TECHNICAL MEMORANDUM

Intensity-Duration-Frequency (IDF) Curves Applicable to Locations Within Tacoma Washington

MG Schaefer Ph.D. P.E.

1.0 OVERVIEW

Intensity-Duration-Frequency (IDF) information about precipitation is commonly used for two applications. The first application is for simplified runoff computations and sizing of conveyance structures for very small urban watersheds often less than a few acres in size. The second application is for evaluating the rarity of short-duration high-intensity precipitation that has been observed at precipitation measuring stations, primarily for use in assessing the rarity of urban flooding.

Short-duration high-intensity precipitation is produced by convective storm activity (commonly called thunderstorms). These convective events occur more frequently in the warm season where atmospheric dynamics and diurnal heating of the earth's surface gives rise to vertical instabilities in the atmosphere which can initiate thunderstorm development. Squall lines associated with cold fronts can also produce localized high-intensity precipitation in the fall and early-winter months. Figure 1 depicts the seasonality of the largest 2-hour precipitation events observed in the Western Washington Lowlands, primarily the Puget Sound Lowlands, for the period from 1941-2003 (Schaefer[8]).

A network of precipitation stations with long records spanning many decades is needed to make reliable estimates of precipitation intensities for development of IDF curves. The City of Tacoma began installation of a network of stations in 2001 that record precipitation on 5-minute and 15-minute intervals. At present, there are insufficient data and record lengths to conduct a reliable precipitation-frequency (PF) analysis for short-duration precipitation using data from stations located within the City of Tacoma.

However, the seasonality and IDF characteristics for short-duration high-intensity precipitation for locations in the lowlands west of the Cascade Mountains in Washington, British Columbia and Oregon are very similar. Therefore, the findings of regional L-moment precipitation-frequency analyses (Hosking and Wallis[3] and L-RAP[5]) that have been conducted for Seattle Washington (Schaefer[9,10]) can be used for the City of Tacoma.
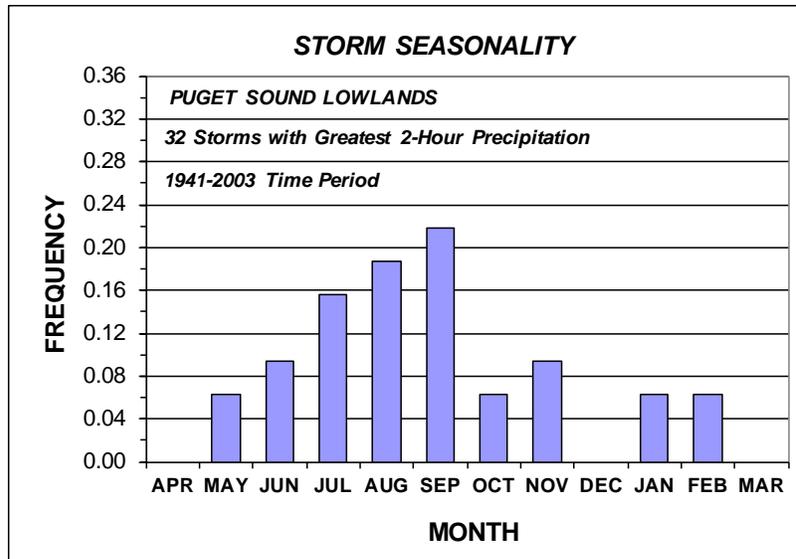
**Figure 1 – Seasonality of Largest Storms at the 2-Hour Duration
Observed in the Lowlands of Western Washington from 1941-2003**

2.0 SHORT-DURATION HIGH-INTENSITY PRECIPITATION-FREQUENCY RELATIONSHIPS

The findings of regional precipitation-frequency studies for short-duration precipitation applicable to the City of Tacoma are based on 17 precipitation stations located within the City of Seattle and operated by Seattle Public Utilities with data obtained for the period from 1965-2007. Another 10 NOAA stations were analyzed that were located within surrounding areas in the Puget Sound Lowlands and had records dating from the mid-1940's. This element of the study for Seattle was conducted for storm inter-durations of 5-minutes through 180-minutes and are directly applicable to the Tacoma area.

The Generalized Extreme Value (GEV) probability distribution was identified as the best-fit probability distribution for short-duration high-intensity precipitation based on the method of L-moments (Hosking and Wallis[3]). The cumulative distribution function (*CDF*) for the GEV distribution is:

$$F(x) = exp(-exp\{-LN(1-\kappa(x-\xi)/\alpha\}/\kappa) \tag{1a}$$

where: *F(x)* is the cumulative distribution function; *x* is the precipitation magnitude; and ξ, α, and κ are location, scale and shape parameters, respectively for precipitation annual maxima series data where $\kappa \neq 0$.

The inverse cumulative distribution function (*x(F)*) for the GEV is:

$$x(F) = \xi + \alpha(1 - (-LN(P))^{\kappa})/\kappa \tag{1b}$$

where: *x(F)* is the quantile function for precipitation; and *P* is the non-exceedance probability where $\kappa \neq 0$.

MGS Engineering Consultants, Inc.   December 9, 2016

The Annual Exceedance Probability (*AEP*) is related to the non-exceedance probability by:

$$AEP = 1 - F(x) \tag{2a}$$

and the commonly used Recurrence Interval (*RI*) as a measure of storm rarity is computed as:

$$RI_{AMS} = 1/AEP \tag{2b}$$

where: RI_{AMS} is the recurrence interval (years) for annual maxima series data.

These findings are based on analyses of precipitation Annual Maxima Series (AMS) data. Estimation of the recurrence intervals for frequent events, more common than 1:10 AEP (10-year recurrence interval) are typically conducted using what is termed Partial Duration Series (PDS) data where all precipitation maxima exceeding a user-specified threshold are included in the analysis. In assembling the PDS data, the threshold is set such that storms that occur several times per year are included in the analysis. Estimates for precipitation magnitudes that occur frequently can be computed using the Langbein[4] adjustment to the findings from the analyses of AMS data as:

$$RI_{PDS} = 1/(-LN(1 - 1/RI_{AMS}) \tag{2c}$$

where: RI_{PDS} is the estimated recurrence interval (years) for a partial duration series data analysis.

Table 1a lists the regional L-moment statistics for the Seattle Metropolitan Area for short storm inter-durations from 5-minutes through 180-minutes. Table 1b lists the distribution parameters for inter-durations from 5-minutes through 180-minutes. The term inter-duration is synonymous with the common usage of duration except that inter-duration is intended to highlight that a duration is being considered at a time interval within the storm which may be shorter than the total storm duration.

Table 1a – Regional L-Moment Statistics for Seattle Metropolitan Area for Short-Duration High-Intensity Convective Events Applicable to Areas Within the City of Tacoma

STORM INTER-DURATION (Minutes)	REGIONAL L-MOMENT STATISTICS		
	At-Site Mean (in)	L-Cv	L-Skewness
5	0.136	0.2185	0.2700
10	0.186	0.2050	0.2650
15	0.223	0.1975	0.2600
20	0.251	0.1920	0.2550
30	0.298	0.1840	0.2500
45	0.352	0.1760	0.2450
60	0.403	0.1705	0.2400
120	0.564	0.1575	0.2200
180	0.708	0.1500	0.2100

MGS Engineering Consultants, Inc.

December 9, 2016

Table 1b – Distribution Parameters for the Generalized Extreme Value Distribution for Short-Duration High-Intensity Convective Events Applicable to Areas Within the City of Tacoma

STORM INTER-DURATION (Minutes)	GEV DISTRIBUTION PARAMETERS		
	Location ξ	Scale α	Shape κ
5	0.1086	0.0366	-0.1502
10	0.1510	0.0473	-0.1429
15	0.1827	0.0551	-0.1357
20	0.2072	0.0608	-0.1284
30	0.2483	0.0698	-0.1211
45	0.2961	0.0795	-0.1137
60	0.3413	0.0889	-0.1064
120	0.4858	0.1187	-0.0767
180	0.6155	0.1442	-0.0616

3.0 PRECIPITATION-FREQUENCY RELATIONSHIPS APPLICABLE TO TACOMA WASHINGTON

Figure 1a depicts precipitation-frequency relationships for durations from 5-minutes through 60-minutes applicable to the Tacoma area. These precipitation-frequency curves were produced using Equations 1a and 2a and Table 1b parameter values to compute annual exceedance probabilities. Equations 2b and 2c were then used to compute recurrence intervals. Figure 1b depicts the precipitation-frequency relations expressed in the conventional Intensity-Duration-Frequency (IDF) format and Tables 2a and 2b list tabular values of precipitation intensity and precipitation for selected recurrence intervals.

An Excel workbook has been provided for computation of annual exceedance probabilities and recurrence intervals for user-specified precipitation maxima for durations of 5, 10, 15, 20, 30, 45, 60, 120 and 180-minutes.
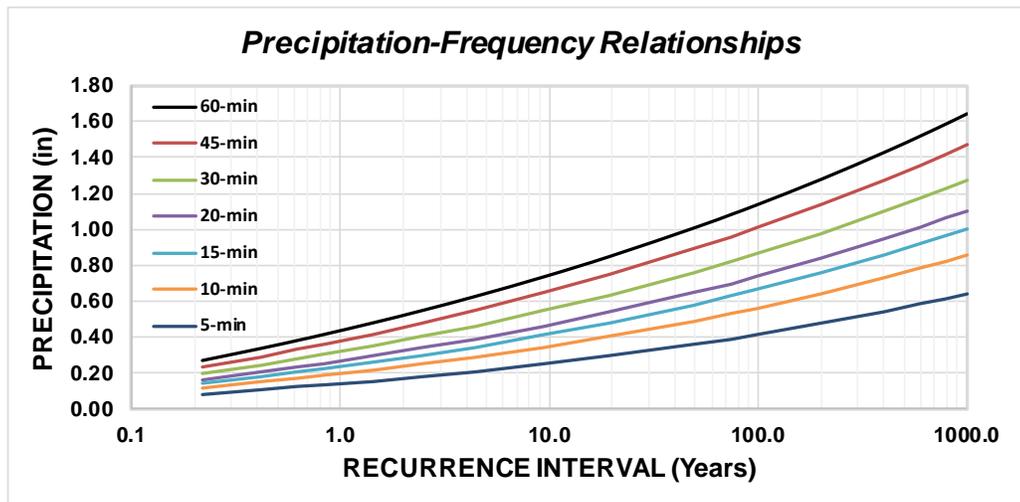

Figure 2a – Precipitation-Frequency Relationships for Precipitation Annual Maxima for Short-Duration Precipitation Applicable to the City of Tacoma
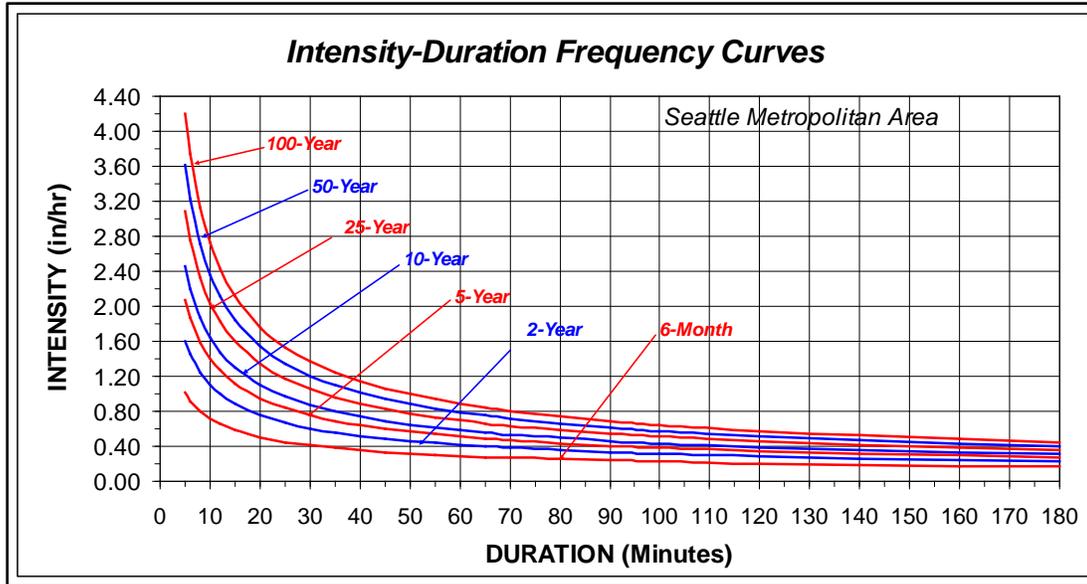
Figure 2b – Precipitation-Frequency Relationships Expressed as Intensity-Duration-Frequency Curves for Short-Duration Precipitation Applicable to the City of Tacoma

Table 2a – Intensity-Duration-Frequency Values for Durations from 5-Minutes through 180-Minutes for Selected Recurrence Intervals Applicable to the City of Tacoma

DURATION (min)	PRECIPITATION INTENSITIES (in/hr)							
	RECURRENCE INTERVAL (Years)							
	6-Month	2-Yr	5-Yr	10-Yr	20-Yr	25-Yr	50-Yr	100-Yr
5	1.01	1.60	2.08	2.45	2.92	3.08	3.61	4.20
6	0.92	1.45	1.87	2.21	2.62	2.76	3.23	3.75
8	0.80	1.24	1.59	1.87	2.21	2.32	2.71	3.13
10	0.71	1.10	1.40	1.64	1.93	2.03	2.36	2.72
12	0.65	1.00	1.27	1.48	1.74	1.82	2.11	2.43
15	0.58	0.88	1.12	1.30	1.52	1.60	1.84	2.11
20	0.50	0.75	0.95	1.10	1.28	1.34	1.54	1.76
25	0.45	0.67	0.84	0.97	1.12	1.18	1.35	1.53
30	0.41	0.61	0.76	0.87	1.01	1.05	1.21	1.37
35	0.38	0.56	0.69	0.80	0.92	0.96	1.10	1.24
40	0.35	0.52	0.64	0.74	0.85	0.89	1.01	1.14
45	0.33	0.49	0.60	0.69	0.79	0.83	0.94	1.06
50	0.32	0.46	0.57	0.65	0.74	0.78	0.88	0.99
55	0.30	0.44	0.54	0.61	0.70	0.73	0.83	0.94
60	0.29	0.42	0.51	0.58	0.67	0.70	0.79	0.89
65	0.28	0.40	0.49	0.56	0.64	0.66	0.75	0.84
70	0.27	0.38	0.47	0.53	0.61	0.64	0.72	0.80
80	0.25	0.36	0.43	0.49	0.56	0.59	0.66	0.74
90	0.24	0.33	0.41	0.46	0.52	0.55	0.62	0.69
100	0.22	0.32	0.38	0.43	0.49	0.51	0.58	0.64
120	0.20	0.29	0.35	0.39	0.44	0.46	0.52	0.57
140	0.19	0.26	0.32	0.36	0.40	0.42	0.47	0.52
160	0.18	0.24	0.29	0.33	0.37	0.39	0.43	0.48
180	0.17	0.23	0.27	0.31	0.35	0.36	0.40	0.45

Table 2b – Intensity-Duration-Frequency Values Expressed in Inches for Durations from 5-Minutes through 180-Minutes for Selected Recurrence Intervals Applicable to the City of Tacoma

DURATION (min)	PRECIPITATION (inches)							
	RECURRENCE INTERVAL (Years)							
	6-Month	2-Yr	5-Yr	10-Yr	20-Yr	25-Yr	50-Yr	100-Yr
5	0.084	0.133	0.173	0.204	0.243	0.257	0.301	0.350
6	0.092	0.145	0.187	0.221	0.262	0.276	0.323	0.375
8	0.106	0.165	0.212	0.249	0.294	0.310	0.361	0.417
10	0.119	0.183	0.234	0.274	0.322	0.339	0.394	0.454
12	0.130	0.199	0.253	0.295	0.347	0.365	0.422	0.486
15	0.145	0.221	0.279	0.324	0.380	0.399	0.461	0.528
20	0.168	0.252	0.316	0.366	0.427	0.448	0.515	0.588
25	0.187	0.279	0.349	0.402	0.468	0.490	0.561	0.639
30	0.205	0.303	0.378	0.435	0.504	0.527	0.603	0.684
35	0.221	0.325	0.404	0.464	0.536	0.561	0.640	0.725
40	0.237	0.345	0.428	0.491	0.566	0.592	0.674	0.762
45	0.251	0.365	0.451	0.516	0.594	0.620	0.705	0.796
50	0.264	0.383	0.472	0.539	0.620	0.647	0.735	0.828
55	0.277	0.400	0.492	0.561	0.644	0.672	0.762	0.858
60	0.289	0.416	0.511	0.582	0.668	0.696	0.788	0.887
65	0.301	0.431	0.529	0.602	0.690	0.719	0.813	0.913
70	0.312	0.446	0.546	0.621	0.711	0.741	0.837	0.939
80	0.334	0.474	0.579	0.657	0.751	0.782	0.881	0.987
90	0.354	0.501	0.609	0.691	0.787	0.820	0.923	1.032
100	0.373	0.525	0.638	0.722	0.822	0.855	0.961	1.073
120	0.408	0.571	0.691	0.780	0.885	0.920	1.031	1.149
140	0.441	0.613	0.739	0.832	0.942	0.979	1.095	1.217
160	0.471	0.651	0.783	0.880	0.995	1.033	1.153	1.279
180	0.500	0.688	0.824	0.925	1.044	1.083	1.207	1.337

SELECTED REFERENCES

1. Benjamin JR and Cornell CA, Probability and Statistics for Civil Engineers, McGraw-Hill, 1970.

2. Cunnane C, Unbiased Plotting Positions - A Review, Journal of Hydrology, 37, 205-222, 1978.

3. Hosking JRM and Wallis JR, Regional Frequency Analysis – An Approach Based on L-Moments, Cambridge Press, 1997.

4. Langbein WB, Annual Floods and the Partial Duration Flood Series, Transaction American Geophysical Union, Vol 30, pp879-881, 1949.

5. L-RAP, L-Moments Regional Analysis Program, developed by MG Schaefer and BL Barker, MGS Software LLC, Olympia WA.

6. Schaefer MG, Regional Analyses of Precipitation Annual Maxima in Washington State, Water Resources Research, Vol.26, No.1, pp119-132, January,1990.

7. Schaefer MG, Characteristics of Extreme Precipitation Events in Washington State, Washington State Dept. of Ecology, Report 89-51, October 1989.

8. Schaefer MG, Barker BL, Taylor GH and Wallis JR, Regional Precipitation-Frequency Analysis and Spatial Mapping of Precipitation for 24-Hour and 2-Hour Durations in Western Washington, prepared for Washington State Department of Transportation, Report WA-RD 544.1, MGS Engineering Consultants, March 2002.

9. Schaefer MG, Analyses of Precipitation-Frequency and Storm Characteristics for the City of Seattle, prepared for Seattle Public Utilities, March 2003.

10. Schaefer MG, Assessment of City of Seattle Intensity-Duration-Frequency Curves With Addition of Storm Data from 2003-2007, prepared for Seattle Public Utilities, October 2007

11. Stedinger JR, Vogel RM and Foufoula-Georgiou E, Frequency Analysis of Extreme Events, Chapter 18, Handbook of Hydrology, D Maidment (editor), McGraw-Hill Inc, NY 1993.

12. Weiss LL, Ratio of True to Fixed Interval Maximum Rainfall, Journal Hydraulics, ASCE, 90(HY1), pp77-82, 1964.