Appendix D

Hydrology Methodology Memorandum

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DRAFT MEMORANDUM

TO:	Roger Leventhal, PE	DATE:	March 16, 2016
FROM:	Dan Schaaf, PE Sarah Rahimi, PE	JOB#:	MARN.01.15
SUBJECT:	Calibration of a Design Storm Hydrologic Model		

Purpose

This technical memorandum presents the calibration method and the design storm hydrologic model developed for the Marin County watershed. This calibration process is purely a statistical one, i.e., given a 100-year design storm over a watershed, what watershed parameters are needed to convert that rainfall into, not just any runoff hydrograph, but a 100-year hydrograph with a 100-year peak discharge that mimics the statistics of the 100-year peak discharge at the stream gage location.

A design storm hydrologic model is used to estimate peak discharge during different frequency storm events (e.g. the 100-year design storm or the 10-year design storm). It should be noted that a design storm is a hypothetical storm and is not an actual rainfall event. Therefore, this type of model cannot be used to replicate a specific event in time. Once calibrated, a design storm hydrologic model can be used to study the effect of changing land use or cover on peak discharge, and analyzing the effects of the change in storage on downstream discharges.

Gages for Calibration

One of the steps in the calibration process is to locate nearby stream gages with long-term records (ideally 30 years or more of record). These watersheds need to be able to have a log-Pearson Type III statistical analysis done on the stream gauge records for instantaneous peak discharge as well as for volume of discharge for various durations. The gauged must be in compliance with Bulletin 17B guidelines. These guidelines will eliminate streams on which there are large storage facilities, streams that are subject to the effects of urbanization, and streams that have greatly modified conveyance systems.

Active and non-active stream gages were located from USGS in the vicinity of Marin County, this included Alameda County, Contra Costa County, Marin County, Napa County, Sonoma County, San Mateo County, and Solano County. The approximately 222 active and non-active gages were cataloged using the length of record, presence of upstream storage, and urbanization. Gages were evaluated for statistical processing by the following criteria:

Length of Record

Gages with lengths of record less than 30 years were removed from consideration for the statistical analysis. The 30-year cut off was developed by using Table 9-1 in Bulletin 17b for the 0.01 recurrence interval and an upper limit of 0.75 and a lower limit of 0.25. This would provide a difference of 0.5. This means that with 30 years of data, the estimate of the 100-year discharge is good to within ½ of the Standard Deviation of the data approximately 50 percent of the time. This criterion was applied to all the gages except for the Arroyo Corte Madera Del Presidio gage. This gage only had record length of 18 years, however, this was deemed acceptable due to its close proximity to Marin County.

Upstream Storage

Gages which were affected by upstream storage modification such as a reservoir or dam where removed from consideration for statistical analysis. The function of a reservoir can have a significant effect upon the downstream flow regime. Very often the lower peak discharges are modified by the reservoir to such an extent that the upstream watershed does not contribute to downstream flow. Higher flood events are modified by the natural attenuation of flood waves as they pass through the reservoir. Water supply reservoirs have varying water levels depending upon time of year and antecedent runoff. The storage in those reservoirs can significantly affect downstream discharges. According to Bulletin 17B existence of upstream reservoir would make the downstream gage record non-homogeneous and therefore not appropriate for frequency analysis.

Urbanization

Gages with which are affected by urbanization were removed from consideration for statistical analysis. Watershed changes due to urbanization impact the homogeneity of the stream gage record according to Bulletin 17B. The Bulletin goes on to state that "Only records which represent relatively constant watershed conditions should be used for frequency analysis."

Based on the above evaluation criteria, the original 222 stream gages were narrowed to 4 gages that will be subject to statistical analysis. This final cut left four watersheds with gage data (in general) of 30 or more years, without significant urbanization or upstream storages. These are shown below in Table 1.

Table 1. Gages Determined for Calibration

USGS Station Number	Station Name	ID	Years of Record	Number of Records
11458500	SONOMA C A AGUA CALIENTE CA	Sonoma	1955-2015	40
11460100	ARROYO CORTE MADERA DEL PRESIDIO	Arroyo	1966-1985	18
11460000	CORTE MADERA C A ROSS CA	Corte Madera	1951-2015	43
11182500	SAN RAMON C A SAN RAMON CA	San Ramon	1953-2015	62

Flow Frequency Analyses

Flood frequency analyses were performed on the four remaining gage stations for instantaneous peak values using bulletin 17b guidelines in U.S. Army Corps of Engineers' Statistical Software Package (HEC-SSP) HEC-SSP. HEC-SSP is a statistical software program that allows the user to perform statistical analyses of hydrologic data. The resulting flood frequency curve and confidence intervals are plotted on a log-normal scale (see attached plots). A weighted skew was used which weights the computed station skew with the generalized regional skew. The regional skew was taken from the map in Bulletin 17b and a value of 0.302 was consistently used for the regional skew mean standard error. This value was obtained from national skew map in Bulletin 17b. Attachment A presents the frequency curves for each gage.

Design Storm

The 24-hr design storm pattern was developed using a 10-min timestep and was based on NOAA Altas-14 statistics. For each gage, NOAA Atlas-14 24-hr point precipitation frequency estimates (as shown in Table 2) were applied the design storm pattern to develop the design storms for the 10-yr, 25-yr, 50-yr, 100-yr events.

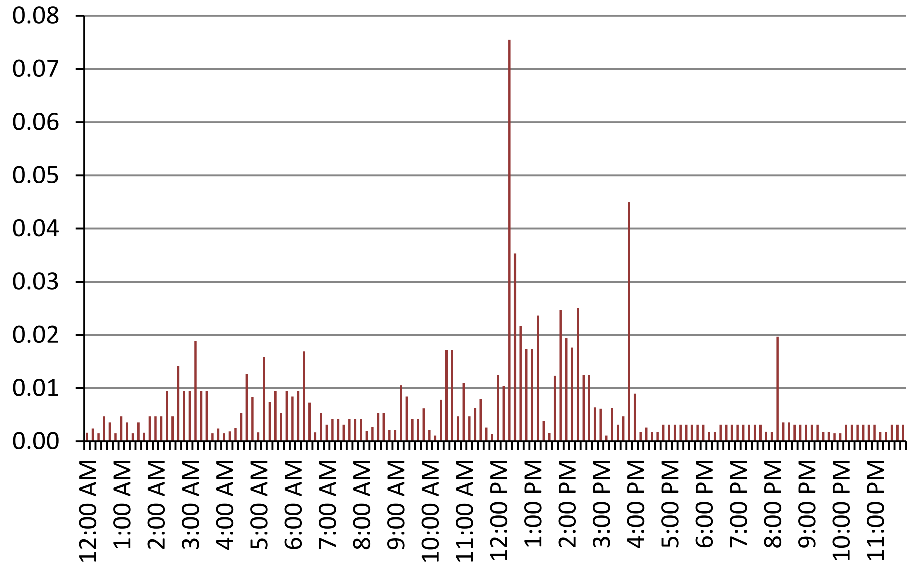

Figure 1. 24-hr Design Storm Pattern

Table 2. NOAA Atlas-14 24-hr Point Precipitation Frequency Estimates

Gage Location	10-yr	25-yr	50-yr	100-yr
SONOMA C A AGUA CALIENTE CA	6.83	8.11	9.07	10.0
ARROYO CORTE MADERA DEL PRESIDIO	6.38	7.83	9.02	10.3
CORTE MADERA C A ROSS CA	6.64	8.03	9.10	10.20
SAN RAMON C A SAN RAMON CA	4.30	5.20	5.90	6.62

Watershed Modeling

U.S. Army Corps of Engineers' HEC-HMS 4.1 (USACE, 2015) was used to develop the peak design storm flows for each subbasin. HEC-HMS is a software program created by the USACE to simulate the process of precipitation and runoff in watersheds, the program creates hydrographs for basin runoff. To do this, the program requires the watershed parameters, meteorological model, control specifications, and timeseries data. Four storm events were modeled: the 10-, 25-, 50-, and 100-yr storm events. A 100-year storm event is an event that has a 100-year recurrence interval, meaning is has a 1% chance of occurring in any given year.

Rainfall-Runoff Parameters

To develop a hydrologic model it is important to determine a number of physical parameters that represent the hydrology of the watershed to be modeled. The number and types of parameters are a function of the hydrologic model to be used. The Initial and Constant method was selected as the loss method, and Soil Conservation Service (SCS) Unit Hydrograph was selected as the transform method.

Loss Method: Initial and Constant

Initial and Constant method requires an Initial Loss (in), a Constant Loss Rate (in/hr), and a percent impervious (%). Since Initial Loss does not have an impact on the peak runoff flow, a value of zero was chosen. Constant Loss Rate was based on land cover and soil group within the watershed. The Hydrologic Soils Group (HSG) data was taken from the National Cooperative Soil Survey Geographic database (SSURGO) and land cover was based on the 2011 National Land Cover Dataset (NLCD).

Impervious area characterizes the amount of area, in percent, within the watershed that will experience negligible loss. No loss calculations are carried out on the impervious area. Percent impervious was calculated based on the 2011 NLCD dataset and values presented in Table 3.

Table 3. Percent Impervious Based on Land Cover

Land Cover	Percent Impervious
Developed, Open Space	11%
Developed, Low Intensity	22%
Developed, Medium Intensity	42%
Developed High Intensity	90%

Transform Method: Soil Conservation Service (SCS) Unit Hydrograph

A unit hydrograph is a numerical representation of the time response of catchment runoff caused by one inch of excess rainfall applied uniformly over a unit of time. The SCS Unit Hydrograph model is a dimensionless, single peak unit hydrograph. This methodology requires only an estimate of basin lag, which is the time from the beginning of excess rainfall (i.e., direct runoff) to the point in time when fifty percent of the runoff has passed the catch point. Basin lag time is a function of basin geometry and basin roughness, or basin N-value shown in the following equation. Basin roughness was based on the 2011 National Land Cover Dataset (NLCD) as shown in Table 4.

$$Lag = KN\left[\frac{LL_c}{\sqrt{S}}\right]^{0.38}$$

Where:

K: for L> 1.7 miles K = 24, for rest K = 15.22 + 2.1464*L + 8.6981/L

L: length of the longest flow path

Lc: length of the longest water course measured from the outlet to a point opposite the watershed area centroid

S: average stream slope

N: Basin roughness factor

Table 4. Basin Roughness Based on Land Cover

ID	Area (SQ MI)	Soils	Dominant Land Covers	Basin N
Arroyo	4.88	30% B 22% C 48% D	33% Developed Open Space 22% Evergreen Forest 13% Shrub/Scrub 12% Developed, Low Intensity	0.08
Corte Madera	16.97	91% C 9% D	27% Developed, Open Space 23% Evergreen Forest 11% Grasslands/Herbaceous 11% Shrub/Scrub	0.08
San Ramon	5.75	7% B 60% C 32% D	41% Grasslands/Herbaceous 41% Mixed Forest	0.07
Sonoma	58.75	26% B 19% C 55% D	30% Evergreen Forest 25% Shrub/Scrub 14% Mixed Forest 12% Grasslands/Herbaceous	0.08

Calibration

Using the peak flow rates developed from the flow frequency analyses for each gage, the constant loss rates were varied so that the peak runoff discharge approximately matched the peak discharge from the gauged statistics. To match the peak discharge from the gauged statistics, the original constant loss rates were increased by 20% for the 10-year event, 30% for the 25-yr event, 50% for the 50-yr event, and 70% for the 100-yr event. The calibrated constant loss rates used for each modeled event are presented in Table 5 through Table 8, and are approximately 20% to 70% greater than the original initial values. The final calibrated loss rates are presented in Table 9.

Table 5. Calibrated Constant Loss Rates (10-yr)

Land Use	HSG-A	HSG-B	HSG-C	HSG-D
Forest	0.61	0.5	0.28	0.18
Urban	0.6	0.5	0.3	0.25
Rural	0.55	0.45	0.25	0.15

Table 6. Calibrated Constant Loss Rates (25-yr)

Land Use	HSG-A	HSG-B	HSG-C	HSG-D
Forest	0.79	0.65	0.36	0.23
Urban	0.78	0.65	0.39	0.33
Rural	0.72	0.59	0.33	0.20

Table 7. Calibrated Constant Loss Rates (50-yr)

Land Use	HSG-A	HSG-B	HSG-C	HSG-D
Forest	0.92	0.75	0.42	0.27
Urban	0.90	0.75	0.45	0.38
Rural	0.83	0.68	0.38	0.23

Table 8. Calibrated Constant Loss Rates (100-yr)

Land Use	HSG-A	HSG-B	HSG-C	HSG-D
Forest	1.04	0.85	0.48	0.31
Urban	1.02	0.85	0.51	0.43
Rural	0.94	0.77	0.43	0.26

Table 9. Final constant loss rates

Factor	1.7	1.5	1.3	1.2
Event	100-yr	50-yr	25-yr	10-yr
Arroyo	0.51	0.45	0.39	0.36
Corte Madera	0.46	0.4	0.35	0.32
San Ramon	0.42	0.37	0.32	0.3
Sonoma	0.46	0.41	0.35	0.32

It is important to note that a design storm hydrologic mode only provides an estimate with an inherent error. The model is not a perfect representation of the hydrology of the watershed. It is best if the error can be established for the hydrologic model so that those using the model can plan factors of safety into designs. Common errors of hydrologic models range in the plus or minus 20% to the plus or minus 30% or greater range. It is best to have at least three stream gauge records and their corresponding statistics so that a better estimate of this standard error can be determined.

The modeled peak flows from the gaged watersheds matched the frequency curves relatively well using calibrated constant loss rates except for the San Ramon watershed. The percent differences between the flow frequency event and calibrated flows are shown in Table 10.

Table 10. Percent Error for All Watershed Gages

Watershed	100-yr Percent Difference	50-yr Percent Difference	25-yr Percent Difference	10-yr Percent Difference	Average
Arroyo	-16%	-15%	-22%	-14%	-17%
Corte Madera	5%	4%	-9%	-2%	-1%
San Ramon	-53%	-47%	-39%	-30%	-43%
Sonoma	15%	14%	15%	13%	14%
RMS	**29%**	**26%**	**24%**	**18%**	**24%**
Mean Error	**-12%**	**-11%**	**-14%**	**-8%**	**-11%**

*Percent Difference = (Calibrated flow – frequency flow)/frequency flow

Because the San Ramon watershed percent error between the calibrated peak flow and the frequency curve was relatively large, dropping the San Ramon gage from the calibration was investigated. To do this, the rainfall statistics between the NOAA Altas-14 and the design storm were reviewed. The rainfall statistics between NOAA Altas-14 and the design storm were approximately 15% different for the San Ramon gage as compared to the other gages where the differences were 1% to 6%. Lastly, the calibrated flows were plotted against the confidence interval envelop curves. The San Ramon calibrated flows was the only watershed that consistently plotted outside of the confidence interval. Thus based on these two tests, it was determined that dropping the gage from the calibration process was valid.

Table 11 shows the percent error results without the San Ramon gage.

Table 11. Percent Error for Arroyo, Corte Madera, and Sonoma Watershed Gages

Watershed	100-yr Percent Difference	50-yr Percent Difference	25-yr Percent Difference	10-yr Percent Difference	Average
Arroyo	-16%	-15%	-22%	-14%	-17%
Corte Madera	5%	4%	-8%	-2%	-1%
Sonoma	15%	14%	15%	13%	14%
RMS	**13%**	**12%**	**16%**	**11%**	**13%**
Mean Error	**1%**	**1%**	**-5%**	**-1%**	**-1%**

*Percent Difference = (Calibrated flow – frequency flow)/frequency flow

Conclusion

Calibration was based on the statistics from three gages: Arroyo Corte Madera Del Presidio, Corte Madera CA Ross CA, and Sonoma CA Agua Caliente CA. The constant loss rates were the only parameter calibrated and these were increased from the initial estimates by approximately 20% to 70%. On average, the root mean square was 13% and the mean error was -1% between the calibrated flows and the flow frequency curve.