

Precipitation: **Pavg [in] =** 36.5 **Prank =** 2.1
Moderate rainfall on east side of Russian River valley.

Orography: **ORO [%] =** 5% **OROrank =** 3.5
Located on west slope of mountain; strong orographic influence.

Topography: **SL [%] =** 6.0 **SLrank =** 0.5
Small drainage area with low slope.

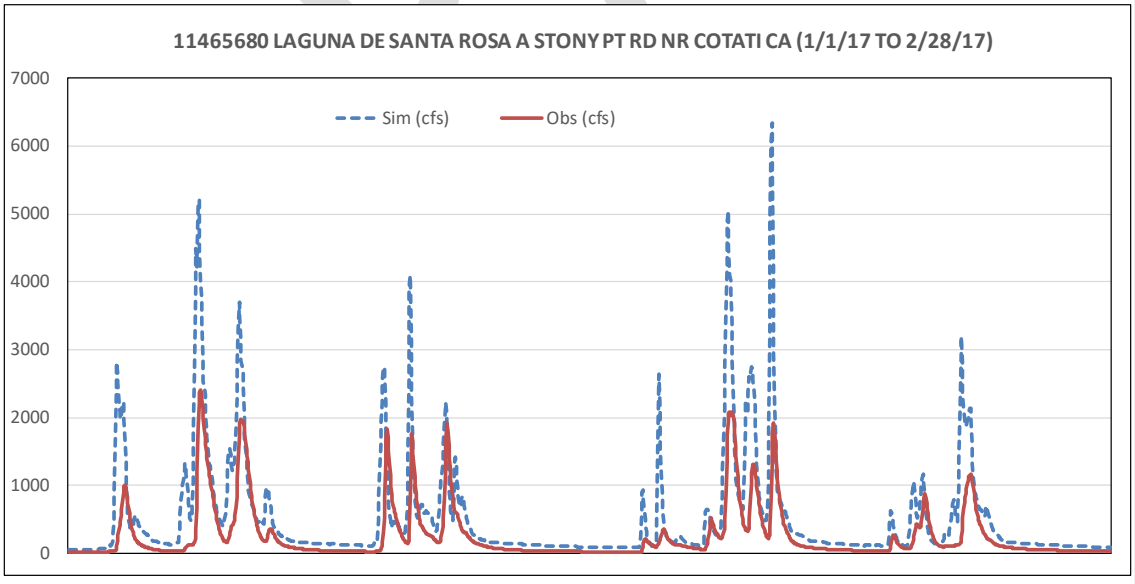
Soils: **HGD [%] =** 75.2 **HGDrank =** 4.4
High percentage impervious soils represents wetlands.

Water management: **STOR [kaf] =** 0.0 **DISTURB =** 2.7
No reservoir regulation. Flow routing through wetlands poor.

Assessment of NWM Performance:

The NWM simulation over-predicted streamflows for the entire period; the runoff volume bias exceeds +100%. Overall performance is poor due to runoff storage and attenuation in wetlands. See https://en.wikipedia.org/wiki/Laguna_de_Santa_Rosa.

Gage #	11465680
Gage Name	LAGUNA DE SANTA ROSA A STONY PT RD NR COTATI CA
County	Sonoma
Area [mi^2]	40.8
CNRFC	No
Qpeak [cfs]	3980
Qpeak Year	2005
Q500 [cfs]	12720
Q200 [cfs]	10959
Q100 [cfs]	9653
Q50 [cfs]	8271
Q25 [cfs]	6933
Q10 [cfs]	5172
CC	0.74
PBias	104%
NSE	-1.33
Score (1-5)	0.26
Assess	Poor
HAT (1-3)	1.02



AQPI
Advanced Quantitative Precipitation Information

11466170 MATANZAS C A SANTA ROSA CA

Site Description:

Matanzas Creek springs from the northern slope of Sonoma Mountain and flows northward into Bennett Valley to join Santa Rosa Creek. The upper reaches have gradients up to fifteen percent on Sonoma Mtn. Channel has been deepened 4 to 5 meters to minimize urban flooding where it flows through Quaternary alluvium of the Santa Rosa Plain.

Remarks from USGS Site Report:

No regulation or diversion upstream from station

Watershed Factors:

Precipitation: **Pavg [in] =** 41.7 **Prank =** 2.5
Moderate rainfall on east side of Russian River valley.

Orography: **ORO [%] =** 32% **OROrank =** 3.5
Located on west slope of mountain; strong orographic influence.

Topography: **SL [%] =** 12.2 **SLrank =** 1.7
Moderate slope

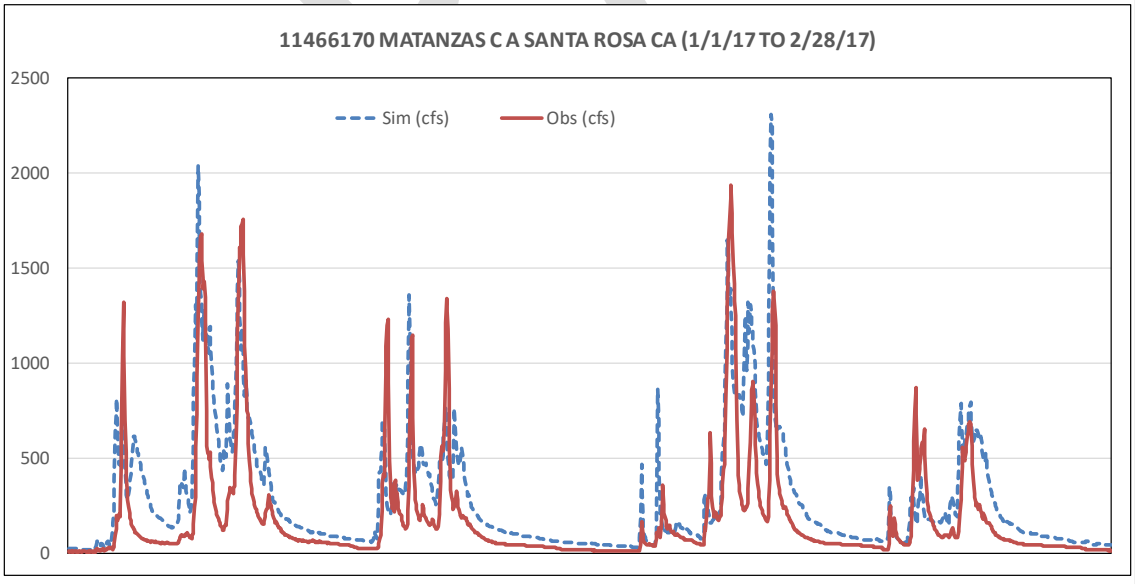
Soils: **HGD [%] =** 73.4 **HGDrank =** 4.3
High percentage impervious soils.

Water management: **STOR [kaf] =** 2.3 **DISTURB =** 3.5
No reservoir regulation. Flow routing through wetlands poor.

Assessment of NWM Performance:

Overall performance is good for flood peaks, but the NWM over-estimates on the recessions. Perhaps the channel loses water into the gravel substrate. https://en.wikipedia.org/wiki/Matanzas_Creek

Gage #	11466170
Gage Name	MATANZAS C A SANTA ROSA CA
County	Sonoma
Area [mi^2]	21.0
CNRFC	No
Qpeak [cfs]	3700
Qpeak Year	2005
Q500 [cfs]	7527
Q200 [cfs]	6491
Q100 [cfs]	5722
Q50 [cfs]	4908
Q25 [cfs]	4120
Q10 [cfs]	3084
CC	0.77
PBias	54%
NSE	0.38
Score (1-5)	2.31
Assess	Moderate
HAT (1-3)	1.38



11466200 SANTA ROSA C A SANTA ROSA CA

Site Description:

Santa Rosa Creek is a 22-mile-long (35 km) stream in Sonoma County, California, which rises on Hood Mountain and discharges to the Laguna de Santa Rosa by way of the Santa Rosa Flood Control Channel. Though it begins as a wild stream in the Mayacamas Mountains, Santa Rosa Creek is culverted for part of its course through the city of Santa Rosa's downtown, and flood flows are diverted into Spring Lake.

Remarks from USGS Site Report:

Water is diverted into Spring Lake, 5.9 mi upstream, during flood events. Diversions upstream for irrigation of about 5,000 acres.

Watershed Factors:

Precipitation: **Pavg [in] =** 42.4 **Prank =** 2.6
Moderate rainfall on east side of Russian River valley.

Orography: **ORO [%] =** 33% **OROrank =** 3.5
Located on west slope of mountain; strong orographic influence.

Topography: **SL [%] =** 15.8 **SLrank =** 2.4
Moderate slope

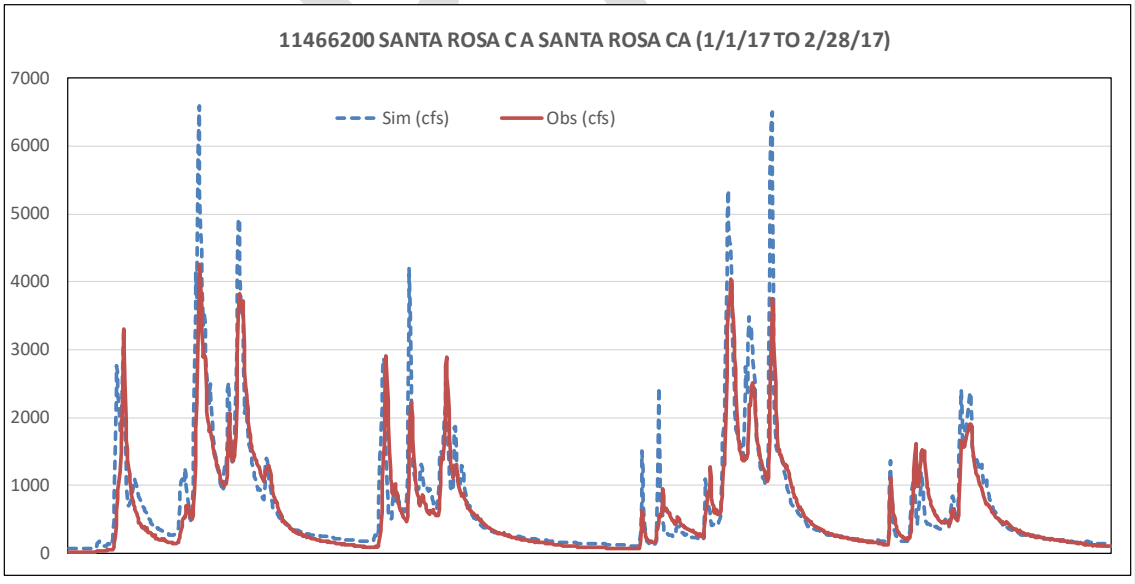
Soils: **HGD [%] =** 63.5 **HGDrank =** 3.7
High percentage impervious soils.

Water management: **STOR [kaf] =** 6.1 **DISTURB =** 3.1
Diversion of flood peaks to Spring Lake.

Assessment of NWM Performance:

Overall performance is good for flood peaks with some over-estimation, but the model does well across skill metrics wirh low bias and high NSE.

Gage #	11466200
Gage Name	SANTA ROSA C A SANTA ROSA CA
County	Sonoma
Area [mi^2]	57.0
CNRFC	No
Qpeak [cfs]	9080
Qpeak Year	1940
Q500 [cfs]	14635
Q200 [cfs]	12555
Q100 [cfs]	11017
Q50 [cfs]	9394
Q25 [cfs]	7826
Q10 [cfs]	5776
CC	0.90
PBias	12%
NSE	0.69
Score (1-5)	4.03
Assess	Excellent
HAT (1-3)	1.98



11466320 SANTA ROSA C A WILLOWSIDE RD NR SANTA ROSA CA

Site Description:

Santa Rosa Creek is a 22-mile-long (35 km) stream in Sonoma County, California, which rises on Hood Mountain and discharges to the Laguna de Santa Rosa by way of the Santa Rosa Flood Control Channel. Though it begins as a wild stream in the Mayacamas Mountains, Santa Rosa Creek is culverted for part of its course through the city of Santa Rosa's downtown, and flood flows are diverted into Spring Lake.

Remarks from USGS Site Report:

Water diverted into Spring Lake during floods

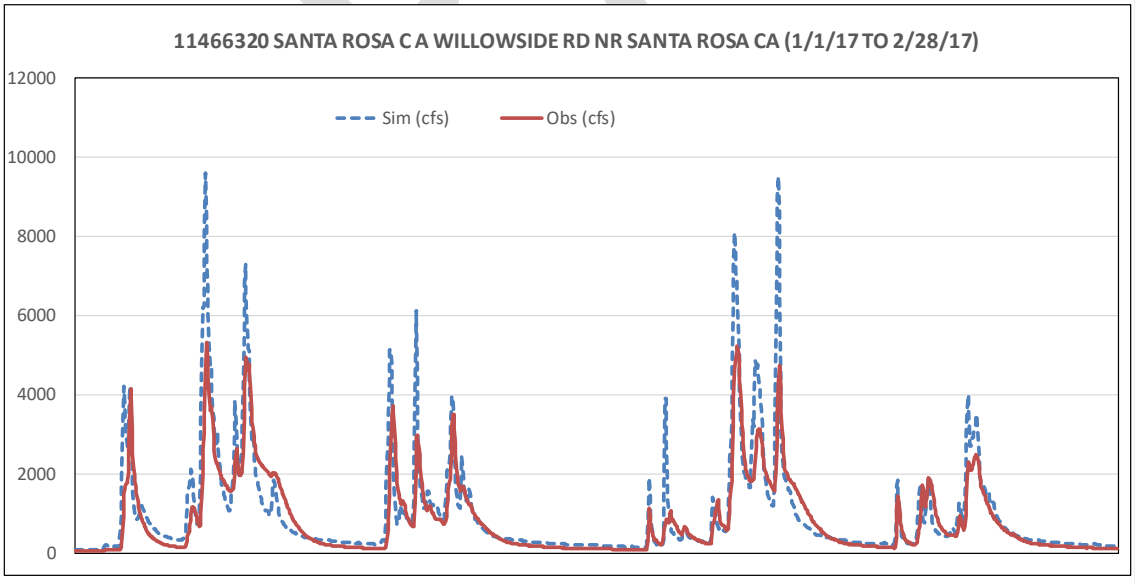
Watershed Factors:

Precipitation:	**Pavg [in] =**	40.4	**Prank =**	2.4	
		Moderate rainfall on east side of Russian River valley.			
Orography:	**ORO [%] =**	7%	**ORO rank =**	1.2	
		Located in valley, low orographc effect.			
Topography:	**SL [%] =**	12.2	**SL rank =**	1.7	
				Moderate slope	
Soils:	**HGD [%] =**	55.1	**HGD rank =**	3.1	
		Moderately high percentage impervious soils.			
Water management:	**STOR [kaf] =**	7.0	**DISTURB =**	3.8	
		Diversion of flood peaks to Spring Lake.			

Assessment of NWM Performance:

The NWM simulation over-predicted flood peaks, perhaps due to diversions into Spring Lake. Overall performance is good for flood peaks with some over-estimation, but the model does well across skill metrics wirh low bias and high NSE.

Gage #	11466320
Gage Name	SANTA ROSA C A WILLOWSIDE RD NR SANTA ROSA CA
County	Sonoma
Area [mi^2]	77.6
CNRFC	No
Qpeak [cfs]	8100
Qpeak Year	2019
Q500 [cfs]	22270
Q200 [cfs]	19272
Q100 [cfs]	17046
Q50 [cfs]	14687
Q25 [cfs]	12385
Q10 [cfs]	9332
CC	0.87
PBias	17%
NSE	0.52
Score (1-5)	3.56
Assess	Good
HAT (1-3)	1.74



11466800 Mark West Creek near Mirabel Heights, CA

Site Description:

Mark West Creek is a 29.9-mile-long (48.1 km) stream that rises in the Mayacamas Mountains of Sonoma County. Discharge waters of Mark West Creek reach the Russian River after a confluence with the Laguna de Santa Rosa.

Remarks from USGS Site Report:

No regulation upstream of station, some diversion for irrigation of about 11,000 acres.

Watershed Factors:

Precipitation: **Pavg [in] =** 39.6 **Prank =** 2.3
Moderate rainfall on east side of Russian River valley.

Orography: **ORO [%] =** 0% **OROrank =** 0.6
Located in valley, low orographc effect.

Topography: **SL [%] =** 9.2 **SLrank =** 1.1
Moderate slope; drainds wetland area.

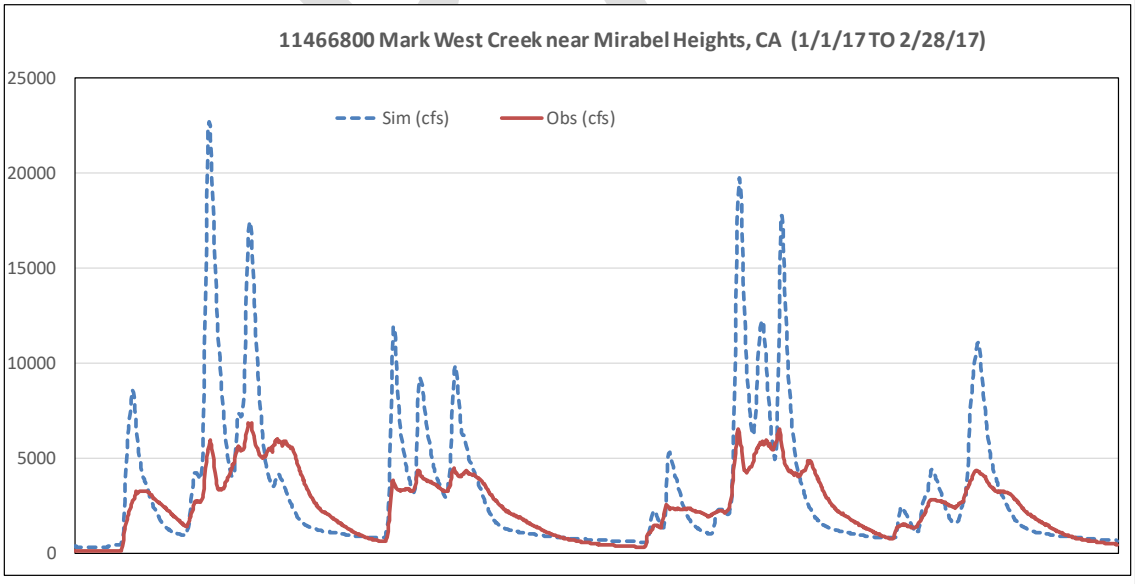
Soils: **HGD [%] =** 52.1 **HGDrank =** 2.9
Moderately high percentage impervious soils.

Water management: **STOR [kaf] =** 12.8 **DISTURB =** 4.6
Routed flows through Laguna de Santa Rosa geatly attenuated.

Assessment of NWM Performance:

The NWM simulation greatly over-predicted flood peaks and compares poorly to observed flows in general. The poor performance is perhaps due to inflows from the Laguna de Santa Rosa which drains a large wetland area in the valley. Inflows from the Laguna de Santa Rosa wetland area are attenuated; NWM routing does not represent this influence.

Gage #	11466800
Gage Name	MARK WEST CREEK NEAR MIRABEL HEIGHTS, CA
County	Sonoma
Area [mi^2]	251
CNRFC	No
Qpeak [cfs]	11300
Qpeak Year	2005
Q500 [cfs]	56080
Q200 [cfs]	48525
Q100 [cfs]	42931
Q50 [cfs]	37006
Q25 [cfs]	31195
Q10 [cfs]	23463
CC	0.75
PBias	30%
NSE	-1.99
Score (1-5)	2.12
Assess	Mediocre
HAT (1-3)	0.93



11467000 RUSSIAN R NR GUERNEVILLE CA

Site Description:

The Russian River is a southward-flowing river that drains 1,485 sq mi (3,850 km2)of Sonoma and Mendocino counties in Northern California. The Guerneville gage is the most downstream gage on the mainstem. The site is well known for the high flood levels that occur. Flows are regulated by Lake Mendocino (~100 mi^2) and Lake Sonoma on Dry Creek (130 mi^2).

Remarks from USGS Site Report:

Flow regulated by Lake Mendocino 77 mi upstream, beginning November 1958, and by Lake Sonoma 26 mi upstream.

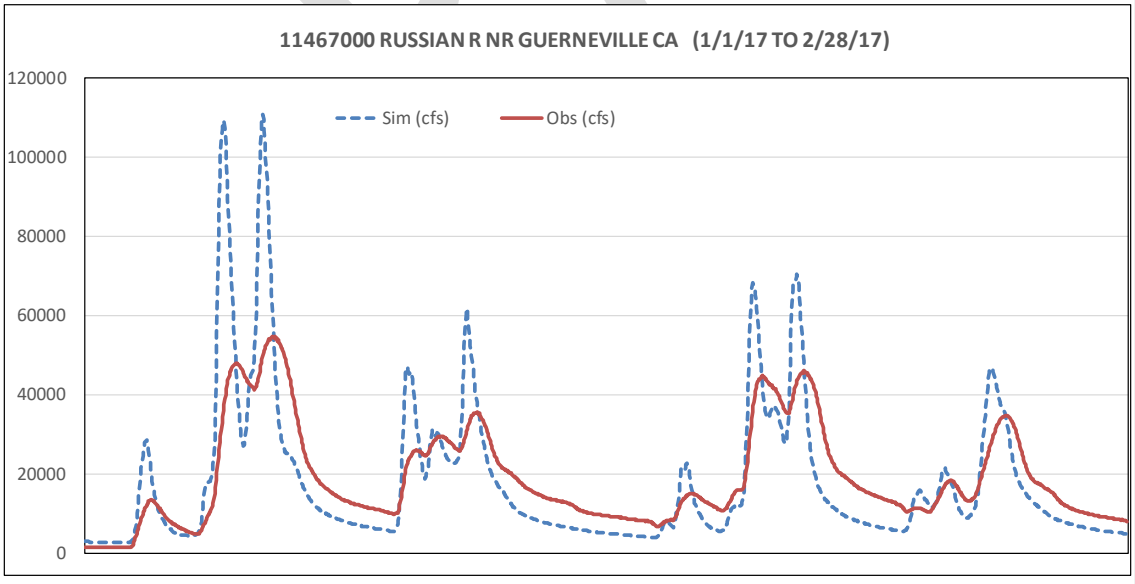
Watershed Factors:

Precipitation:	**Pavg [in] =**	45.3	**Prank =**	2.9
	Moderate rainfall over Russian River valley.			
Orography:	**ORO [%] =**	-5%	**OROrank =**	0.2
	Located in valley, low orographc effect.			
Topography:	**SL [%] =**	18.8	**SLrank =**	2.9
	Moderate to steep slopes, variable.			
Soils:	**HGD [%] =**	31.5	**HGDrank =**	1.6
	Moderate percentage pervious soils.			
Water management:	**STOR [kaf] =**	624.0	**DISTURB =**	3.8
	Reservoirs and diversions a major factor.			

Assessment of NWM Performance:

The NWM simulation greatly over-predicted flood peaks and compares poorly to observed flows in general. The poor performance is attributed to water management factors not represented in the NWM.Reservoir regulation and water management factors seem evident in the comparison to observed flows.

Gage #	11467000
Gage Name	RUSSIAN R NR GUERNEVILLE CA
County	Sonoma
Area [mi^2]	1338
CNRFC	GUEC1
Qpeak [cfs]	102000
Qpeak Year	1986
Q500 [cfs]	168899
Q200 [cfs]	147509
Q100 [cfs]	131641
Q50 [cfs]	114785
Q25 [cfs]	98001
Q10 [cfs]	75282
CC	0.78
PBias	-5%
NSE	0.05
Score (1-5)	2.88
Assess	Moderate
HAT (1-3)	1.83



11466800 AUSTIN C NR CAZADERO CA

Site Description:

Austin Creek is a 16-mile-long (25.7 km) southward-flowing stream which drains the east side of the Coast Range of western Sonoma County, CA. It empties into the Russian River about 4 miles (6 km) from the Pacific Ocean. As of 2000, Austin Creek and all its major tributaries all supported steelhead trout.

Remarks from USGS Site Report:

No regulation or diversion upstream from station.

Watershed Factors:

Precipitation: **Pavg [in] =** 64.0 **Prank =** 5.0
Highest rainfall in region. Rainfall mapping a concern.

Orography: **ORO [%] =** 18% **OROrank =** 2.3
East side of mountains not well mapped

Topography: **SL [%] =** 28.9 **SLrank =** 4.8
Very steep slopes.

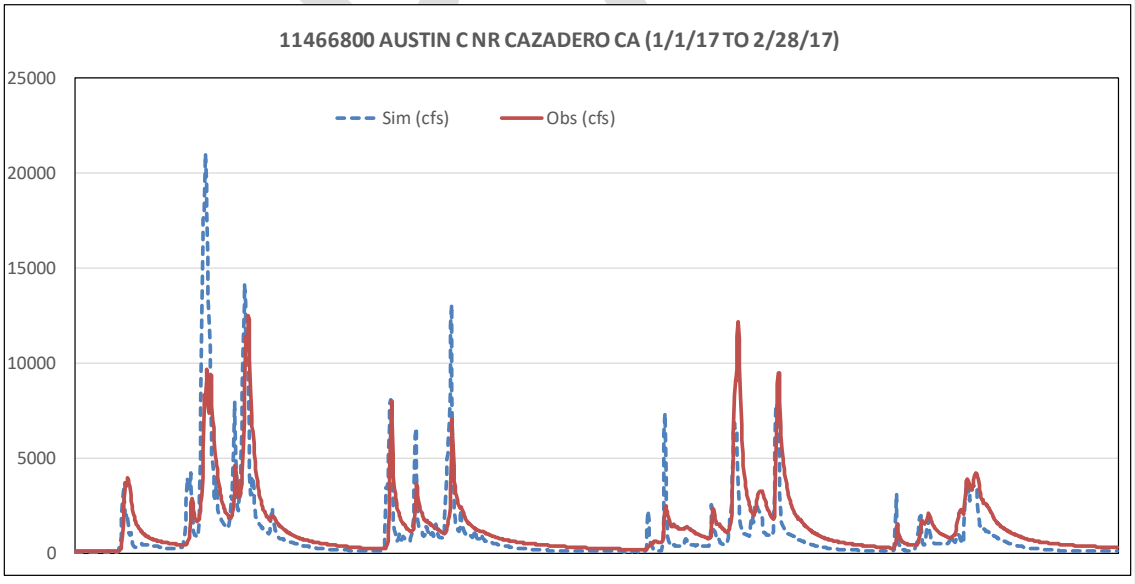
Soils: **HGD [%] =** 12.7 **HGDrank =** 0.4
Moderate percentage pervious soils.

Water management: **STOR [kaf] =** 0.0 **DISTURB =** 0.6
No regulation, some irrigation.

Assessment of NWM Performance:

The NWM simulationshowed mixed results - some flood peaks were over-estimated and the negative bias indicates not all water accounted for. Precipitation mapping on the east side of the Coastal Range may be problematic.

Gage #	11467200
Gage Name	AUSTIN C NR CAZADERO CA
County	Sonoma
Area [mi^2]	63
CNRFC	No
Qpeak [cfs]	20900
Qpeak Year	2014
Q500 [cfs]	21318
Q200 [cfs]	18594
Q100 [cfs]	16561
Q50 [cfs]	14400
Q25 [cfs]	12278
Q10 [cfs]	9432
CC	0.74
PBias	-24%
NSE	0.28
Score (1-5)	2.82
Assess	Moderate
HAT (1-3)	1.18



11467510 SF GUALALA R NR THE SEA RANCH CA

Site Description:

The Gualala River is located on the northern coast of California. The headwaters of the 40-mile-long (64 km) river are high in the Coast Range, and it empties into the Pacific Ocean. The watershed is sparsely populated. Timber production is the predominant land use, historically and currently. The most important problem for the watershed is excessive erosion due to logging roads and forest clearing.

Remarks from USGS Site Report:

Some diversion for agriculture and domestic use

Watershed Factors:

Precipitation: **Pavg [in] =** 57.2 **Prank =** 4.3

Highest rainfall in region. Rainfall mapping a concern.

Orography: **ORO [%] =** 36% **OROrank =** 4.3

Orographic effects of Coast Range seem represented OK.

Topography: **SL [%] =** 26.2 **SLrank =** 4.3

Very steep slopes.

Soils: **HGD [%] =** 6.1 **HGDrank =** 0.0

Low percentage impervious soils.

Water management: **STOR [kaf] =** 0.8 **DISTURB =** 1.3

Little regulation, some irrigation and domestic uses.

Assessment of NWM Performance:

The NWM simulation showed generally good results. A major flood peak was over-estimated, but otherwise the model tracked well with observations.

Gage #	11467200
Gage Name	AUSTIN C NR CAZADERO CA
County	Sonoma
Area [mi^2]	63
CNRFC	No
Qpeak [cfs]	28500
Qpeak Year	2014
Q500 [cfs]	48668
Q200 [cfs]	42591
Q100 [cfs]	38058
Q50 [cfs]	33240
Q25 [cfs]	28468
Q10 [cfs]	22021
CC	0.86
PBias	-13%
NSE	0.69
Score (1-5)	3.99
Assess	Good
HAT (1-3)	1.73