

COMPARATIVE ANALYSIS OF IDF CURVES AT SELECTED SITES IN UTAH

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UDOT RESEARCH & DEVELOPMENT REPORT ABSTRACT

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Abstract: This study consists of two parts. Section 1 deals with analyzing the magnitude of orographic effect on IDF curves in four strategic regions in Utah. For the Wasatch North Region the precipitation is statistically different at the 90% confidence level for over three quarters of the data points. As might be expected, in all of these cases the leeward precipitation was less than the windward precipitation. The amount of the difference ranged from about 25% to 50%. For the other three regions, the precipitation was statistically different at the 90% confidence level for fewer than 15% of the data points. In general, in cases where there were significant differences, the leeward precipitation was less than the windward precipitation. The second part of this study is presented in Section 2, and it deals with the comparison of IDF curves from two different sources. In general, the NOAA (new) precipitation estimates were less than the UCC (old) precipitation estimates for return periods of 50 years or less. The amounts of the differences ranged from about 5% to 33%. Hydraulic structure designs based on the UCC estimates with return periods of 50 years or less are most likely more conservative than those based on NOAA curves.					
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ABSTRACT

The Utah Department of Transportation (UDOT) is frequently concerned with estimating peak flows for the design of hydraulic structures in relatively small watersheds. Traditionally UDOT has used the Rational Formula, to compute peak flows for watersheds of 300 acres or less in size. This methodology is particularly sensitive to the estimated rate of precipitation that is used in the calculation. When available, precipitation data are obtained from point gages in the form of Intensity-Duration-Frequency (IDF) curves. In areas where gages are lacking UDOT has traditionally used an expansion of Technical Paper No. 24, Parts I and II to develop IDF curves. The estimates of peak flows can be no more accurate than the accuracy of the IDF data used to generate them.

Because of the great land area and the relative scarcity of data monitoring sites in Utah, IDF curves may not be available for a specific area of interest. United States Geological Survey (USGS) regression equations are available for estimating precipitation over large areas. However, these estimates are based on the averaging of data over large scale watersheds and are not always reliable for small catchments. Therefore, it is frequently necessary to extrapolate data from the closest data source to the design site using conventional engineering techniques.

This study consists of two parts. The first part is described in Section 1 of this report. Typically extrapolation techniques do not account for the orographic effects of predominate wind direction over mountain ridges. Section 1 deals with analyzing the magnitude of this orographic effect on IDF curves in four strategic regions in Utah. A methodology was developed and a computer program was written so that large amounts of data could be efficiently processed. The methodology was applied to the four regions using NOAA IDF curves. For the Wasatch North Region the precipitation is statistically different at the 90% confidence level for over three quarters of the data points. As might be expected, in all of these cases the leeward precipitation was less than the windward precipitation. The amount of the difference ranged from about 25% to 50%. For the other three regions, the precipitation was statistically different at the 90% confidence level for fewer than 15% of the data points. In general, in cases where there were significant differences, the leeward precipitation was less than the windward precipitation. Tables 2 through 5 show the results of the analysis for return periods of 2, 5, 10, 25, 50 100, 200, 500, and 1000 years; and durations of 5, 10, 15, 30, 60, 120, 180, 360, 720, 1440 (1 day), 2820 (2 day) and 5640 (4 day) minutes. The high return periods (e.g. over 100 years) and the long durations (e.g. above 1 day) are included because the data were available and it was interesting to see how these extreme extrapolations behaved. These values are not statistically meaningful.

The second part of this study is presented in Section 2, and it deals with the comparison of IDF curves from two different sources. For many years UDOT has been using IDF curves that were created by the methodology developed at the Utah Climate Center (UCC). More recently IDF curves have been published on the NOAA web site at: <http://hdsc.nws.noaa.gov>. The object of this study is to compare the UCC IDF curves

with the NOAA IDF curves in order to determine if one might be generally more conservative than the other.

In general, the NOAA (new) precipitation estimates were less than the UCC (old) precipitation estimates for return periods of 50 years or less. The amounts of the differences ranged from about 5% to 33%. Hydraulic structure designs based on the UCC estimates with return periods of 50 years or less are most likely more conservative.

The differences between NOAA and UCC IDF curves were mixed for return periods of 100 years or greater. For the Heber, Moab, and Salt Lake City sites the NOAA values were generally greater than the UCC values. The amounts of the differences ranged from about 2% to 50%. Hydraulic structure designs based on the NOAA estimates for return periods of 100 years or greater are most likely more conservative in these cases. Tables 16, 19, 22, and 25 provide the specific results for each intensity and duration at the four sites. It is not surprising to find greater variation at return periods of 100 years or greater because these data are based on extreme extrapolations. They are included here in order to provide a comprehensive analysis, but they are not statistically meaningful.

Much of the analysis presented in this report was conducted using Visual Basic code interfaced with Excel workbooks. The data used in the study as well as the computer programs are included on a CD accompanying this report.

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INTRODUCTION

The Utah Department of Transportation (UDOT) is frequently concerned with estimating peak flows for the design of hydraulic structures in relatively small watersheds. Traditionally UDOT has used the Rational Formula, to compute peak flows for watersheds of 300 acres or less in size. This methodology is particularly sensitive to the estimated rate of precipitation that is used in the calculation. When available, precipitation data are obtained from point gages in the form of Intensity-Duration-Frequency (IDF) curves. In areas where gages are lacking UDOT has traditionally used an expansion of Technical Paper No. 24, Parts I and II to develop IDF curves. The estimates of peak flows can be no more accurate than the accuracy of the IDF data used to generate them.

Because of the great land area and the relative scarcity of data monitoring sites in Utah, IDF curves may not be available for a specific area of interest. United States Geological Survey (USGS) regression equations are available for estimating precipitation over large areas. However, these estimates are based on the averaging of data over large scale watersheds and are not always reliable for small catchments. Therefore, it is frequently necessary to extrapolate data from the closest data source to the design site using conventional engineering techniques.

This study consists of two parts. The first part is described in Section 1 of this report. Typically extrapolation techniques do not account for the orographic effects of predominate wind direction over mountain ridges. Section 1 deals with analyzing the magnitude of this orographic effect on IDF curves in four strategic regions in Utah. A methodology was developed and a computer program was written so that large amounts of data could be efficiently processed. The methodology was applied to the four regions using NOAA IDF curves. Results of the comparisons are presented in tables and graphs.

The second part of this study is presented in Section 2, and it deals with the comparison of IDF curves from two different sources. For many years UDOT has been using IDF curves that were created by the methodology developed at the Utah Climate Center (UCC). More recently IDF curves have been published on the NOAA web site at: <http://hdsc.nws.noaa.gov>. The object of this study is to compare the UCC IDF curves with the NOAA IDF curves in order to determine if one might be generally more conservative than the other. The results are presented in tables and graphs.

Much of the analysis presented in this report was conducted using Visual Basic code interfaced with Excel workbooks. The data used in the study as well as the computer programs are included on a CD accompanying this report.

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SECTION 1: OROGRAPHIC EFFECTS

Introduction

Because of the great land area in Utah and the relative scarcity of data monitoring sites, there is seldom sufficient river flow data available to directly estimate peak flows for the design of drainage structures. It is frequently necessary for a design agency to extrapolate data from one watershed to another using conventional engineering techniques. Typically these techniques involve the use of precipitation IDF curves, and they do not account for the effects of predominate wind direction over mountain ridges. However, as a result of doing site specific analyses, engineers have noticed what they believe to be significant orographic effects.

The purpose of this research is to identify precipitation stations in four strategic geographical regions in Utah and to statistically analyze the precipitation IDF curves for orographic effects.

Data

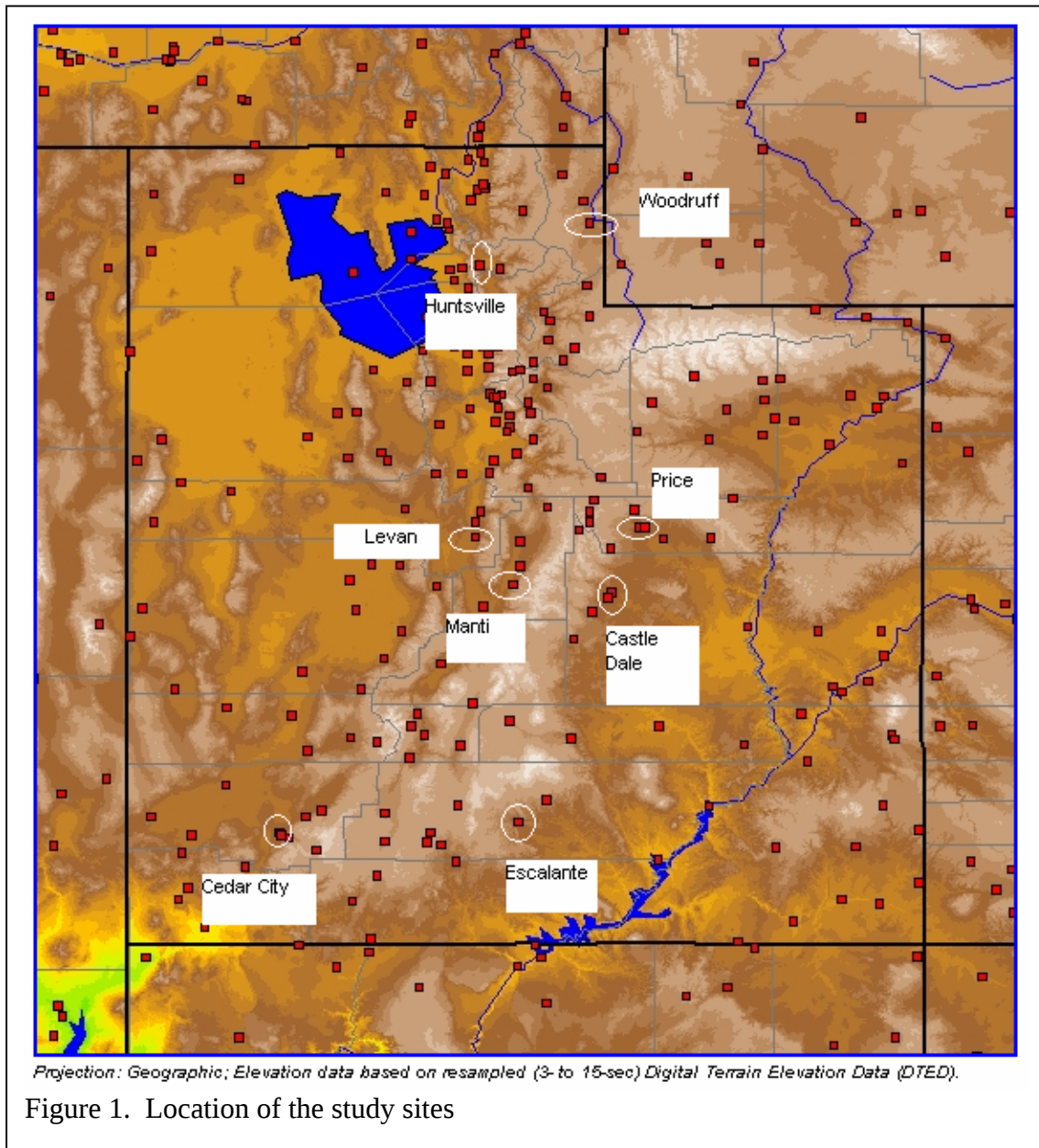
In consultation with personnel at the Utah Department of Transportation (UDOT) and the Utah Climate Center (UCC), four regions were selected for analysis as shown in Table 1.

Table 1. Utah Regions						
No.	Region	Side of the mountain	Site	Longitude	Latitude	Elevation (ft)
1.	Wasatch North	Windward	Huntsville Monastery	111.716 W	41.215 N	6560
		Leeward	Woodruff	111.15 W	41.53 N	6320
2.	Wasatch South	Windward	Levan	111.86 W	39.56 N	5300
		Leeward	Price	110.8 W	39.616 N	5700
3.	Wasatch Plateau	Windward	Manti	111.65 W	39.25 N	5740
		Leeward	Castle Dale	111.016 W	29.2 N	5620
4.	Paunsang mountain Plateau Escalante Mountains	Windward	Cedar City	112.983 W	37.65 N	6450
		Leeward	Escalante	111.6 W	37.76 N	5818

Two precipitation sites were selected in each region; one on the windward side and one on the leeward side as shown in the table. In order to eliminate the effects of elevation,

care was taken to choose the same elevations for both the windward and leeward stations in each region.

A map displaying the sites is shown in Figure 1 (obtained from <http://hdsc.nws.noaa.gov>). Figures 2 through 4 show enlarged views of the study areas (obtained from: <http://uk.multimap.com/index/US46.htm>).



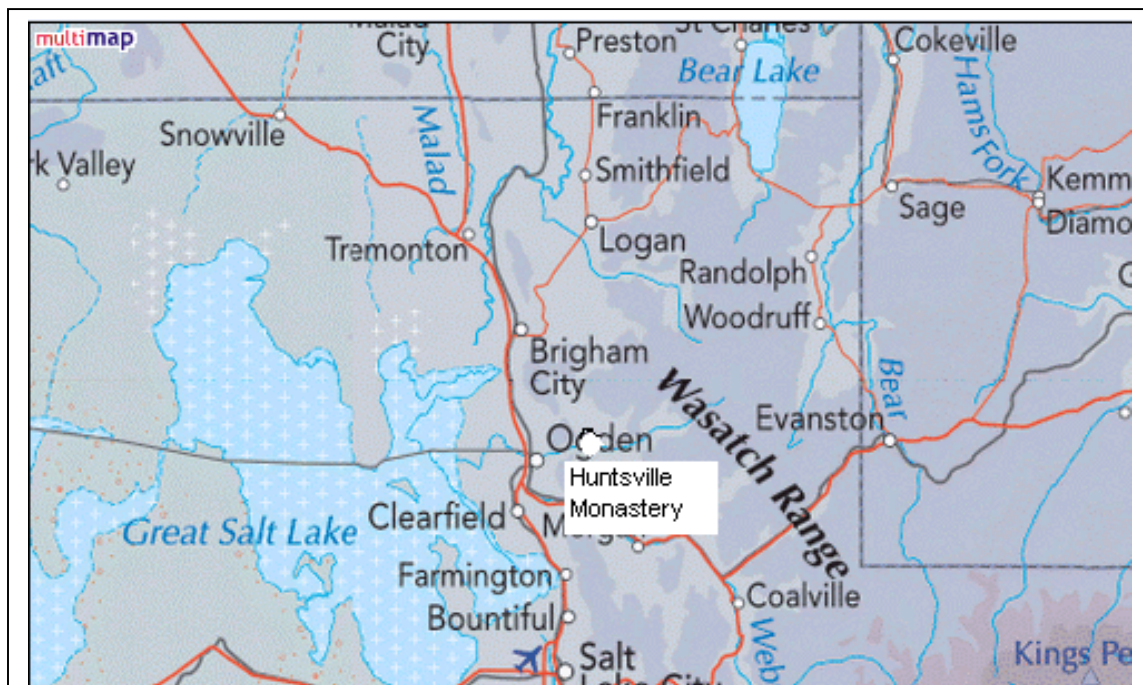


Figure 2. Huntsville Monastery (Windward), Woodruff (Leeward) Region

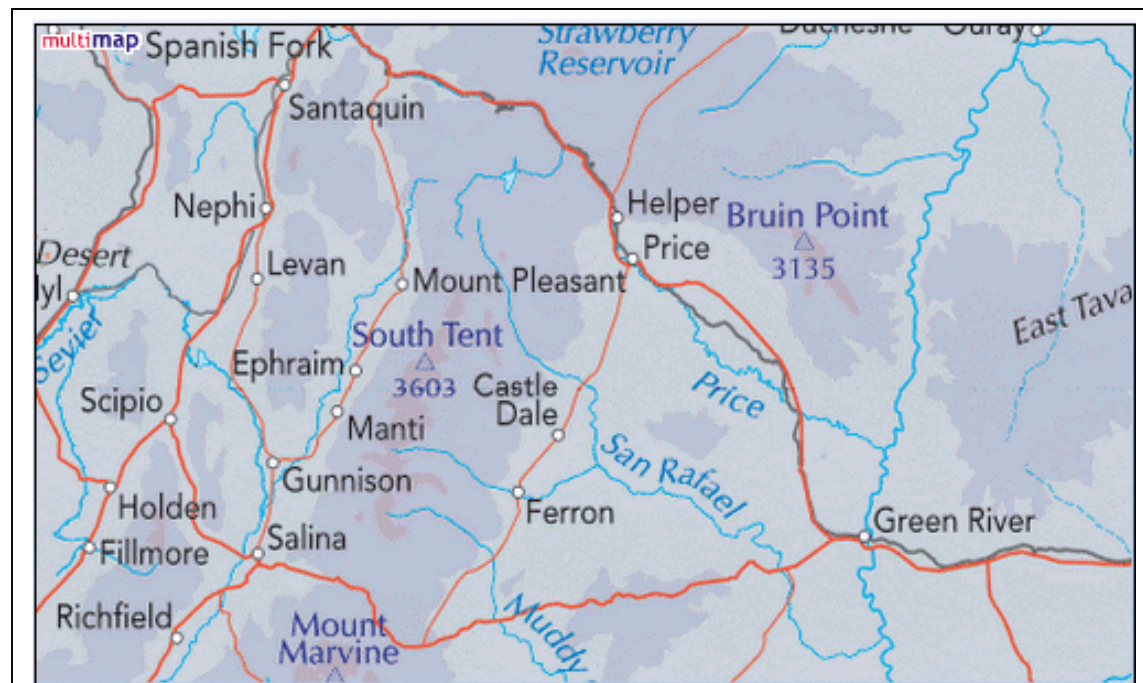


Figure 3. Levan (Windward), Price (Leeward) Region and Manti (Windward), Castle Dale (Leeward) Region.



The complete tables of IDF data for these sites are shown in Appendix A.

Analysis

Percentage Difference of the Means

Using the mean precipitation values from the tables in Appendix A, the relative amount of precipitation at the leeward site compared to the windward site was calculated for each intensity and duration as follows:

$$\frac{(\text{Leeward}) - (\text{Windward})}{(\text{Windward})} (100) \quad (1)$$

The results, expressed as percentages, are shown in Tables 2 through 5. The shaded cells in the tables indicate that the differences are not significant at the 90% confidence level. The high return periods (e.g. over 100 years) and the long durations (e.g. 2 day, 4 day) are included because the data were available and it was interesting to see how these extreme extrapolations behaved. However, these values are not statistically meaningful.

The data in Tables 2 through 5 are shown as graphs in Figures 5 through 8.

**Table 2. Percentage Difference of Mean Precipitation Between Windward and Leeward Sides –
HUNTSVILLE MONASTERY AND WOODRUFF**

Duration:- Return period	5-min	10- min	15- min	30- min	1-hr (60- min)	2-hr (120- min)	3-hr (180- min)	6-hr (360- min)	12-hr (720- min)	24-hr (1440- min)	48-hr (2880- min)	4-day (5760- min)
2	-27.98	-28.31	-27.74	-28.26	-28.07	-34.21	-34.48	-40.00	-46.15	-37.50	-40.00	-66.67
5	-26.35	-26.55	-26.74	-26.98	-26.92	-29.17	-30.56	-37.50	-40.00	-40.00	-50.00	-50.00
10	-25.68	-25.62	-25.86	-25.64	-25.77	-28.81	-28.57	-33.33	-44.44	-45.45	-42.86	-50.00
25	-24.95	-24.93	-24.92	-24.88	-25.20	-28.95	-26.42	-33.33	-38.10	-38.46	-50.00	-60.00
50	-24.79	-24.61	-24.73	-24.70	-24.52	-27.47	-28.13	-29.73	-41.67	-42.86	-44.44	-50.00
100	-24.62	-24.50	-24.56	-24.59	-24.87	-27.27	-27.63	-30.23	-40.74	-43.75	-50.00	-50.00
200	-24.45	-24.59	-24.64	-24.66	-24.56	-26.52	-27.78	-30.61	-40.00	-41.18	-40.00	-57.14
500	-25.22	-25.15	-25.28	-25.32	-25.26	-26.79	-27.19	-29.51	-37.14	-36.84	-41.67	-50.00
1000	-26.13	-26.07	-26.12	-26.05	-25.99	-26.37	-27.94	-29.17	-35.90	-38.10	-41.67	-50.00

**Table 3. Percentage Difference of Mean Precipitation Between Windward and Leeward Sides –
LEVAN AND PRICE WAREHOUSES**

Duration:- Return period	5-min	10- min	15- min	30- min	1-hr (60- min)	2-hr (120- min)	3-hr (180- min)	6-hr (360- min)	12-hr (720- min)	24-hr (1440- min)	48-hr (2880- min)	4-day (5760- min)
2	3.91	4.41	4.46	3.95	4.26	0.00	-4.55	-7.14	-11.11	0.00	0.00	0.00
5	0.80	1.05	1.27	0.94	0.00	-5.13	-3.57	-5.88	-18.18	-14.29	0.00	0.00
10	0.00	0.00	0.00	0.00	0.00	-4.26	-5.88	-10.00	-8.33	0.00	0.00	-33.33
25	0.25	0.65	0.39	0.00	0.94	-6.56	-7.14	-8.33	-14.29	-11.11	0.00	0.00
50	0.61	0.81	0.65	0.48	0.78	-5.56	-6.12	-11.11	-12.50	-10.00	-16.67	0.00
100	1.54	1.35	1.36	1.21	1.31	-4.71	-6.90	-6.45	-11.76	-9.09	0.00	-25.00
200	2.75	2.85	2.76	2.73	2.76	-5.94	-5.88	-5.56	-10.53	0.00	-14.29	0.00
500	4.19	4.28	4.07	4.12	4.44	-3.23	-3.57	-2.33	-4.35	-7.69	-12.50	-20.00
1000	4.94	4.94	5.03	5.14	4.91	-1.38	-2.04	0.00	-3.85	0.00	-11.11	-20.00

**Table 4. Percentage Difference of Mean Precipitation Between Windward and Leeward Sides –
MANTI AND CASTLE DALE**

Duration:- Return period	5-min	10- min	15- min	30- min	1-hr (60- min)	2-hr (120- min)	3-hr (180- min)	6-hr (360- min)	12-hr (720- min)	24-hr (1440- min)	48-hr (2880- min)	4-day (5760- min)
2	-4.73	-4.69	-4.72	-5.56	-4.55	-7.41	-9.52	-7.69	-12.50	0.00	0.00	0.00
5	-3.81	-3.35	-3.38	-4.00	-4.84	-5.56	-7.69	-6.25	-10.00	0.00	0.00	0.00
10	-1.04	-1.36	-1.10	-1.63	-1.32	-4.55	-9.38	-10.53	-16.67	-14.29	0.00	0.00
25	0.26	0.70	0.42	0.63	0.00	-3.57	-5.13	-8.70	-7.69	0.00	-20.00	-33.33
50	2.64	2.31	2.10	2.60	2.52	-1.52	0.00	-7.69	-13.33	-11.11	0.00	0.00
100	4.81	4.87	4.71	4.80	4.23	1.28	0.00	-3.45	-6.25	0.00	-16.67	0.00
200	6.87	6.98	6.97	7.01	6.55	2.17	3.23	3.13	-5.56	0.00	0.00	-25.00
500	9.70	9.59	9.60	9.50	9.62	5.26	6.58	7.69	5.00	0.00	-14.29	0.00
1000	11.61	11.58	11.62	11.68	11.48	7.58	7.87	8.89	8.70	8.33	0.00	-20.00

**Table 5. Percentage Difference of Mean Precipitation Between Windward and Leeward Sides –
CEDAR CITY AP AND ESCALANTE**

Duration:- Return period	5-min	10- min	15- min	30-min	1-hr (60- min)	2-hr (120- min)	3-hr (180- min)	6-hr (360- min)	12-hr (720- min)	24-hr (1440- min)	48-hr (2880- min)	4-day (5760- min)
2	-13.57	-13.69	-13.67	-13.83	-13.79	-11.76	-12.00	-12.50	-10.00	0.00	0.00	0.00
5	-12.90	-13.14	-12.82	-12.98	-12.35	-13.04	-12.12	-10.00	-15.38	14.29	0.00	0.00
10	-13.04	-13.42	-13.41	-12.73	-12.75	-10.71	-10.26	-12.50	-7.14	12.50	0.00	0.00
25	-12.36	-12.44	-12.58	-12.33	-12.50	-10.96	-8.16	-13.79	-11.76	22.22	20.00	33.33
50	-11.73	-11.85	-11.84	-11.61	-11.52	-10.23	-8.47	-12.12	-10.53	18.18	33.33	33.33
100	-10.78	-10.71	-10.67	-10.56	-10.55	-9.52	-9.86	-10.53	-13.64	25.00	28.57	25.00
200	-9.92	-9.90	-9.90	-10.05	-10.00	-8.80	-9.41	-6.98	-8.33	30.77	25.00	25.00
500	-8.38	-8.30	-8.38	-8.37	-8.25	-7.01	-7.55	-3.77	0.00	26.67	33.33	20.00
1000	-7.06	-7.17	-7.06	-7.04	-6.94	-5.91	-6.40	-4.76	-3.13	37.50	44.44	40.00

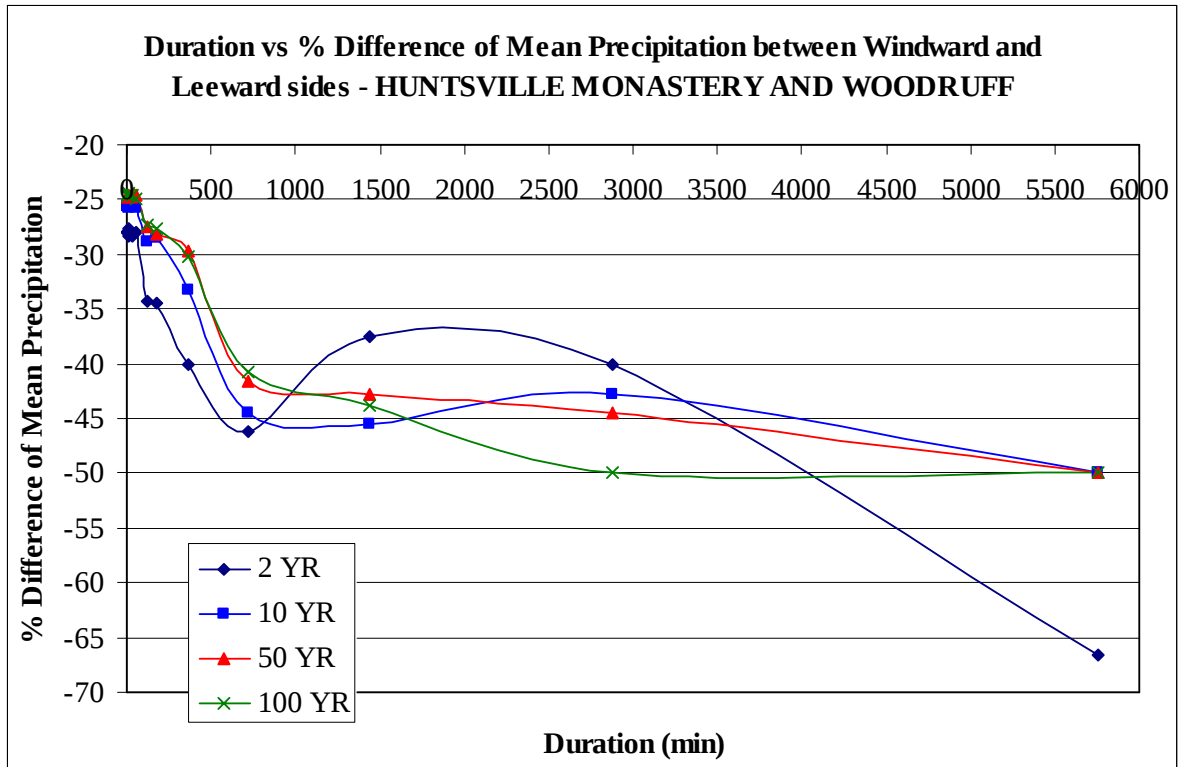


Figure 5. Percent Difference of Woodward Minus Huntsville Monastery.

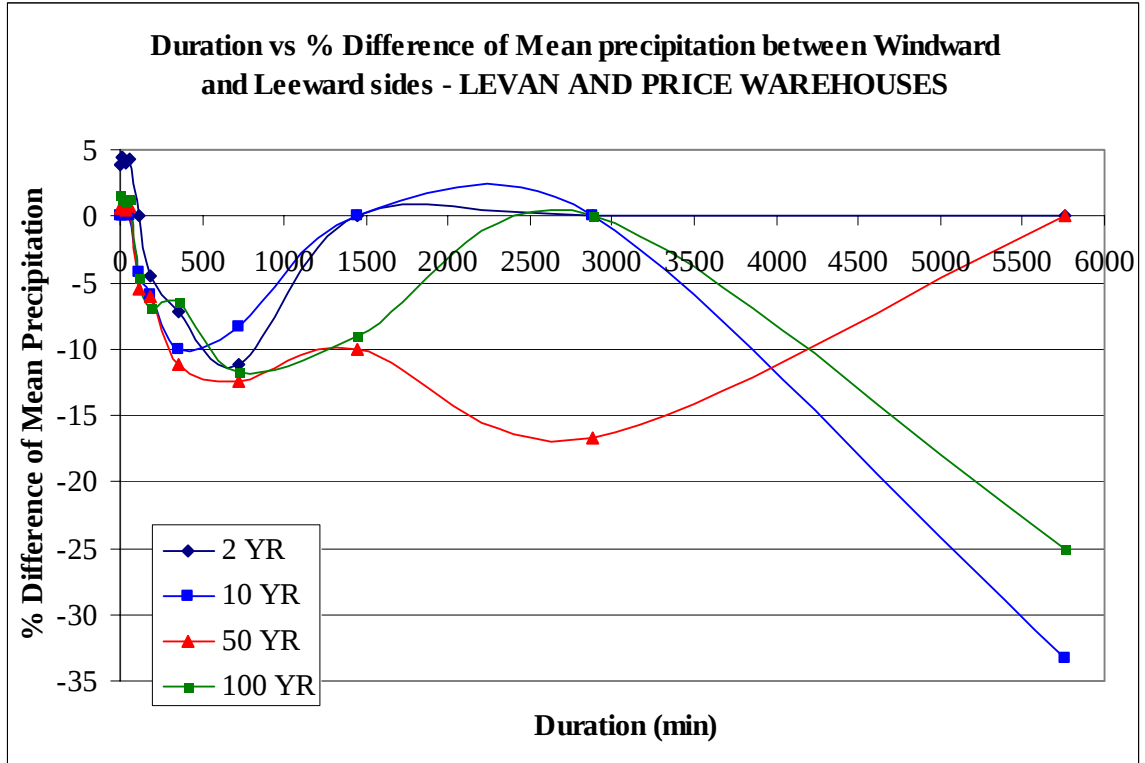


Figure 6. Percent Difference of Price Warehouses Minus Levan.

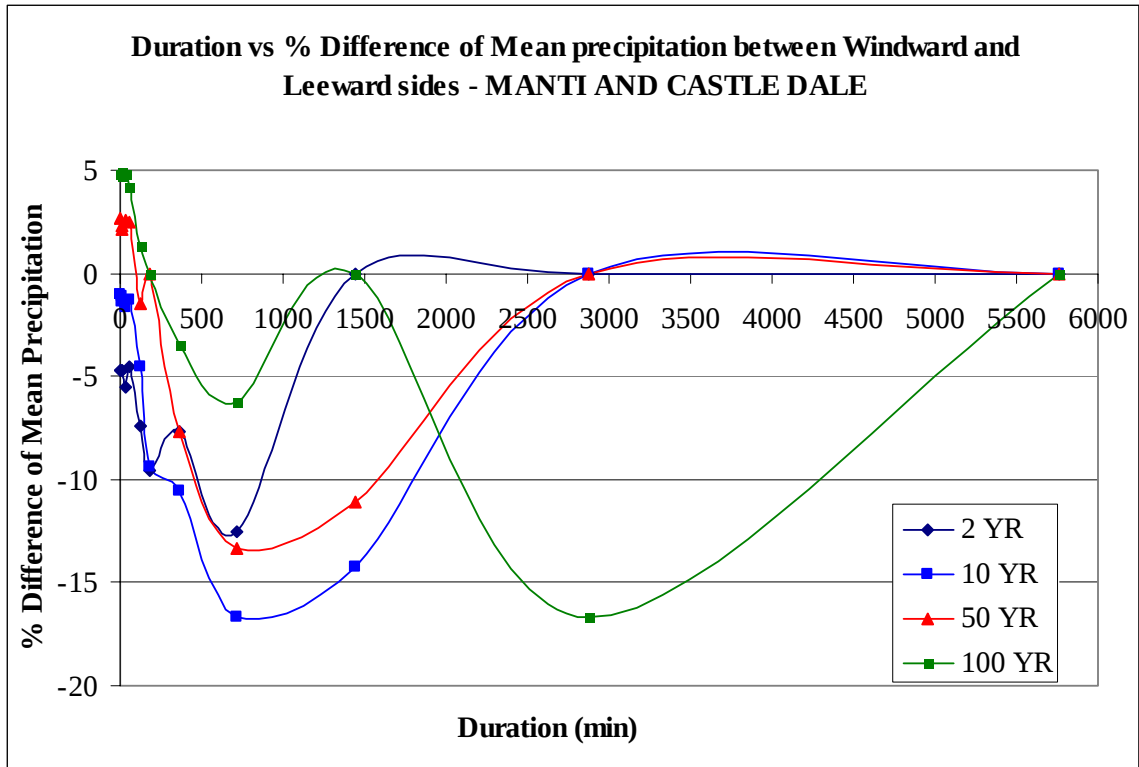


Figure 7. Percent Difference of Castle Dale Minus Manti.

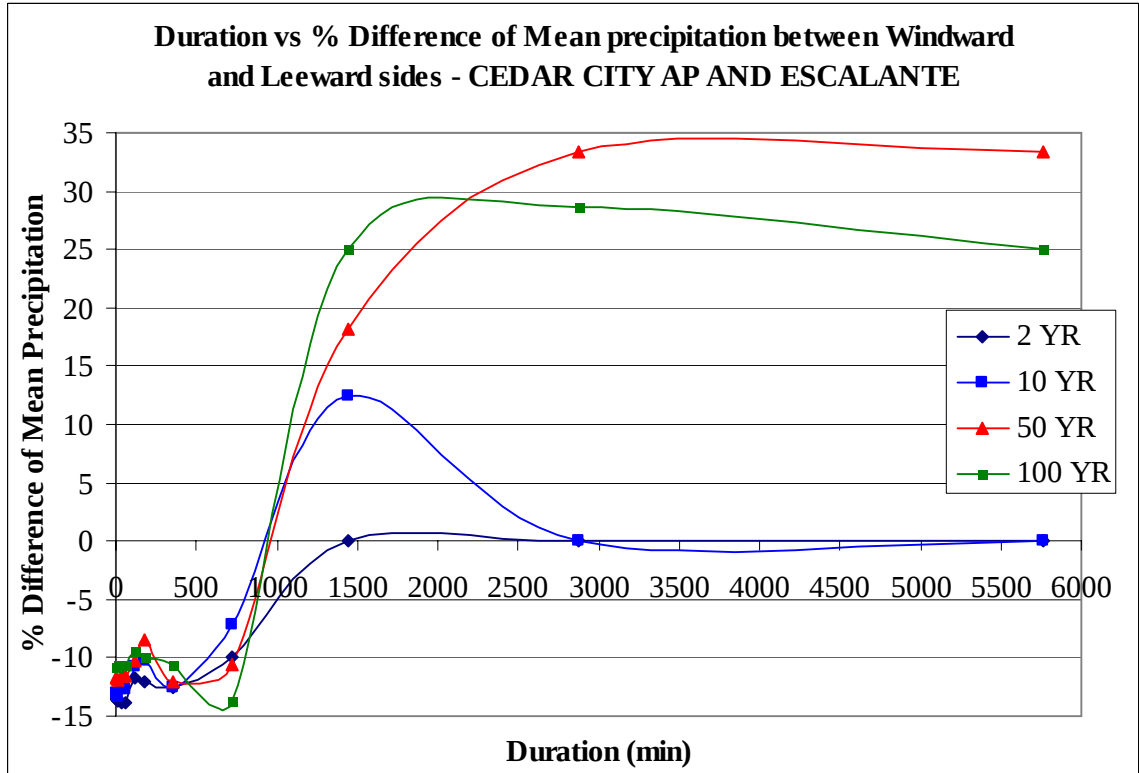


Figure 8. Percent Difference of Escalante Minus Cedar City AP.

Statistical Significance of the Difference of the Means

The tables in Appendix A provide the upper and lower bounds of the 90% confidence interval as well as the mean for each intensity and duration. These upper and lower bounds are based on analysis of the annual maximum series which are then converted to partial duration maxima series. For more information about how the data in the tables were obtained visit the web site at <http://hdsc.nws.noaa.gov>.

The “Z” test is a common statistical technique used for hypothesis testing. In this study the following hypothesis is tested:

Null Hypothesis: “The means of the precipitation for the windward and leeward stations are the same”.

Alternate Hypothesis: “The means of the precipitation for the windward and leeward stations are different”.

The “Z” statistic is calculated as follows:

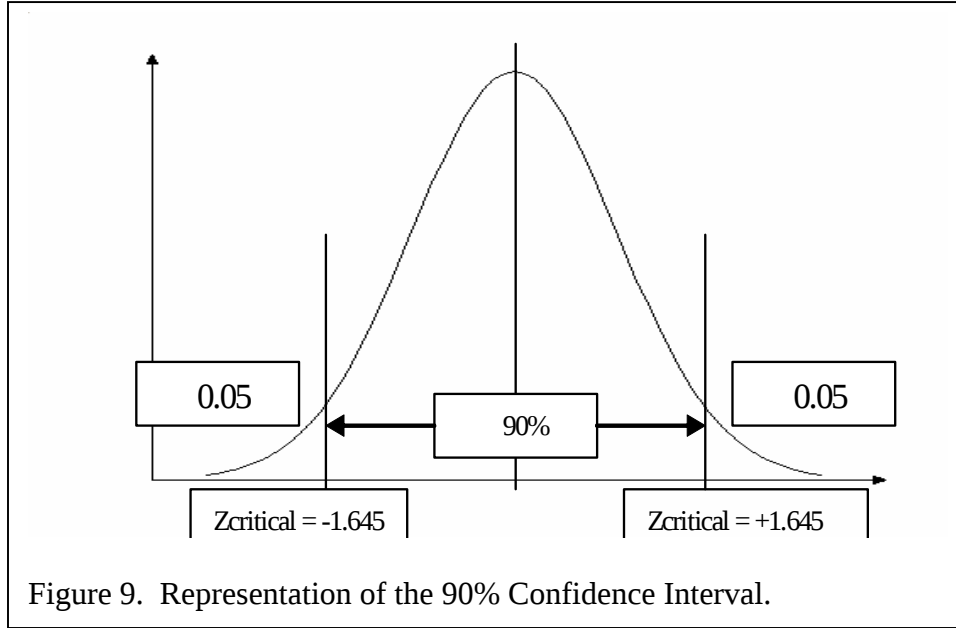
$$Z = \frac{\text{Mean1} - \text{Mean2}}{\sqrt{\frac{\text{std.dev1}^2}{n1} + \frac{\text{std.dev2}^2}{n2}}} \quad (2)$$

where Mean1: the mean precipitation for the leeward site
Mean2: the mean precipitation for the windward site
Std.dev1: the standard deviation for the leeward site
Std.dev2: the standard deviation for the windward site
n1: the total number of observations used in obtaining Mean1
n2: the total number of observations used in obtaining Mean2

The analysis incorporates the following assumption:

1. The total number of observations used in obtaining the means is large.
2. The distribution of the difference of the means is normal.
3. The sample variance is representative of the population variance.

Z_{critical} is defined as the standard deviation representing a specified probability of occurrence on the normal distribution curve. For example in Figure 9, a Z_{critical} of ± 1.645 represents the 90% confidence interval. If the Z statistic falls outside of Z_{critical} then the Null Hypothesis is rejected at the specified confidence interval; in this case 90%.



The value of $\left(\frac{\text{std.dev}}{\sqrt{n}}\right)$ can be calculated from the values at the 90% confidence bounds in the tables in Appendix A as follows:

$$\left(\frac{\text{std.dev}}{\sqrt{n}}\right) = \frac{(90\% \text{ confidence bound}) - \text{Mean}}{1.645} \quad (3)$$

Tables 6 through 9 contain the absolute values of Z for the four regions. Some of the mean precipitation values at two and four day durations are too small for an accurate comparison. In these cases the results are not meaningful, and “NM” is displayed in the tables.

Table 6. Z Values for HUNTSVILLE MONASTERY AND WOODRUFF

Duration:- Return Period	5 min	10 min	15 min	30 min	60 min	120 min	3 hr	6 hr	12 hr	24 hr	48 hr	4 day
2	2.680	2.720	2.667	2.636	2.600	3.667	4.212	5.264	8.828	4.414	4.653	NM
5	2.514	2.515	2.567	2.585	2.595	3.194	3.836	5.922	5.475	5.885	NM	NM
10	2.314	2.308	2.341	2.281	2.316	2.964	3.234	4.624	6.204	5.202	4.414	NM
25	2.044	2.074	2.058	2.065	2.063	2.718	2.555	4.207	5.264	5.202	5.885	4.414
50	1.851	1.849	1.843	1.839	1.825	2.246	2.483	3.174	4.904	6.242	5.885	NM
100	1.664	1.654	1.652	1.663	1.679	1.988	2.185	2.851	4.207	5.150	7.357	NM
200	1.464	1.470	1.475	1.473	1.470	1.687	1.842	2.339	3.531	4.277	4.162	5.885
500	1.288	1.285	1.294	1.296	1.287	1.439	1.539	1.995	2.802	3.950	5.202	9.306
1000	1.191	1.189	1.194	1.191	1.182	1.247	1.422	1.706	2.183	3.060	4.562	NM

Table 7. Z Values for LEVAN AND PRICE WAREHOUSES

Duration:- Return Period	5 min	10 min	15 min	30 min	60 min	120 min	3 hr	6 hr	12 hr	24 hr	48 hr	4 day
2	0.321	0.357	0.362	0.322	0.357	0.000	0.465	1.163	1.163	0.000	NM	NM
5	0.064	0.084	0.103	0.076	0.000	0.489	0.357	0.658	2.326	1.471	NM	NM
10	0.000	0.000	0.000	0.000	0.000	0.404	0.619	1.163	0.912	0.000	0.000	2.326
25	0.018	0.047	0.029	0.000	0.069	0.580	0.734	0.931	1.551	1.471	NM	NM
50	0.042	0.055	0.044	0.033	0.053	0.443	0.497	1.163	1.316	1.471	2.326	NM
100	0.098	0.085	0.086	0.077	0.082	0.338	0.517	0.546	1.163	1.471	0.000	NM
200	0.156	0.162	0.156	0.155	0.157	0.377	0.387	0.423	0.931	0.000	2.326	0.000
500	0.204	0.208	0.198	0.200	0.216	0.174	0.205	0.145	0.332	0.798	1.471	1.471
1000	0.217	0.217	0.221	0.226	0.215	0.067	0.105	0.000	0.258	0.000	1.040	2.326

Table 8. Z Values for MANTI AND CASTLE DALE

Duration:- Return Period	5 min	10 min	15 min	30 min	60 min	120 min	3 hr	6 hr	12 hr	24 hr	48 hr	4 day
2	0.400	0.400	0.403	0.473	0.401	0.697	0.981	0.912	1.471	NM	NM	NM
5	0.327	0.290	0.288	0.344	0.414	0.525	0.816	0.775	1.471	NM	NM	NM
10	0.083	0.110	0.089	0.133	0.109	0.431	1.046	1.316	2.943	2.326	NM	NM
25	0.019	0.051	0.031	0.046	0.000	0.304	0.456	0.912	0.775	0.000	2.326	NM
50	0.180	0.158	0.143	0.177	0.171	0.116	0.000	0.765	1.825	2.326	NM	NM
100	0.301	0.304	0.295	0.300	0.264	0.085	0.000	0.304	0.658	0.000	2.326	NM
200	0.388	0.394	0.393	0.397	0.368	0.133	0.208	0.228	0.514	0.000	NM	2.326
500	0.470	0.465	0.465	0.461	0.467	0.278	0.364	0.487	0.320	0.000	2.326	NM
1000	0.509	0.508	0.510	0.512	0.503	0.353	0.386	0.494	0.505	0.564	0.000	2.326

Table 9. Z Values for CEDAR CITY AP AND ESCALANTE												
Duration:- Return Period	5 min	10 min	15 min	30 min	60 min	120 min	3 hr	6 hr	12 hr	24 hr	48 hr	4 day
2	1.180	1.201	1.193	1.206	1.200	1.163	1.369	1.551	1.163	0.000	NM	NM
5	1.133	1.152	1.117	1.128	1.056	1.328	1.427	1.316	1.825	1.471	NM	NM
10	1.126	1.167	1.158	1.106	1.095	1.028	1.154	1.745	0.775	1.163	0.000	NM
25	0.977	0.980	0.991	0.971	0.999	1.003	0.808	1.861	1.316	2.943	2.326	NM
50	0.869	0.882	0.879	0.856	0.848	0.869	0.750	1.427	1.028	2.943	NM	NM
100	0.731	0.728	0.726	0.717	0.711	0.726	0.792	1.034	1.396	2.737	4.653	2.326
200	0.612	0.611	0.611	0.620	0.619	0.594	0.676	0.537	0.714	2.943	2.943	2.326
500	0.454	0.449	0.453	0.453	0.446	0.399	0.465	0.251	0.000	2.257	3.121	1.471
1000	0.346	0.351	0.346	0.345	0.341	0.306	0.354	0.291	0.194	2.527	2.943	2.943

RESULTS

Tables 10 through 13 indicate whether or not there was a significant difference at the 90% level (i.e. $Z > 1.645$) based on the Z values in Tables 6 through 9.

Table 10. HUNTSVILLE MONASTERY AND WOODRUFF												
Duration:- Return Period	5 min	10 min	15 min	30 min	60 min	120 min	3 hr	6 hr	12 hr	24 hr	48 hr	4 day
2	Different	Different	Different	Different	Different	Different	Different	Different	Different	Different	Different	
5	Different	Different	Different	Different	Different	Different	Different	Different	Different	Different		
10	Different	Different	Different	Different	Different	Different	Different	Different	Different	Different	Different	
25	Different	Different	Different	Different	Different	Different	Different	Different	Different	Different	Different	Different
50	Different	Different	Different	Different	Different	Different	Different	Different	Different	Different	Different	
100	Different	Different	Different	Different	Different	Different	Different	Different	Different	Different	Different	
200	Same	Same	Same	Same	Same	Different	Different	Different	Different	Different	Different	Different
500	Same	Same	Same	Same	Same	Same	Same	Different	Different	Different	Different	Different
1000	Same	Same	Same	Same	Same	Same	Same	Different	Different	Different	Different	

Table 11. LEVAN AND PRICE WAREHOUSES

Duration:- Return Period	5 min	10 min	15 min	30 min	60 min	120 min	3 hr	6 hr	12 hr	24 hr	48 hr	4 day
2	Same	Same	Same	Same	Same	Same	Same	Same	Same	Same		
5	Same	Same	Same	Same	Same	Same	Same	Same	Different	Same		
10	Same	Same	Same	Same	Same	Same	Same	Same	Same	Same	Same	Different
25	Same	Same	Same	Same	Same	Same	Same	Same	Same	Same		
50	Same	Same	Same	Same	Same	Same	Same	Same	Same	Same	Different	
100	Same	Same	Same	Same	Same	Same	Same	Same	Same	Same	Same	
200	Same	Same	Same	Same	Same	Same	Same	Same	Same	Same	Different	Same
500	Same	Same	Same	Same	Same	Same	Same	Same	Same	Same	Same	Same
1000	Same	Same	Same	Same	Same	Same	Same	Same	Same	Same	Same	Different

Table 12. MANTI AND CASTLE DALE

Duration:- Return Period	5 min	10 min	15 min	30 min	60 min	120 min	3 hr	6 hr	12 hr	24 hr	48 hr	4 day
2	Same	Same	Same	Same	Same	Same	Same	Same	Same			
5	Same	Same	Same	Same	Same	Same	Same	Same	Same			
10	Same	Same	Same	Same	Same	Same	Same	Same	Different	Different		
25	Same	Same	Same	Same	Same	Same	Same	Same	Same	Same	Different	
50	Same	Same	Same	Same	Same	Same	Same	Same	Different	Different		
100	Same	Same	Same	Same	Same	Same	Same	Same	Same	Same	Different	
200	Same	Same	Same	Same	Same	Same	Same	Same	Same	Same		Different
500	Same	Same	Same	Same	Same	Same	Same	Same	Same	Same	Different	
1000	Same	Same	Same	Same	Same	Same	Same	Same	Same	Same	Same	Different

Table 13. CEDAR CITY AP AND ESCALANTE

Duration:- Return Period	5 min	10 min	15 min	30 min	60 min	120 min	3 hr	6 hr	12 hr	24 hr	48 hr	4 day
2	Same	Same	Same	Same	Same	Same	Same	Same	Same	Same		
5	Same	Same	Same	Same	Same	Same	Same	Same	Different	Same		
10	Same	Same	Same	Same	Same	Same	Same	Different	Same	Same	Same	
25	Same	Same	Same	Same	Same	Same	Same	Different	Same	Different	Different	
50	Same	Same	Same	Same	Same	Same	Same	Same	Same	Different		
100	Same	Same	Same	Same	Same	Same	Same	Same	Same	Different	Different	Different
200	Same	Same	Same	Same	Same	Same	Same	Same	Same	Different	Different	Different
500	Same	Same	Same	Same	Same	Same	Same	Same	Same	Different	Different	Same
1000	Same	Same	Same	Same	Same	Same	Same	Same	Same	Different	Different	Different

The following 36 bar charts show the calculated Z values. The horizontal red lines on each chart indicate the 95% confidence boundaries (± 1.96). If a bar extends beyond one of these lines it indicates that the means are statistically different.

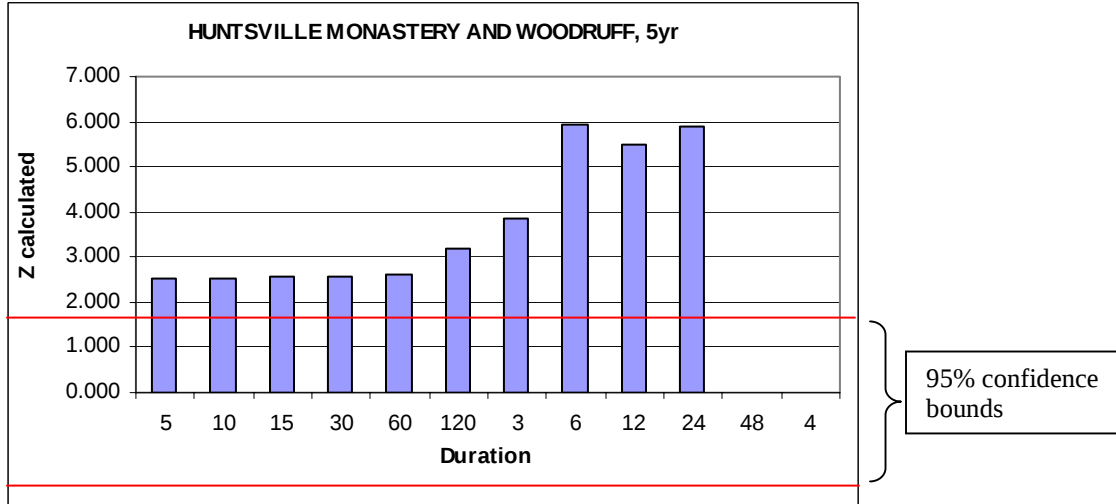
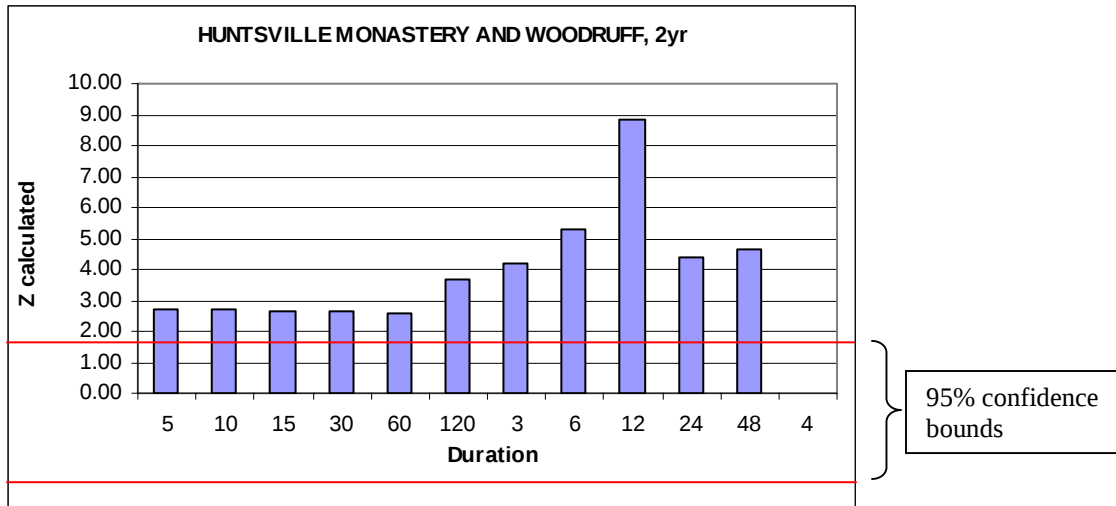
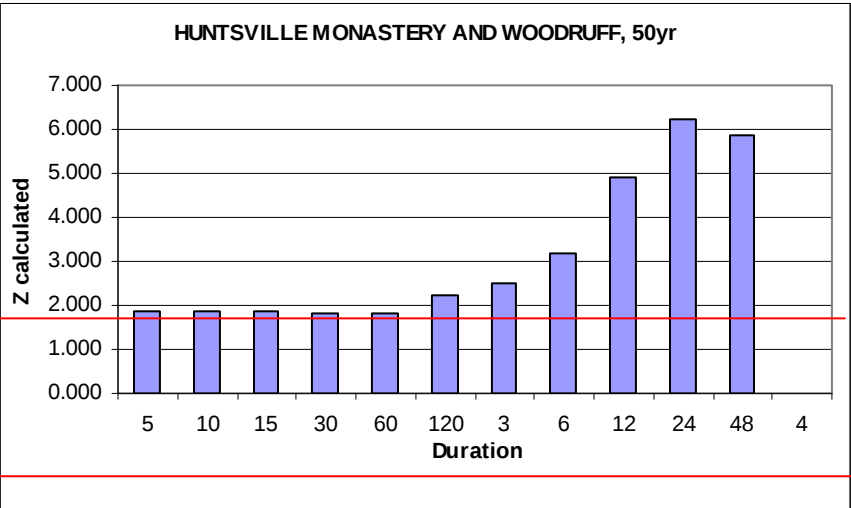
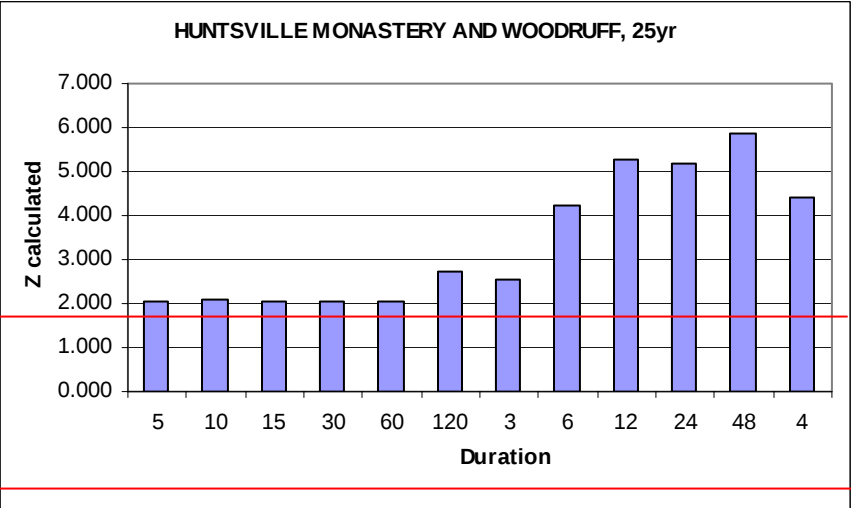
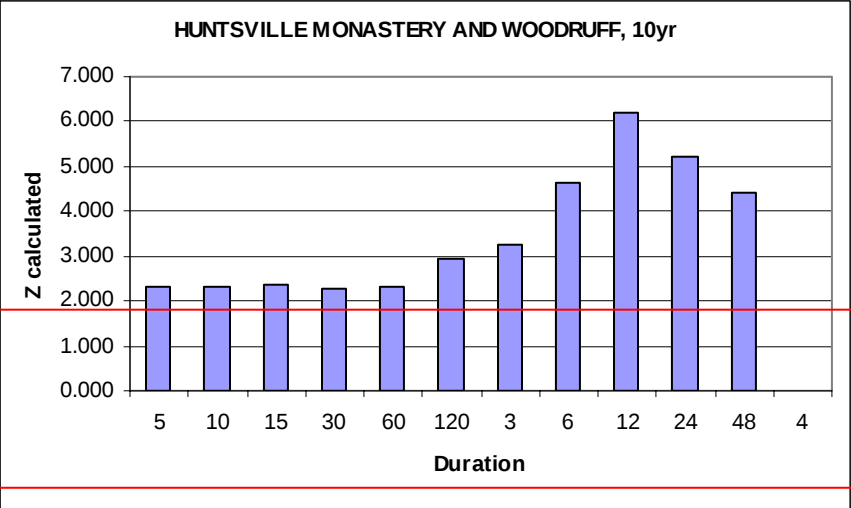
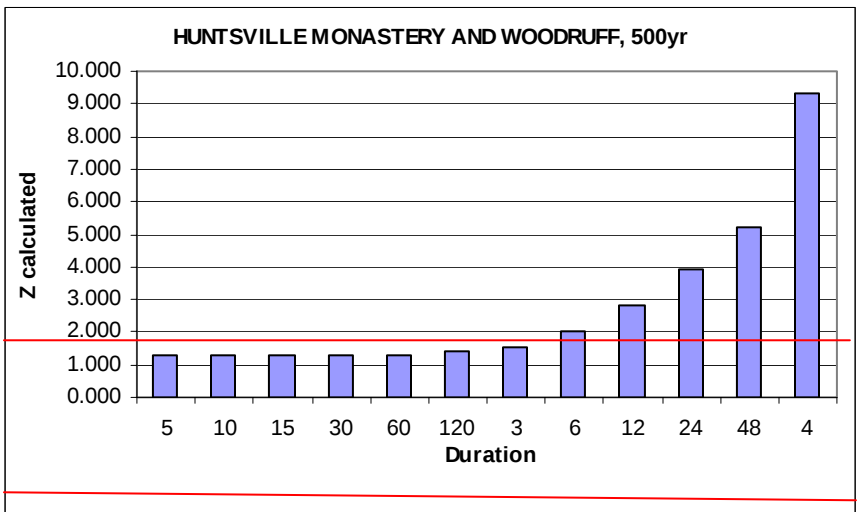
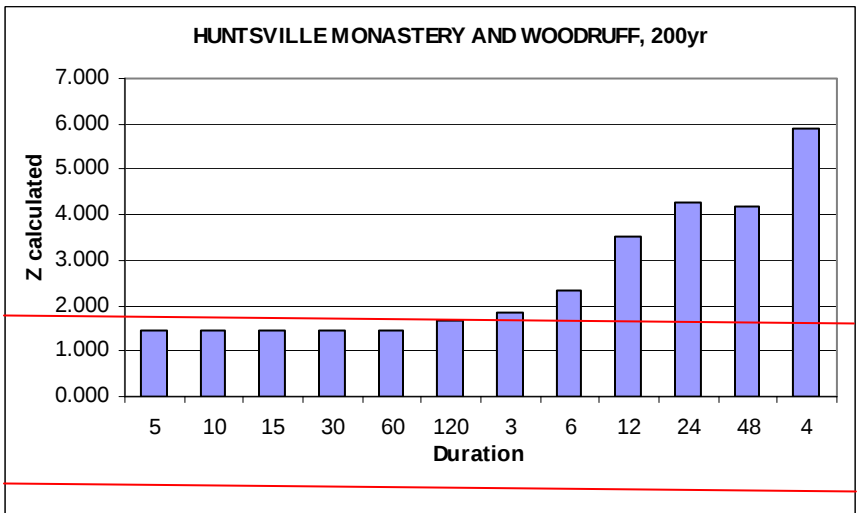
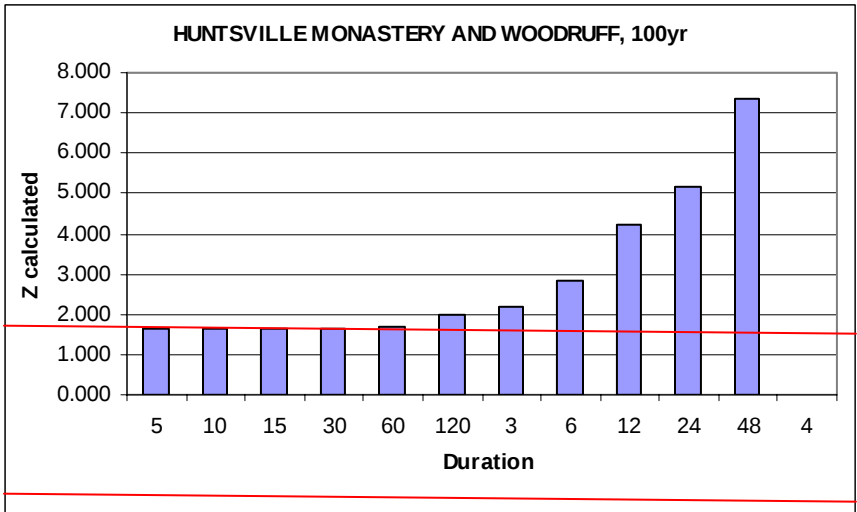
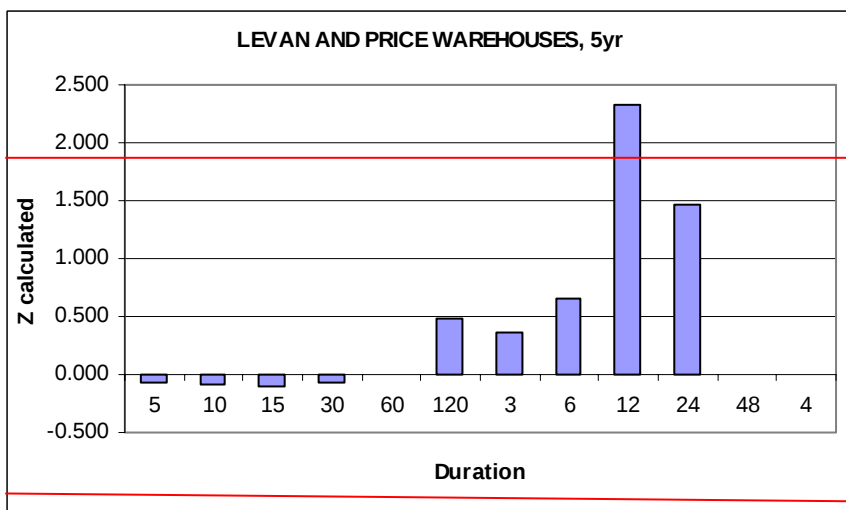
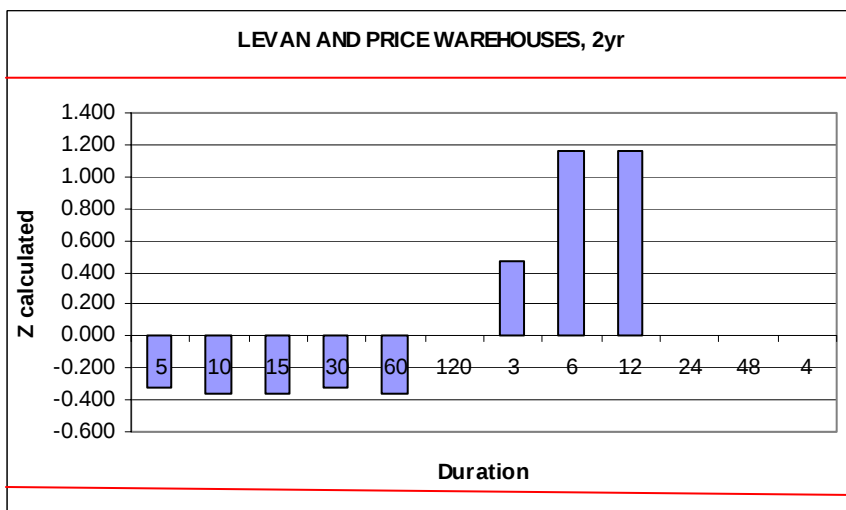
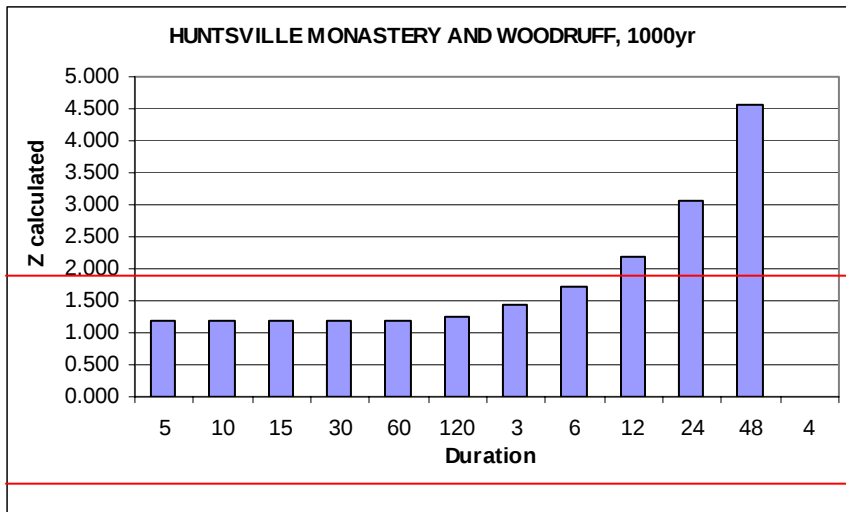
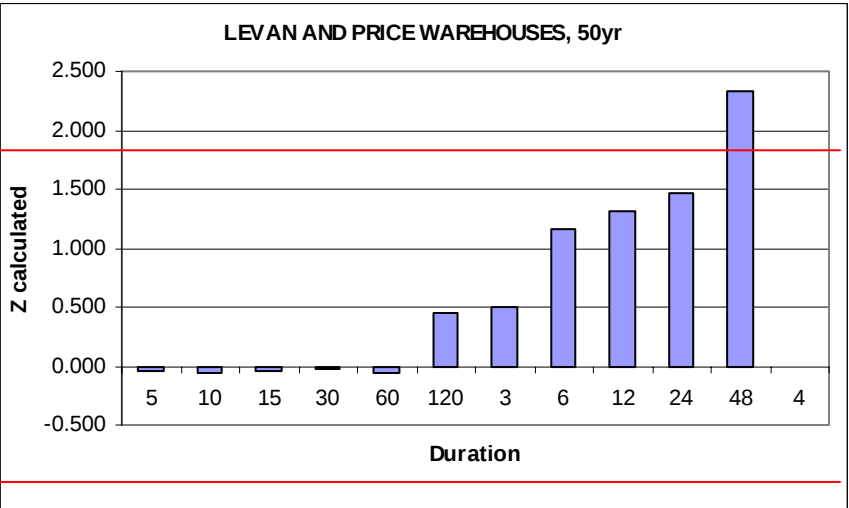
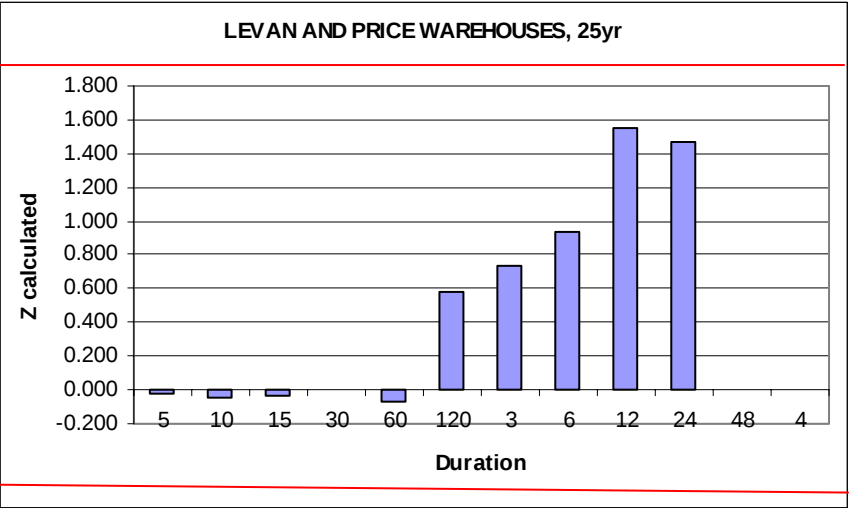
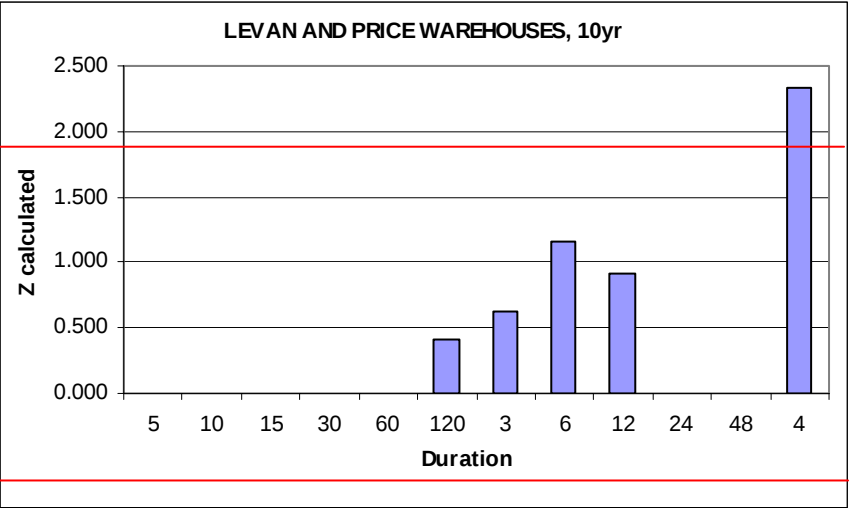


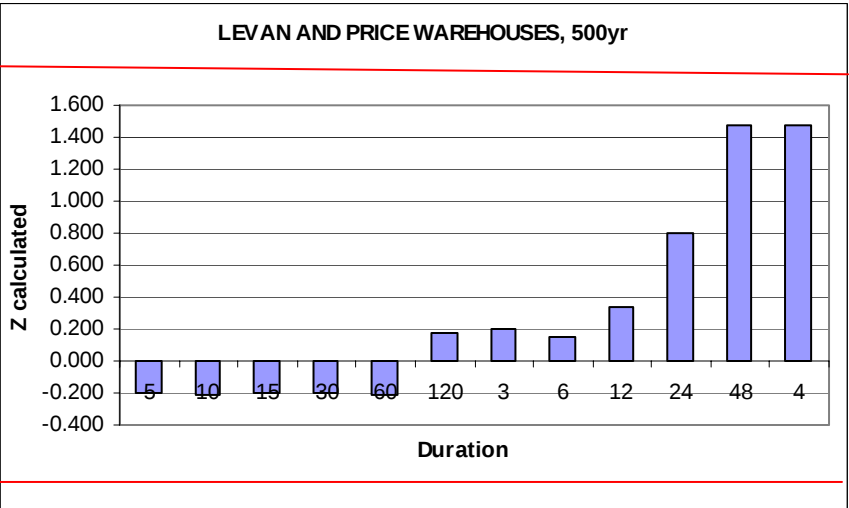
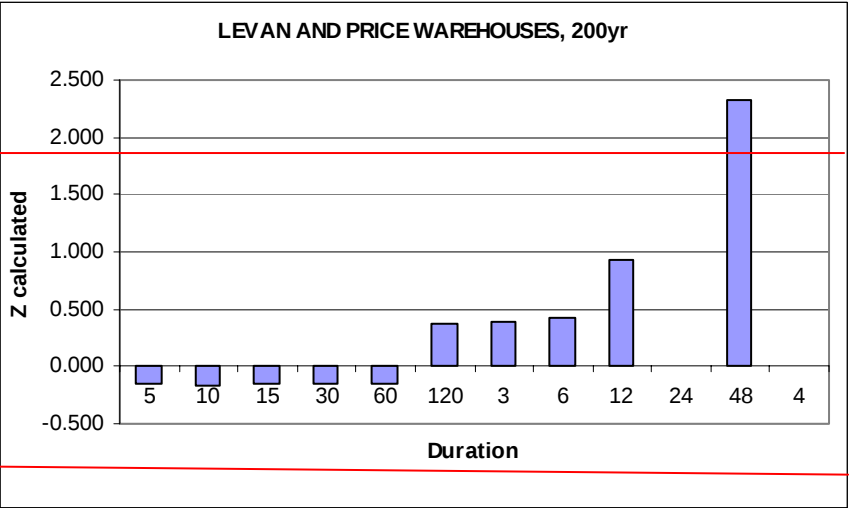
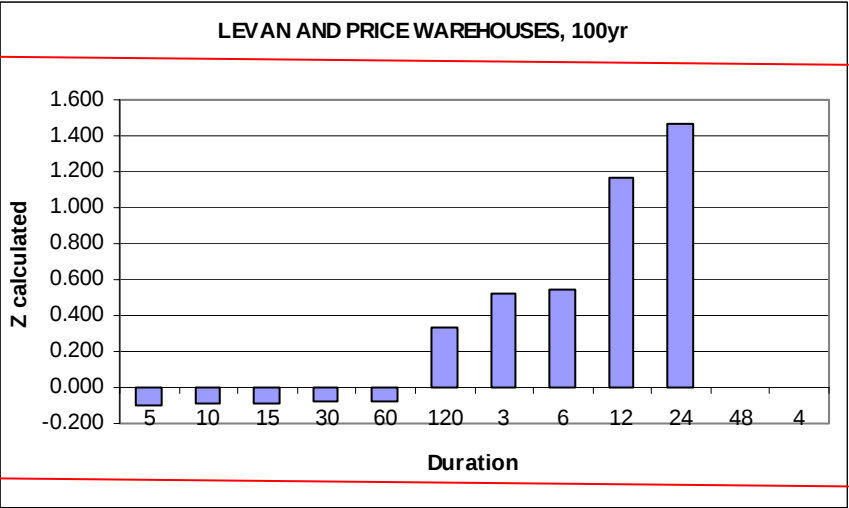
Figure11.

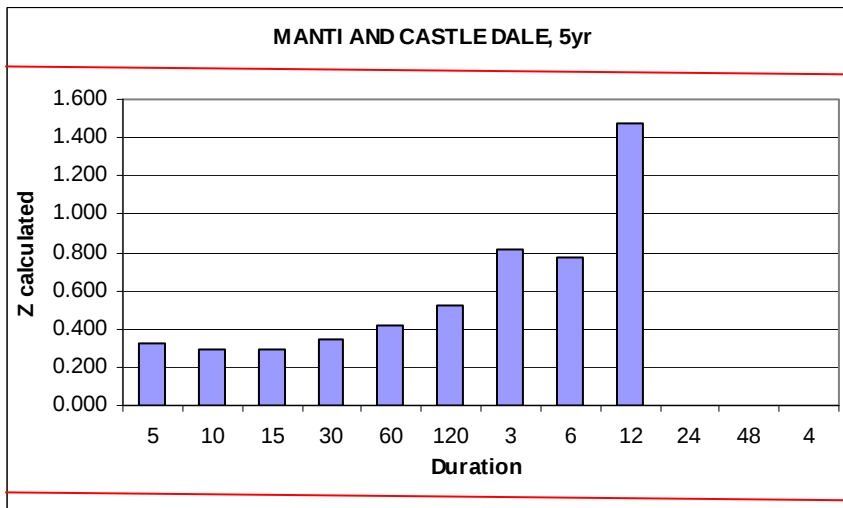
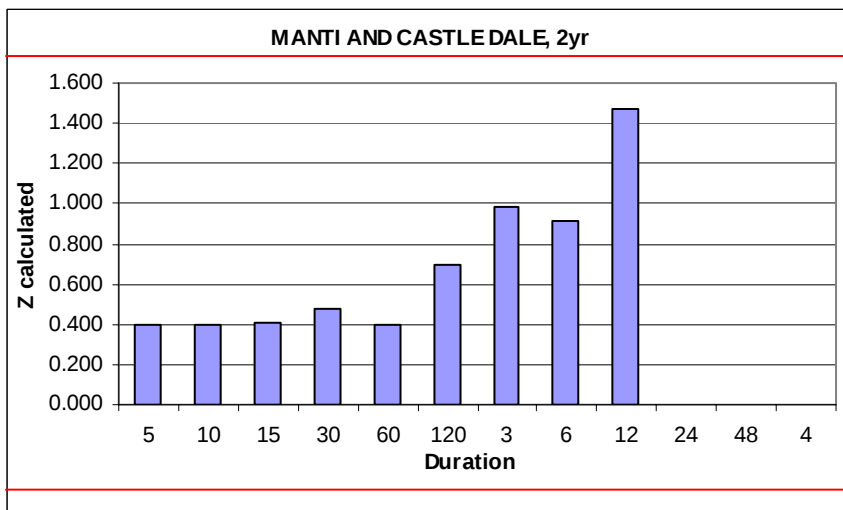
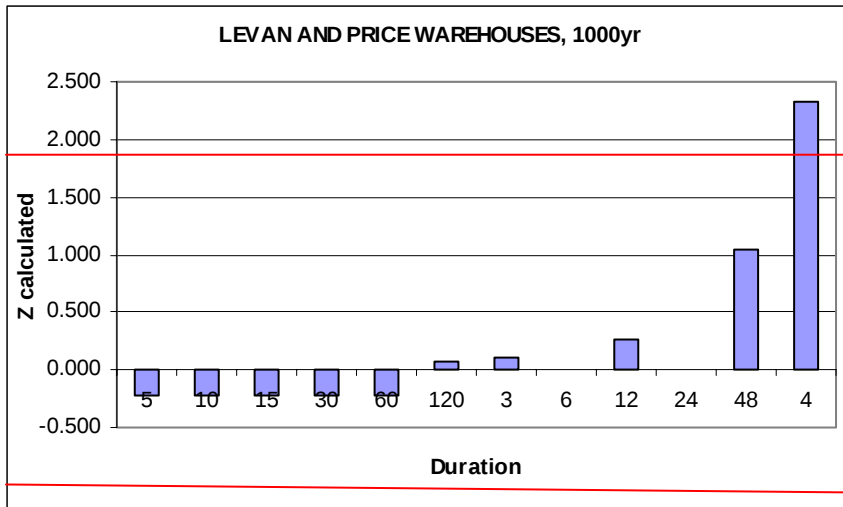


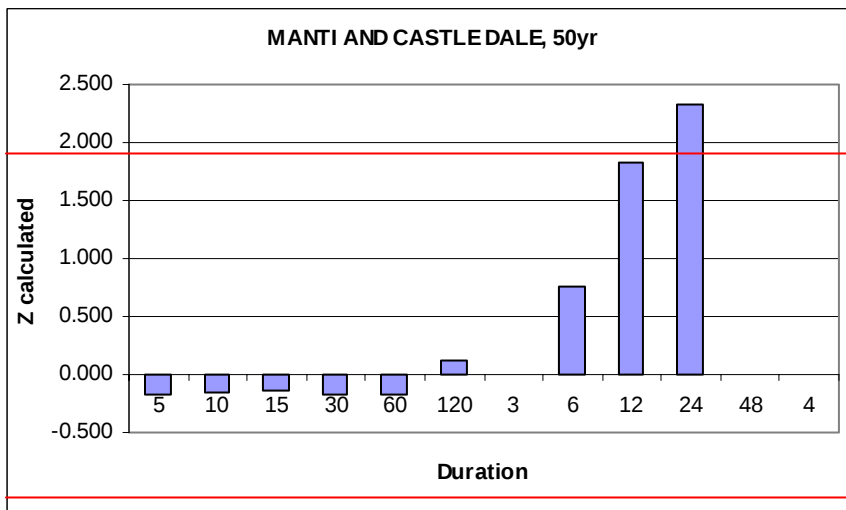
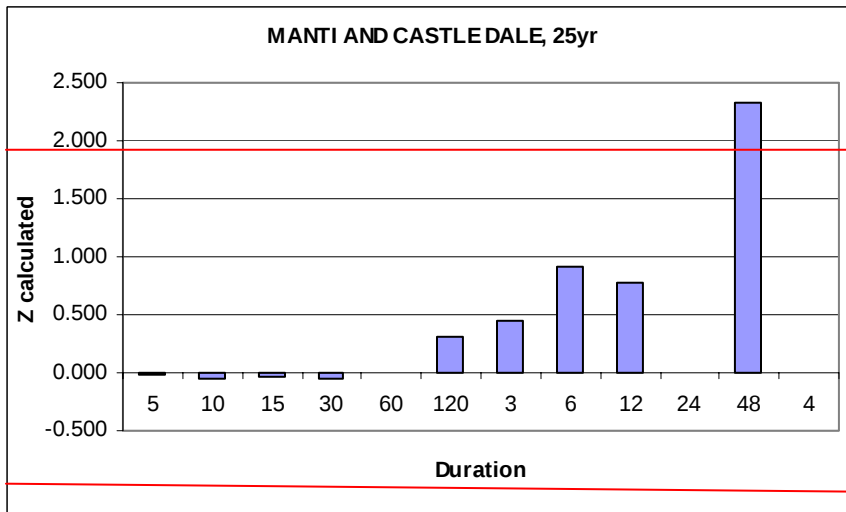
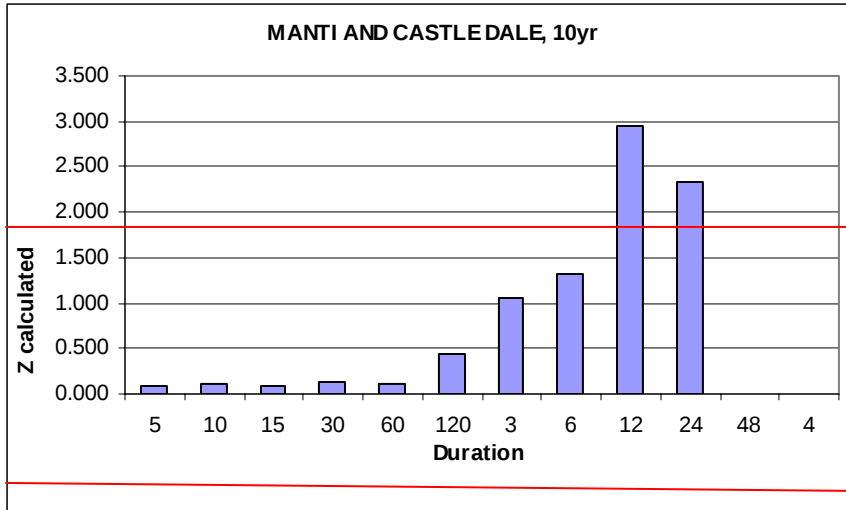


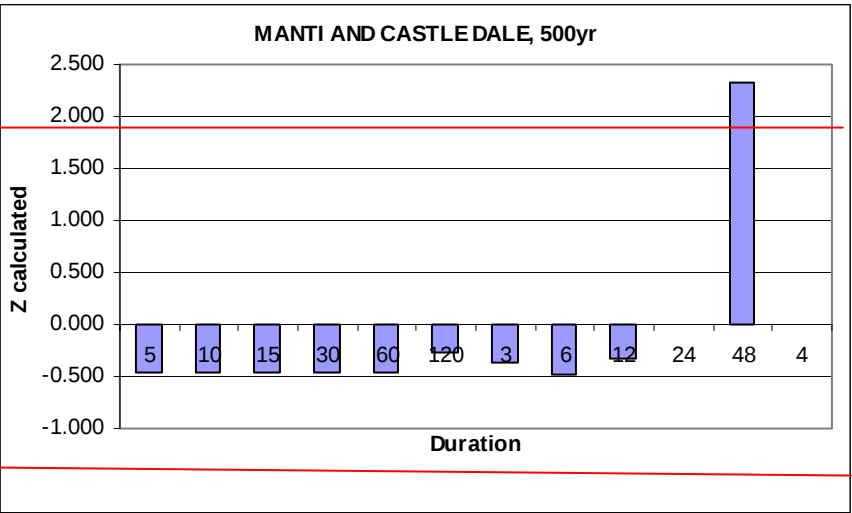
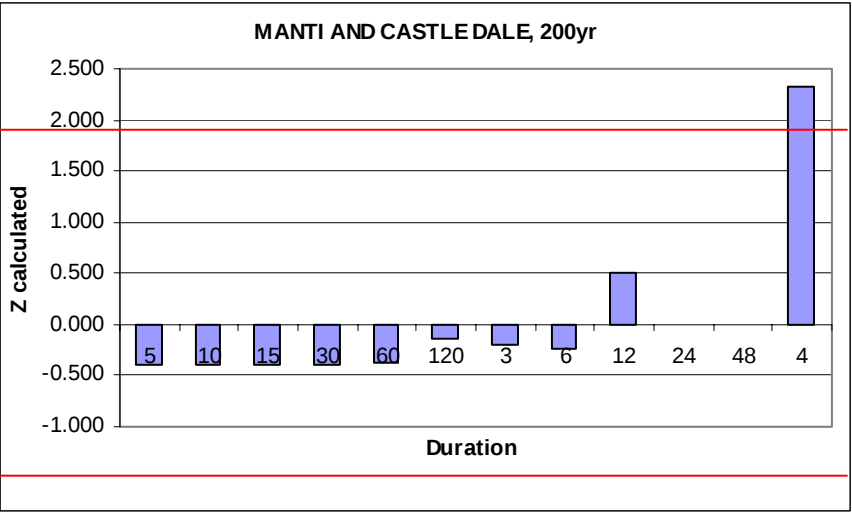
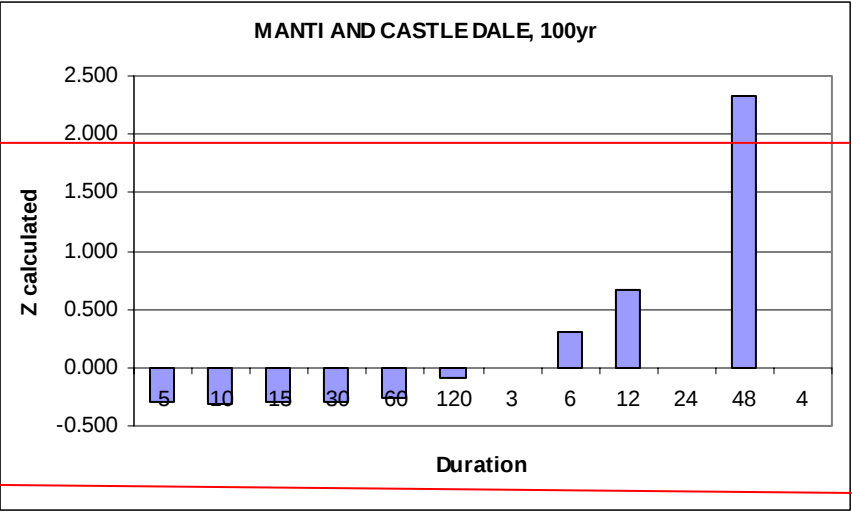


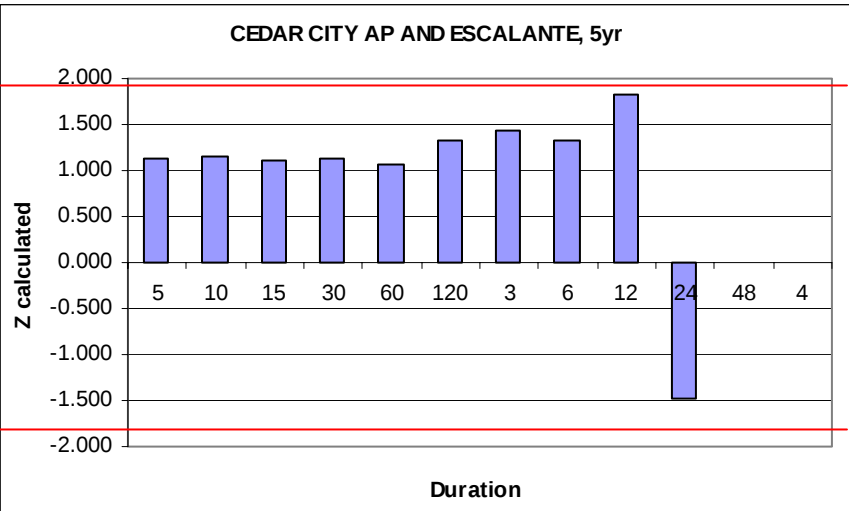
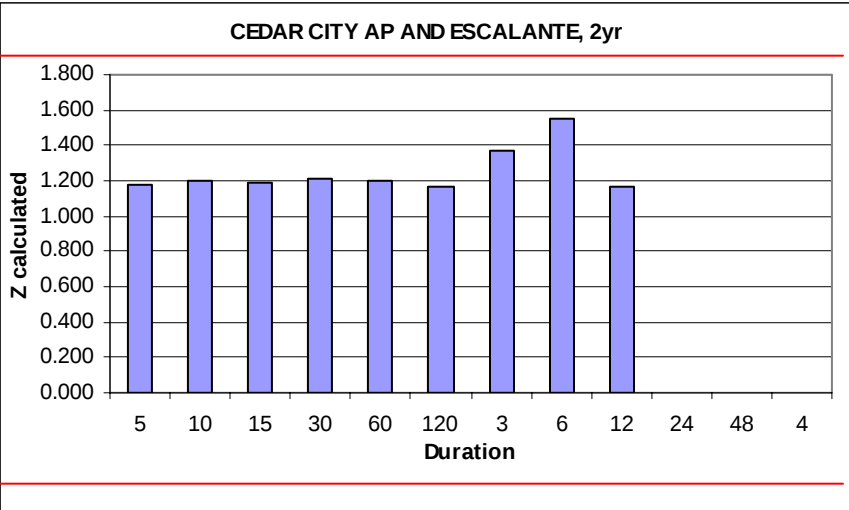
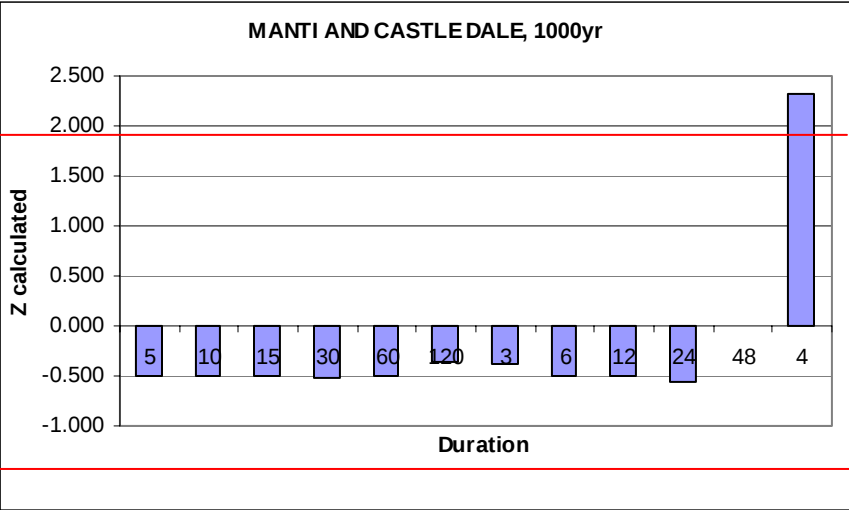


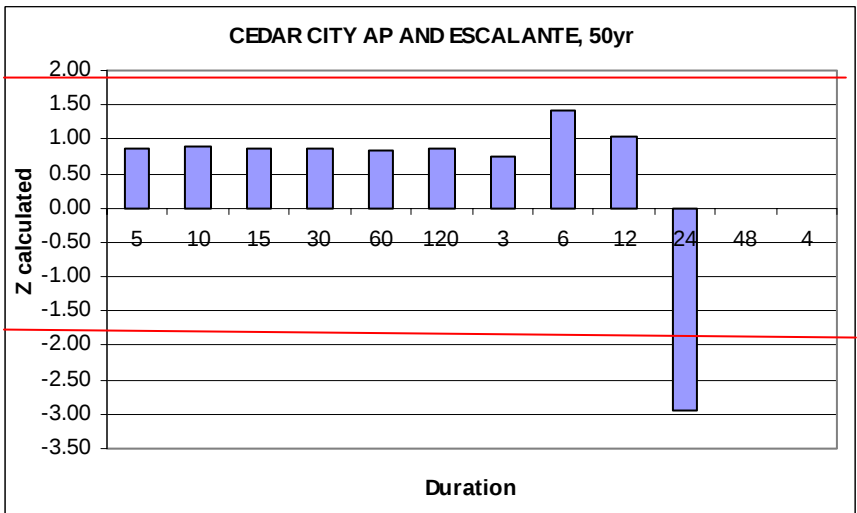
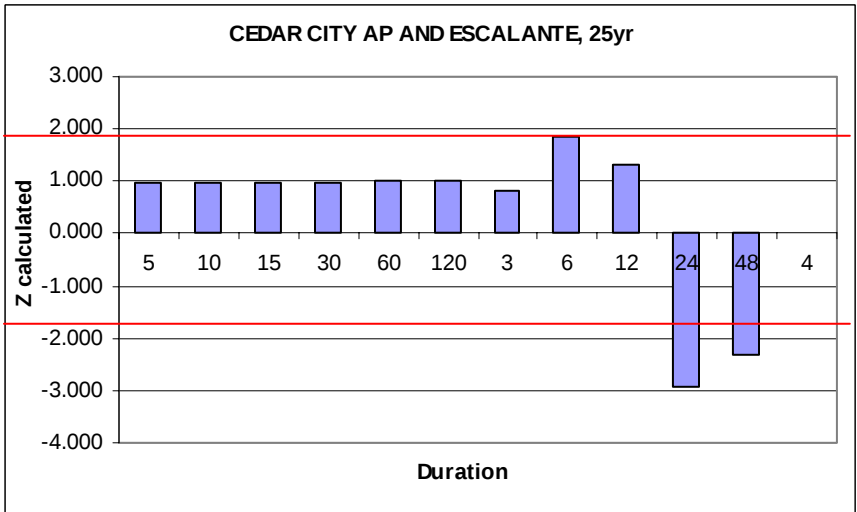
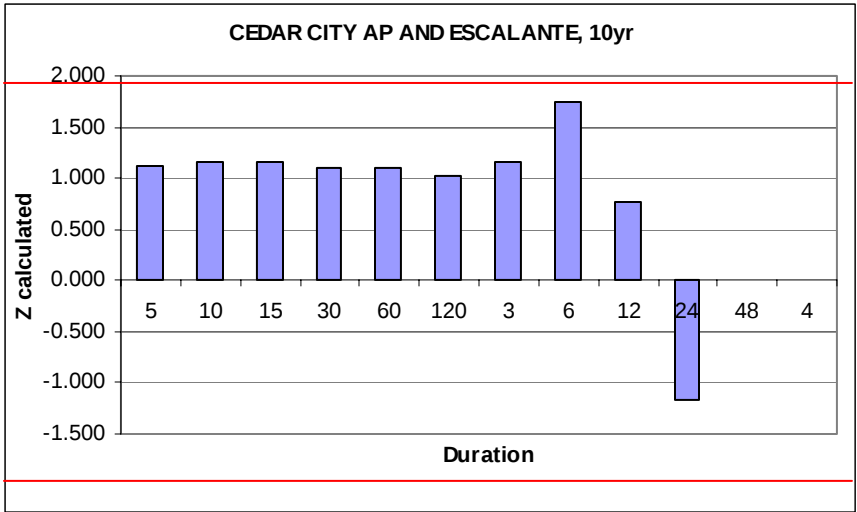


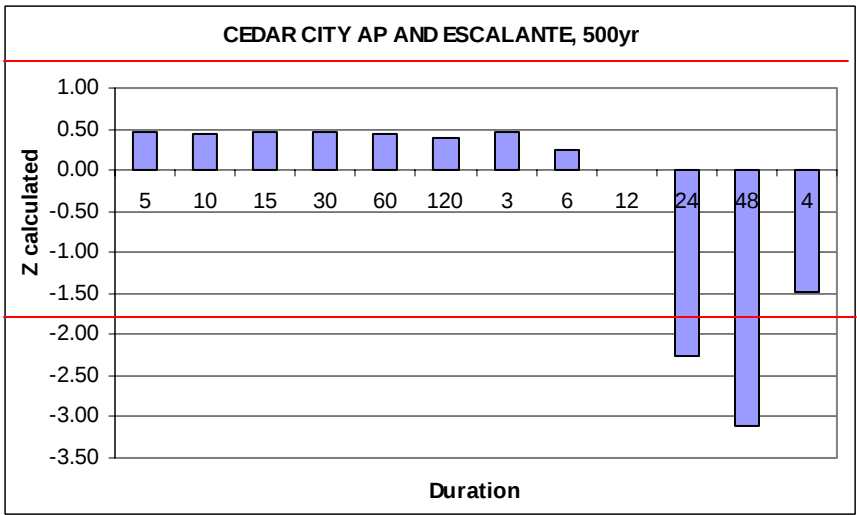
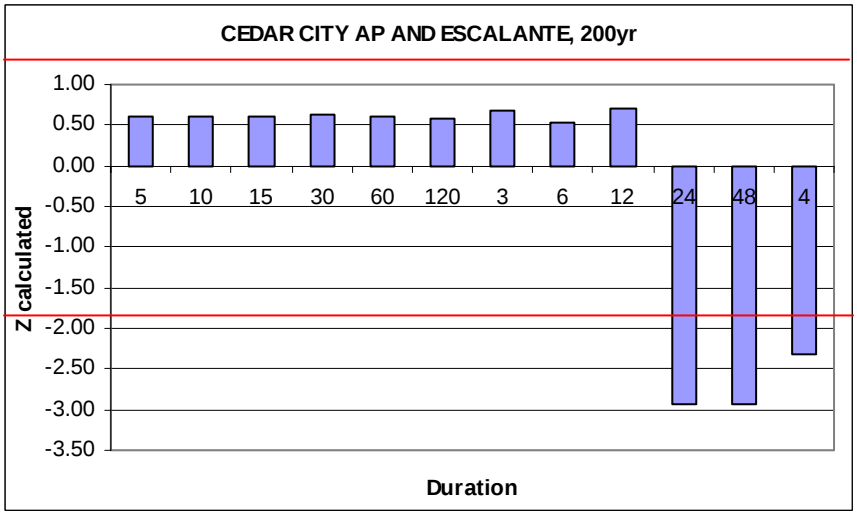
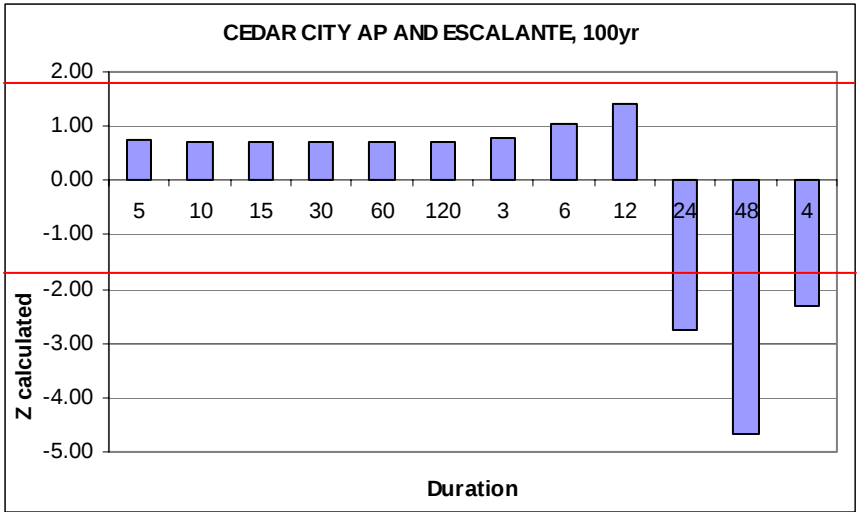


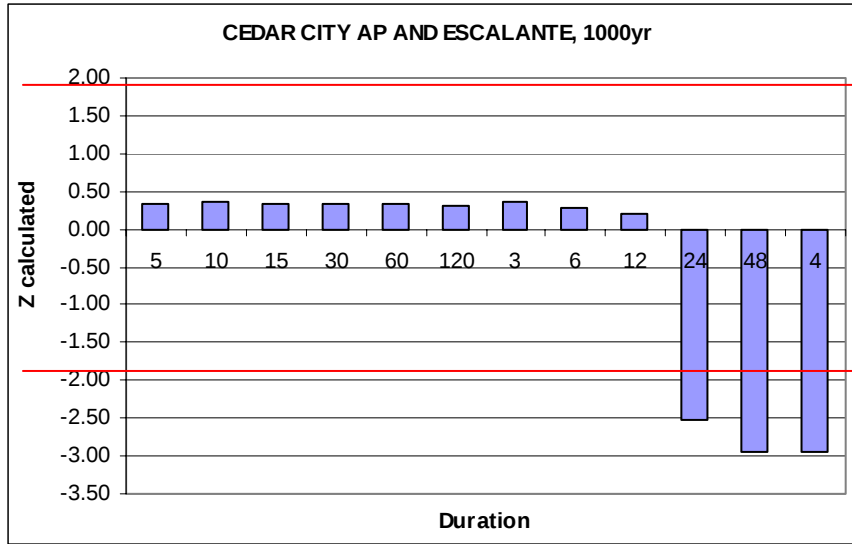












Conclusions

This study presents a methodology for comparing IDF curves at two sites, and utilizes the methodology to analyze for orographic effects on precipitation in four regions in Utah.

The methodology consists of obtaining data from the NOAA web site including the upper and lower 90% confidence bounds. The mean and the bounds are then used to calculate the composite standard deviation:

$$\sqrt{\frac{\text{std.dev1}^2}{n1} + \frac{\text{std.dev2}^2}{n2}}$$

where

$$\left(\frac{\text{std.dev}}{\sqrt{n}} \right) = \frac{(\text{90\% confidence bound}) - \text{Mean}}{1.645}$$

The “Z” statistic can then be calculated for the data pair:

$$Z = \frac{\text{Mean1} - \text{Mean2}}{\sqrt{\frac{\text{std.dev1}^2}{n1} + \frac{\text{std.dev2}^2}{n2}}}$$

The Z statistic can be compared to the standard normal distribution to test the Null Hypothesis: “The two means are statistically the same”. The null hypothesis is false at the 90% confidence level for values of Z falling outside the range of ± 1.645 and at the

95% confidence level for values of Z outside the range of ± 1.96 . A computer program was written so that large amounts of data could be efficiently processed.

The orographic effects on precipitation at the sites can be inferred by considering the two complementary tables for the site pair:

1. The percentage difference of the mean precipitation for the specified intensity-duration at the leeward site compared to the windward site (Tables 2 – 5 and Charts 5 – 8).
2. The statistical significance of the difference (Tables 6 – 9).

The shaded cells in Tables 2 through 5 indicate that the differences are not significant at the 90% confidence level.

Wasatch North Region (Huntsville Monastery and Woodruff)

The mean precipitation is statistically different at the 90% confidence level for three quarters of the intensity-duration cases. In all of these cases the leeward precipitation was less than the windward precipitation. The amount of the differences ranged from about 25% to 50%. Consequently a person extrapolating data from a leeward data site to a windward catchment would probably be underestimating the magnitude.

Wasatch South (Levan and Price)

The mean precipitation is statistically different at the 90% confidence level for about 7% of intensity-duration cases. In all of these cases the leeward precipitation was less than the windward precipitation. The amount of the differences ranged from about 11% to 25%.

Wasatch Plateau (Manti and Castle Dale)

The mean precipitation is statistically different at the 90% confidence level for about 4% of intensity-duration cases. In all of these cases the leeward precipitation was less than the windward precipitation. The amount of the differences ranged from about 14% to 33%.

Paunsang Mountain Plateau, Escalante Mountains (Cedar City and Escalante)

The mean precipitation is statistically different at the 90% confidence level for about 16% of intensity-duration cases. In all of these cases the leeward precipitation was less than the windward precipitation. The amount of the differences ranged from about 14% to 33%.

SECTION 2: COMPARISON OF IDF CURVES FROM DIFFERENT SOURCES

Introduction

For many years, UDOT has been using Intensity-Duration-Frequency (IDF) curves that were created by the methodology developed at the Utah Climate Center (UCC). More recently IDF curves have been published on the NOAA web site at: <http://hdsc.nws.noaa.gov>. These two systems have been used to estimate the IDF curves which form the basis for estimating point rainfall events. The rainfall events are used in turn to estimate peak flows which are a principal parameter for the design of roadway culverts and other hydraulic structures.

The object of this study is to compare the UCC IDF curves with the NOAA IDF curves at a sampling of four sites in Utah.

Data

Intensity-Duration-Frequency curves were obtained from the two sources for sites in four strategic regions in Utah. One source was the Utah Climate Center (UCC) computer model. The UCC model has been used in association with the design of hundreds of culverts in Utah. The second source was the national data provided by the National Oceanic & Atmospheric Administration (NOAA). The NOAA source is the most accessible.

In consultation with personnel at the Utah Department of Transportation (UDOT) and the Utah Climate Center (UCC), four sites were selected:

Heber
Moab
Salt Lake City
St. George

The UCC data is hereafter referred to as the OLD Data and the NOAA data as the NEW Data. The relative amount of precipitation for the NEW IDF compared to the OLD IDF was calculated for each intensity and duration as follows:

$$\frac{(\text{NEW IDF}) - (\text{OLD IDF})}{(\text{OLD IDF})} (100) \quad (4)$$

The results expressed as percentages are shown for each of the sites in Tables 16, 19, 22, and 25. It is not surprising to find greater variation at return periods of 100 years or greater because these data are based on extreme extrapolations. They are included here in order to provide a comprehensive analysis, but they are not statistically meaningful.

Graphs of the results follow the respective tables.

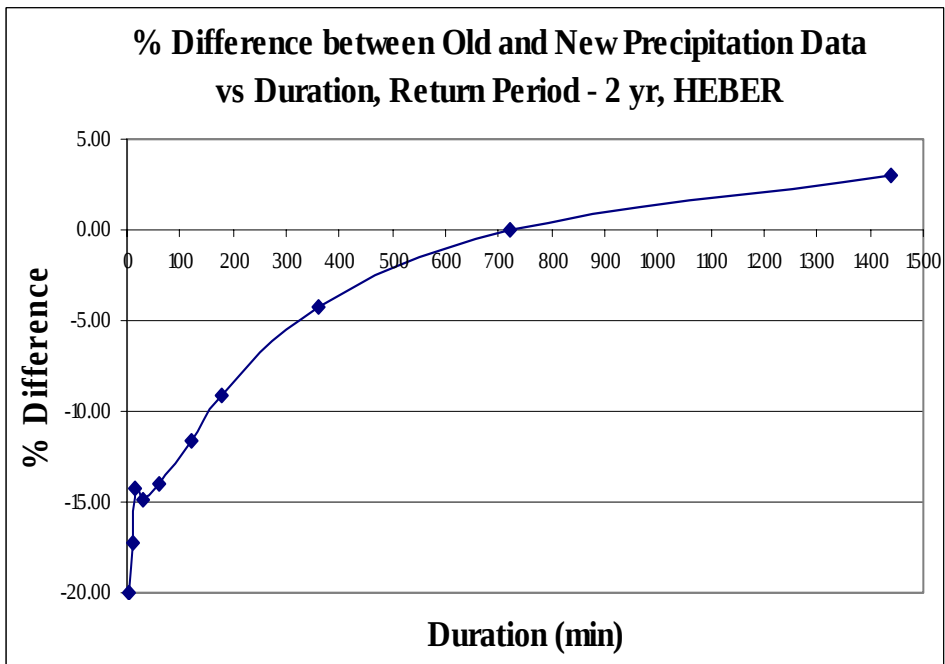
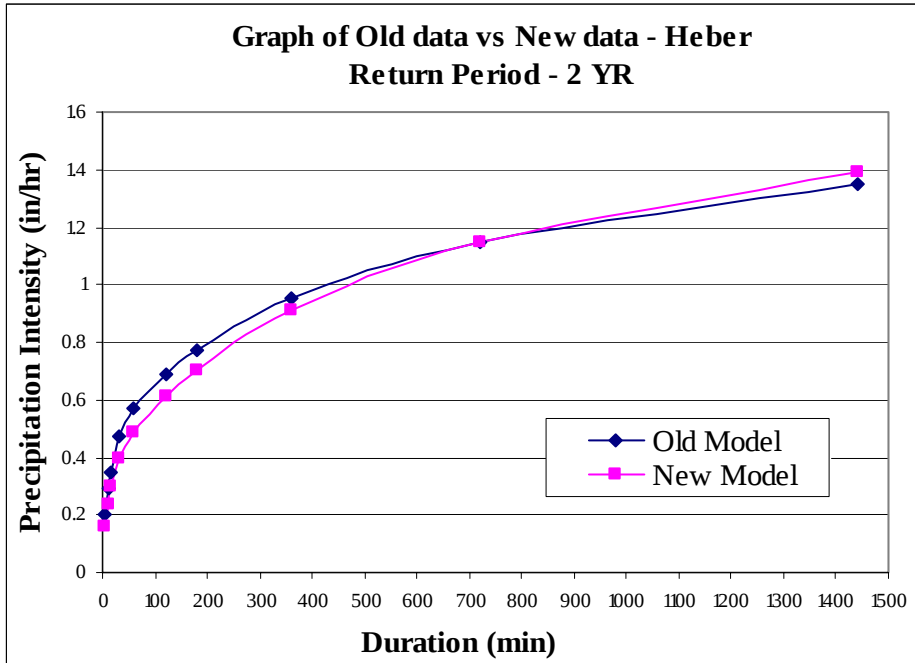
Heber Analysis

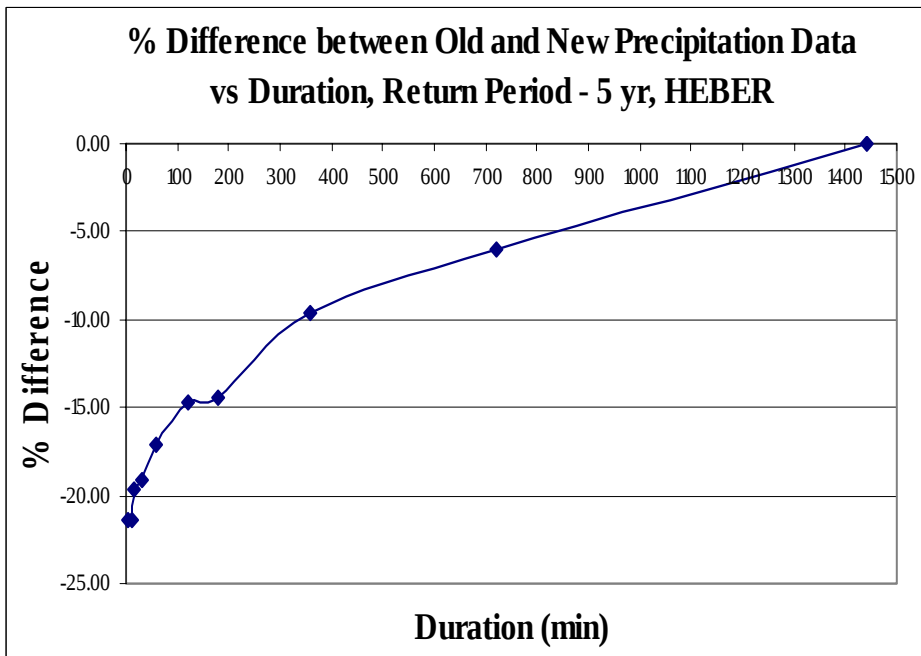
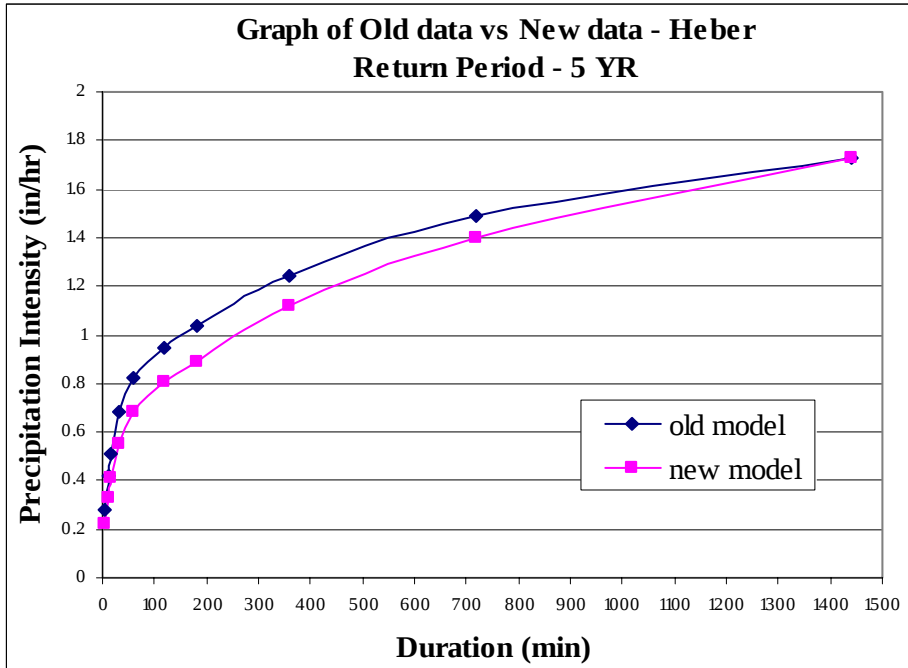
The results, expressed as percentages, are shown for Heber in the following tables and graphs.

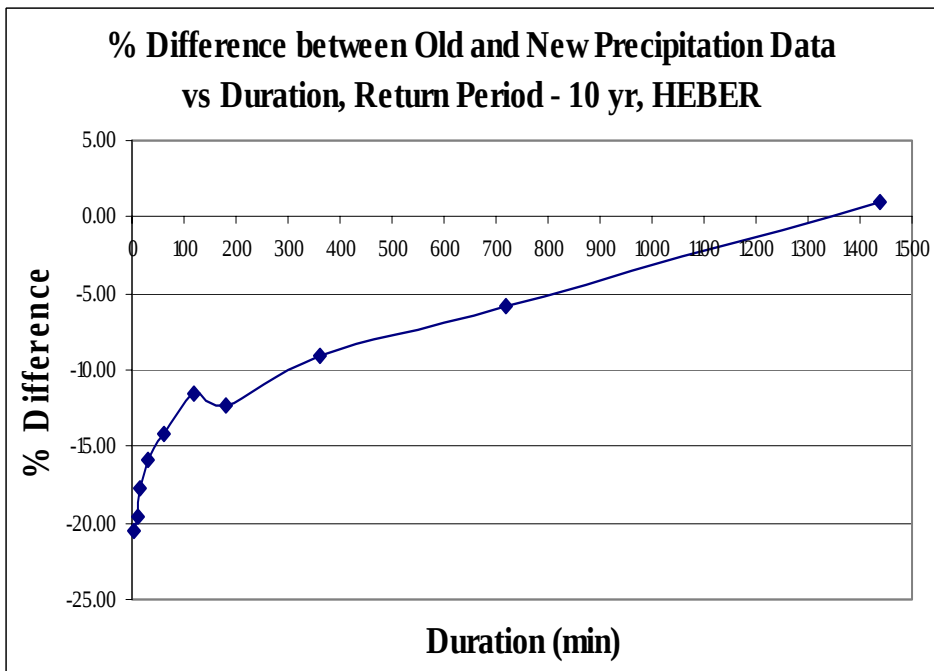
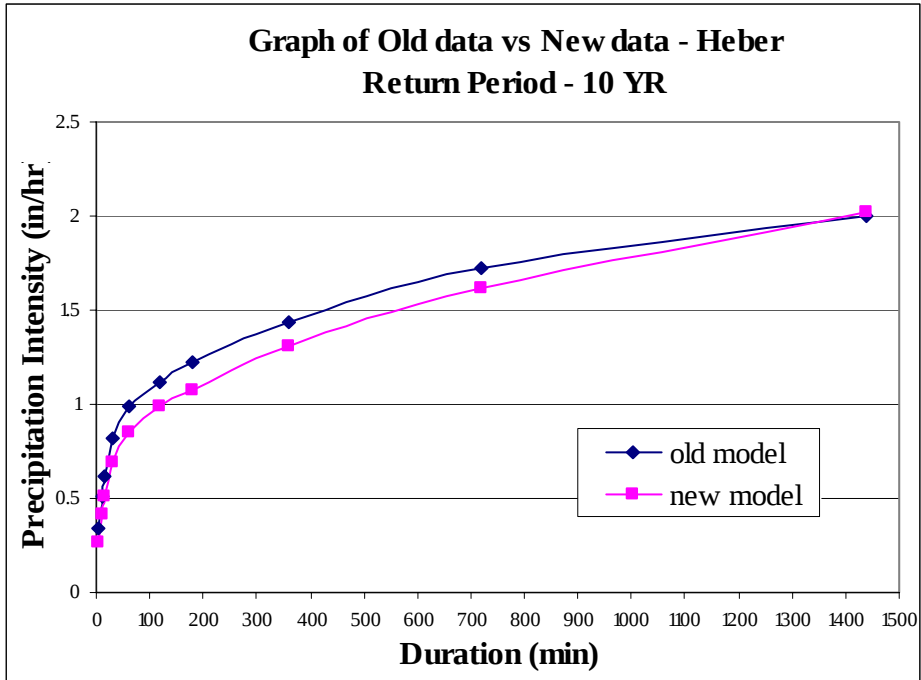
Table 14. HEBER Lon (dd), -111.4156, Lat (dd), 40.4922, Elev (feet), 5587										
OLD DATA										
Duration:- Return Period	5- min	10- min	15- min	30- min	1-hr (60- min)	2-hr (120- min)	3-hr (180- min)	6-hr (360- min)	12-hr (720- min)	24-hr (1440- min)
2-YR	0.2	0.29	0.35	0.47	0.57	0.69	0.77	0.95	1.15	1.35
5-YR	0.28	0.42	0.51	0.68	0.82	0.95	1.04	1.24	1.49	1.73
10-YR	0.34	0.51	0.62	0.82	0.99	1.12	1.22	1.44	1.72	2
25-YR	0.41	0.63	0.76	1.01	1.21	1.36	1.48	1.72	2.04	2.37
50-YR	0.47	0.72	0.87	1.16	1.39	1.55	1.67	1.93	2.3	2.66
100-YR	0.53	0.81	0.98	1.31	1.56	1.74	1.87	2.15	2.55	2.95
500-YR	0.67	1.02	1.24	1.65	1.96	2.16	2.32	2.65	3.13	3.62

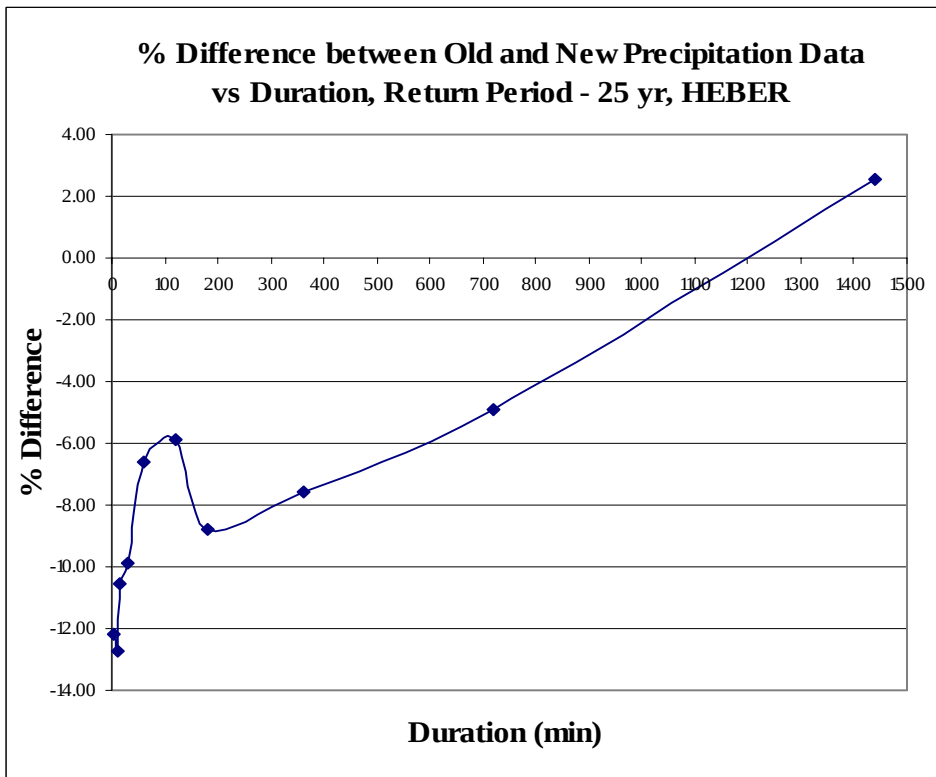
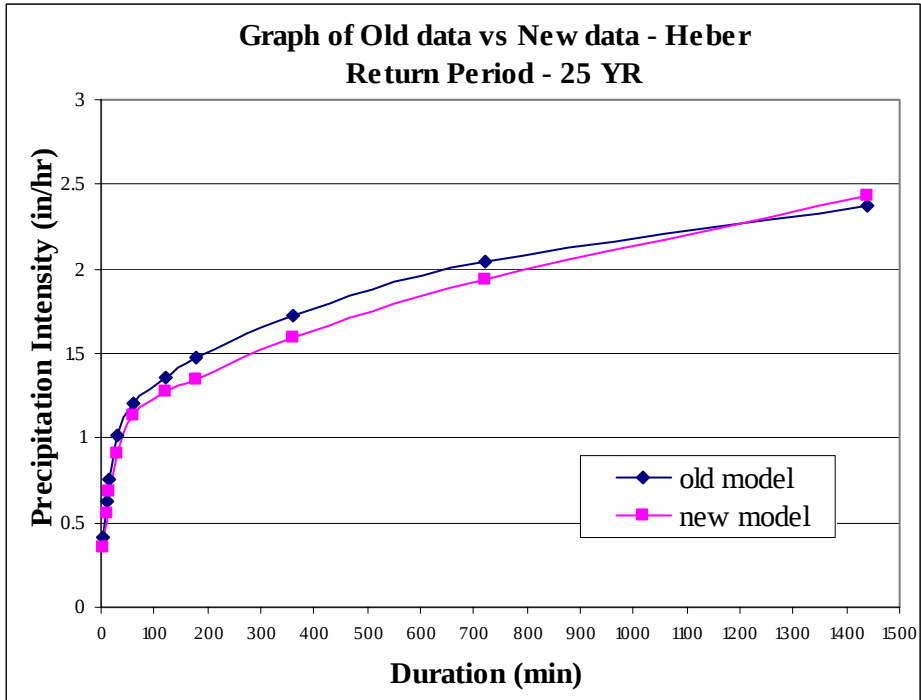
Table 15. HEBER Lon (dd), -111.4156, Lat (dd), 40.4922, Elev (feet), 5587										
NEW DATA										
Duration:- Return period	5- min	10- min	15- min	30- min	1-hr (60- min)	2-hr (120- min)	3-hr (180- min)	6-hr (360- min)	12-hr (720- min)	24-hr (1440- min)
2-YR	0.16	0.24	0.3	0.4	0.49	0.61	0.7	0.91	1.15	1.39
5-YR	0.22	0.33	0.41	0.55	0.68	0.81	0.89	1.12	1.4	1.73
10-YR	0.27	0.41	0.51	0.69	0.85	0.99	1.07	1.31	1.62	2.02
25-YR	0.36	0.55	0.68	0.91	1.13	1.28	1.35	1.59	1.94	2.43
50-YR	0.44	0.67	0.83	1.12	1.38	1.55	1.6	1.82	2.19	2.76
100-YR	0.54	0.81	1.01	1.36	1.68	1.87	1.9	2.08	2.47	3.1
500-YR	0.83	1.26	1.56	2.1	2.6	2.87	2.9	2.93	3.23	4.01

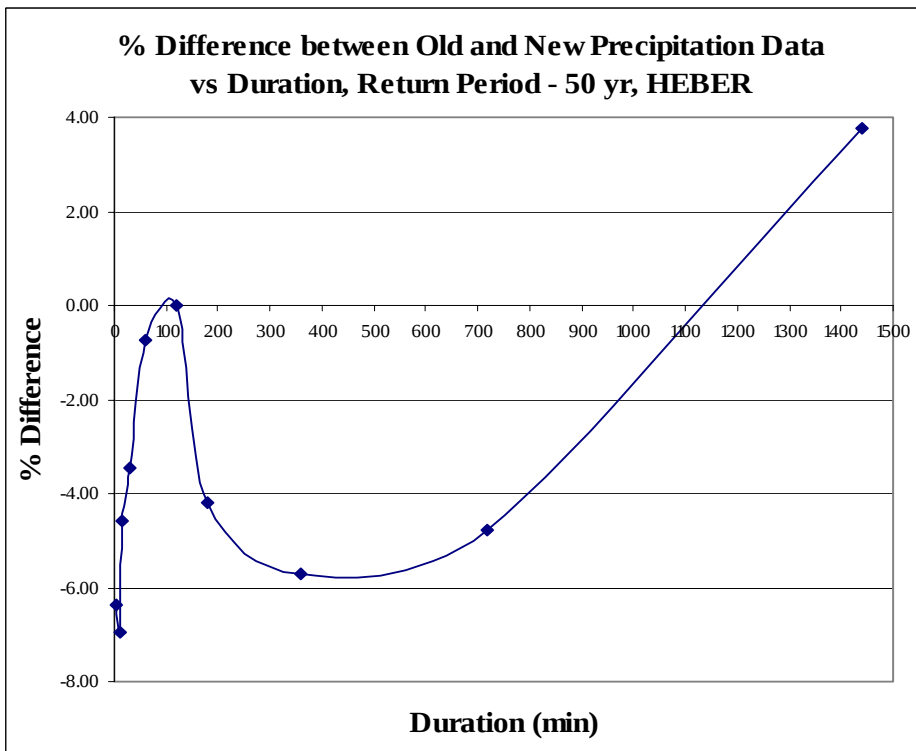
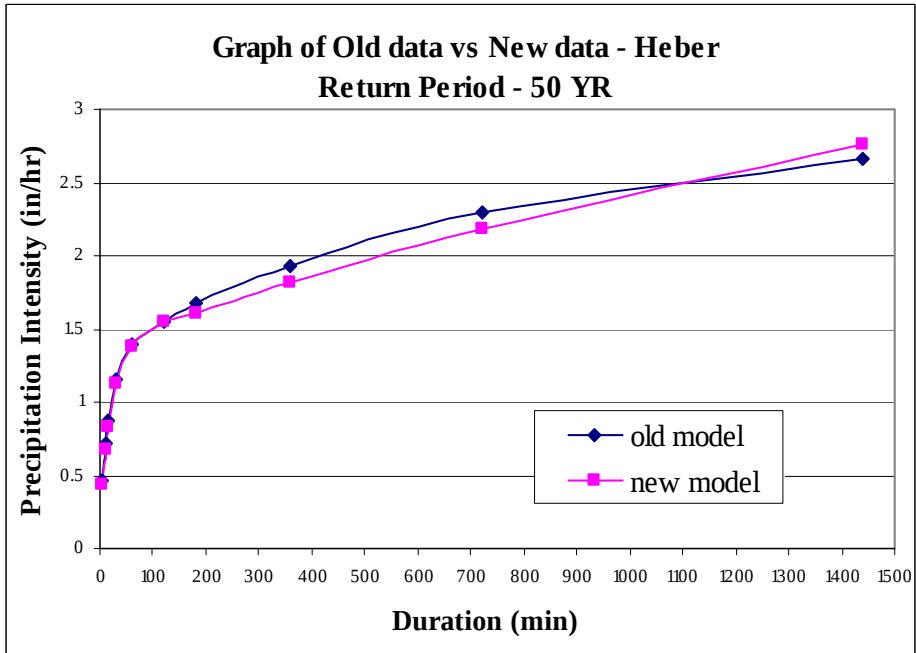
Table 16. HEBER Percentage Difference between the Old data and New data										
Duration:- Return Period	5-min	10-min	15- min	30-min	1-hr (60- min)	2-hr (120- min)	3-hr (180- min)	6-hr (360- min)	12- hr (720- min)	24-hr (1440- min)
2-YR	-20.00	-17.24	-14.29	-14.89	-14.04	-11.59	-9.09	-4.21	0.00	2.96
5-YR	-21.43	-21.43	-19.61	-19.12	-17.07	-14.74	-14.42	-9.68	-6.04	0.00
10-YR	-20.59	-19.61	-17.74	-15.85	-14.14	-11.61	-12.30	-9.03	-5.81	1.00
25-YR	-12.20	-12.70	-10.53	-9.90	-6.61	-5.88	-8.78	-7.56	-4.90	2.53
50-YR	-6.38	-6.94	-4.60	-3.45	-0.72	0.00	-4.19	-5.70	-4.78	3.76
100-YR	1.89	0.00	3.06	3.82	7.69	7.47	1.60	-3.26	-3.14	5.08
500-YR	23.88	23.53	25.81	27.27	32.65	32.87	25.00	10.57	3.19	10.77

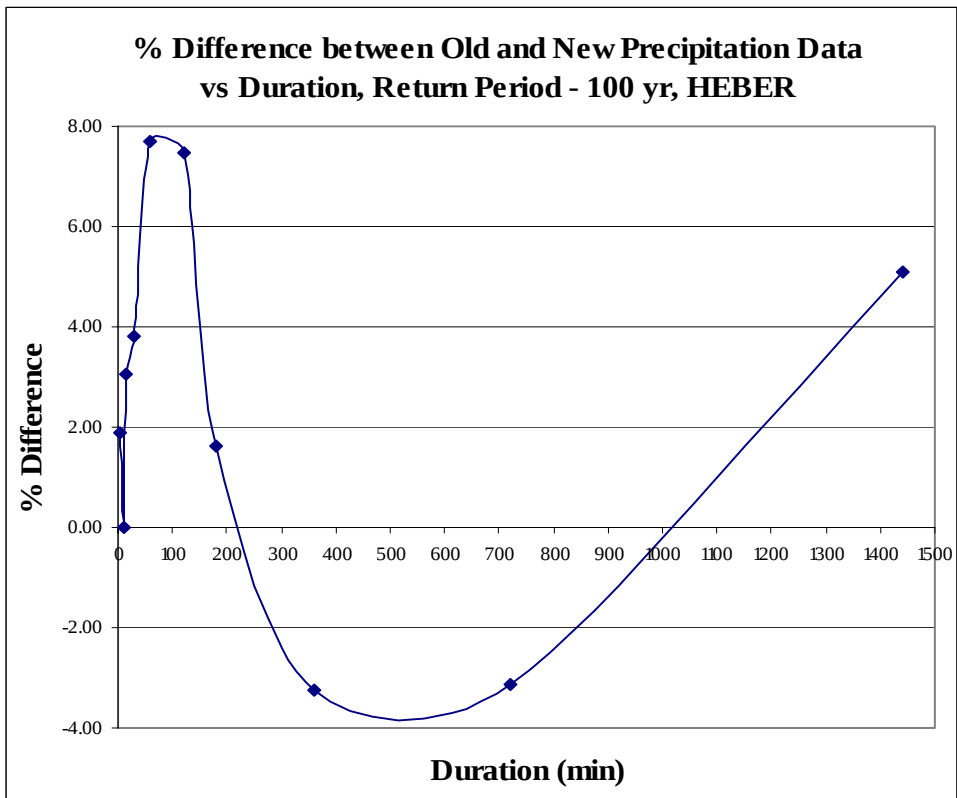
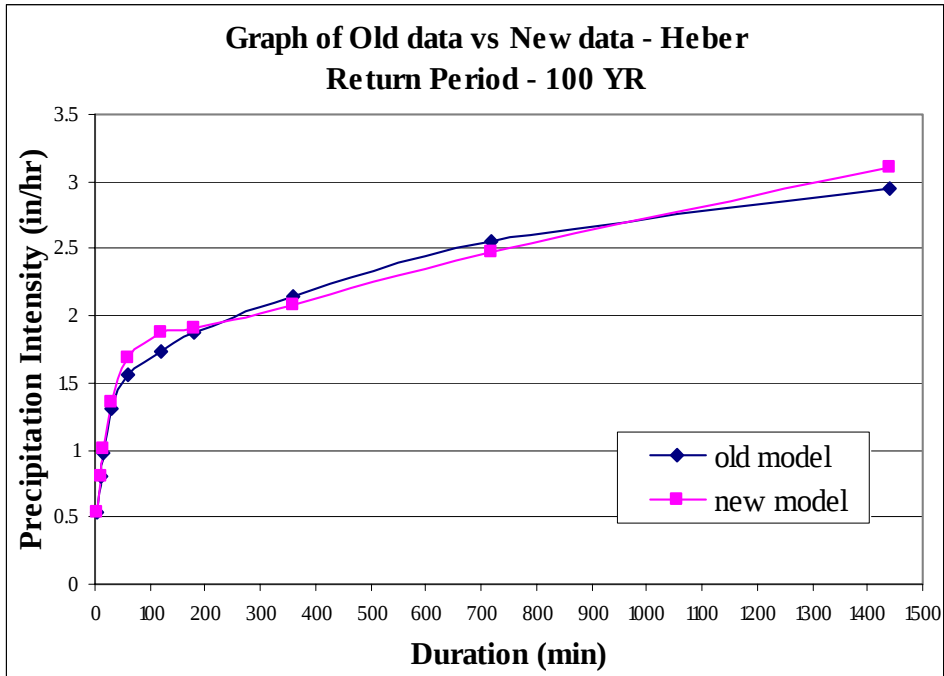


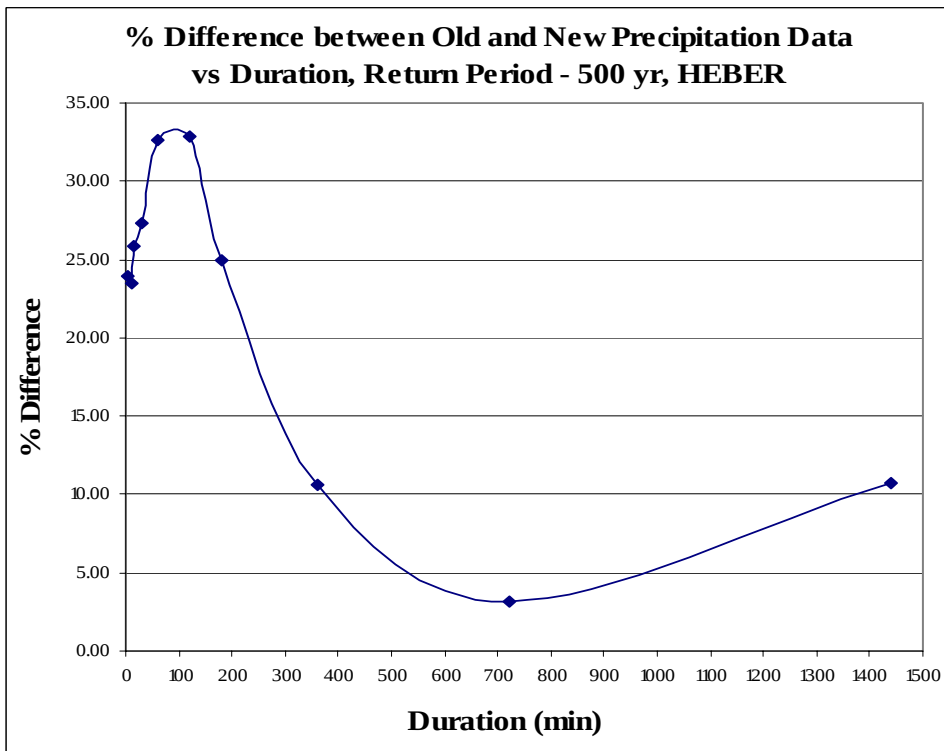
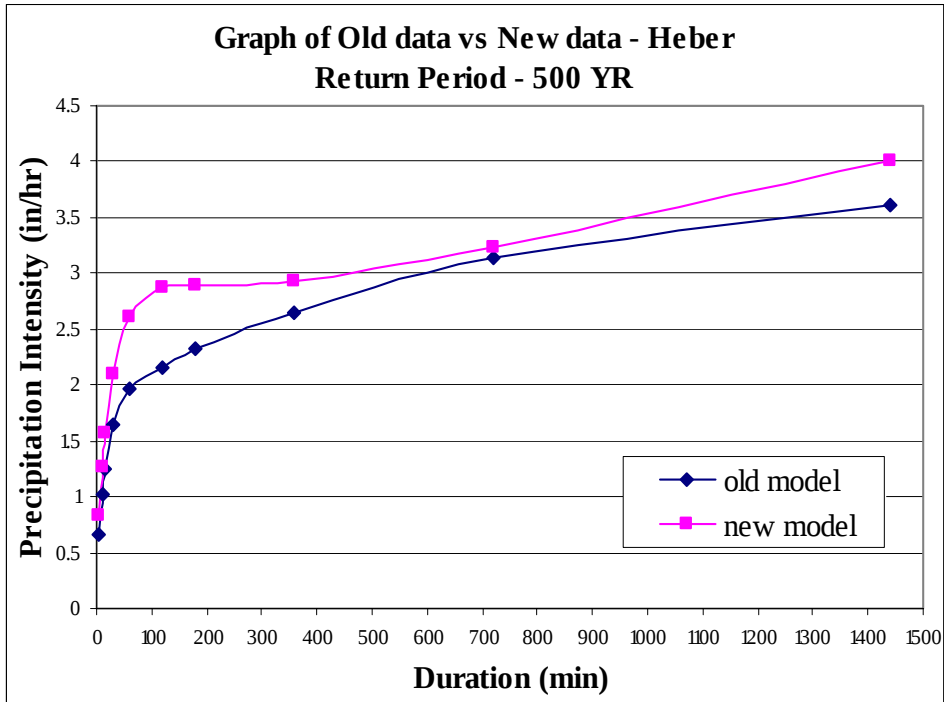












Moab Analysis

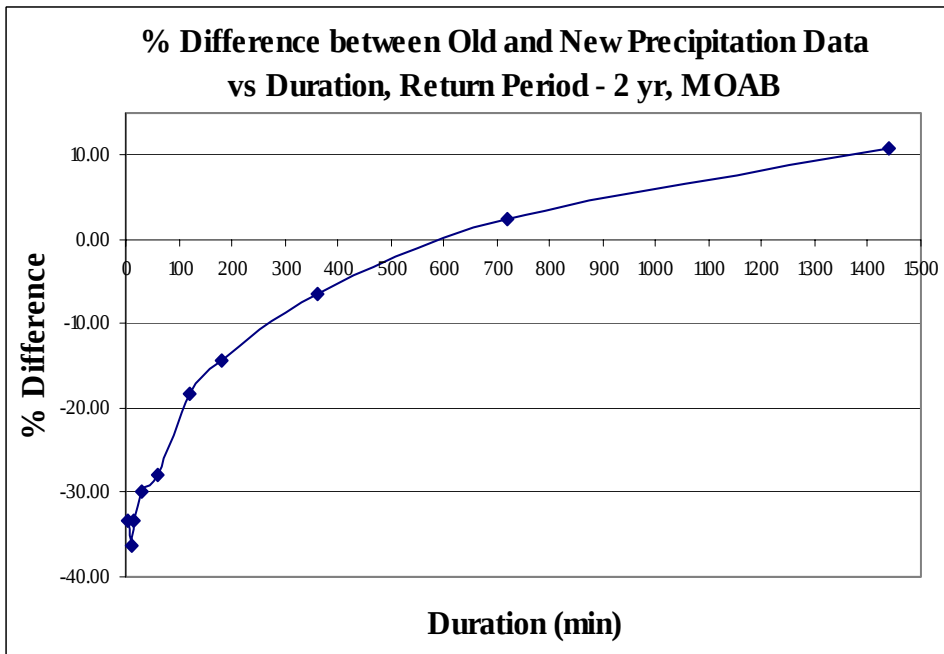
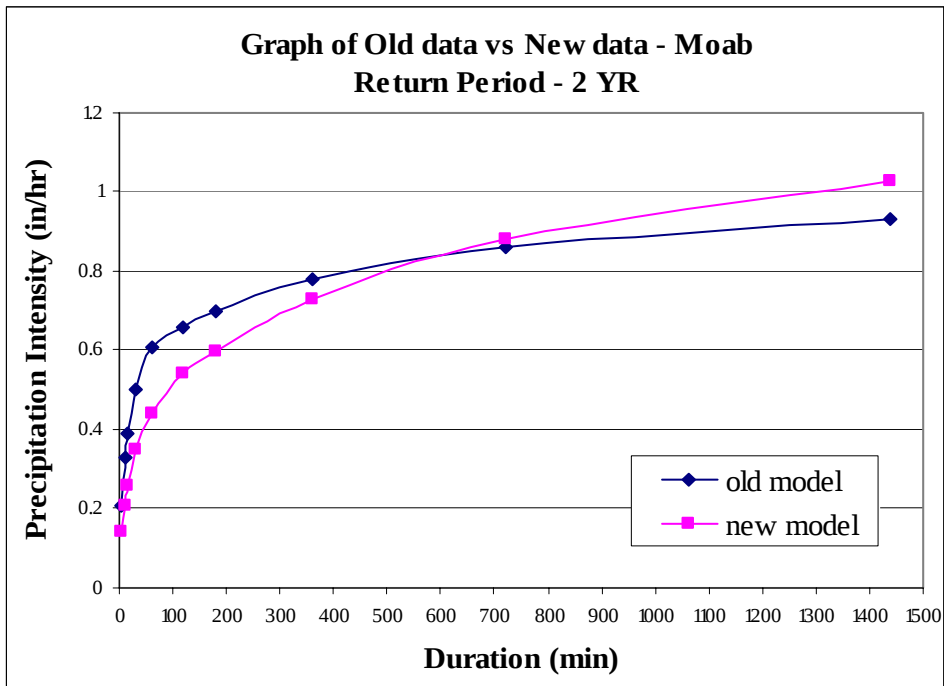
The results, expressed as percentages, are shown for Moab in the following tables and graphs..

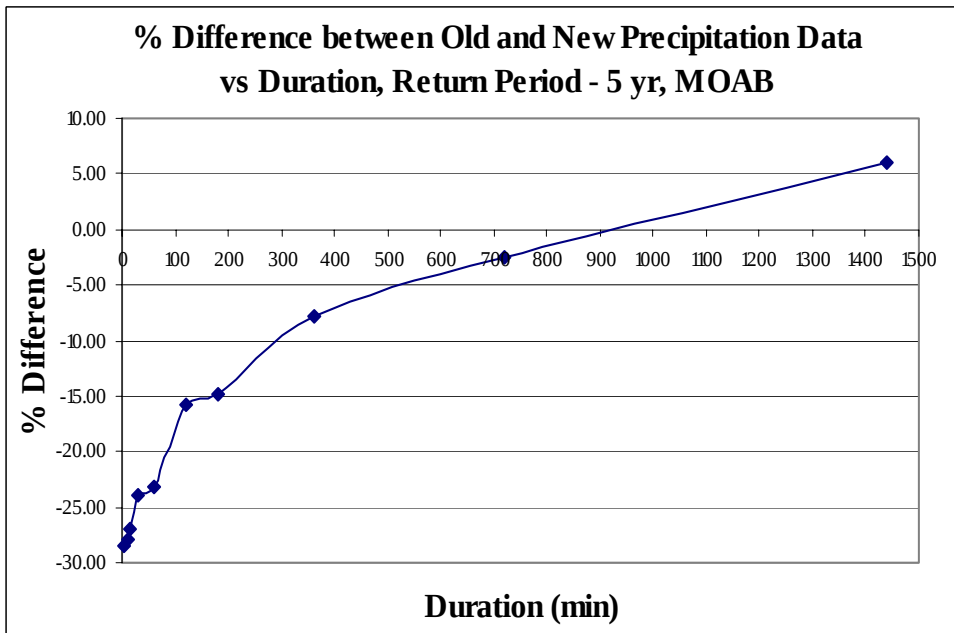
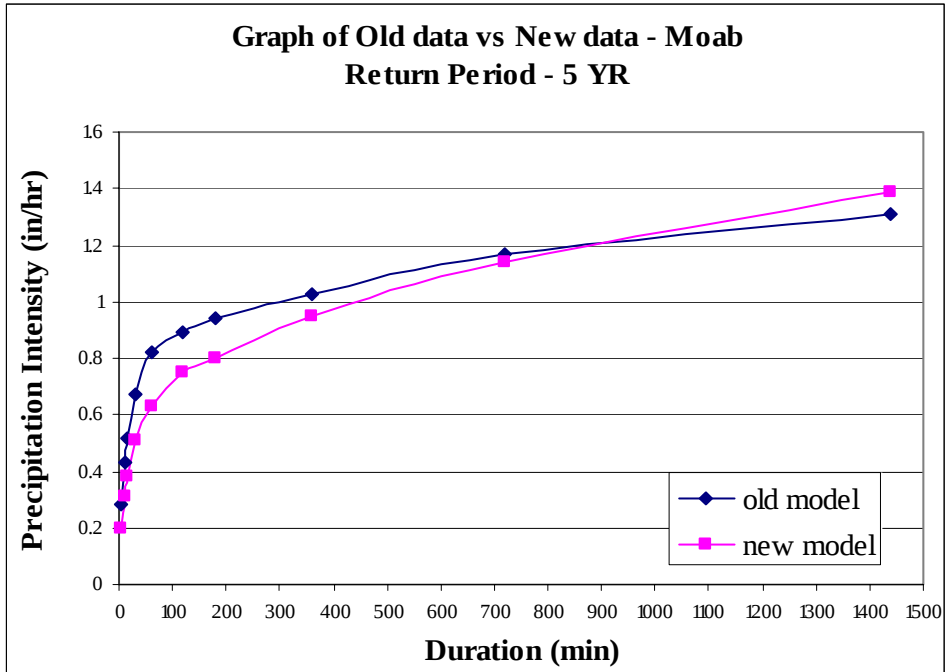
Table 17. MOAB Lon (dd), -109.5667, Lat (dd), 38.5833, Elev (feet), 3986										
OLD DATA										
Duration:- Return Period	5-min	10- min	15- min	30- min	1-hr (60- min)	2-hr (120- min)	3-hr (180- min)	6-hr (360- min)	12- hr (720- min)	24-hr (1440- min)
2-YR	0.21	0.33	0.39	0.5	0.61	0.66	0.7	0.78	0.86	0.93
5-YR	0.28	0.43	0.52	0.67	0.82	0.89	0.94	1.03	1.17	1.31
10-YR	0.32	0.5	0.61	0.79	0.97	1.05	1.1	1.2	1.38	1.57
25-YR	0.38	0.59	0.73	0.95	1.17	1.26	1.32	1.43	1.68	1.92
50-YR	0.43	0.67	0.83	1.08	1.33	1.43	1.49	1.62	1.9	2.19
100-YR	0.48	0.74	0.92	1.21	1.49	1.59	1.67	1.8	2.13	2.46
500-YR	0.59	0.92	1.14	1.5	1.85	1.98	2.06	2.22	2.65	3.08

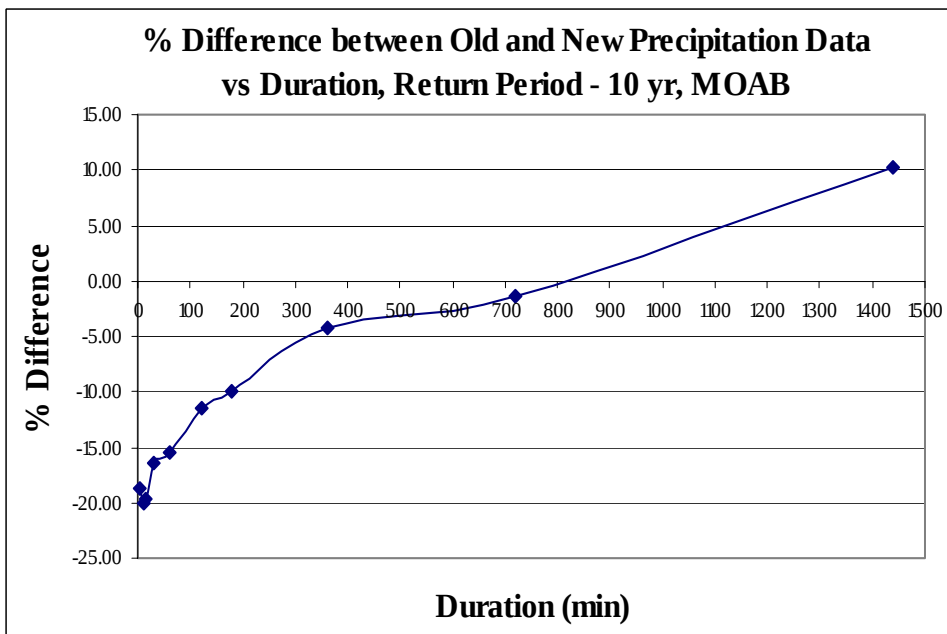
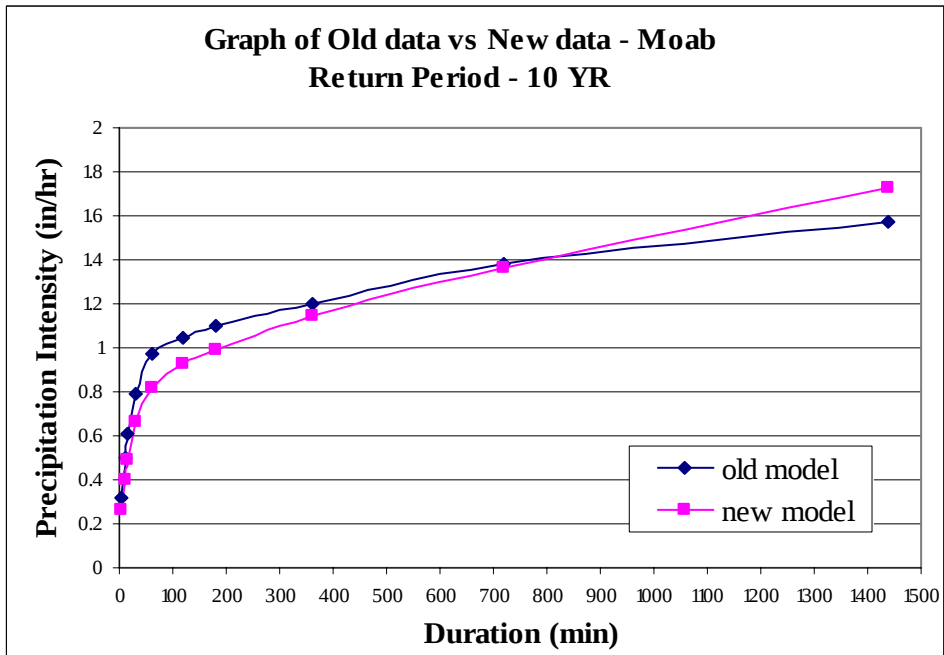
Table 18. MOAB Lon (dd), -109.5667, Lat (dd), 38.5833, Elev (feet), 3986										
NEW DATA										
Duration:- Return Period	5-min	10- min	15- min	30- min	1-hr (60- min)	2-hr (120- min)	3-hr (180- min)	6-hr (360- min)	12-hr (720- min)	24-hr (1440- min)
2-YR	0.14	0.21	0.26	0.35	0.44	0.54	0.6	0.73	0.88	1.03
5-YR	0.2	0.31	0.38	0.51	0.63	0.75	0.8	0.95	1.14	1.39
10-YR	0.26	0.4	0.49	0.66	0.82	0.93	0.99	1.15	1.36	1.73
25-YR	0.35	0.54	0.66	0.89	1.1	1.25	1.3	1.45	1.67	2.28
50-YR	0.44	0.67	0.83	1.12	1.39	1.54	1.58	1.72	1.92	2.78
100-YR	0.55	0.83	1.03	1.39	1.72	1.89	1.91	2.04	2.2	3.39
500-YR	0.88	1.33	1.66	2.23	2.76	2.99	3	3.14	3.19	5.26

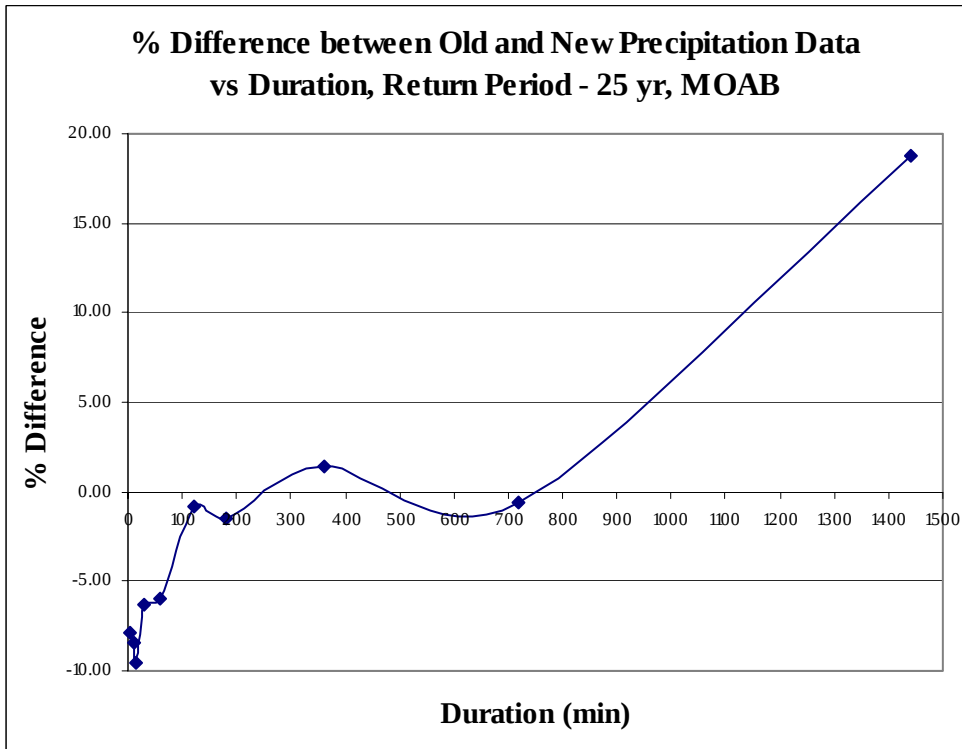
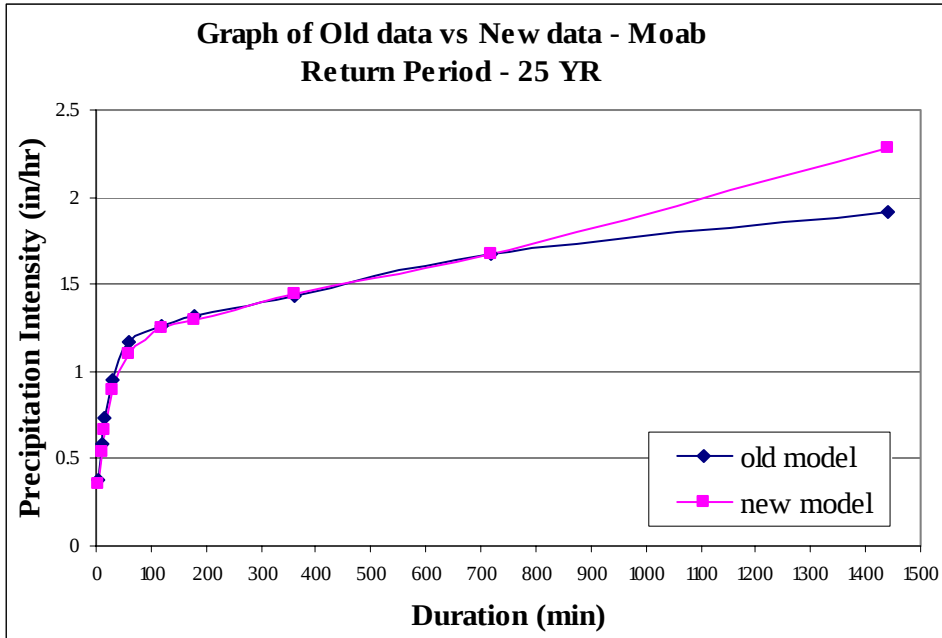
Table 19. MOAB

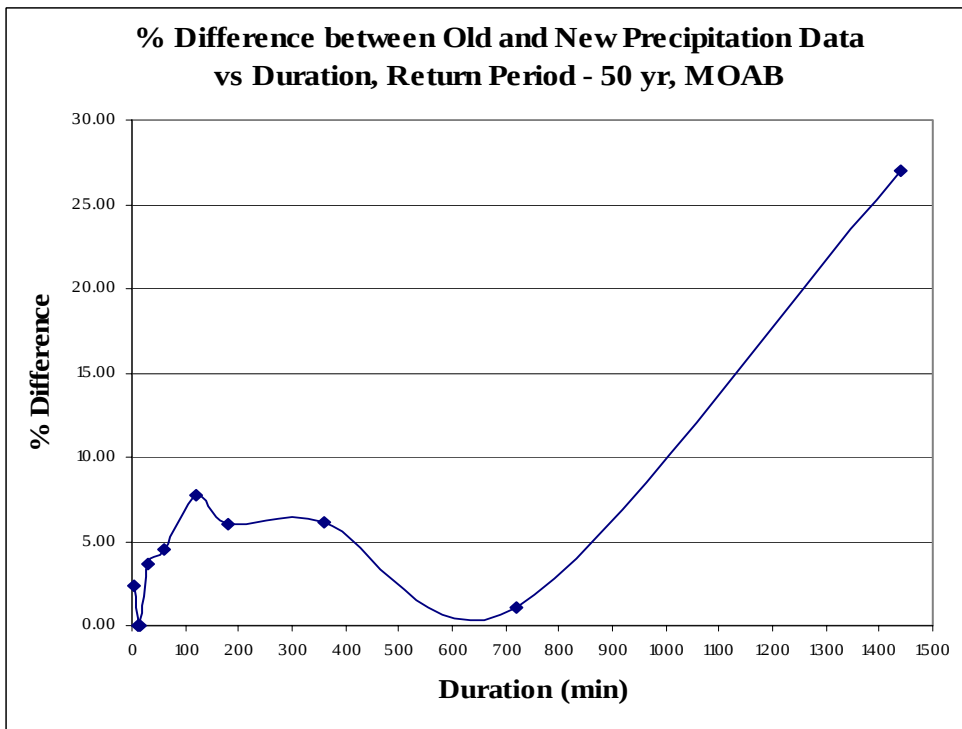
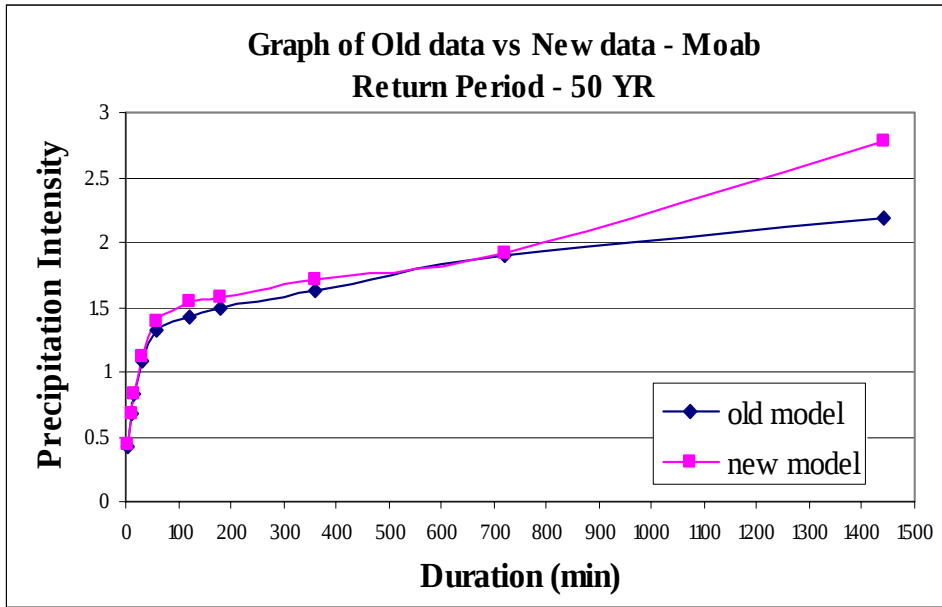
Percentage Difference between the Old data and New data										
Duration:- Return Period	5-min	10-min	15-min	30-min	1-hr (60- min)	2-hr (120- min)	3-hr (180- min)	6-hr (360- min)	12-hr (720- min)	24-hr (1440- min)
2-YR	-33.33	-36.36	-33.33	-30.00	-27.87	-18.18	-14.29	-6.41	2.33	10.75
5-YR	-28.57	-27.91	-26.92	-23.88	-23.17	-15.73	-14.89	-7.77	-2.56	6.11
10-YR	-18.75	-20.00	-19.67	-16.46	-15.46	-11.43	-10.00	-4.17	-1.45	10.19
25-YR	-7.89	-8.47	-9.59	-6.32	-5.98	-0.79	-1.52	1.40	-0.60	18.75
50-YR	2.33	0.00	0.00	3.70	4.51	7.69	6.04	6.17	1.05	26.94
100-YR	14.58	12.16	11.96	14.88	15.44	18.87	14.37	13.33	3.29	37.80
500-YR	49.15	44.57	45.61	48.67	49.19	51.01	45.63	41.44	20.38	70.78

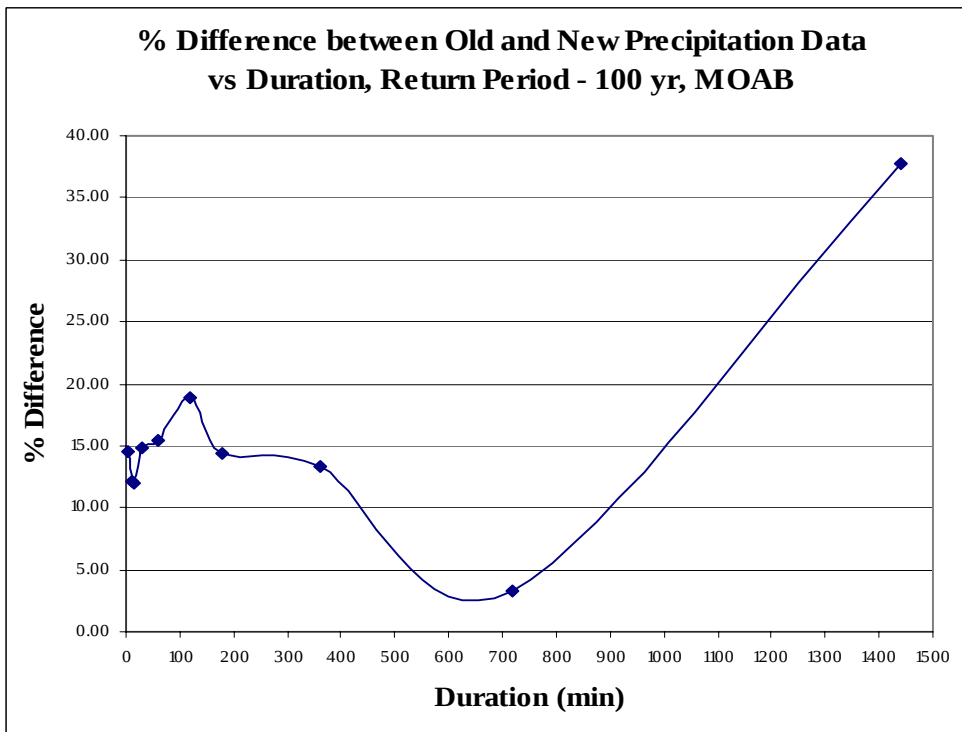
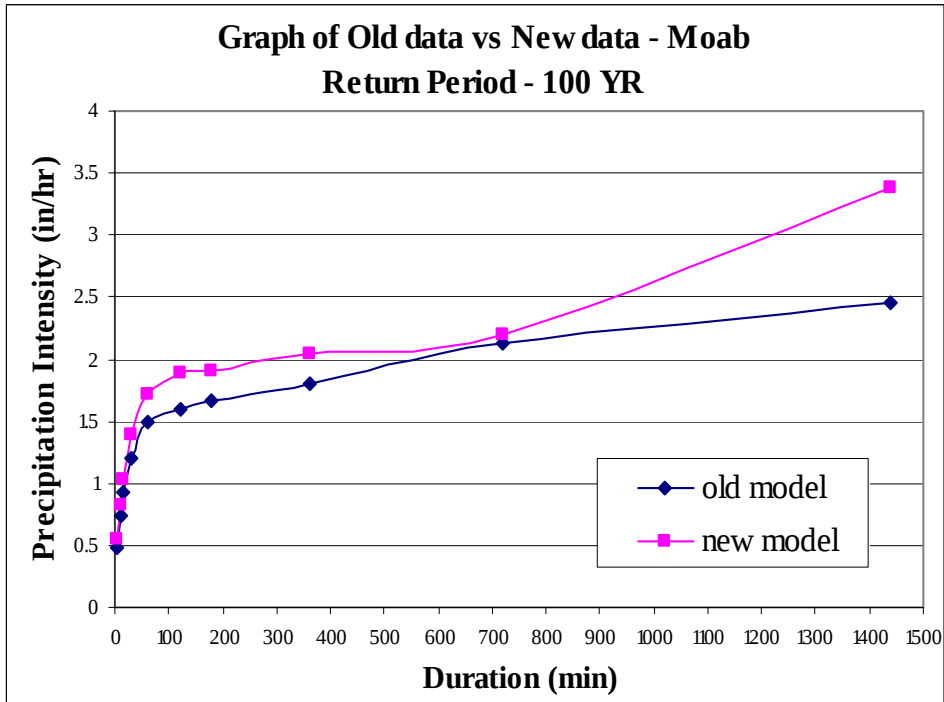


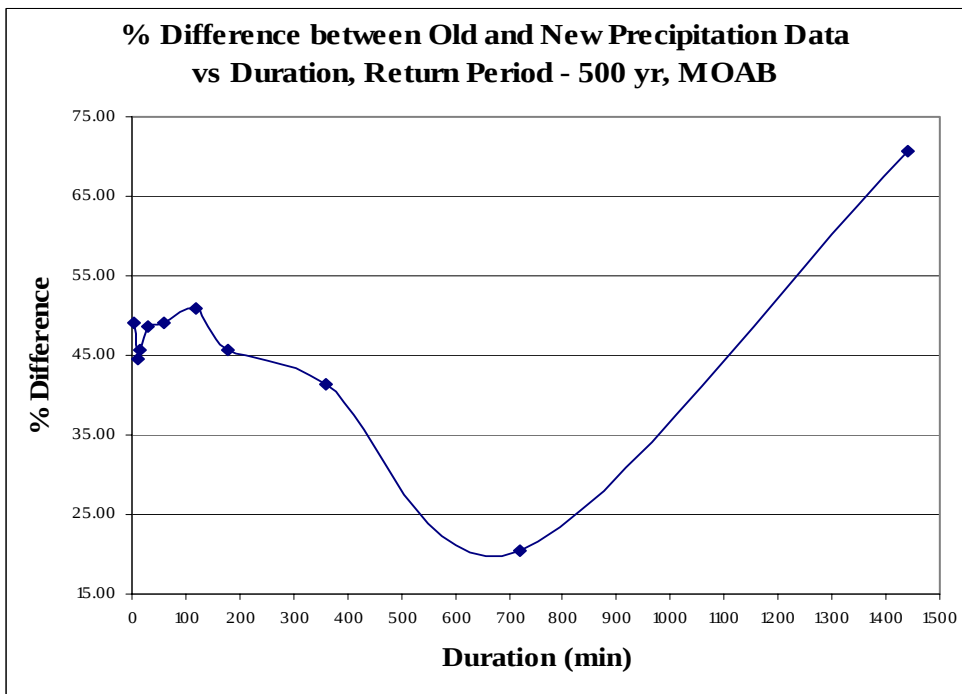
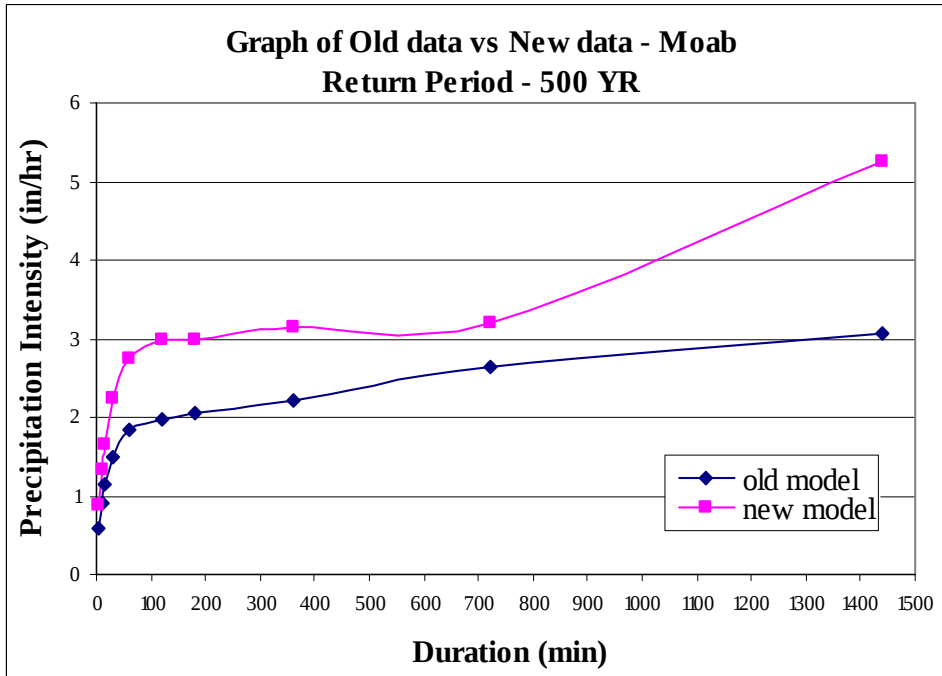












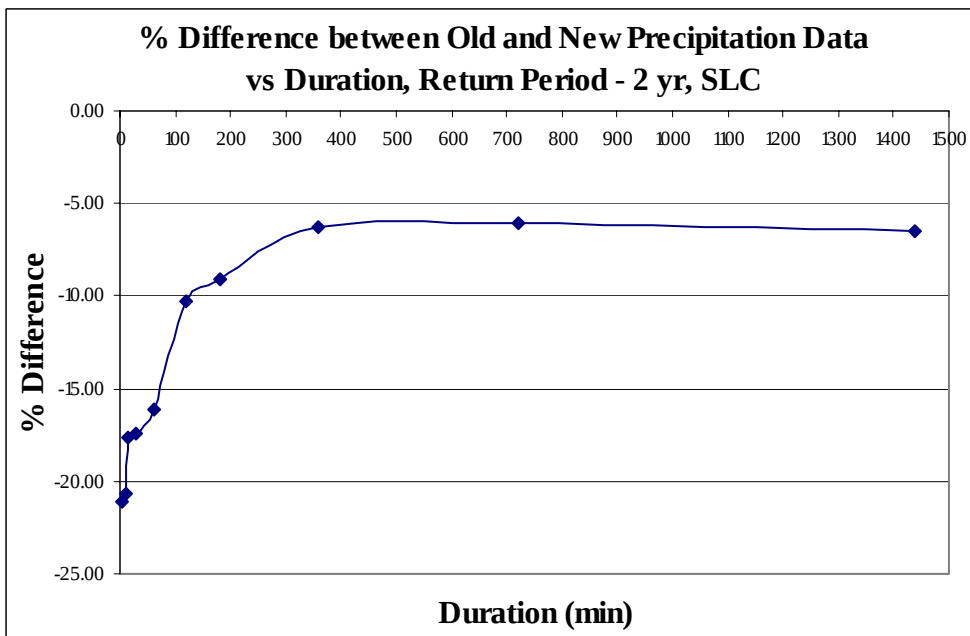
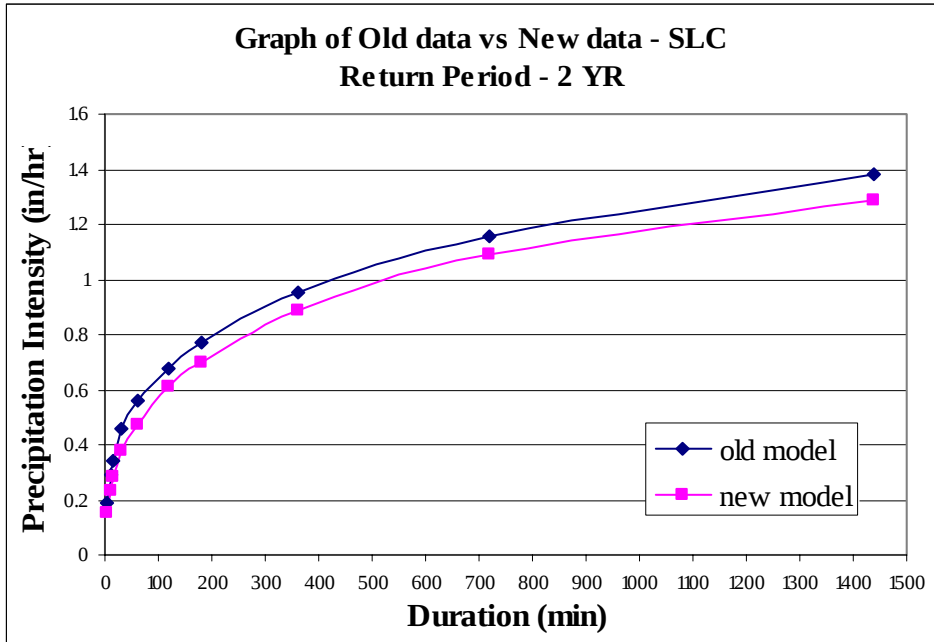
Salt Lake City Analysis

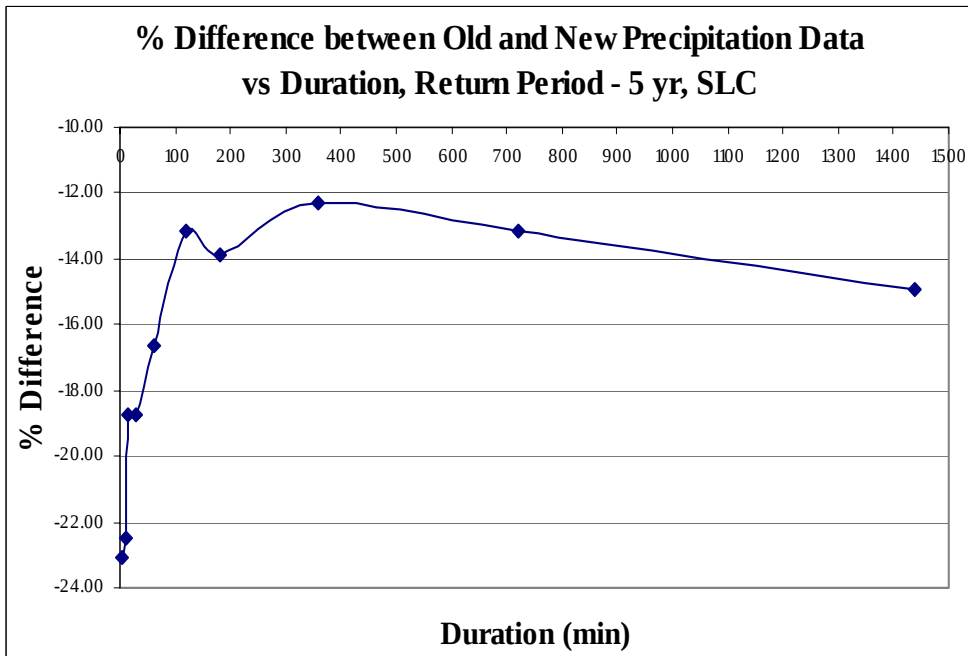
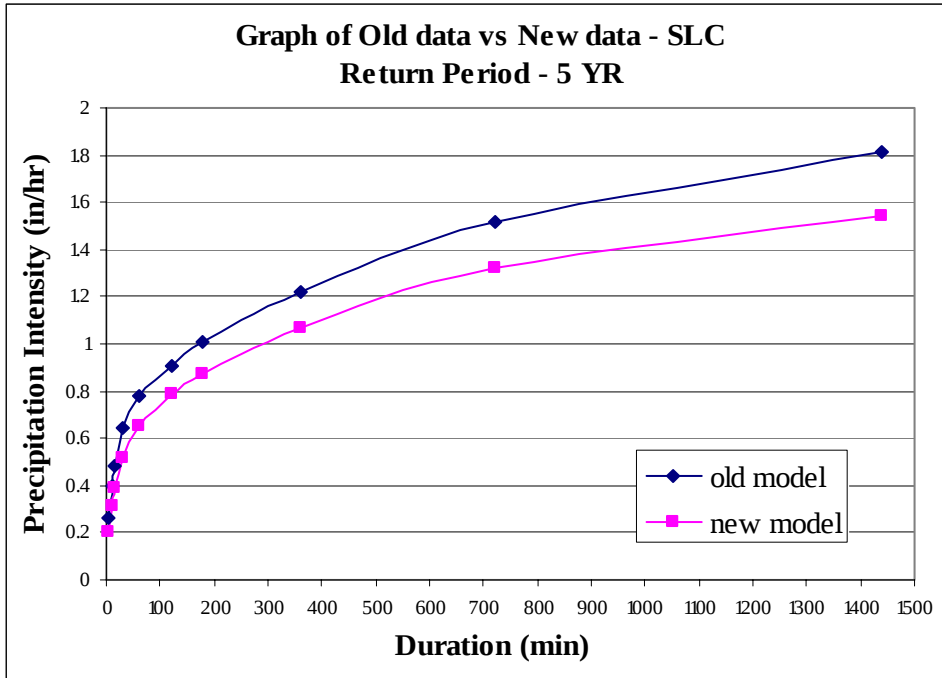
The results, expressed as percentages, are shown for Salt Lake City in the following tables and graphs..

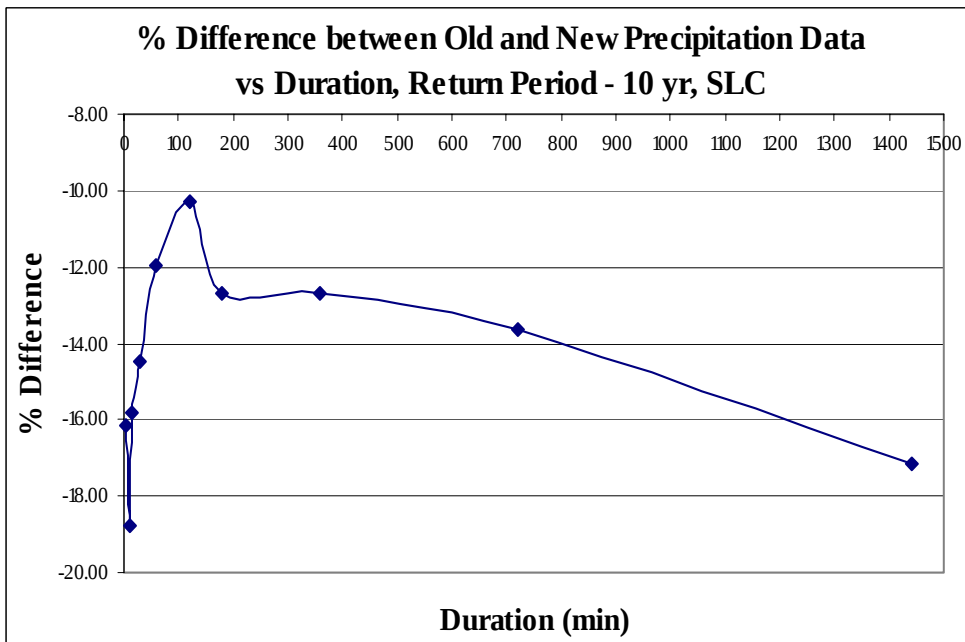
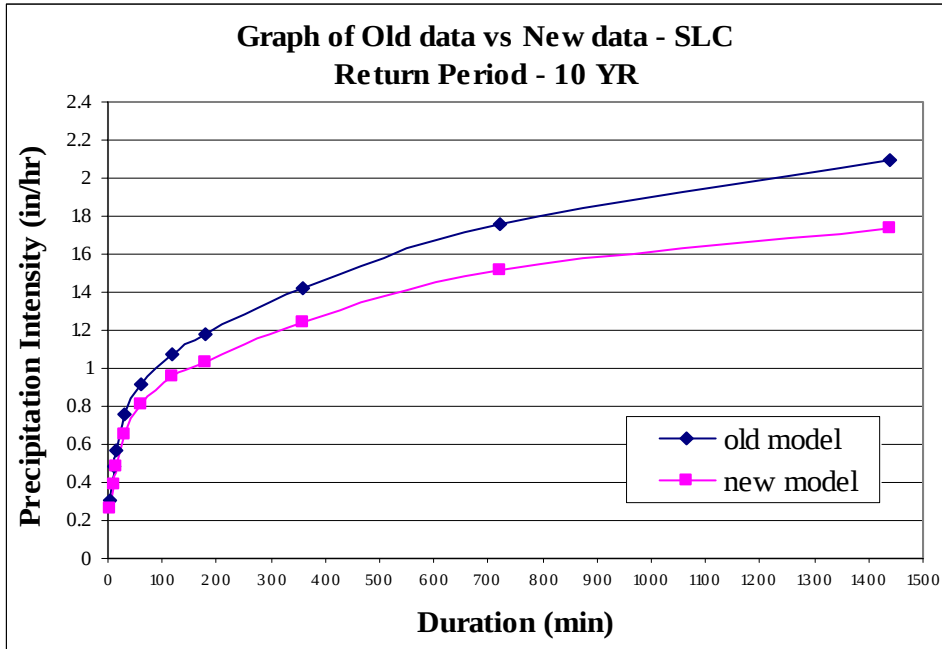
Table 20. SLC Lon (dd), -111.9167, Lat (dd), 40.7, Elev (feet), 4235										
OLD DATA										
Duration:- Return Period	5-min	10- min	15- min	30- min	1-hr (60- min)	2-hr (120- min)	3-hr (180- min)	6-hr (360- min)	12- hr (720- min)	24-hr (1440- min)
2-YR	0.19	0.29	0.34	0.46	0.56	0.68	0.77	0.95	1.16	1.38
5-YR	0.26	0.4	0.48	0.64	0.78	0.91	1.01	1.22	1.52	1.81
10-YR	0.31	0.48	0.57	0.76	0.92	1.07	1.18	1.42	1.76	2.1
25-YR	0.38	0.58	0.7	0.94	1.12	1.29	1.42	1.68	2.1	2.51
50-YR	0.43	0.66	0.8	1.07	1.27	1.46	1.6	1.89	2.36	2.83
100-YR	0.49	0.74	0.9	1.2	1.43	1.63	1.78	2.1	2.63	3.15
500-YR	0.61	0.93	1.13	1.5	1.78	2.02	2.2	2.58	3.23	3.88

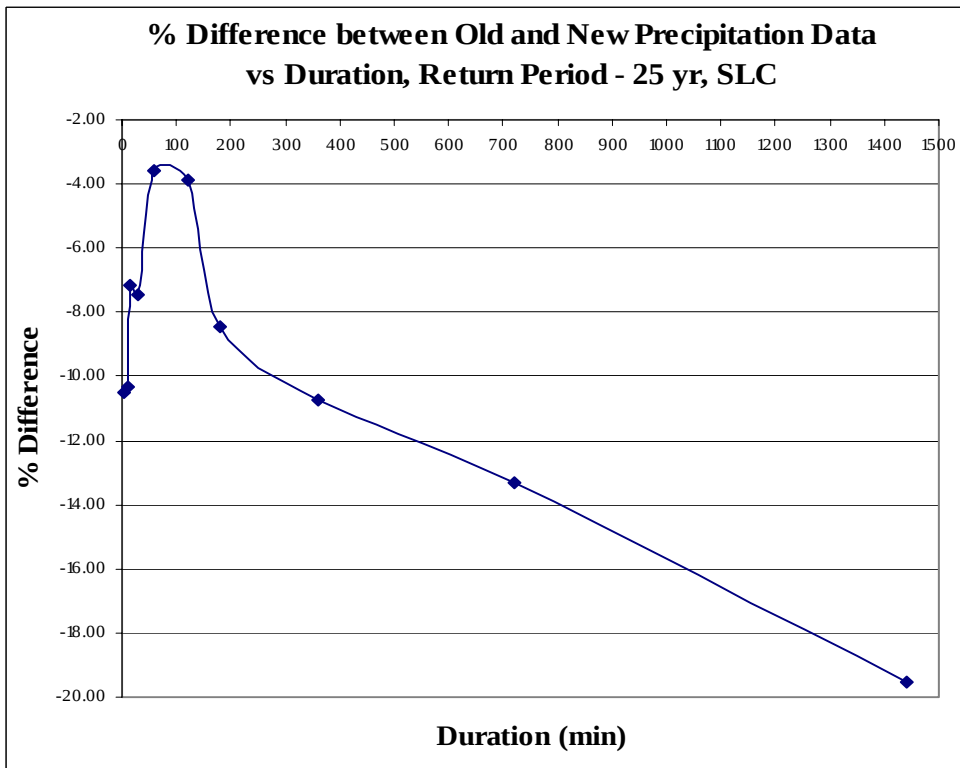
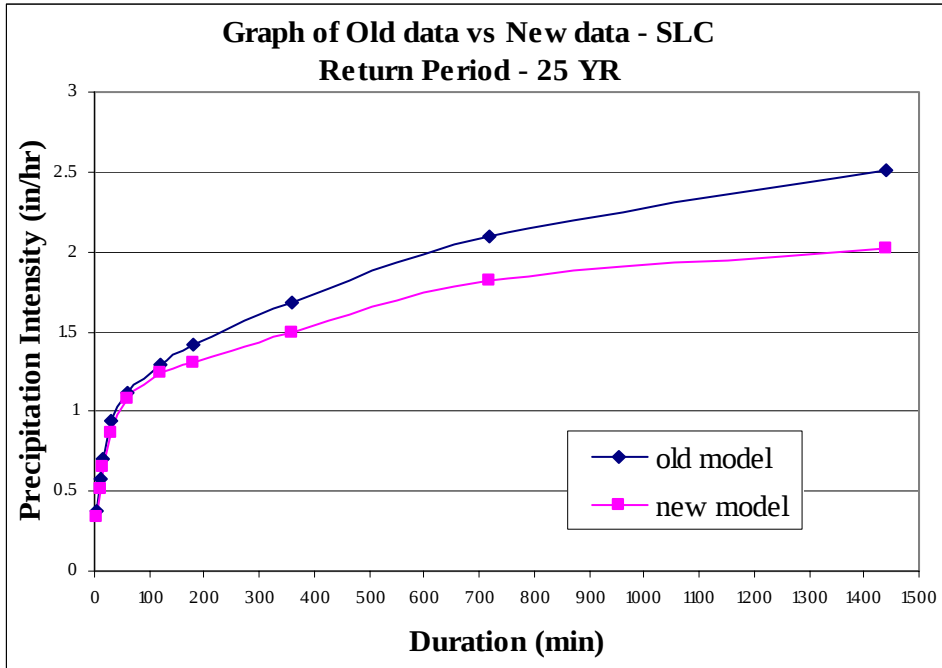
Table 21. SLC Lon (dd), -111.9167, Lat (dd), 40.7, Elev (feet), 4235										
NEW DATA										
Duration:- Return Period	5- min	10-min	15- min	30- min	1-hr (60- min)	2-hr (120- min)	3-hr (180- min)	6-hr (360- min)	12-hr (720- min)	24-hr (1440- min)
2-YR	0.15	0.23	0.28	0.38	0.47	0.61	0.7	0.89	1.09	1.29
5-YR	0.2	0.31	0.39	0.52	0.65	0.79	0.87	1.07	1.32	1.54
10-YR	0.26	0.39	0.48	0.65	0.81	0.96	1.03	1.24	1.52	1.74
25-YR	0.34	0.52	0.65	0.87	1.08	1.24	1.3	1.5	1.82	2.02
50-YR	0.42	0.64	0.8	1.07	1.33	1.5	1.53	1.71	2.06	2.25
100-YR	0.52	0.79	0.98	1.32	1.63	1.81	1.82	1.96	2.33	2.47
500-YR	0.82	1.24	1.54	2.08	2.57	2.79	2.82	2.85	3.04	3.07

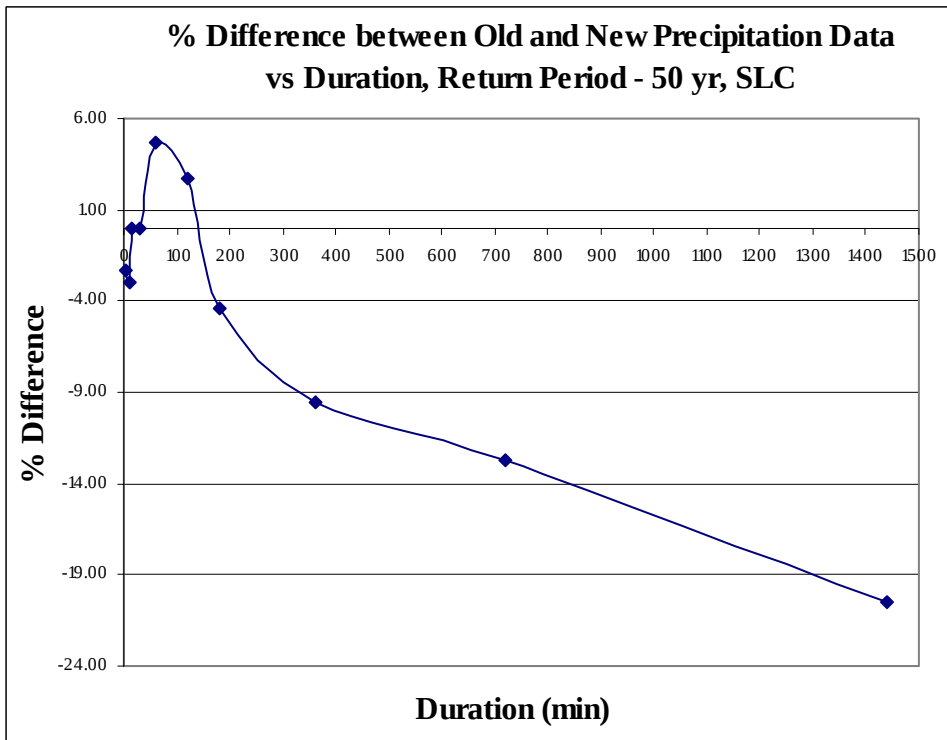
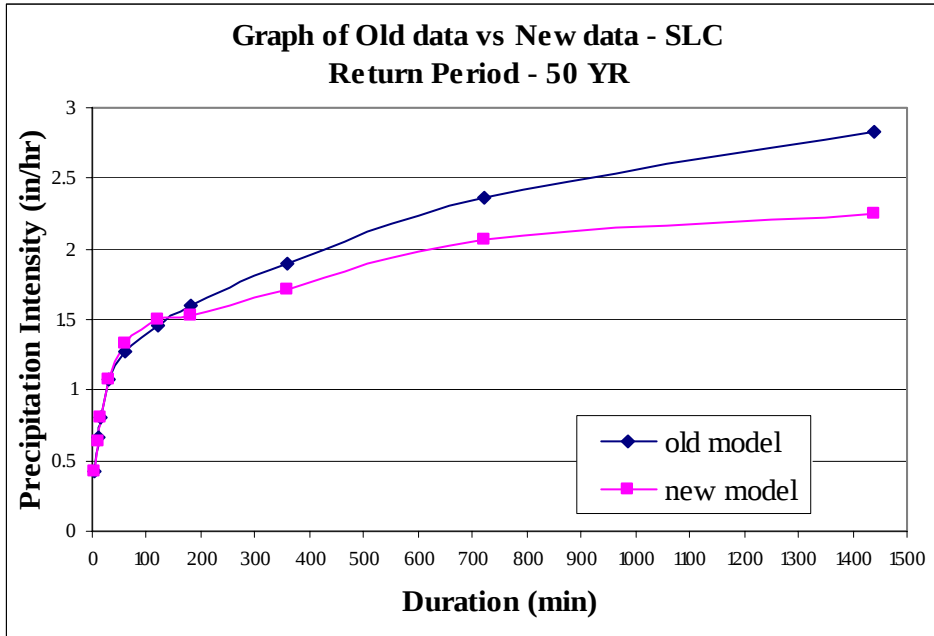
Table 22. SLC										
Percentage Difference between the Old data and New data										
Duration:- Return Period	5-min	10- min	15-min	30-min	1-hr (60- min)	2-hr (120- min)	3-hr (180- min)	6-hr (360- min)	12-hr (720- min)	24-hr (1440- min)
2-YR	-21.05	-20.69	-17.65	-17.39	-16.07	-10.29	-9.09	-6.32	-6.03	-6.52
5-YR	-23.08	-22.50	-18.75	-18.75	-16.67	-13.19	-13.86	-12.30	-13.16	-14.92
10-YR	-16.13	-18.75	-15.79	-14.47	-11.96	-10.28	-12.71	-12.68	-13.64	-17.14
25-YR	-10.53	-10.34	-7.14	-7.45	-3.57	-3.88	-8.45	-10.71	-13.33	-19.52
50-YR	-2.33	-3.03	0.00	0.00	4.72	2.74	-4.38	-9.52	-12.71	-20.49
100-YR	6.12	6.76	8.89	10.00	13.99	11.04	2.25	-6.67	-11.41	-21.59
500-YR	34.43	33.33	36.28	38.67	44.38	38.12	28.18	10.47	-5.88	-20.88

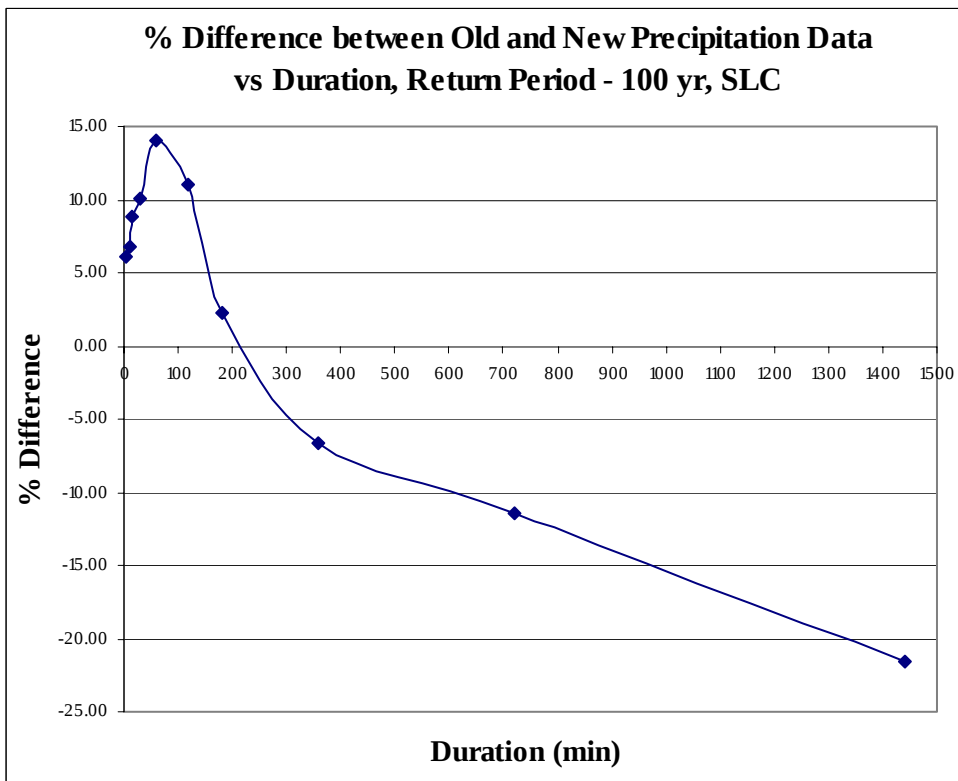
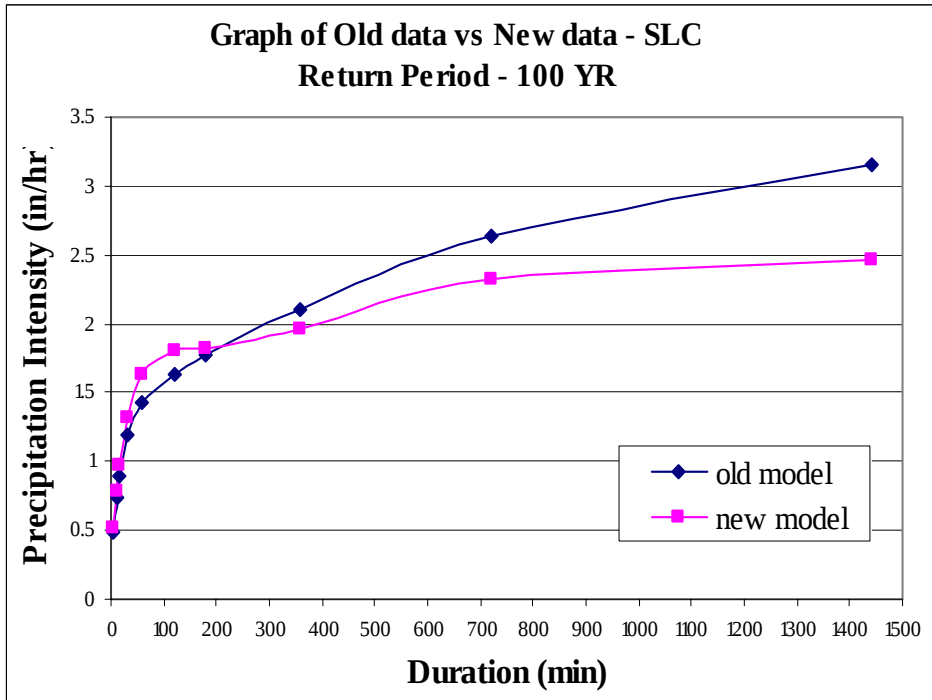


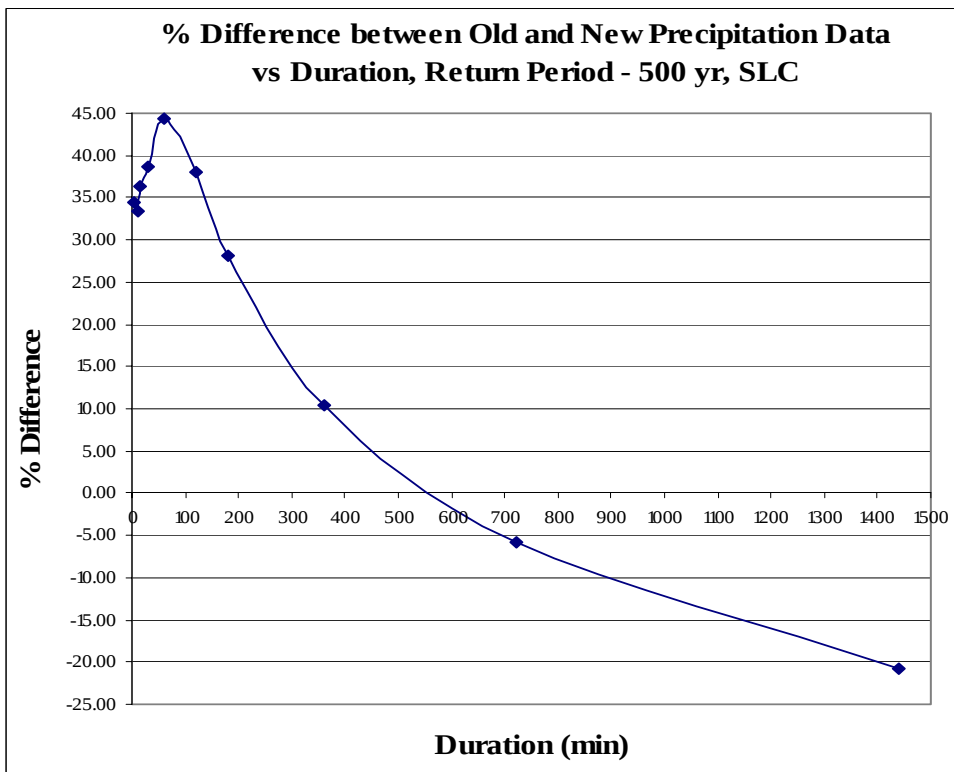
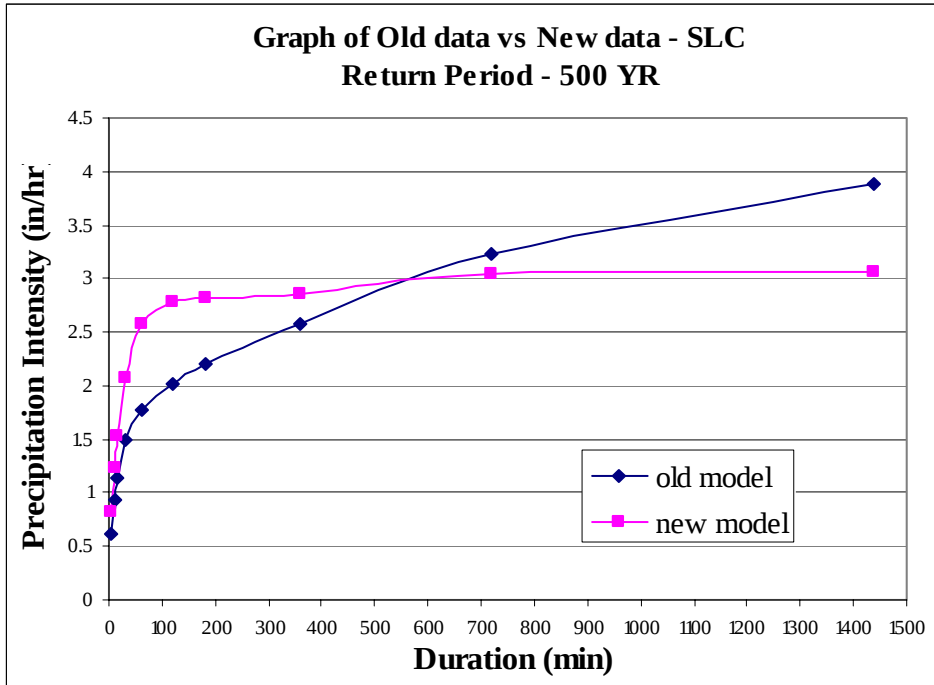












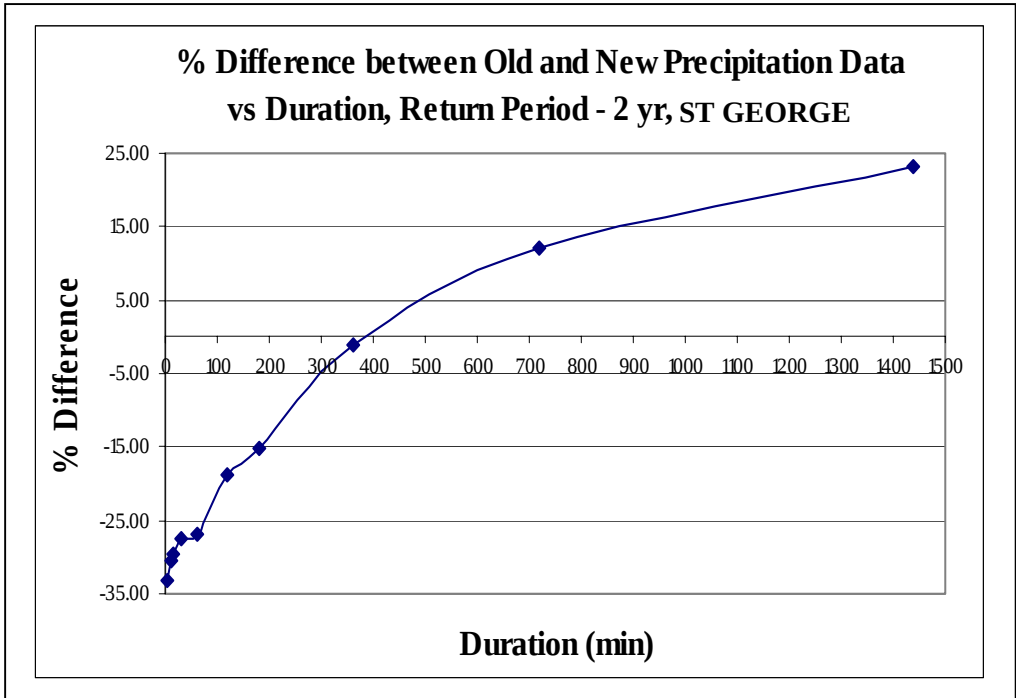
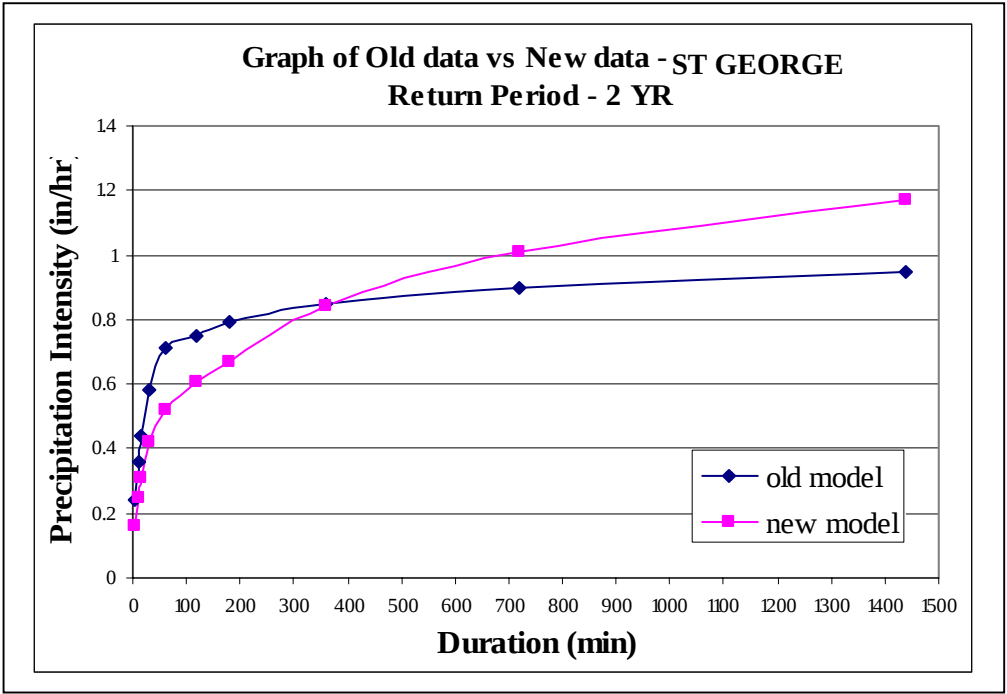
St. George Analysis

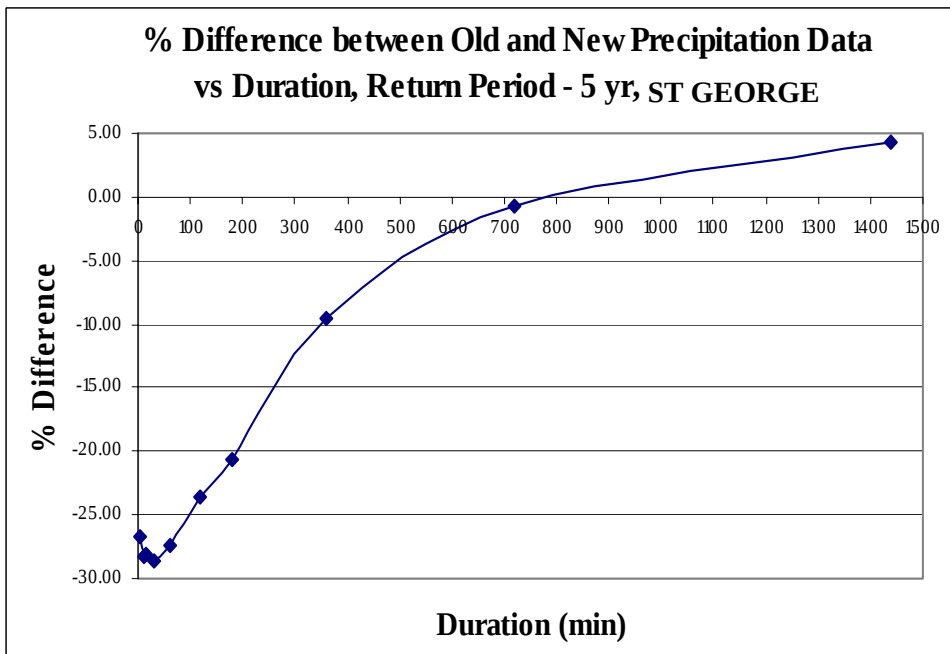
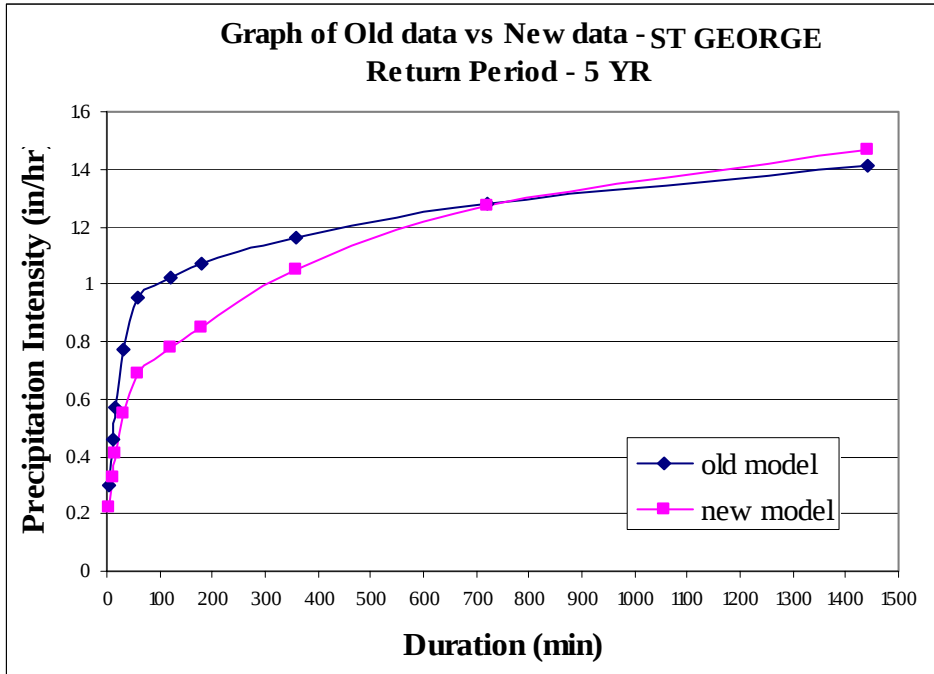
The results, expressed as percentages, are shown for St. George in the following tables and graphs..

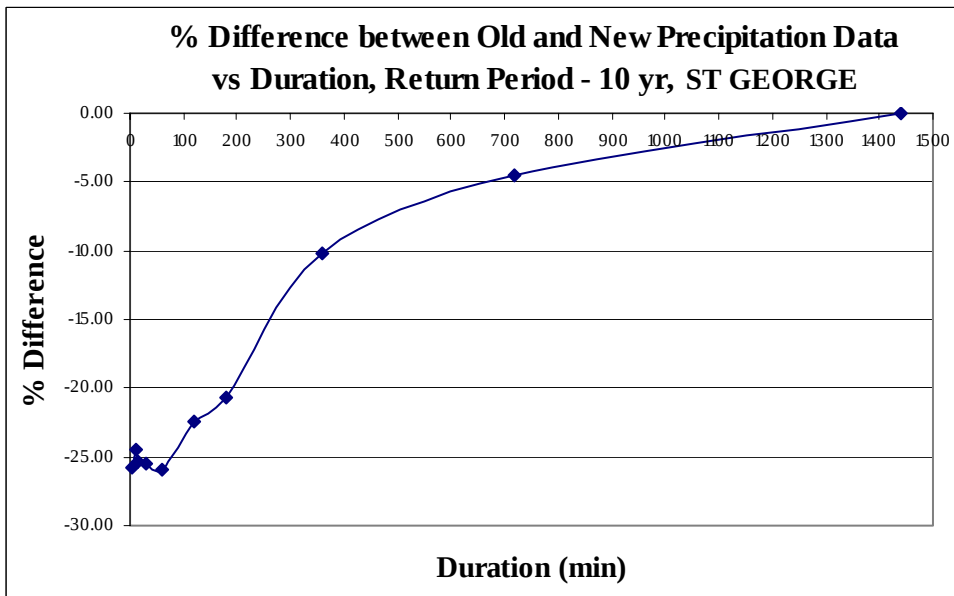
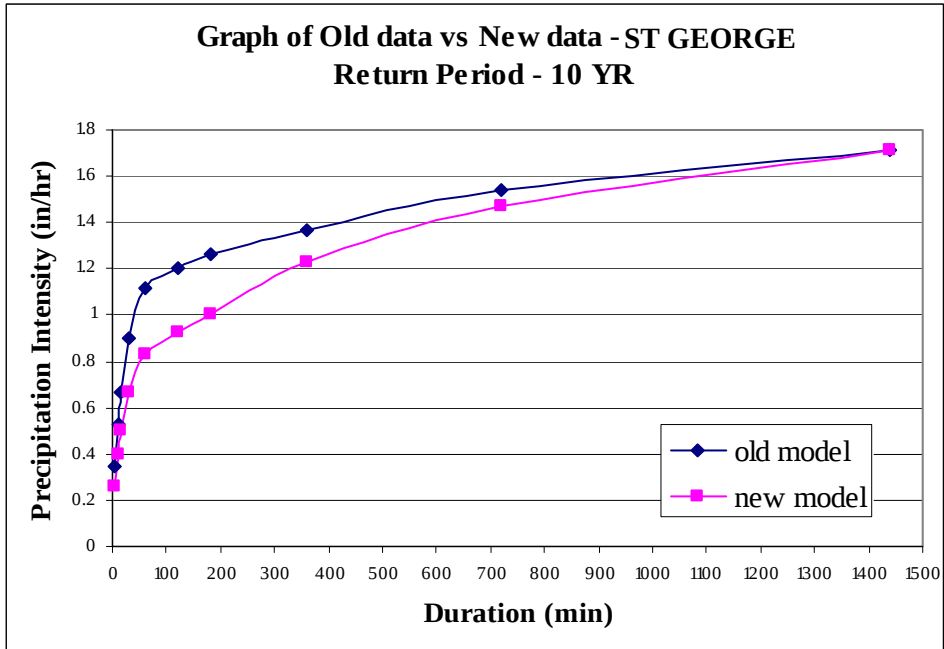
Table 23. ST GEORGE Lon (dd), -113.5672, Lat (dd), 37.1061, Elev (feet), 2719										
OLD DATA										
Duration:- Return Period	5-min	10- min	15- min	30- min	1-hr (60- min)	2-hr (120- min)	3-hr (180- min)	6-hr (360- min)	12-hr (720- min)	24-hr (1440- min)
2-YR	0.24	0.36	0.44	0.58	0.71	0.75	0.79	0.85	0.9	0.95
5-YR	0.3	0.46	0.57	0.77	0.95	1.02	1.07	1.16	1.28	1.41
10-YR	0.35	0.53	0.67	0.9	1.12	1.2	1.26	1.37	1.54	1.71
25-YR	0.41	0.63	0.8	1.08	1.35	1.45	1.52	1.65	1.89	2.12
50-YR	0.46	0.71	0.9	1.22	1.53	1.65	1.73	1.88	2.16	2.44
100-YR	0.51	0.78	1.01	1.36	1.7	1.84	1.93	2.1	2.42	2.75
500-YR	0.63	0.96	1.24	1.69	2.12	2.29	2.4	2.61	3.05	3.48

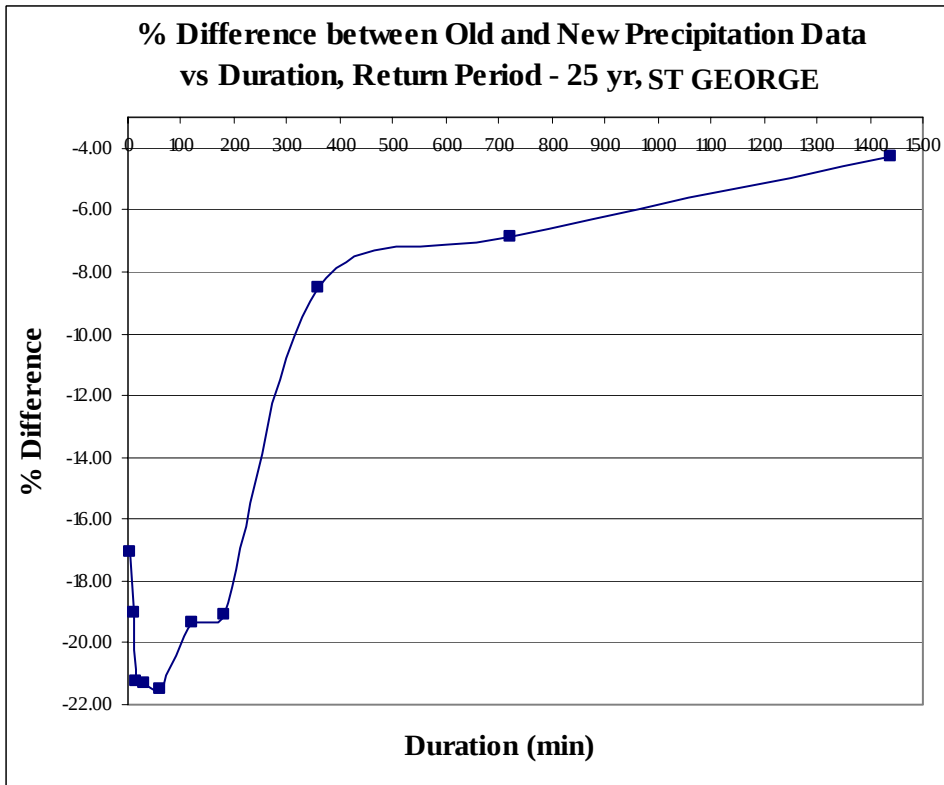
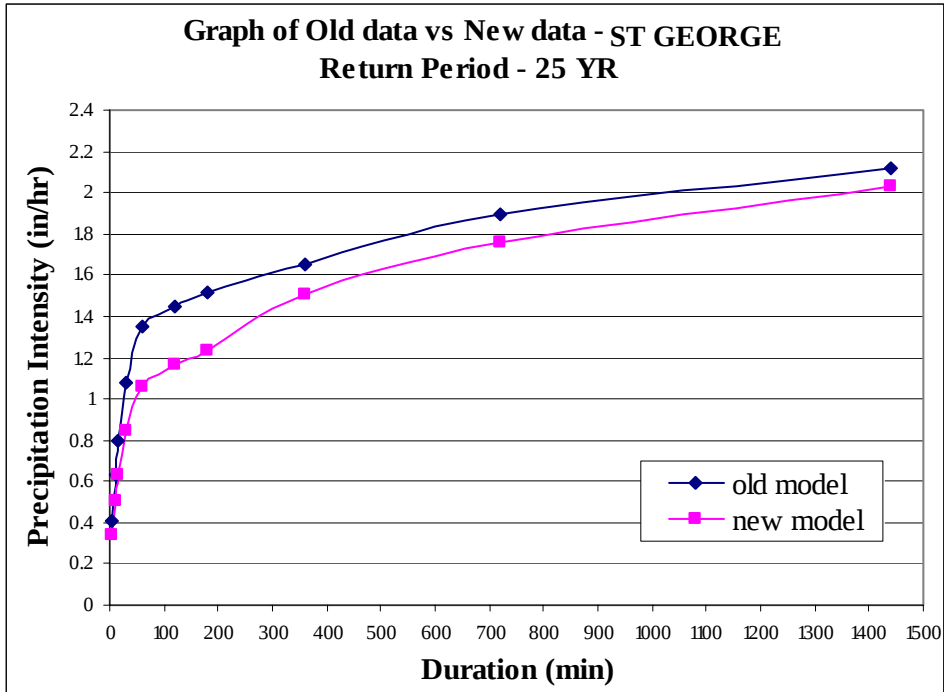
Table 24. ST GEORGE Lon (dd), -113.5672, Lat (dd), 37.1061, Elev (feet), 2719										
NEW DATA										
Duration:- Return Period	5-min	10-min	15- min	30- min	1-hr (60- min)	2-hr (120- min)	3-hr (180- min)	6-hr (360- min)	12-hr (720- min)	24-hr (1440- min)
2-YR	0.16	0.25	0.31	0.42	0.52	0.61	0.67	0.84	1.01	1.17
5-YR	0.22	0.33	0.41	0.55	0.69	0.78	0.85	1.05	1.27	1.47
10-YR	0.26	0.4	0.5	0.67	0.83	0.93	1	1.23	1.47	1.71
25-YR	0.34	0.51	0.63	0.85	1.06	1.17	1.23	1.51	1.76	2.03
50-YR	0.4	0.6	0.75	1.01	1.25	1.36	1.41	1.72	1.98	2.29
100-YR	0.47	0.71	0.88	1.19	1.47	1.58	1.62	1.96	2.21	2.54
500-YR	0.67	1.01	1.26	1.69	2.1	2.18	2.19	2.56	2.79	3.16

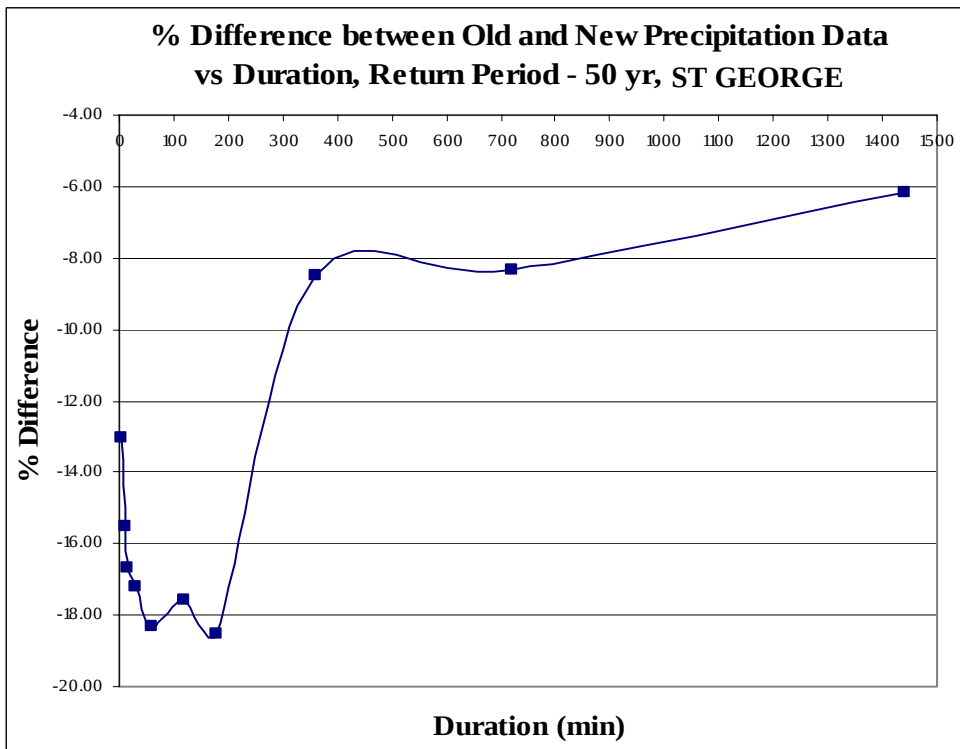
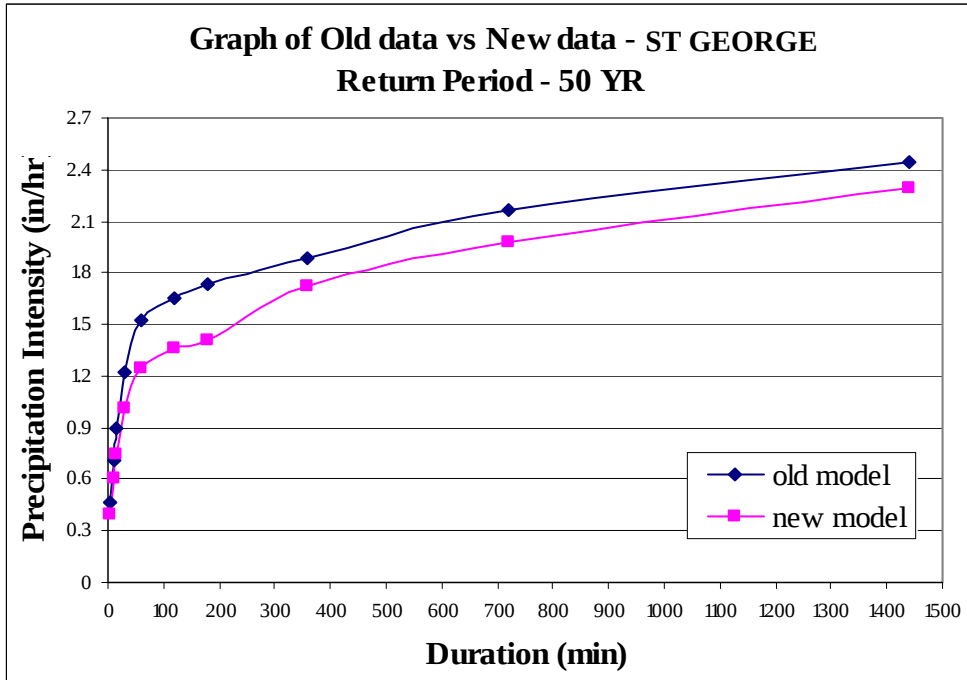
Table 25. ST GEORGE										
Percentage Difference between the Old data and New data										
Duration:- Return Period	5-min	10-min	15- min	30-min	1-hr (60- min)	2-hr (120- min)	3-hr (180- min)	6-hr (360- min)	12- hr (720- min)	24-hr (1440- min)
2-YR	-33.33	-30.56	-29.55	-27.59	-26.76	-18.67	-15.19	-1.18	12.22	23.16
5-YR	-26.67	-28.26	-28.07	-28.57	-27.37	-23.53	-20.56	-9.48	-0.78	4.26
10-YR	-25.71	-24.53	-25.37	-25.56	-25.89	-22.50	-20.63	-10.22	-4.55	0.00
25-YR	-17.07	-19.05	-21.25	-21.30	-21.48	-19.31	-19.08	-8.48	-6.88	-4.25
50-YR	-13.04	-15.49	-16.67	-17.21	-18.30	-17.58	-18.50	-8.51	-8.33	-6.15
100-YR	-7.84	-8.97	-12.87	-12.50	-13.53	-14.13	-16.06	-6.67	-8.68	-7.64
500-YR	6.35	5.21	1.61	0.00	-0.94	-4.80	-8.75	-1.92	-8.52	-9.20

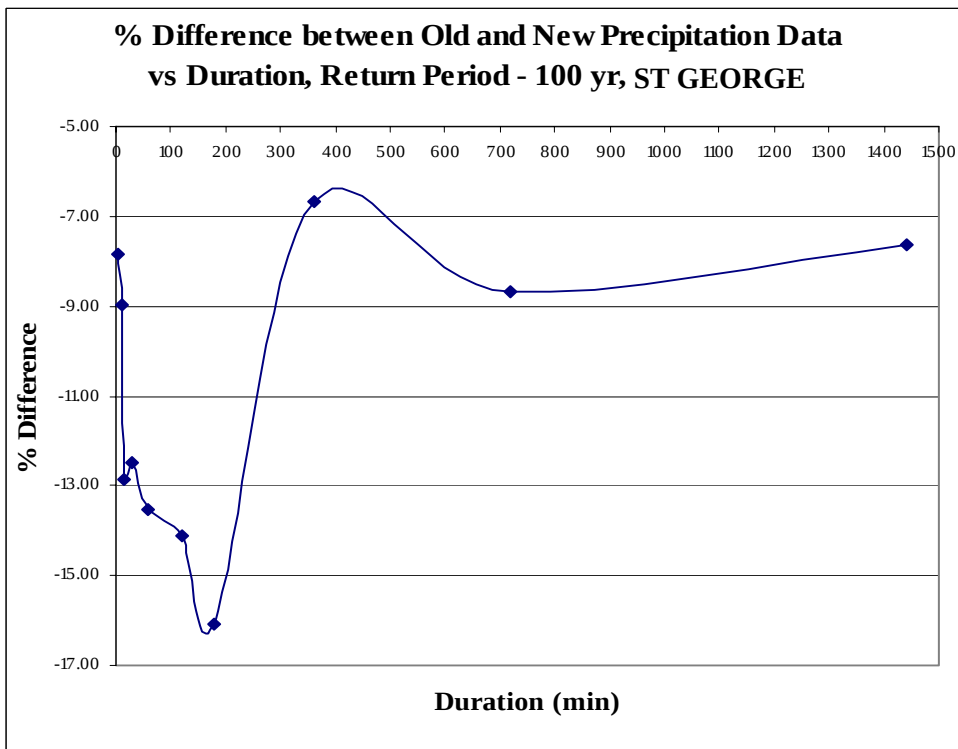
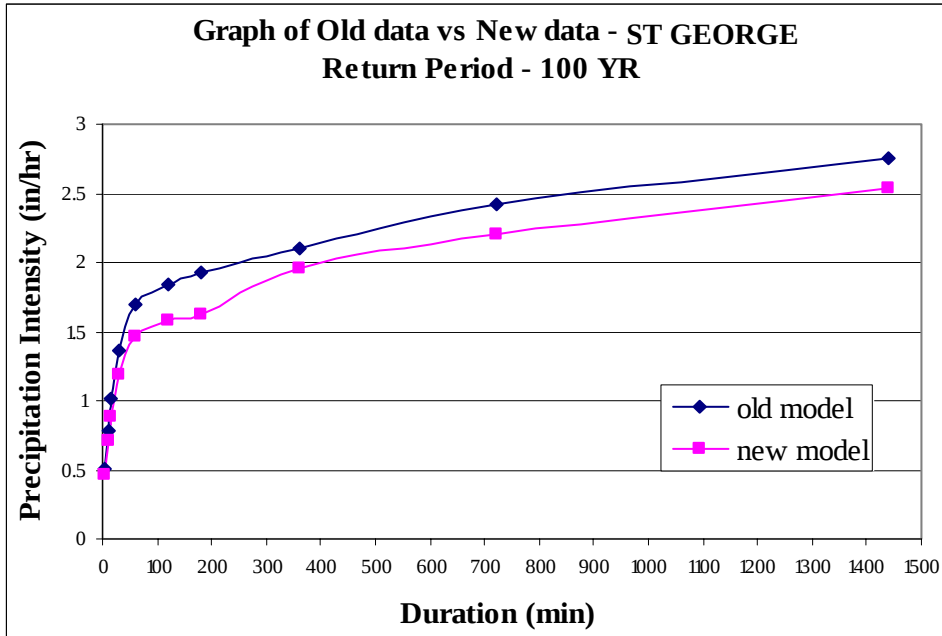


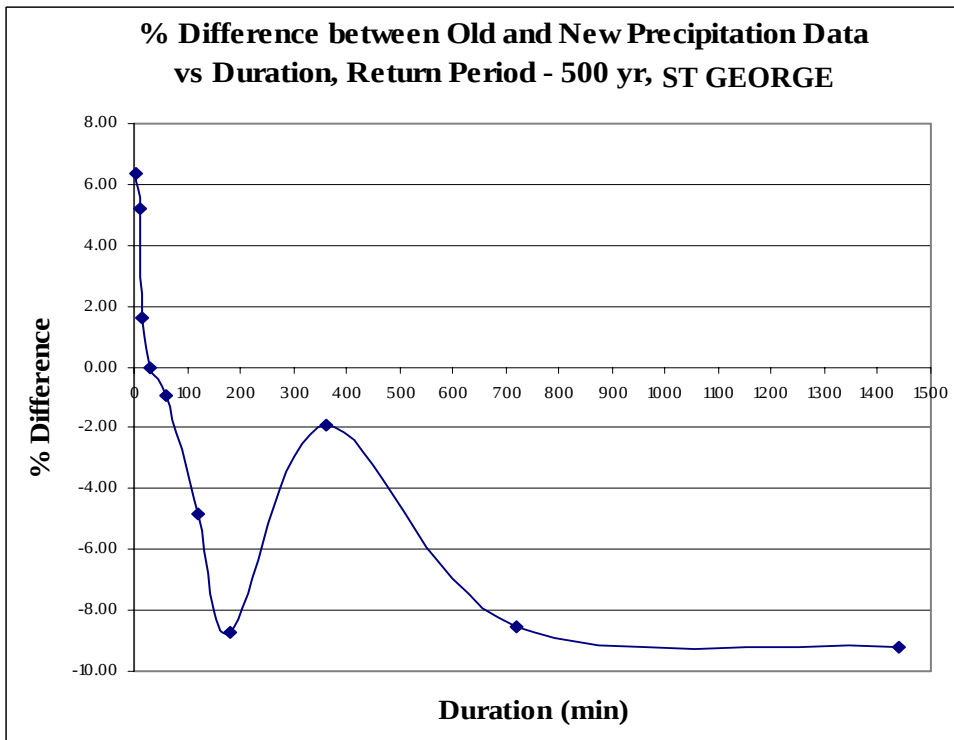
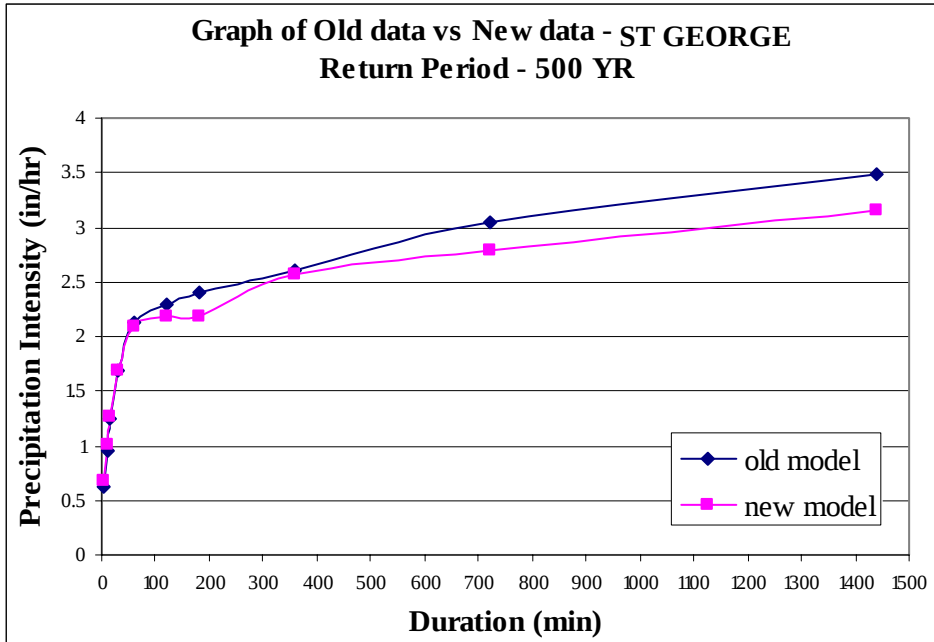












Conclusions

In general, the NOAA (New) precipitation estimates were less than the UCC (Old) precipitation estimates for return periods of 50 years or less. The amounts of the differences ranged from about 5% to 33%. Hydraulic structure designs based on the UCC estimates with return periods of 50 years or less are most likely quite conservative.

The differences between NOAA and UCC IDF curves were mixed for return periods of 100 years or greater. For the Heber, Moab, and Salt Lake City sites the NOAA values were generally greater than the UCC values. The amounts of the differences ranged from about 2% to 50%. Hydraulic structure designs based on the NOAA estimates for return periods of 100 years or greater are most likely conservative.

Tables 16, 19, 22, and 25 provide the specific results for each intensity and duration at the four sites. Graphs of the differences between the NOAA and UCC IDF curves are also provided following each table.

ENCLOSED CD

A CD is enclosed containing this report as an MS Word document. In addition, it contains three Excel Workbook with the raw data and analyses. The CD also contains a variety of files and web links for information about peak flow estimation methods for small to medium size watersheds.

APPENDIX A

IDF DATA FOR:

HUNTSVILLE MONASTERY

WOODRUFF

LEVAN

PRICE WAREHOUSES

MANTI

CASTLE DALE

CEDAR CITY AP

ESCALANTE

HUNTSVILLE MONASTERY, UTAH (42-4135) 41.24°N 111.7114°W 5118 feet (Windward)

Precipitation Intensity Estimates (in/hr)

Duration:-	5	10	15	30	60	120	3	6	12	24	48	4	7	10	20	30	45	60
Return period	min	min	min	min	min	min	hr	hr	hr	hr	hr	day	day	day	day	day	day	day
2	2.18	1.66	1.37	0.92	0.57	0.38	0.29	0.2	0.13	0.08	0.05	0.03	0.02	0.02	0.01	0.01	0.01	0.01
5	2.96	2.26	1.87	1.26	0.78	0.48	0.36	0.24	0.15	0.1	0.06	0.04	0.03	0.02	0.01	0.01	0.01	0.01
10	3.7	2.81	2.32	1.56	0.97	0.59	0.42	0.27	0.18	0.11	0.07	0.04	0.03	0.02	0.02	0.01	0.01	0.01
25	4.85	3.69	3.05	2.05	1.27	0.76	0.53	0.33	0.21	0.13	0.08	0.05	0.04	0.03	0.02	0.01	0.01	0.01
50	5.93	4.51	3.72	2.51	1.55	0.91	0.64	0.37	0.24	0.14	0.09	0.06	0.04	0.03	0.02	0.02	0.01	0.01
100	7.19	5.47	4.52	3.05	1.89	1.1	0.76	0.43	0.27	0.16	0.1	0.06	0.04	0.03	0.02	0.02	0.01	0.01
200	8.71	6.63	5.48	3.69	2.28	1.32	0.9	0.49	0.3	0.17	0.1	0.07	0.05	0.04	0.02	0.02	0.01	0.01
500	11.18	8.51	7.04	4.74	2.93	1.68	1.14	0.61	0.35	0.19	0.12	0.08	0.05	0.04	0.02	0.02	0.02	0.01
1000	13.51	10.28	8.5	5.72	3.54	2.01	1.36	0.72	0.39	0.21	0.12	0.08	0.06	0.04	0.03	0.02	0.02	0.01

Upper bound of the 90% confidence interval, Precipitation Intensity Estimates (in/hr)

Duration	5	10	15	30	60	120	3	6	12	24	48	4	7	10	20	30	45	60
period	min	min	min	min	min	min	hr	hr	hr	hr	hr	day	day	day	day	day	day	day
2	2.54	1.93	1.6	1.08	0.67	0.43	0.32	0.22	0.14	0.09	0.06	0.03	0.03	0.02	0.01	0.01	0.01	0.01
5	3.44	2.63	2.17	1.46	0.90	0.55	0.40	0.26	0.17	0.11	0.07	0.04	0.03	0.02	0.02	0.01	0.01	0.01
10	4.3	3.27	2.7	1.82	1.13	0.67	0.48	0.30	0.19	0.13	0.08	0.05	0.03	0.03	0.02	0.01	0.01	0.01
25	5.68	4.31	3.57	2.40	1.49	0.87	0.61	0.36	0.23	0.15	0.09	0.06	0.04	0.03	0.02	0.02	0.01	0.01
50	7.01	5.33	4.41	2.97	1.84	1.06	0.74	0.42	0.27	0.16	0.10	0.06	0.04	0.03	0.02	0.02	0.01	0.01
100	8.6	6.55	5.41	3.64	2.25	1.30	0.89	0.49	0.30	0.18	0.11	0.07	0.05	0.04	0.02	0.02	0.02	0.01
200	10.64	8.1	6.69	4.51	2.79	1.59	1.09	0.59	0.35	0.20	0.12	0.08	0.05	0.04	0.02	0.02	0.02	0.01
500	14.06	10.7	8.84	5.95	3.69	2.08	1.42	0.75	0.42	0.22	0.13	0.08	0.06	0.04	0.03	0.02	0.02	0.02
1000	17.44	13.27	10.96	7.38	4.57	2.56	1.73	0.91	0.50	0.25	0.14	0.09	0.07	0.05	0.03	0.02	0.02	0.02

Lower bound of the 90% confidence interval, Precipitation Intensity Estimates (in/hr)

Duration	5	10	15	30	60	120	3	6	12	24	48	4	7	10	20	30	45	60
Return period	min	min	min	min	min	min	hr	hr	hr	hr	hr	day	day	day	day	day	day	day
2	1.92	1.46	1.21	0.81	0.50	0.33	0.26	0.18	0.12	0.07	0.05	0.03	0.02	0.02	0.01	0.01	0.01	0.01
5	2.6	1.98	1.64	1.10	0.68	0.43	0.32	0.22	0.14	0.09	0.05	0.03	0.02	0.02	0.01	0.01	0.01	0.01
10	3.17	2.41	2	1.34	0.83	0.51	0.38	0.25	0.16	0.10	0.06	0.04	0.03	0.02	0.01	0.01	0.01	0.01
25	4.08	3.11	2.57	1.73	1.07	0.65	0.46	0.29	0.19	0.12	0.07	0.04	0.03	0.02	0.02	0.01	0.01	0.01
50	4.85	3.69	3.05	2.05	1.27	0.76	0.54	0.33	0.21	0.13	0.08	0.05	0.03	0.03	0.02	0.01	0.01	0.01
100	5.7	4.34	3.58	2.41	1.49	0.89	0.63	0.37	0.23	0.14	0.09	0.05	0.04	0.03	0.02	0.01	0.01	0.01
200	6.66	5.07	4.19	2.82	1.75	1.03	0.72	0.41	0.25	0.15	0.09	0.06	0.04	0.03	0.02	0.02	0.01	0.01
500	8.04	6.12	5.06	3.41	2.11	1.23	0.87	0.50	0.29	0.17	0.10	0.07	0.05	0.03	0.02	0.02	0.01	0.01
1000	9.25	7.04	5.82	3.92	2.42	1.40	1.00	0.57	0.32	0.18	0.11	0.07	0.05	0.04	0.02	0.02	0.01	0.01

WOODRUFF, UTAH (42-9595) 41.525°N 111.1494°W 6312 feet (Leeward)																		
Precipitation Intensity Estimates (in/hr)																		
Duration	5	10	15	30	60	120	3	6	12	24	48	4	7	10	20	30	45	60
Return period	min	min	min	min	min	min	hr	hr	hr	hr	hr	day	day	day	day	day	day	day
2	1.57	1.19	0.99	0.66	0.41	0.25	0.19	0.12	0.07	0.05	0.03	0.01	0.01	0.01	0	0	0	0
5	2.18	1.66	1.37	0.92	0.57	0.34	0.25	0.15	0.09	0.06	0.03	0.02	0.01	0.01	0.01	0	0	0
10	2.75	2.09	1.72	1.16	0.72	0.42	0.3	0.18	0.1	0.06	0.04	0.02	0.01	0.01	0.01	0	0	0
25	3.64	2.77	2.29	1.54	0.95	0.54	0.39	0.22	0.13	0.08	0.04	0.02	0.02	0.01	0.01	0.01	0	0
50	4.46	3.4	2.8	1.89	1.17	0.66	0.46	0.26	0.14	0.08	0.05	0.03	0.02	0.01	0.01	0.01	0	0
100	5.42	4.13	3.41	2.3	1.42	0.8	0.55	0.3	0.16	0.09	0.05	0.03	0.02	0.01	0.01	0.01	0.01	0
200	6.58	5	4.13	2.78	1.72	0.97	0.65	0.34	0.18	0.1	0.06	0.03	0.02	0.02	0.01	0.01	0.01	0
500	8.36	6.37	5.26	3.54	2.19	1.23	0.83	0.43	0.22	0.12	0.07	0.04	0.02	0.02	0.01	0.01	0.01	0
1000	9.98	7.6	6.28	4.23	2.62	1.48	0.98	0.51	0.25	0.13	0.07	0.04	0.03	0.02	0.01	0.01	0.01	0.01

Upper bound of the 90% confidence interval, Precipitation Intensity Estimates (in/hr)																		
Duration	5	10	15	30	60	120	3	6	12	24	48	4	7	10	20	30	45	60
Return period	min	min	min	min	min	min	hr	hr	hr	hr	hr	day	day	day	day	day	day	day
2	1.81	1.38	1.14	0.77	0.48	0.29	0.22	0.14	0.08	0.05	0.03	0.02	0.01	0.01	0.01	0	0	0
5	2.51	1.91	1.58	1.06	0.66	0.38	0.28	0.17	0.1	0.06	0.03	0.02	0.01	0.01	0.01	0	0	0
10	3.13	2.38	1.97	1.33	0.82	0.47	0.34	0.2	0.12	0.07	0.04	0.02	0.01	0.01	0.01	0.01	0	0
25	4.19	3.18	2.63	1.77	1.1	0.62	0.44	0.25	0.14	0.08	0.05	0.03	0.02	0.01	0.01	0.01	0	0
50	5.15	3.91	3.24	2.18	1.35	0.76	0.53	0.29	0.16	0.09	0.05	0.03	0.02	0.01	0.01	0.01	0	0
100	6.32	4.81	3.98	2.68	1.66	0.93	0.64	0.34	0.19	0.1	0.06	0.03	0.02	0.02	0.01	0.01	0.01	0
200	7.76	5.91	4.89	3.29	2.04	1.14	0.77	0.4	0.21	0.11	0.06	0.04	0.02	0.02	0.01	0.01	0.01	0
500	10.1	7.69	6.36	4.28	2.65	1.49	1	0.51	0.26	0.13	0.07	0.04	0.03	0.02	0.01	0.01	0.01	0.01
1000	12.31	9.37	7.74	5.21	3.23	1.82	1.21	0.62	0.31	0.16	0.08	0.04	0.03	0.02	0.01	0.01	0.01	0.01
Lower bound of the 90% confidence interval, Precipitation Intensity Estimates (in/hr)																		
Duration	5	10	15	30	60	120	3	6	12	24	48	4	7	10	20	30	45	60
Return period	min	min	min	min	min	min	hr	hr	hr	hr	hr	day	day	day	day	day	day	day
2	1.39	1.06	0.88	0.59	0.37	0.23	0.17	0.11	0.07	0.04	0.02	0.01	0.01	0.01	0	0	0	0
5	1.93	1.47	1.22	0.82	0.51	0.3	0.23	0.14	0.08	0.05	0.03	0.02	0.01	0.01	0.01	0	0	0
10	2.39	1.82	1.5	1.01	0.63	0.37	0.27	0.16	0.09	0.06	0.03	0.02	0.01	0.01	0.01	0	0	0
25	3.08	2.35	1.94	1.31	0.81	0.47	0.34	0.2	0.11	0.07	0.04	0.02	0.01	0.01	0.01	0.01	0	0
50	3.68	2.81	2.32	1.56	0.97	0.55	0.4	0.22	0.13	0.08	0.04	0.03	0.02	0.01	0.01	0.01	0	0
100	4.36	3.32	2.74	1.85	1.14	0.65	0.46	0.25	0.14	0.08	0.05	0.03	0.02	0.01	0.01	0.01	0	0
200	5.1	3.88	3.21	2.16	1.34	0.75	0.52	0.29	0.16	0.09	0.05	0.03	0.02	0.01	0.01	0.01	0	0
500	6.14	4.68	3.87	2.6	1.61	0.91	0.63	0.35	0.18	0.1	0.06	0.03	0.02	0.02	0.01	0.01	0.01	0
1000	7.02	5.35	4.42	2.98	1.84	1.04	0.72	0.4	0.2	0.11	0.06	0.04	0.02	0.02	0.01	0.01	0.01	0

LEVAN, UTAH (42-5065) 39.5542°N 111.8669°W 5295 feet (Windward)																		
Precipitation Intensity Estimates (in/hr)																		
Duration	5	10	15	30	60	120	3	6	12	24	48	4	7	10	20	30	45	60
Return period	min	min	min	min	min	min	hr	hr	hr	hr	hr	day	day	day	day	day	day	day
2	1.79	1.36	1.12	0.76	0.47	0.29	0.22	0.14	0.09	0.05	0.03	0.02	0.01	0.01	0.01	0.01	0	0
5	2.5	1.9	1.57	1.06	0.66	0.39	0.28	0.17	0.11	0.07	0.04	0.02	0.02	0.01	0.01	0.01	0.01	0
10	3.12	2.38	1.96	1.32	0.82	0.47	0.34	0.2	0.12	0.07	0.04	0.03	0.02	0.01	0.01	0.01	0.01	0.01
25	4.06	3.08	2.55	1.72	1.06	0.61	0.42	0.24	0.14	0.09	0.05	0.03	0.02	0.02	0.01	0.01	0.01	0.01
50	4.88	3.71	3.07	2.07	1.28	0.72	0.49	0.27	0.16	0.1	0.06	0.03	0.02	0.02	0.01	0.01	0.01	0.01
100	5.83	4.44	3.67	2.47	1.53	0.85	0.58	0.31	0.17	0.11	0.06	0.04	0.03	0.02	0.01	0.01	0.01	0.01
200	6.91	5.26	4.35	2.93	1.81	1.01	0.68	0.36	0.19	0.11	0.07	0.04	0.03	0.02	0.01	0.01	0.01	0.01
500	8.59	6.54	5.41	3.64	2.25	1.24	0.84	0.43	0.23	0.13	0.08	0.05	0.03	0.02	0.01	0.01	0.01	0.01
1000	10.12	7.7	6.36	4.28	2.65	1.45	0.98	0.5	0.26	0.14	0.09	0.05	0.03	0.02	0.01	0.01	0.01	0.01

Upper bound of the 90% confidence interval, Precipitation Intensity Estimates (in/hr)																		
Duration	5	10	15	30	60	120	3	6	12	24	48	4	7	10	20	30	45	60
Return period	min	min	min	min	min	min	hr	hr	hr	hr	hr	day	day	day	day	day	day	day
2	2.05	1.57	1.29	0.87	0.54	0.33	0.25	0.15	0.1	0.06	0.03	0.02	0.01	0.01	0.01	0.01	0	0
5	2.87	2.18	1.8	1.22	0.75	0.44	0.32	0.19	0.12	0.07	0.04	0.02	0.02	0.01	0.01	0.01	0.01	0
10	3.6	2.74	2.26	1.53	0.94	0.53	0.38	0.22	0.13	0.08	0.05	0.03	0.02	0.01	0.01	0.01	0.01	0.01
25	4.67	3.55	2.94	1.98	1.22	0.68	0.47	0.27	0.16	0.09	0.05	0.03	0.02	0.02	0.01	0.01	0.01	0.01
50	5.65	4.3	3.55	2.39	1.48	0.82	0.56	0.3	0.18	0.1	0.06	0.04	0.02	0.02	0.01	0.01	0.01	0.01
100	6.8	5.17	4.28	2.88	1.78	0.98	0.67	0.36	0.2	0.11	0.07	0.04	0.03	0.02	0.01	0.01	0.01	0.01
200	8.16	6.2	5.13	3.45	2.14	1.17	0.8	0.42	0.22	0.12	0.07	0.05	0.03	0.02	0.01	0.01	0.01	0.01
500	10.33	7.87	6.5	4.38	2.71	1.47	1	0.52	0.27	0.13	0.08	0.05	0.03	0.02	0.02	0.01	0.01	0.01
1000	12.35	9.4	7.77	5.23	3.24	1.74	1.18	0.61	0.31	0.16	0.09	0.06	0.04	0.03	0.02	0.01	0.01	0.01
Lower bound of the 90% confidence interval, Precipitation Intensity Estimates (in/hr)																		
Duration	5	10	15	30	60	120	3	6	12	24	48	4	7	10	20	30	45	60
Return period	min	min	min	min	min	min	hr	hr	hr	hr	hr	day	day	day	day	day	day	day
2	1.6	1.21	1	0.68	0.42	0.26	0.2	0.13	0.08	0.05	0.03	0.02	0.01	0.01	0.01	0	0	0
5	2.2	1.67	1.38	0.93	0.58	0.35	0.26	0.16	0.1	0.06	0.04	0.02	0.01	0.01	0.01	0.01	0	0
10	2.72	2.08	1.72	1.16	0.71	0.42	0.31	0.18	0.11	0.07	0.04	0.02	0.02	0.01	0.01	0.01	0.01	0
25	3.46	2.63	2.18	1.47	0.91	0.53	0.38	0.22	0.13	0.08	0.05	0.03	0.02	0.01	0.01	0.01	0.01	0.01
50	4.08	3.1	2.56	1.73	1.07	0.62	0.43	0.24	0.14	0.09	0.05	0.03	0.02	0.02	0.01	0.01	0.01	0.01
100	4.78	3.63	3	2.02	1.25	0.71	0.49	0.27	0.16	0.1	0.06	0.04	0.02	0.02	0.01	0.01	0.01	0.01
200	5.52	4.2	3.47	2.34	1.45	0.82	0.57	0.31	0.17	0.11	0.06	0.04	0.03	0.02	0.01	0.01	0.01	0.01
500	6.55	4.99	4.12	2.78	1.72	0.97	0.68	0.36	0.2	0.12	0.07	0.04	0.03	0.02	0.01	0.01	0.01	0.01
1000	7.45	5.68	4.69	3.16	1.95	1.09	0.77	0.41	0.22	0.12	0.08	0.05	0.03	0.02	0.01	0.01	0.01	0.01

PRICE WAREHOUSES, UTAH (42-7026) 39.6167°N 110.8°W 5764 feet (Leeward)

Precipitation Intensity Estimates (in/hr)

Duration	5	10	15	30	60	120	3	6	12	24	48	4	7	10	20	30	45	60
Return period	min	min	min	min	min	min	hr	hr	hr	hr	hr	day	day	day	day	day	day	day
2	1.86	1.42	1.17	0.79	0.49	0.29	0.21	0.13	0.08	0.05	0.03	0.02	0.01	0.01	0.01	0	0	0
5	2.52	1.92	1.59	1.07	0.66	0.37	0.27	0.16	0.09	0.06	0.04	0.02	0.01	0.01	0.01	0.01	0	0
10	3.12	2.38	1.96	1.32	0.82	0.45	0.32	0.18	0.11	0.07	0.04	0.02	0.02	0.01	0.01	0.01	0	0
25	4.07	3.1	2.56	1.72	1.07	0.57	0.39	0.22	0.12	0.08	0.05	0.03	0.02	0.01	0.01	0.01	0.01	0
50	4.91	3.74	3.09	2.08	1.29	0.68	0.46	0.24	0.14	0.09	0.05	0.03	0.02	0.02	0.01	0.01	0.01	0.01
100	5.92	4.5	3.72	2.5	1.55	0.81	0.54	0.29	0.15	0.1	0.06	0.03	0.02	0.02	0.01	0.01	0.01	0.01
200	7.1	5.41	4.47	3.01	1.86	0.95	0.64	0.34	0.17	0.11	0.06	0.04	0.02	0.02	0.01	0.01	0.01	0.01
500	8.95	6.82	5.63	3.79	2.35	1.2	0.81	0.42	0.22	0.12	0.07	0.04	0.03	0.02	0.01	0.01	0.01	0.01
1000	10.62	8.08	6.68	4.5	2.78	1.43	0.96	0.5	0.25	0.14	0.08	0.04	0.03	0.02	0.01	0.01	0.01	0.01

Upper bound of the 90% confidence interval, Precipitation Intensity Estimates (in/hr)

Duration	5	10	15	30	60	120	3	6	12	24	48	4	7	10	20	30	45	60
Return period	min	min	min	min	min	min	hr	hr	hr	hr	hr	day	day	day	day	day	day	day
2	2.2	1.67	1.38	0.93	0.57	0.33	0.24	0.14	0.09	0.06	0.03	0.02	0.01	0.01	0.01	0	0	0
5	2.96	2.26	1.86	1.25	0.78	0.42	0.3	0.18	0.1	0.07	0.04	0.02	0.01	0.01	0.01	0.01	0	0
10	3.68	2.8	2.32	1.56	0.96	0.51	0.36	0.2	0.12	0.08	0.05	0.03	0.02	0.01	0.01	0.01	0.01	0
25	4.79	3.65	3.02	2.03	1.26	0.65	0.44	0.24	0.14	0.09	0.05	0.03	0.02	0.02	0.01	0.01	0.01	0.01
50	5.81	4.42	3.65	2.46	1.52	0.78	0.53	0.27	0.15	0.1	0.06	0.03	0.02	0.02	0.01	0.01	0.01	0.01
100	7.01	5.34	4.41	2.97	1.84	0.93	0.63	0.33	0.17	0.11	0.07	0.04	0.02	0.02	0.01	0.01	0.01	0.01
200	8.48	6.46	5.34	3.59	2.22	1.13	0.76	0.39	0.2	0.12	0.07	0.04	0.03	0.02	0.01	0.01	0.01	0.01
500	10.94	8.33	6.88	4.64	2.87	1.45	0.98	0.5	0.25	0.14	0.08	0.05	0.03	0.02	0.01	0.01	0.01	0.01
1000	13.18	10.03	8.29	5.58	3.45	1.74	1.17	0.6	0.3	0.16	0.09	0.05	0.03	0.03	0.02	0.01	0.01	0.01

Lower bound of the 90% confidence interval, Precipitation Intensity Estimates (in/hr)

Duration	5	10	15	30	60	120	3	6	12	24	48	4	7	10	20	30	45	60
Return period	min	min	min	min	min	min	hr	hr	hr	hr	hr	day	day	day	day	day	day	day
2	1.64	1.25	1.03	0.69	0.43	0.25	0.19	0.12	0.07	0.05	0.03	0.02	0.01	0.01	0	0	0	0
5	2.18	1.66	1.38	0.93	0.57	0.32	0.23	0.14	0.08	0.05	0.03	0.02	0.01	0.01	0.01	0	0	0
10	2.72	2.08	1.71	1.15	0.71	0.39	0.28	0.16	0.09	0.06	0.04	0.02	0.01	0.01	0.01	0.01	0	0
25	3.43	2.61	2.16	1.45	0.9	0.48	0.34	0.19	0.11	0.07	0.04	0.02	0.02	0.01	0.01	0.01	0	0
50	4.03	3.07	2.54	1.71	1.06	0.56	0.38	0.21	0.12	0.08	0.05	0.03	0.02	0.01	0.01	0.01	0.01	0
100	4.75	3.61	2.98	2.01	1.24	0.65	0.45	0.25	0.13	0.09	0.05	0.03	0.02	0.02	0.01	0.01	0.01	0.01
200	5.46	4.16	3.44	2.31	1.43	0.74	0.51	0.28	0.15	0.09	0.06	0.03	0.02	0.02	0.01	0.01	0.01	0.01
500	6.53	4.97	4.1	2.76	1.71	0.88	0.62	0.34	0.18	0.1	0.06	0.03	0.02	0.02	0.01	0.01	0.01	0.01
1000	7.4	5.63	4.65	3.13	1.94	1.01	0.7	0.39	0.21	0.11	0.06	0.04	0.02	0.02	0.01	0.01	0.01	0.01

MANTI, UTAH (42-5402) 39.2581°N 111.6314°W 5698 feet (Windward)																		
Precipitation Intensity Estimates (in/hr)																		
Duration	5	10	15	30	60	120	3	6	12	24	48	4	7	10	20	30	45	60
Return period	min	min	min	min	min	min	hr	hr	hr	hr	hr	day	day	day	day	day	day	day
2	1.69	1.28	1.06	0.72	0.44	0.27	0.21	0.13	0.08	0.05	0.03	0.02	0.01	0.01	0.01	0	0	0
5	2.36	1.79	1.48	1	0.62	0.36	0.26	0.16	0.1	0.06	0.03	0.02	0.01	0.01	0.01	0.01	0	0
10	2.89	2.2	1.82	1.23	0.76	0.44	0.32	0.19	0.12	0.07	0.04	0.02	0.01	0.01	0.01	0.01	0	0
25	3.78	2.87	2.38	1.6	0.99	0.56	0.39	0.23	0.13	0.08	0.05	0.03	0.02	0.01	0.01	0.01	0.01	0.01
50	4.54	3.46	2.86	1.92	1.19	0.66	0.45	0.26	0.15	0.09	0.05	0.03	0.02	0.01	0.01	0.01	0.01	0.01
100	5.4	4.11	3.4	2.29	1.42	0.78	0.53	0.29	0.16	0.09	0.06	0.03	0.02	0.02	0.01	0.01	0.01	0.01
200	6.4	4.87	4.02	2.71	1.68	0.92	0.62	0.32	0.18	0.1	0.06	0.04	0.02	0.02	0.01	0.01	0.01	0.01
500	7.94	6.05	5	3.37	2.08	1.14	0.76	0.39	0.2	0.11	0.07	0.04	0.03	0.02	0.01	0.01	0.01	0.01
1000	9.3	7.08	5.85	3.94	2.44	1.32	0.89	0.45	0.23	0.12	0.07	0.05	0.03	0.02	0.01	0.01	0.01	0.01

Upper bound of the 90% confidence interval, Precipitation Intensity Estimates (in/hr)																		
Duration	5	10	15	30	60	120	3	6	12	24	48	4	7	10	20	30	45	60
Return period	min	min	min	min	min	min	hr	hr	hr	hr	hr	day	day	day	day	day	day	day
2	1.91	1.45	1.2	0.81	0.5	0.3	0.22	0.14	0.09	0.05	0.03	0.02	0.01	0.01	0.01	0	0	0
5	2.63	2	1.65	1.11	0.69	0.39	0.29	0.18	0.11	0.06	0.04	0.02	0.01	0.01	0.01	0.01	0	0
10	3.25	2.48	2.05	1.38	0.85	0.48	0.34	0.21	0.12	0.07	0.04	0.02	0.02	0.01	0.01	0.01	0.01	0
25	4.24	3.23	2.67	1.8	1.11	0.61	0.43	0.25	0.15	0.08	0.05	0.03	0.02	0.01	0.01	0.01	0.01	0.01
50	5.11	3.89	3.21	2.16	1.34	0.73	0.5	0.28	0.16	0.09	0.05	0.03	0.02	0.02	0.01	0.01	0.01	0.01
100	6.14	4.68	3.87	2.6	1.61	0.88	0.6	0.32	0.18	0.1	0.06	0.04	0.02	0.02	0.01	0.01	0.01	0.01
200	7.37	5.6	4.63	3.12	1.93	1.04	0.71	0.36	0.2	0.11	0.06	0.04	0.02	0.02	0.01	0.01	0.01	0.01
500	9.36	7.13	5.89	3.97	2.45	1.31	0.89	0.45	0.23	0.12	0.07	0.04	0.03	0.02	0.01	0.01	0.01	0.01
1000	11.1	8.45	6.98	4.7	2.91	1.55	1.05	0.53	0.27	0.14	0.08	0.05	0.03	0.02	0.01	0.01	0.01	0.01
Lower bound of the 90% confidence interval, Precipitation Intensity Estimates (in/hr)																		
Duration	5	10	15	30	60	120	3	6	12	24	48	4	7	10	20	30	45	60
Return period	min	min	min	min	min	min	hr	hr	hr	hr	hr	day	day	day	day	day	day	day
2	1.52	1.16	0.96	0.64	0.4	0.25	0.19	0.12	0.08	0.05	0.03	0.02	0.01	0.01	0.01	0	0	0
5	2.14	1.63	1.34	0.9	0.56	0.33	0.25	0.15	0.09	0.06	0.03	0.02	0.01	0.01	0.01	0.01	0	0
10	2.59	1.97	1.63	1.1	0.68	0.4	0.29	0.18	0.11	0.06	0.04	0.02	0.01	0.01	0.01	0.01	0	0
25	3.29	2.51	2.07	1.39	0.86	0.49	0.35	0.21	0.12	0.07	0.04	0.03	0.02	0.01	0.01	0.01	0.01	0
50	3.88	2.95	2.44	1.64	1.02	0.58	0.4	0.23	0.14	0.08	0.05	0.03	0.02	0.01	0.01	0.01	0.01	0.01
100	4.51	3.44	2.84	1.91	1.18	0.66	0.46	0.26	0.15	0.09	0.05	0.03	0.02	0.02	0.01	0.01	0.01	0.01
200	5.2	3.95	3.27	2.2	1.36	0.76	0.53	0.28	0.16	0.1	0.06	0.03	0.02	0.02	0.01	0.01	0.01	0.01
500	6.18	4.7	3.88	2.62	1.62	0.9	0.63	0.34	0.18	0.11	0.06	0.04	0.02	0.02	0.01	0.01	0.01	0.01
1000	7	5.32	4.4	2.96	1.83	1.01	0.71	0.38	0.2	0.11	0.07	0.04	0.03	0.02	0.01	0.01	0.01	0.01

CASTLE DALE, UTAH (42-1214) 39.2078°N 111.0122°W 5652 feet (Leeward)																		
Precipitation Intensity Estimates (in/hr)																		
Duration	5	10	15	30	60	120	3	6	12	24	48	4	7	10	20	30	45	60
Return period	min	min	min	min	min	min	hr	hr	hr	hr	hr	day	day	day	day	day	day	day
2	1.61	1.22	1.01	0.68	0.42	0.25	0.19	0.12	0.07	0.05	0.03	0.02	0.01	0.01	0	0	0	0
5	2.27	1.73	1.43	0.96	0.59	0.34	0.24	0.15	0.09	0.06	0.03	0.02	0.01	0.01	0.01	0	0	0
10	2.86	2.17	1.8	1.21	0.75	0.42	0.29	0.17	0.1	0.06	0.04	0.02	0.01	0.01	0.01	0	0	0
25	3.79	2.89	2.39	1.61	0.99	0.54	0.37	0.21	0.12	0.08	0.04	0.02	0.02	0.01	0.01	0.01	0	0
50	4.66	3.54	2.92	1.97	1.22	0.65	0.45	0.24	0.13	0.08	0.05	0.03	0.02	0.01	0.01	0.01	0	0
100	5.66	4.31	3.56	2.4	1.48	0.79	0.53	0.28	0.15	0.09	0.05	0.03	0.02	0.01	0.01	0.01	0.01	0
200	6.84	5.21	4.3	2.9	1.79	0.94	0.64	0.33	0.17	0.1	0.06	0.03	0.02	0.02	0.01	0.01	0.01	0
500	8.71	6.63	5.48	3.69	2.28	1.2	0.81	0.42	0.21	0.11	0.06	0.04	0.02	0.02	0.01	0.01	0.01	0.01
1000	10.38	7.9	6.53	4.4	2.72	1.42	0.96	0.49	0.25	0.13	0.07	0.04	0.03	0.02	0.01	0.01	0.01	0.01

Upper bound of the 90% confidence interval, Precipitation Intensity Estimates (in/hr)																		
Duration	5	10	15	30	60	120	3	6	12	24	48	4	7	10	20	30	45	60
Return period	min	min	min	min	min	min	hr	hr	hr	hr	hr	day	day	day	day	day	day	day
2	1.92	1.46	1.21	0.81	0.5	0.3	0.22	0.13	0.08	0.05	0.03	0.02	0.01	0.01	0	0	0	0
5	2.7	2.05	1.7	1.14	0.71	0.4	0.28	0.16	0.09	0.06	0.03	0.02	0.01	0.01	0.01	0	0	0
10	3.41	2.59	2.14	1.44	0.89	0.49	0.34	0.19	0.11	0.07	0.04	0.02	0.01	0.01	0.01	0.01	0	0
25	4.54	3.46	2.86	1.92	1.19	0.63	0.44	0.24	0.13	0.08	0.05	0.03	0.02	0.01	0.01	0.01	0	0
50	5.57	4.24	3.5	2.36	1.46	0.77	0.53	0.28	0.15	0.09	0.05	0.03	0.02	0.01	0.01	0.01	0.01	0
100	6.79	5.17	4.27	2.88	1.78	0.94	0.64	0.33	0.17	0.1	0.06	0.03	0.02	0.02	0.01	0.01	0.01	0
200	8.27	6.29	5.2	3.5	2.17	1.14	0.77	0.4	0.2	0.11	0.06	0.04	0.02	0.02	0.01	0.01	0.01	0.01
500	10.7	8.15	6.74	4.53	2.81	1.46	0.99	0.51	0.26	0.13	0.07	0.04	0.03	0.02	0.01	0.01	0.01	0.01
1000	12.95	9.85	8.14	5.48	3.39	1.77	1.2	0.61	0.31	0.16	0.08	0.04	0.03	0.02	0.01	0.01	0.01	0.01
Lower bound of the 90% confidence interval, Precipitation Intensity Estimates (in/hr)																		
Duration	5	10	15	30	60	120	3	6	12	24	48	4	7	10	20	30	45	60
Return period	min	min	min	min	min	min	hr	hr	hr	hr	hr	day	day	day	day	day	day	day
2	1.39	1.06	0.88	0.59	0.37	0.22	0.16	0.1	0.06	0.04	0.03	0.01	0.01	0.01	0	0	0	0
5	1.94	1.48	1.22	0.82	0.51	0.29	0.21	0.13	0.08	0.05	0.03	0.02	0.01	0.01	0.01	0	0	0
10	2.42	1.85	1.53	1.03	0.64	0.36	0.26	0.15	0.09	0.06	0.04	0.02	0.01	0.01	0.01	0	0	0
25	3.14	2.39	1.98	1.33	0.82	0.45	0.32	0.18	0.1	0.07	0.04	0.02	0.01	0.01	0.01	0.01	0	0
50	3.76	2.86	2.36	1.59	0.98	0.53	0.37	0.21	0.12	0.08	0.04	0.03	0.02	0.01	0.01	0.01	0	0
100	4.46	3.4	2.81	1.89	1.17	0.62	0.44	0.24	0.13	0.09	0.05	0.03	0.02	0.01	0.01	0.01	0	0
200	5.23	3.98	3.29	2.22	1.37	0.73	0.51	0.28	0.15	0.09	0.05	0.03	0.02	0.01	0.01	0.01	0.01	0
500	6.35	4.84	4	2.69	1.67	0.88	0.62	0.34	0.17	0.1	0.06	0.03	0.02	0.02	0.01	0.01	0.01	0
1000	7.3	5.56	4.59	3.09	1.91	1.01	0.71	0.39	0.2	0.11	0.06	0.03	0.02	0.02	0.01	0.01	0.01	0

CEDAR CITY AP, UTAH (42-1267) 37.7017°N 113.0972°W 5597 feet (Windward)

Precipitation Intensity Estimates (in/hr)

Duration	5	10	15	30	60	120	3	6	12	24	48	4	7	10	20	30	45	60
Return period	min	min	min	min	min	min	hr	hr	hr	hr	hr	day	day	day	day	day	day	day
2	2.21	1.68	1.39	0.94	0.58	0.34	0.25	0.16	0.1	0.06	0.03	0.02	0.01	0.01	0.01	0	0	0
5	3.1	2.36	1.95	1.31	0.81	0.46	0.33	0.2	0.13	0.07	0.04	0.02	0.01	0.01	0.01	0.01	0	0
10	3.91	2.98	2.46	1.65	1.02	0.56	0.39	0.24	0.14	0.08	0.05	0.03	0.02	0.01	0.01	0.01	0.01	0
25	5.18	3.94	3.26	2.19	1.36	0.73	0.49	0.29	0.17	0.09	0.05	0.03	0.02	0.01	0.01	0.01	0.01	0
50	6.31	4.81	3.97	2.67	1.65	0.88	0.59	0.33	0.19	0.11	0.06	0.03	0.02	0.02	0.01	0.01	0.01	0.01
100	7.61	5.79	4.78	3.22	1.99	1.05	0.71	0.38	0.22	0.12	0.07	0.04	0.02	0.02	0.01	0.01	0.01	0.01
200	9.17	6.97	5.76	3.88	2.4	1.25	0.85	0.43	0.24	0.13	0.08	0.04	0.03	0.02	0.01	0.01	0.01	0.01
500	11.57	8.8	7.28	4.9	3.03	1.57	1.06	0.53	0.27	0.15	0.09	0.05	0.03	0.02	0.01	0.01	0.01	0.01
1000	13.74	10.46	8.64	5.82	3.6	1.86	1.25	0.63	0.32	0.16	0.09	0.05	0.03	0.02	0.01	0.01	0.01	0.01

Upper bound of the 90% confidence interval, Precipitation Intensity Estimates (in/hr)

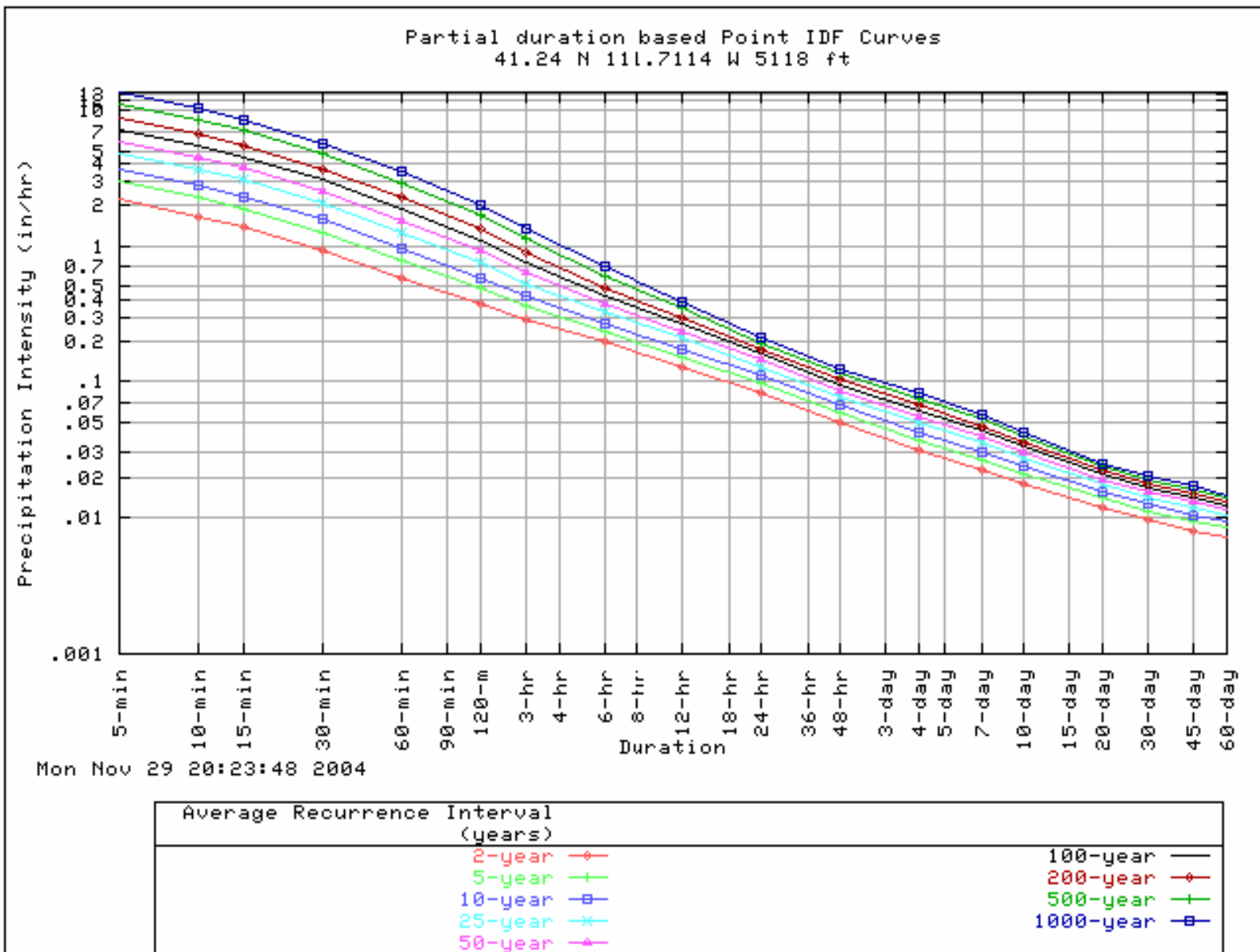
Duration	5	10	15	30	60	120	3	6	12	24	48	4	7	10	20	30	45	60
Return period	min	min	min	min	min	min	hr	hr	hr	hr	hr	day	day	day	day	day	day	day
2	2.51	1.91	1.58	1.06	0.66	0.38	0.27	0.18	0.11	0.06	0.03	0.02	0.01	0.01	0.01	0	0	0
5	3.49	2.66	2.2	1.48	0.92	0.51	0.36	0.22	0.14	0.08	0.04	0.02	0.02	0.01	0.01	0.01	0	0
10	4.38	3.33	2.75	1.85	1.15	0.62	0.43	0.26	0.16	0.09	0.05	0.03	0.02	0.01	0.01	0.01	0.01	0
25	5.84	4.45	3.67	2.47	1.53	0.8	0.55	0.31	0.19	0.1	0.06	0.03	0.02	0.02	0.01	0.01	0.01	0.01
50	7.13	5.42	4.48	3.02	1.87	0.97	0.67	0.36	0.22	0.11	0.06	0.04	0.02	0.02	0.01	0.01	0.01	0.01
100	8.65	6.58	5.44	3.66	2.27	1.19	0.81	0.42	0.24	0.13	0.07	0.04	0.03	0.02	0.01	0.01	0.01	0.01
200	10.55	8.02	6.63	4.47	2.76	1.43	0.97	0.5	0.27	0.14	0.08	0.05	0.03	0.02	0.01	0.01	0.01	0.01
500	13.51	10.28	8.5	5.72	3.54	1.83	1.24	0.63	0.32	0.16	0.09	0.05	0.03	0.02	0.01	0.01	0.01	0.01
1000	16.18	12.31	10.17	6.85	4.24	2.18	1.48	0.75	0.38	0.19	0.1	0.06	0.04	0.03	0.01	0.01	0.01	0.01

Lower bound of the 90% confidence interval, Precipitation Intensity Estimates (in/hr)

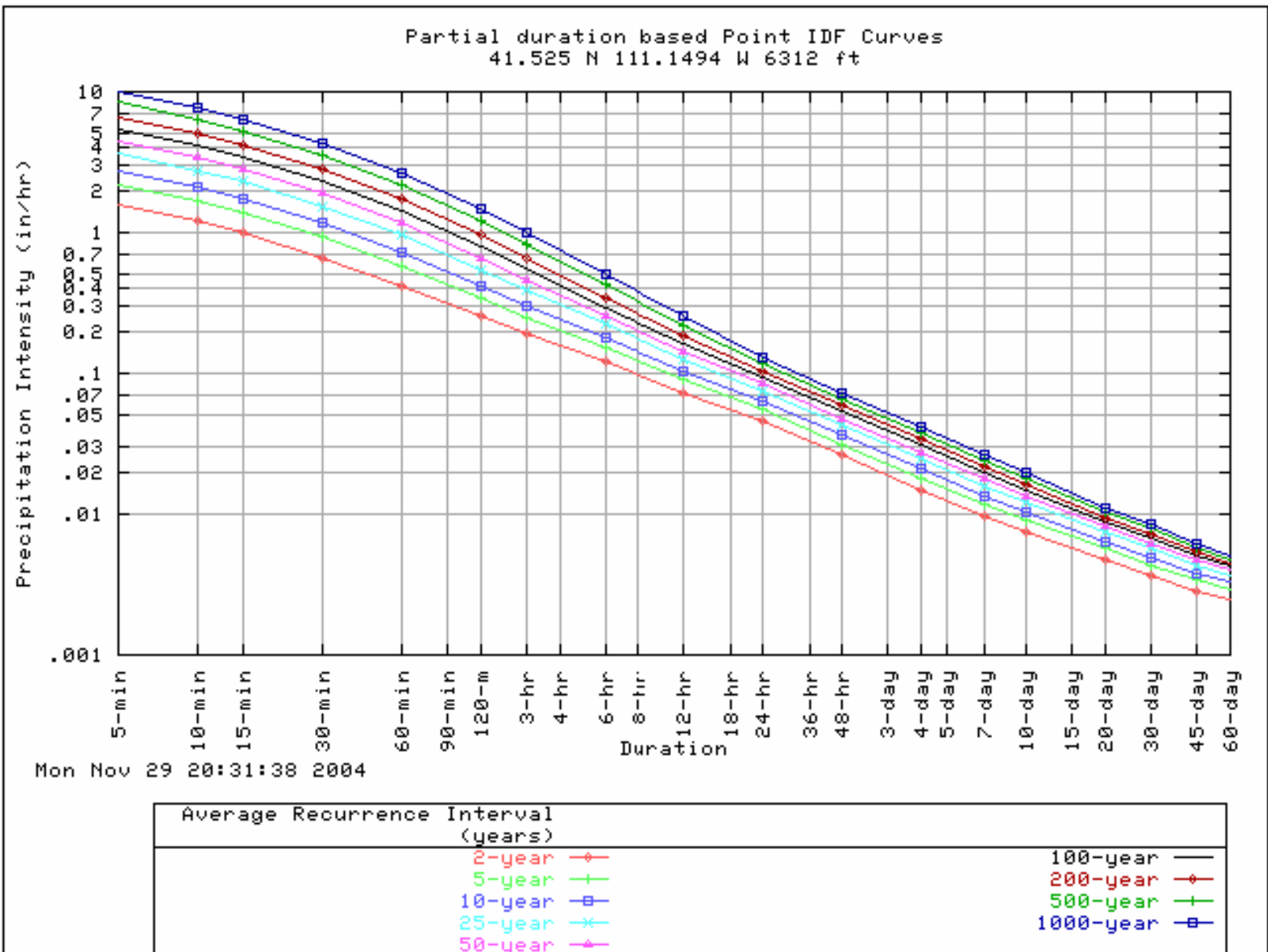
Duration	5	10	15	30	60	120	3	6	12	24	48	4	7	10	20	30	45	60
Return period	min	min	min	min	min	min	hr	hr	hr	hr	hr	day	day	day	day	day	day	day
2	1.96	1.49	1.23	0.83	0.51	0.3	0.23	0.15	0.09	0.05	0.03	0.02	0.01	0.01	0.01	0	0	0
5	2.72	2.07	1.71	1.15	0.71	0.41	0.3	0.19	0.11	0.06	0.04	0.02	0.01	0.01	0.01	0.01	0	0
10	3.42	2.6	2.15	1.45	0.9	0.5	0.36	0.22	0.13	0.07	0.04	0.02	0.02	0.01	0.01	0.01	0	0
25	4.43	3.37	2.78	1.87	1.16	0.63	0.44	0.26	0.15	0.09	0.05	0.03	0.02	0.01	0.01	0.01	0.01	0
50	5.3	4.03	3.33	2.24	1.39	0.75	0.52	0.3	0.17	0.1	0.06	0.03	0.02	0.01	0.01	0.01	0.01	0
100	6.26	4.76	3.94	2.65	1.64	0.89	0.62	0.33	0.19	0.11	0.06	0.03	0.02	0.02	0.01	0.01	0.01	0.01
200	7.36	5.6	4.63	3.12	1.93	1.03	0.71	0.37	0.21	0.12	0.07	0.04	0.02	0.02	0.01	0.01	0.01	0.01
500	8.94	6.8	5.62	3.79	2.34	1.23	0.86	0.45	0.23	0.13	0.08	0.04	0.03	0.02	0.01	0.01	0.01	0.01
1000	10.26	7.81	6.45	4.34	2.69	1.41	0.99	0.52	0.26	0.14	0.08	0.05	0.03	0.02	0.01	0.01	0.01	0.01

ESCALANTE, UTAH (42-2592) 37.7683°N 111.5978°W 5797 feet (Leeward)																		
Precipitation Intensity Estimates (in/hr)																		
Duration	5	10	15	30	60	120	3	6	12	24	48	4	7	10	20	30	45	60
Return period	min	min	min	min	min	min	hr	hr	hr	hr	hr	day	day	day	day	day	day	day
2	1.91	1.45	1.2	0.81	0.5	0.3	0.22	0.14	0.09	0.06	0.03	0.02	0.01	0.01	0.01	0	0	0
5	2.7	2.05	1.7	1.14	0.71	0.4	0.29	0.18	0.11	0.08	0.04	0.02	0.02	0.01	0.01	0.01	0	0
10	3.4	2.58	2.13	1.44	0.89	0.5	0.35	0.21	0.13	0.09	0.05	0.03	0.02	0.01	0.01	0.01	0.01	0
25	4.54	3.45	2.85	1.92	1.19	0.65	0.45	0.25	0.15	0.11	0.06	0.04	0.02	0.02	0.01	0.01	0.01	0.01
50	5.57	4.24	3.5	2.36	1.46	0.79	0.54	0.29	0.17	0.13	0.08	0.04	0.03	0.02	0.01	0.01	0.01	0.01
100	6.79	5.17	4.27	2.88	1.78	0.95	0.64	0.34	0.19	0.15	0.09	0.05	0.03	0.02	0.01	0.01	0.01	0.01
200	8.26	6.28	5.19	3.49	2.16	1.14	0.77	0.4	0.22	0.17	0.1	0.05	0.04	0.03	0.02	0.01	0.01	0.01
500	10.6	8.07	6.67	4.49	2.78	1.46	0.98	0.51	0.27	0.19	0.12	0.06	0.04	0.03	0.02	0.01	0.01	0.01
1000	12.77	9.71	8.03	5.41	3.35	1.75	1.17	0.6	0.31	0.22	0.13	0.07	0.05	0.04	0.02	0.02	0.01	0.01

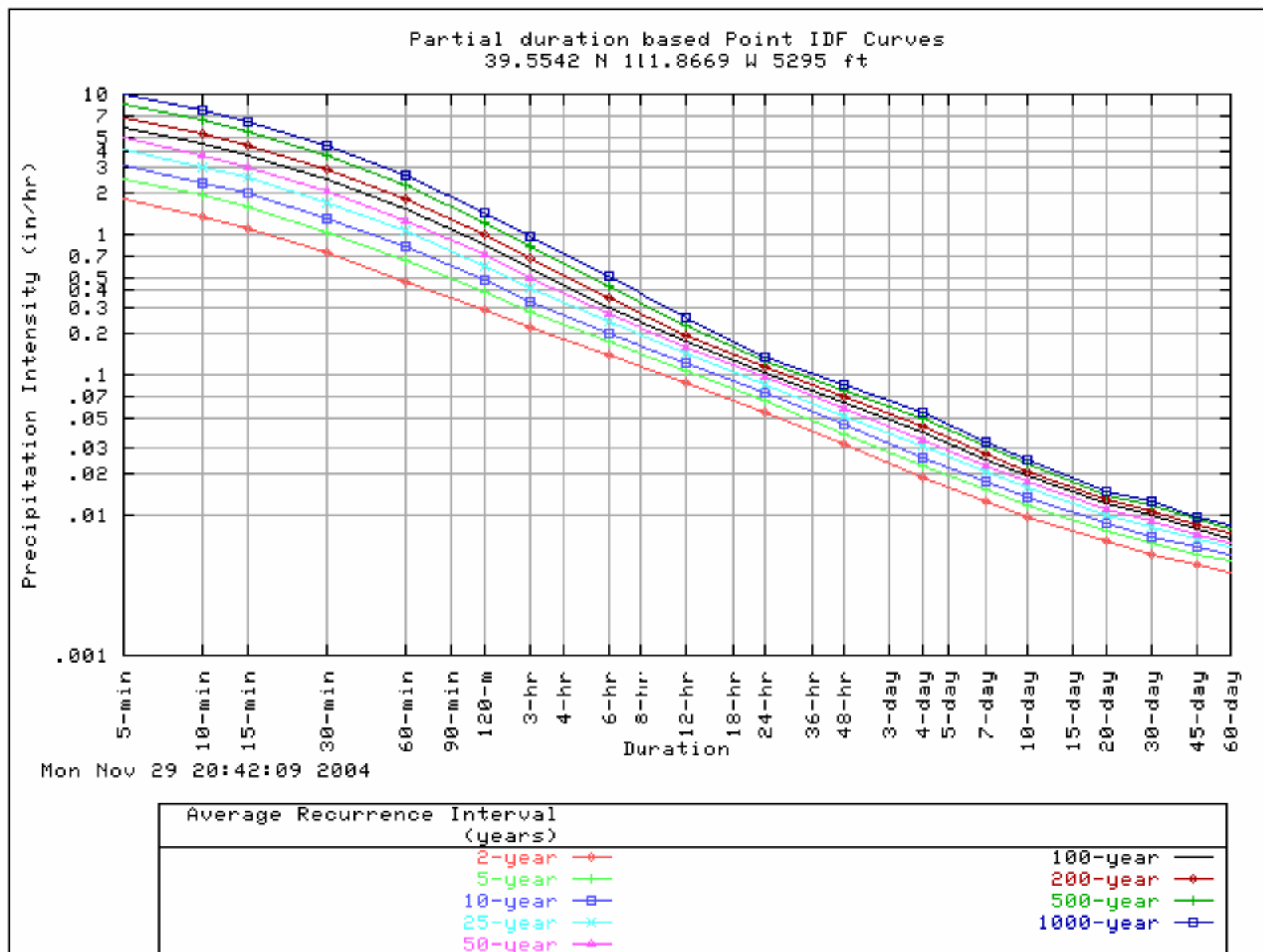
Upper bound of the 90% confidence interval, Precipitation Intensity Estimates (in/hr)																		
Duration	5	10	15	30	60	120	3	6	12	24	48	4	7	10	20	30	45	60
Return period	min	min	min	min	min	min	hr	hr	hr	hr	hr	day	day	day	day	day	day	day
2	2.27	1.72	1.42	0.96	0.59	0.34	0.26	0.16	0.1	0.06	0.04	0.02	0.01	0.01	0.01	0.01	0	0
5	3.17	2.41	2	1.34	0.83	0.46	0.33	0.2	0.12	0.08	0.05	0.03	0.02	0.01	0.01	0.01	0.01	0
10	4	3.04	2.52	1.69	1.05	0.57	0.4	0.23	0.14	0.1	0.06	0.03	0.02	0.02	0.01	0.01	0.01	0.01
25	5.35	4.07	3.37	2.27	1.4	0.74	0.51	0.28	0.17	0.12	0.07	0.04	0.03	0.02	0.01	0.01	0.01	0.01
50	6.6	5.02	4.15	2.8	1.73	0.91	0.62	0.33	0.19	0.14	0.08	0.04	0.03	0.02	0.01	0.01	0.01	0.01
100	8.11	6.17	5.1	3.44	2.13	1.1	0.75	0.39	0.22	0.16	0.09	0.05	0.03	0.03	0.02	0.01	0.01	0.01
200	9.97	7.58	6.27	4.22	2.61	1.35	0.91	0.47	0.26	0.18	0.11	0.06	0.04	0.03	0.02	0.01	0.01	0.01
500	13.02	9.91	8.19	5.52	3.41	1.76	1.18	0.61	0.32	0.21	0.13	0.07	0.05	0.04	0.02	0.02	0.01	0.01
1000	15.96	12.14	10.04	6.76	4.18	2.15	1.44	0.74	0.38	0.24	0.15	0.08	0.05	0.04	0.02	0.02	0.01	0.01
Lower bound of the 90% confidence interval, Precipitation Intensity Estimates (in/hr)																		
Duration	5	10	15	30	60	120	3	6	12	24	48	4	7	10	20	30	45	60
Return period	min	min	min	min	min	min	hr	hr	hr	hr	hr	day	day	day	day	day	day	day
2	1.64	1.25	1.03	0.69	0.43	0.26	0.2	0.13	0.08	0.05	0.03	0.02	0.01	0.01	0.01	0	0	0
5	2.3	1.75	1.45	0.97	0.6	0.35	0.26	0.16	0.1	0.07	0.04	0.02	0.01	0.01	0.01	0.01	0	0
10	2.86	2.18	1.8	1.21	0.75	0.42	0.31	0.19	0.11	0.08	0.05	0.03	0.02	0.01	0.01	0.01	0.01	0
25	3.72	2.83	2.34	1.58	0.98	0.54	0.39	0.23	0.14	0.1	0.06	0.03	0.02	0.02	0.01	0.01	0.01	0.01
50	4.48	3.41	2.82	1.9	1.17	0.65	0.46	0.26	0.15	0.12	0.07	0.04	0.02	0.02	0.01	0.01	0.01	0.01
100	5.3	4.04	3.34	2.25	1.39	0.76	0.53	0.3	0.17	0.13	0.08	0.04	0.03	0.02	0.01	0.01	0.01	0.01
200	6.26	4.76	3.94	2.65	1.64	0.89	0.62	0.34	0.19	0.14	0.09	0.05	0.03	0.02	0.01	0.01	0.01	0.01
500	7.68	5.84	4.83	3.25	2.01	1.08	0.76	0.42	0.23	0.16	0.1	0.05	0.04	0.03	0.02	0.01	0.01	0.01
1000	8.87	6.75	5.58	3.76	2.33	1.25	0.88	0.49	0.26	0.18	0.11	0.06	0.04	0.03	0.02	0.01	0.01	0.01



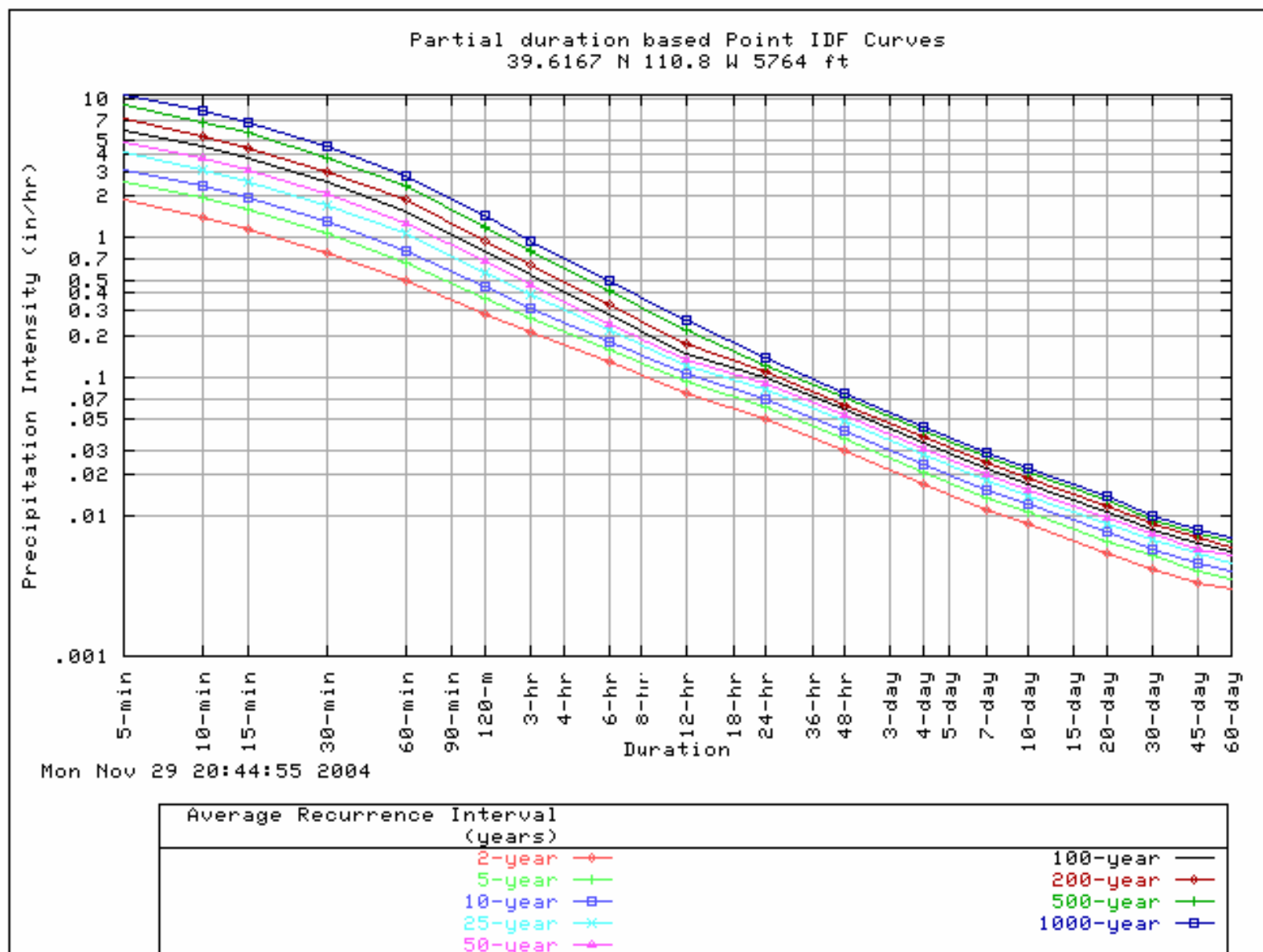
HUNTSVILLE MONASTERY, UTAH (42-4135) 41.24°N 111.7114°W 5118 feet



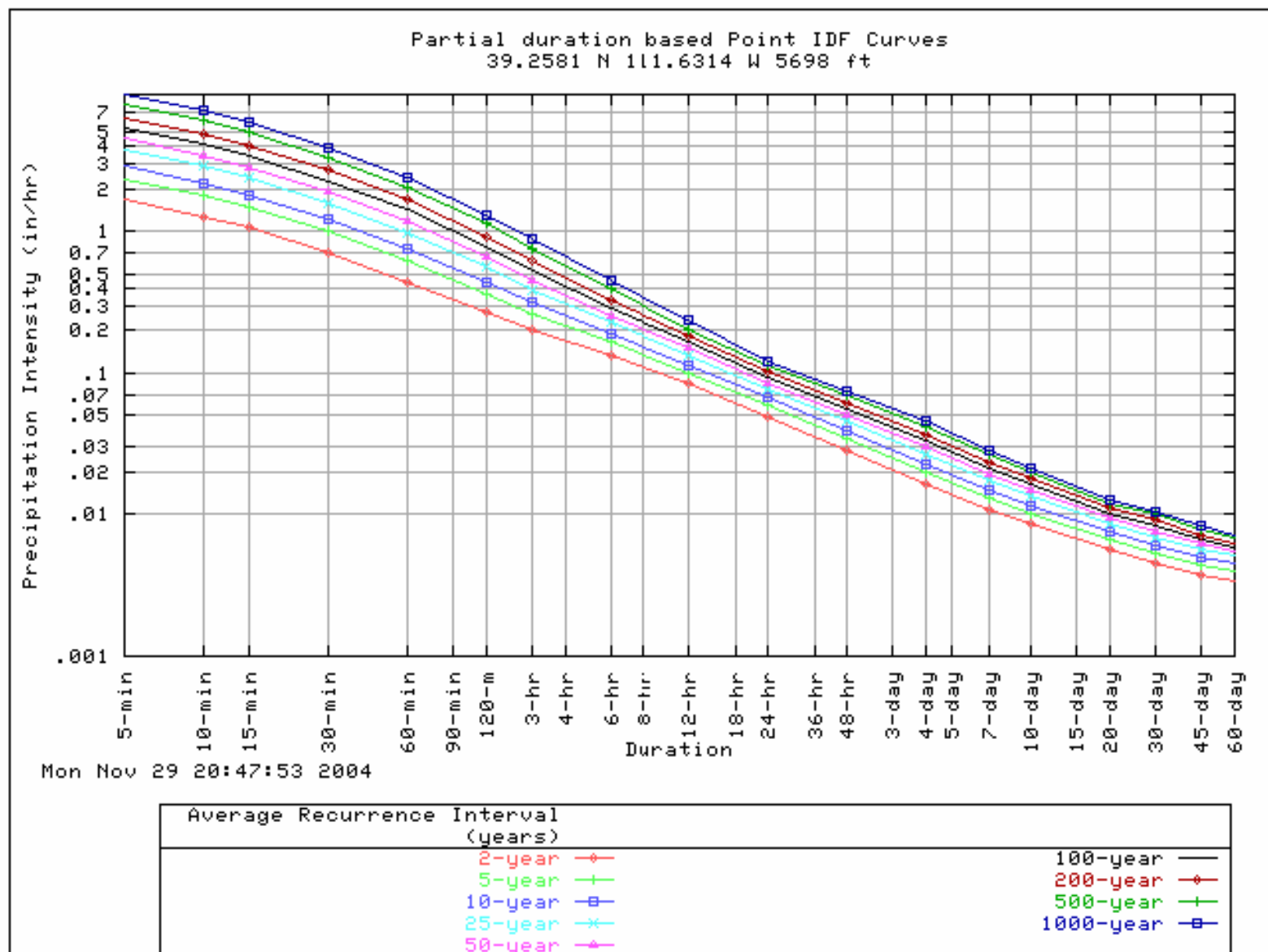
WOODRUFF, UTAH (42-9595) 41.525°N 111.1494°W 6312 feet



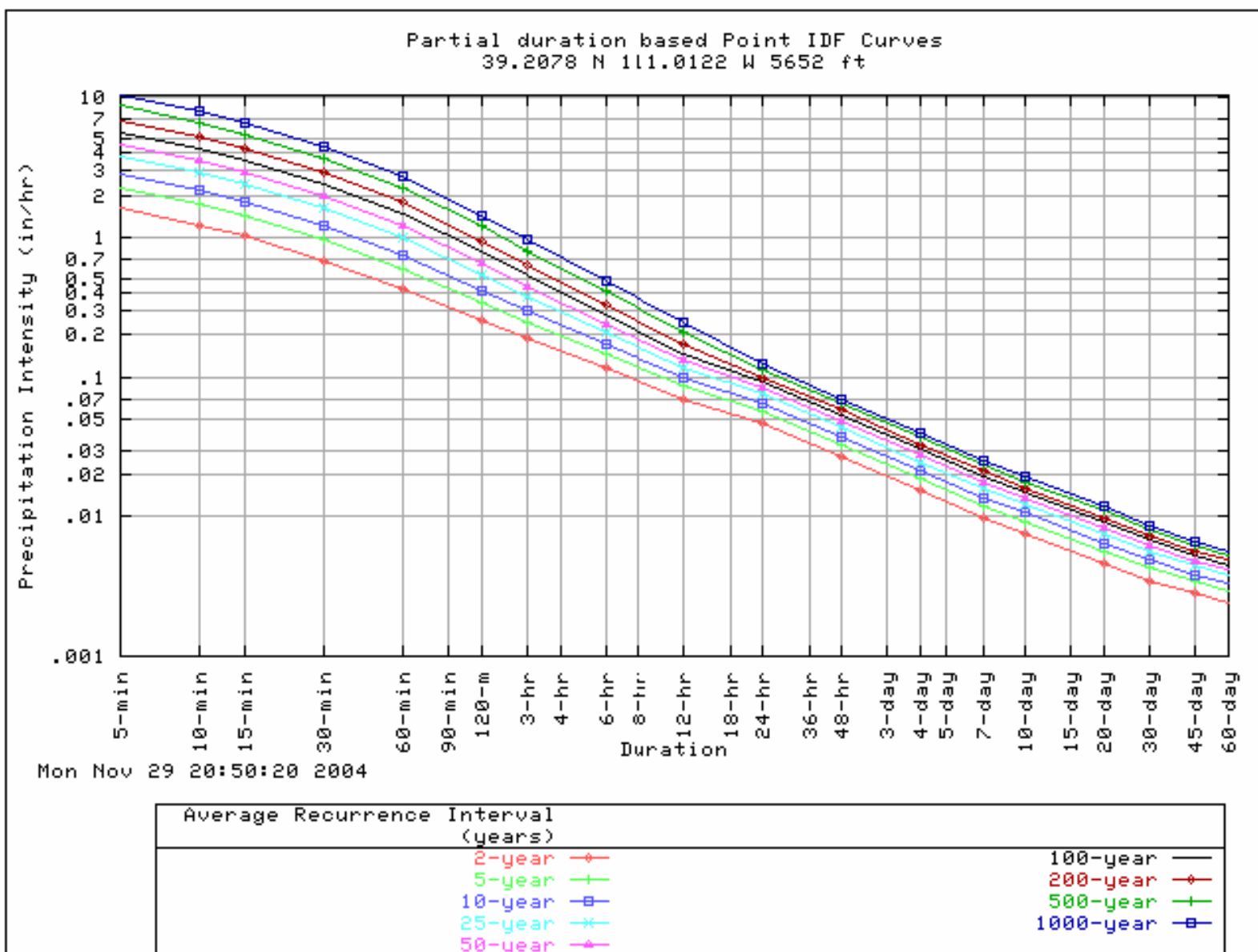
LEVAN, UTAH (42-5065) 39.5542°N 111.8669°W 5295 feet



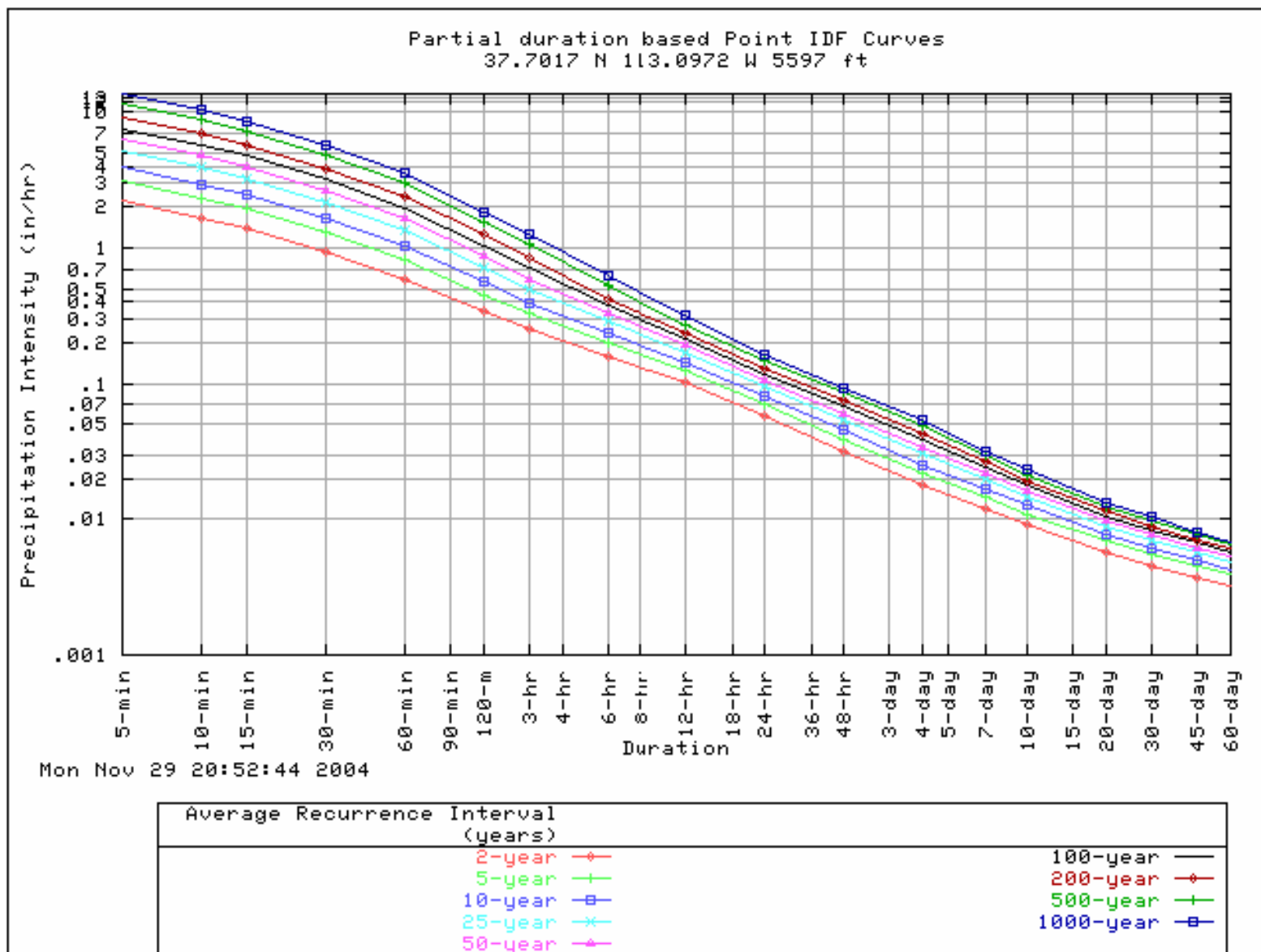
PRICE WAREHOUSES, UTAH (42-7026) 39.6167°N 110.8°W 5764 feet



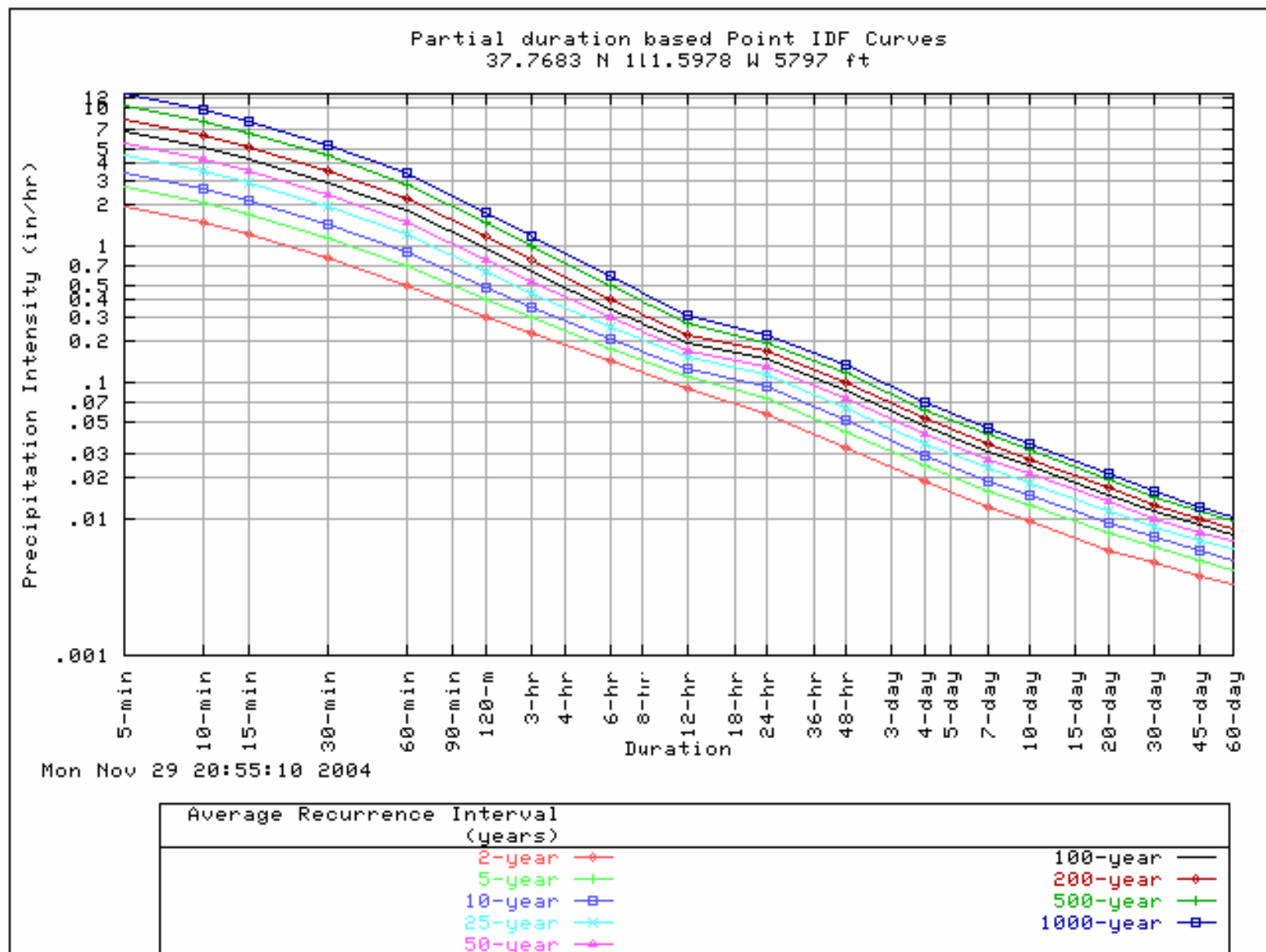
MANTI, UTAH (42-5402) 39.2581°N 111.6314°W 5698 feet



CASTLE DALE, UTAH (42-1214) 39.2078°N 111.0122°W 5652 feet



CEDAR CITY AP, UTAH (42-1267) 37.7017°N 113.0972°W 5597 feet



ESCALANTE, UTAH (42-2592) 37.7683°N 111.5978°W 5797 feet