Climate Projections and Analysis

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Executive Summary

Flood risk assessment generally requires design storm precipitation time series for use in hydrologic and hydraulic models. Precipitation intensity, duration, and frequency (IDF) statistics, referred to as IDF curves are commonly used as the basis for design and analysis of stormwater management facilities, stormwater and combined sewer systems, road drainage design, and flood mitigation. This technical memorandum describes the process of updating IDF curves for Montgomery County (County), projects those IDF curves to future climate conditions, examines historical events, and recommends scenarios for use in future modeling.

Baseline IDF curves were updated with data through 2022 using nine precipitation gages in and around Montgomery County. For future climate planning, near-term (2050) and long-term (2100) planning horizons were selected in a workshop setting with County staff. These time horizons were selected to reflect the likely service life of infrastructure assets, which typically range from 20 to 30 years for electrical and mechanical systems such as motors and pumps, and heating/cooling systems, to 50 to 100 years for structural systems, such as critical buildings, or below ground utilities such as concrete storm drains.

Fifteen baseline IDF and future climate scenarios, and 2 historical events were selected for modeling purposes. These will be combined with land use scenarios developed in Task W2.2 to reflect the combined impact of rainfall and impervious surfaces on current future flood risk. The 17 selected scenarios, and their associated precipitation totals, are listed in Table ES-1.

Table ES-1. Historical, Baseline, and Future Climate Scenarios Recommended for Modeling

Event	Return Period	24-hour Depth (inches)	Total Historical Event Depth (inches)
September 10, 2020 at Silver Spring gage	5-Year (at 2- and 3-hour durations)[a]	-	3.6
July 8, 2019 at Ten Mile Creek gage	500-Year (at 15-, 30-, and 60-minute durations)[a]	-	5.0
Updated Baseline IDF Curve	10-Year	5.4	-
Updated Baseline IDF Curve	25-Year	6.6	-
Updated Baseline IDF Curve	50-Year	7.5	-
Updated Baseline IDF Curve	100-Year	8.4	-
Updated Baseline IDF Curve	500-Year	10.6	-
2050, SSP5-8.5, 50th Percentile	10-Year	6.1	-
2050, SSP5-8.5, 50th Percentile	25-Year	7.5	-
2050, SSP5-8.5, 50th Percentile	50-Year	8.6	-
2050, SSP5-8.5, 50th Percentile	100-Year	9.7	-
2050, SSP5-8.5, 50th Percentile	500-Year	12.4	-
2100, SSP5-8.5, 50th Percentile	10-Year	7.3	-
2100, SSP5-8.5, 50th Percentile	25-Year	9.0	-
2100, SSP5-8.5, 50th Percentile	50-Year	10.4	-
2100, SSP5-8.5, 50th Percentile	100-Year	11.9	-
2100, SSP5-8.5, 50th Percentile	500-Year	15.4	-

[a] Largest return period observed during the event, based on evaluation of multiple durations.

1. Purpose

This technical memorandum (TM) summarizes work conducted under Task W2.1 of the Comprehensive Flood Management Plan Phase 2 (CFMP P2) Flood Risk Assessment and Alternatives Evaluation for Selected Watersheds, and Governance Implementation, Task Order 6 (Contract # 1127041). Task W2.1 includes development of climate scenarios for rainfall inputs to hydrologic and hydraulic (H&H) models, which will be used in subsequent tasks to assess flood risk and flood risk mitigation alternatives in selected watersheds. Task W2.1 includes:

- Develop current and future rainfall projections
- Analyze and select historical storms that can be used for H&H model validation
- Review and select design storms for selected planning horizons, including development of synthetic temporal rainfall distributions for each storm

The overall goal of Task W2.1 is to recommend climate scenarios to be used for H&H modeling. These will be combined with land use scenarios developed in Task W2.2, to reflect the combined impact of rainfall and impervious surfaces on current future flood risk.

2. Background and Introduction

Flood risk assessment generally requires design storm precipitation time series for use in H&H models. The purpose of this analysis is to develop current and future rainfall projections and design storms for use in H&H modeling. The design storms are based on updated baseline precipitation statistics, and projected to future climate conditions.

Precipitation intensity, duration, and frequency (IDF) statistics, referred to as IDF curves are commonly used as the basis for design and analysis of stormwater management facilities, stormwater and combined sewer systems, road drainage design, and flood mitigation. IDF curves are based on statistics associated with observed precipitation events. IDF curves were developed by the National Oceanic and Atmospheric Administration (NOAA) in Atlas 14 Volume 2 using observed precipitation through 2000 (Bonin et al. 2006). Since 2000, numerous large precipitation events have occurred in and around the Montgomery County (County). NOAA's IDF curves are updated here, to reflect more recent data up to 2022 and any effect those have on the County's IDF curves.

This TM describes the methods used to develop updated baseline IDF curves based on the latest observed precipitation in and around the County. These updated baseline IDF curves are used to characterize several historical storm events that occurred within the County. The updated baseline IDF curves are then projected to the years 2050 and 2100, using the latest climate projection science. Finally, design storm rainfall distributions are evaluated and scenarios are recommended for modeling.

Near-term and long-term planning horizons were selected in a workshop setting with County staff, using 2050 and 2100 as general reference points. These time horizons were generally selected to reflect the likely service life of infrastructure assets, which typically range from 20 to 30 years for electrical and mechanical systems such as motors and pumps, and heating/cooling systems, to 50 to 100 years for structural systems, such as critical buildings, or below ground utilities such as concrete storm drains. The 2050 and 2100 years are only used as general indicators used for scenario planning purposes.

3. Updated Baseline IDF Curves

This section describes the methodology and results of updated baseline IDF curves. Updated baseline IDF curves were created using NOAA Atlas 14 annual maxima (Bonnin et al. 2006), appended with recent precipitation data through 2022. The L-Moments statistical package (Hosking 1996) was used to develop 24-hour annual maxima series (AMS) depth statistics based on updated annual maxima. These 24-hour depth statistics were expanded to additional durations and converted from AMS to partial duration series

(PDS) using Atlas 14 ratios (Bonnin et al. 2006). Precipitation statistics based on PDS are typically used for planning and engineering because they are more conservative and appropriate for flood related work. See Attachment 1 for additional discussion of AMS and PDS IDF curves.

3.1 Climate Station Selection

Approximately 68 rainfall gages with daily data in and around the County were evaluated for use in the updated baseline IDF curve analysis. Of those, nine stations were selected for IDF analysis. Selection criteria included:

- Proximity to the County
- Precipitation record length
- Availability of recent data
- Overall data completeness
- Use in Atlas 14 analysis
- Precipitation variability

A map of evaluated and selected stations is presented on Figure 3-1. Information about the selected stations is presented in Table 3-1. Note that the Atlas 14 analysis resulting in NOAA IDF curves was based on precipitation records through 2000, which have been extended through year end of 2022 for this analysis. Atlas 14 values are available at seven of the nine stations selected for analysis (stations not included in Atlas 14 are Damascus 3 SSW, MD US and Sharpsburg 5 S, MD US).

Figure 3-1. Evaluated and Selected Daily Stations

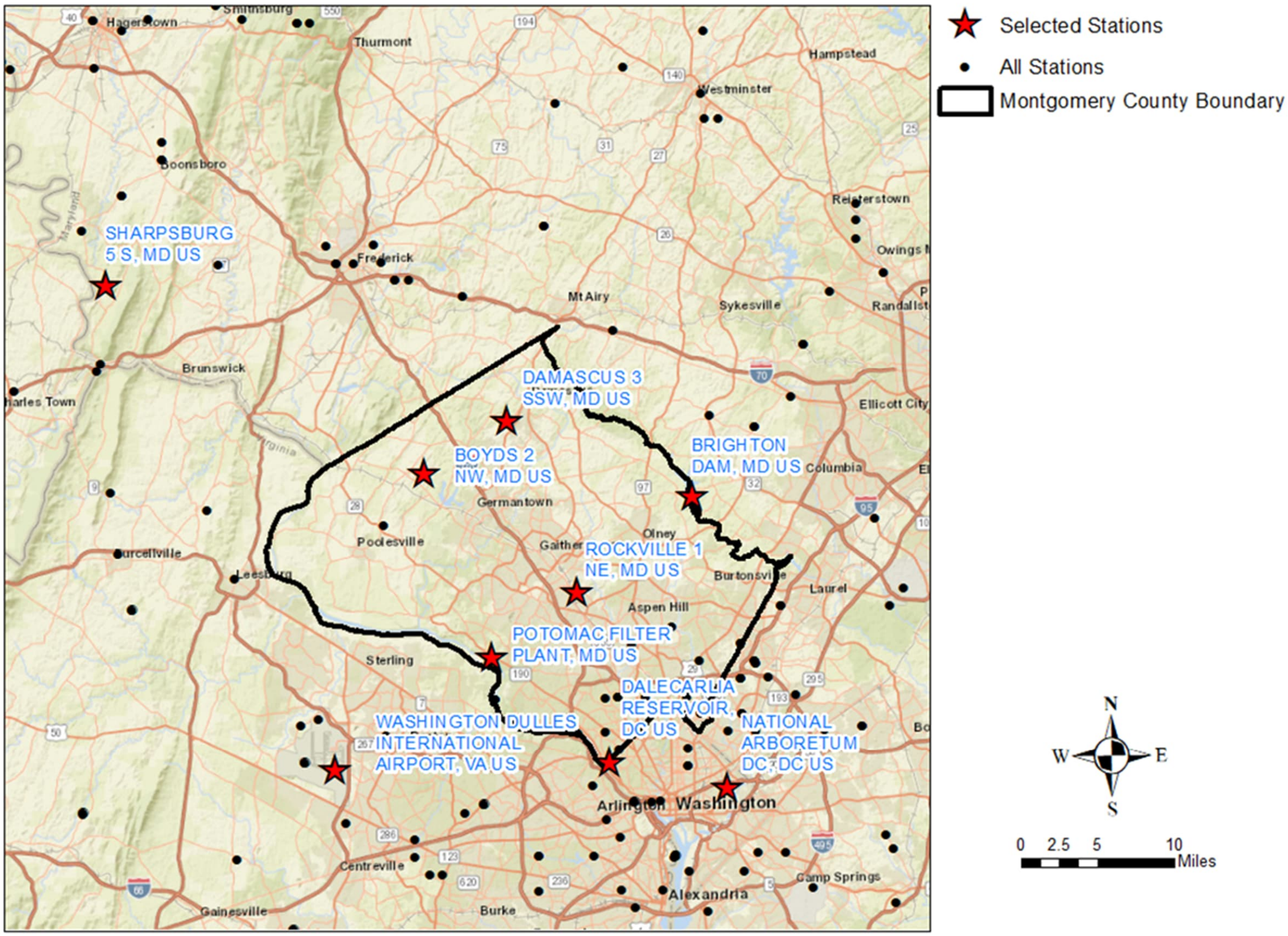


Table 3-1. Selected Daily Precipitation Stations

Station	Station ID	Latitude	Longitude	State	Name	Period of Record Start	Period of Record End	Valid Data Start[a]	Valid Data End	Total Years	Used in Atlas 14
1	GHCND:USC00181032	39.21667	-77.33333	Maryland	BOYDS 2 NW, MD US	11/30/1919	2/27/1991	1920	1990	71	Yes
2	GHCND:USC00181125	39.1911	-77.0069	Maryland	BRIGHTON DAM, MD US	7/31/1948	9/28/2017	1948	2016	69	Yes
3	GHCND:USC00182325	38.9385	-77.1134	Maryland	DALECARLIA RESERVOIR, DC US	7/31/1948	4/29/2023	1945	2022	78	Yes
4	GHCND:USC00182336	39.26495	-77.23196	Maryland	DAMASCUS 3 SSW, MD US	8/31/1973	6/13/2023	1939	2022	84	No
5	GHCND:USC00186350	38.91329	-76.97009	District of Columbia	NATIONAL ARBORETUM DC, DC US	7/31/1948	5/19/2023	1948	2022	75	Yes
6	GHCND:USC00187272	39.04	-77.2541	Maryland	POTOMAC FILTER PLANT, MD US	3/31/1962	2/24/2011	1962	2010	49	Yes
7	GHCND:USC00187705	39.10083	-77.14861	Maryland	ROCKVILLE 1 NE, MD US	12/16/1907	7/30/2007	1908	2006	99	Yes
8	GHCND:USC00188207	39.3983	-77.7212	Maryland	SHARPSBURG 5 S, MD US	5/31/1998	4/29/2022	1999	2021	23	No
9	GHCND:USW00093738	38.93485	-77.44728	Virginia	WASHINGTON DULLES INTERNATIONAL AIRPORT, VA US	3/31/1960	6/13/2023	1954	2022	69	Yes

[a] Note that the valid data start date may be earlier than the station period of record start date due to additional data being available from Atlas 14.

3.2 Data Sources

The following data were obtained from NOAA Atlas 14 Volume 2 (Bonnin et al. 2006), via the NOAA Precipitation Frequency Data Server (https://hdsc.nws.noaa.gov/hdsc/pfds/):

- Station/location-based Atlas 14 IDF curve values for nine selected stations, using both AMS and PDS methodology.
- Geographic Information System (GIS) Grids: IDF patterns for the 10-year, 24-hour and 100-year, 24-hour depths, as PDS. These are interpolated grids of IDF values for all locations not represented by a specific station.
- Annual maxima time series for the seven stations also used to develop Atlas 14 Volume 2.

Daily historical precipitation time series, updated through 2022, were obtained for the nine selected stations from the Global Historical Climate Network (GHCN), using NOAA National Centers for Environmental Information Climate Data Online (https://www.ncei.noaa.gov/maps/daily/).

3.3 Updated Annual Maxima Series

Updated 24-hour IDF curves were developed for the selected stations using the period of record in Table 3-1. For the seven stations also used in Atlas 14, the original Atlas 14 Volume 2 maxima through the year 2000 were used, and the time series were appended through 2022, with more recent annual maxima from GHCN. Annual maxima for the two stations not used in Atlas 14 were compiled using only data from GHCN.

3.4 L-Moments

Updated baseline IDF curves were developed using the L-Moments method. Hosking and Wallis (1997) developed L-Moments (describes the shape of a probability distribution) that are linear combinations of order statistics. NOAA applies the L-Moments method to develop estimates of rainfall frequency in Atlas 14 (Bonnin et al. 2006). The methods are described in Attachment 2.

The primary advantage of L-Moments statistical analysis over conventional moments is that they suffer less from the effects of sampling variability. They also are more robust to outliers and virtually unbiased for small samples. The L-Moments software developed by Hosking provides parameter estimates for seven distributions, provides station discordancy tests, network homogeneity tests, and confidence intervals.

Daily precipitation data were analyzed to obtain annual daily maximum values. The daily data used in this project came from stations where observations were taken once every day at a fixed time (constrained observations). Because of the fixed beginning and ending of observation times (for example, 7 am) at daily stations, it is likely that the constrained daily amounts are lower than the unconstrained 24-hour amounts that actually contribute to runoff. To account for the likely failure of capturing the true-interval maxima, a correction factor of 1.13, consistent with the approach taken in NOAA Atlas 14, was applied to the annual daily maximum precipitation used in this project.

Regional frequency analysis involves augmenting at-site data with data from other sites with similar probability distributions. The procedure for regional frequency analysis involves the following: (1) data screening, (2) partitioning of data into homogeneous subregions, and (3) fitting probability distributions to data within each subregion. These tasks involve subjective and objective decisions regarding outliers, heterogeneity, and goodness-of-fit. The L-Moments software package (Hosking 1996) provides convenient routines for screening, clustering, and frequency analysis of regional data sets based on the L-Moment method.

3.5 Updated Baseline 24-hour Depth at All Stations

Updated IDF baseline curves were developed using the L-Moments method and updated AMS from a region of the nine selected stations (Figure 3-1 and Table 3-1). These stations passed the homogeneity tests described in Attachment 3. Homogeneity tests ensure that an individual station's data are unbiased when compared to other stations in the region of study. The Generalized Extreme Value (GEV) distribution was selected as a suitable distribution, based on its use in Atlas 14 for the stations in Volume 2 Region 8. Region 8 comprises 57 stations across eastern Maryland, southeastern Pennsylvania, and northeastern Virginia. The seven Atlas 14 stations used in this analysis are all in Atlas 14 Volume 2 Region 8.

Updated 24-hour depths were compared to Atlas 14 values for the 10-year and 100-year, 24-hour storms. This updated baseline IDF curve analysis uses a 9-station region for L-Moments analysis, and Atlas 14 uses a much larger 57-station region (Region 8). It is important to note that part of the difference between the updated baseline IDF values and the Atlas 14 values is caused by the difference in region size (number of stations) and thus different regional growth factors. Part of the difference is because of extending the period of record from year 2000 to year 2022. To isolate the impact of region size from increased record length, 24-hour depths were developed using L-Moments for the 9-station region and the Atlas 14 annual maxima record through year 2000. This is shown numerically in Table 3-2 and graphically on Figure 3-2. In general, the change from the 57-station region (Atlas 14) to the 9-station region (L-Moments up to year 2000), increased storm depths for the 10-year event and decreased storm depths for the 100-year event. Adding the additional 22 years of data to the 9-station region has varying effects on the precipitation depth, depending on the station. The changes from the Atlas 14 baseline and the L-Moments analysis with data up to the year 2022 are shown on Figure 3-3. Changes in depth for the 10-year event range from 0.34 inches less, to 0.85 inches greater than baseline. For the 100-year event, the change in depth ranges from 1.41 inches less, to 0.49 inches greater than baseline.

Table 3-2. Comparison of 24-Hour Precipitation Depths in AMS (inches)

Station Name	10-Year			100-Year		
	NOAA Atlas 14[a]	L-Moments up to Year 2000[b]	L-Moments up to year 2022 (Updated Baseline)[b]	NOAA Atlas 14[a]	L-Moments up to Year 2000[b]	L-Moments up to Year 2022 (Updated Baseline)[b]
BOYDS 2 NW, MD US	4.63	4.7	4.64	8.02	7.33	7.2
BRIGHTON DAM, MD US	4.86	4.95	4.94	8.45	7.72	7.66
DALECARLIA RESERVOIR, DC US	4.83	5.1	5.39	8.39	7.96	8.36
DAMASCUS 3 SSW, MD US	4.7	4.62	5.2	8.15	7.21	8.06
NATIONAL ARBORETUM DC, DC US	4.79	5.21	5.27	8.32	8.13	8.18
POTOMAC FILTER PLANT, MD US	4.65	4.64	4.73	8.07	7.25	7.34
ROCKVILLE 1 NE, MD US	4.76	4.42	4.42	8.27	6.9	6.86
SHARPSBURG 5 S, MD US	4.13	NA	4.69	6.56	NA[c]	7.28
WASHINGTON DULLES INTERNATIONAL AIRPORT, VA US	4.59	5.51	5.44	7.95	8.6	8.44

[a] NOAA Atlas 14 values based on a 57 station region

[b] L-Moments values based on a 9-station region around Montgomery County

[c] NA= data not available to analyze pre year 2000

Figure 3-2. Atlas 14 Versus L-Moments until Year 2000 Versus L-Moments until Year 2022 (AMS)

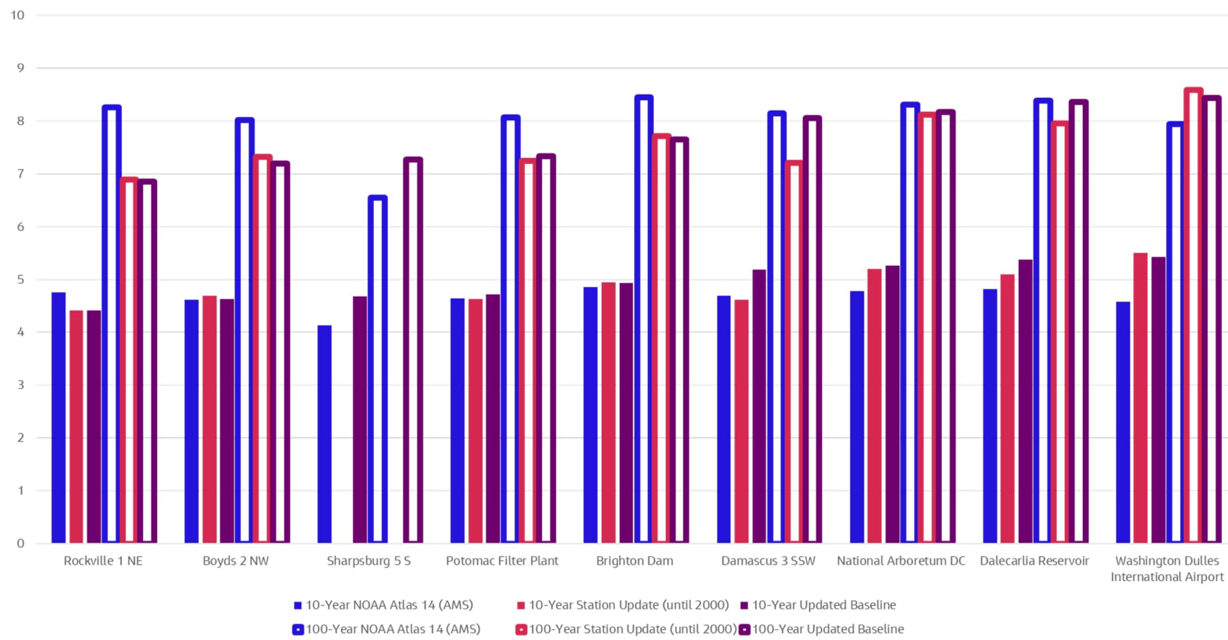
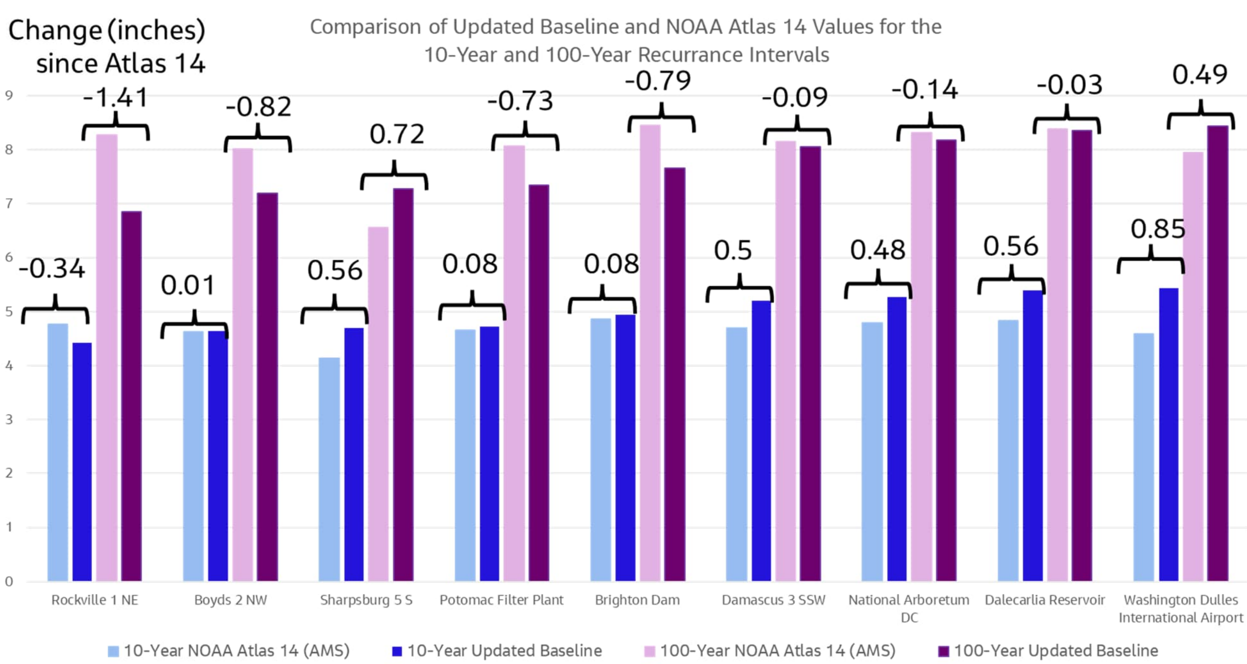


Figure 3-3. Atlas 14 Versus Updated Baseline IDF Values (AMS)

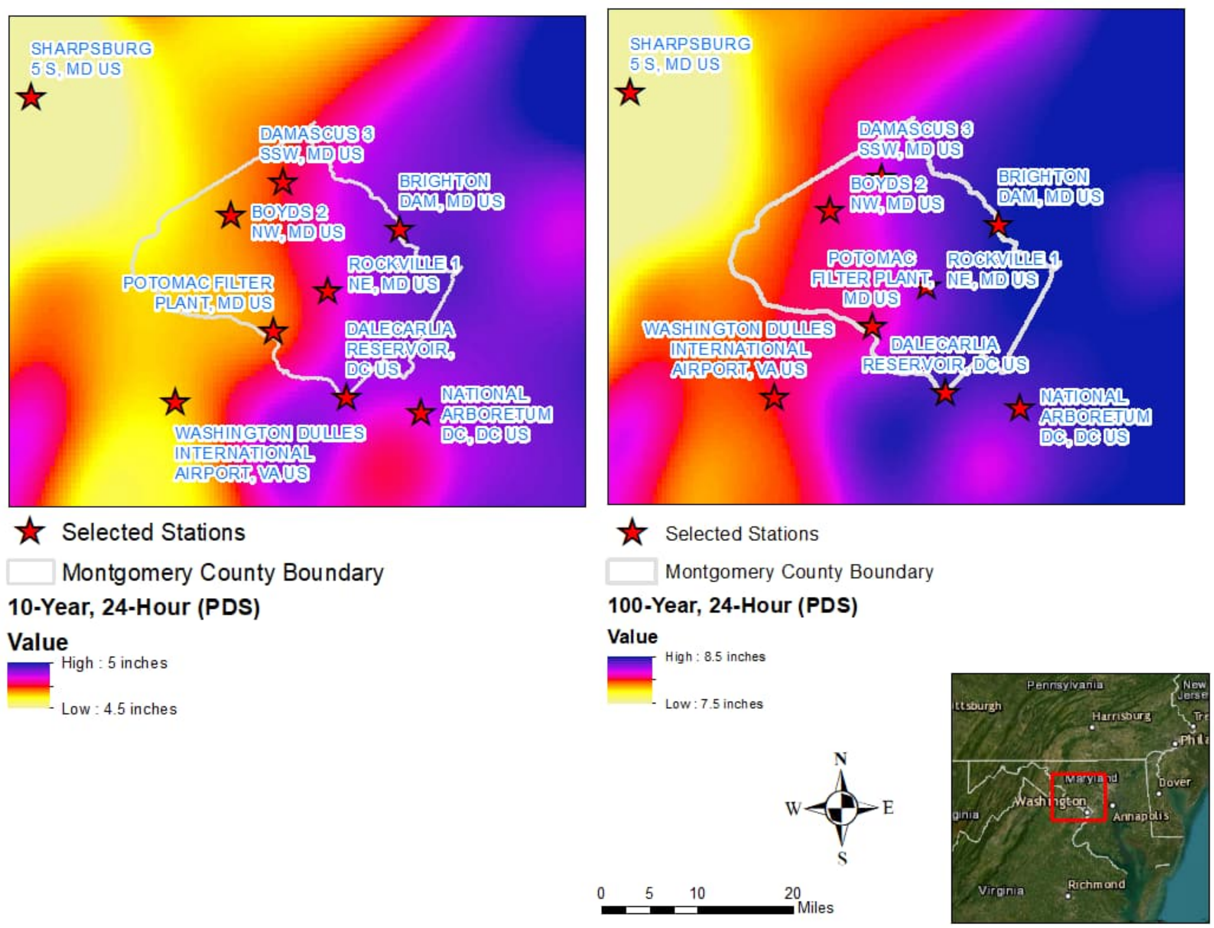


3.6 Representative Station Selection

Precipitation statistics from the Dalecarlia Reservoir were selected as a representative station for the County based on the proximity of the station to County limits and variability in spatially interpolated gridded IDF values from Atlas 14, as shown on Figure 3-4. There is relatively low variation across the County, which supports the use of one selected station for use in creating updated baseline and future IDF curves. Across the County, the Atlas 14 10-year, 24-hour rainfall depth ranges from approximately 4.6 to 5.0 inches. The 100-year event ranges from approximately 7.8 to 8.6 inches. This is a 7 percent and 9 percent difference across the County for the 10-year and 100-year events, respectively.

The south/southeastern side of the County contains the higher IDF values, as well as the more developed portions of the County. Since the Dalecarlia Reservoir gage is also located in this area, it was selected as the representative station.

Figure 3-4. Precipitation Variation over the County from Atlas 14



3.7 Updated Baseline IDF Curves at Selected Station

Only the 24-hour duration depth-frequency statistics were updated using the L-Moments method and annual maxima data through 2022. Additional durations were scaled from the 24-hour values using factors from Atlas 14, shown in Table 3-3. The ratios outlined in Attachment 1 were used to convert AMS depth values to PDS depth values. The resulting updated baseline IDF curves at the selected station

(Dalecarlia Reservoir) for all durations are presented both as a table with discrete values in Table 3-4 and as a graph showing the relative difference between depths are varying durations on Figure 3-5.

The updated baseline 10-, 25-, 50-, 100-, and 500-year, 24-hour events are recommended for modeling purposes.

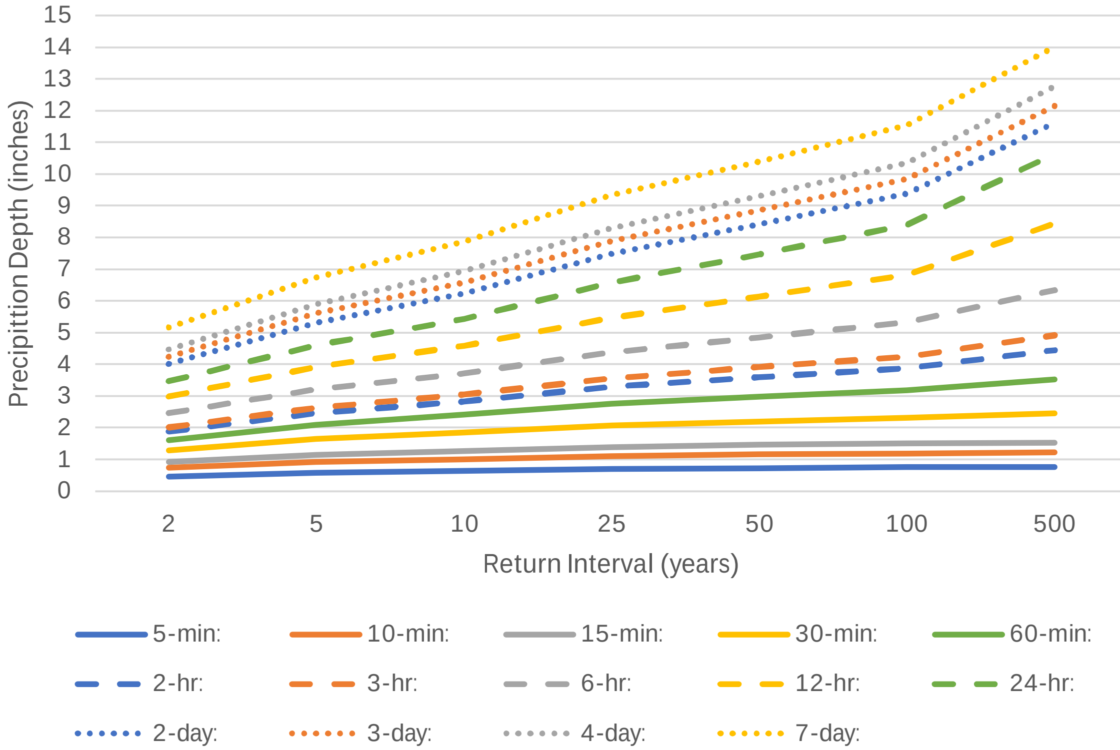
Table 3-3. Depth Ratios to 24-Hour Duration (unitless, from selected station – Dalecarlia Reservoir)

Duration	2-Year	5-Year	10-Year	25-Year	50-Year	100-Year	500-Year
5-min	0.29	0.27	0.26	0.25	0.24	0.24	0.22
10-min	0.46	0.43	0.42	0.40	0.39	0.37	0.35
15-min	0.58	0.55	0.53	0.51	0.49	0.47	0.44
30-min	0.80	0.78	0.77	0.75	0.74	0.73	0.70
60-min	1.00	1.00	1.00	1.00	1.00	1.00	1.00
2-hr	1.17	1.18	1.18	1.20	1.21	1.23	1.26
3-hr	1.25	1.26	1.27	1.29	1.32	1.34	1.39
6-hr	0.71	0.70	0.68	0.67	0.65	0.63	0.60
12-hr	0.86	0.85	0.84	0.83	0.82	0.81	0.79
24-hr	1.00	1.00	1.00	1.00	1.00	1.00	1.00
2-day	1.16	1.16	1.15	1.14	1.13	1.12	1.09
3-day	1.22	1.22	1.21	1.20	1.19	1.17	1.14
4-day	1.29	1.28	1.27	1.26	1.25	1.23	1.20
7-day	1.49	1.47	1.45	1.42	1.39	1.38	1.32

Table 3-4. Updated Baseline IDF Curves for Montgomery County (Depth in inches, in PDS Converted from AMS, from selected station – Dalecarlia Reservoir)

Duration	2-Year	5-Year	10-Year	25-Year	50-Year	100-Year	500-Year
5-min	0.46	0.57	0.63	0.69	0.72	0.75	0.78
10-min	0.74	0.91	1.01	1.10	1.15	1.19	1.22
15-min	0.93	1.15	1.27	1.39	1.45	1.50	1.54
30-min	1.29	1.65	1.85	2.07	2.19	2.30	2.46
60-min	1.62	2.10	2.41	2.75	2.97	3.17	3.53
2-hr	1.89	2.47	2.85	3.30	3.61	3.89	4.45
3-hr	2.02	2.64	3.06	3.56	3.92	4.24	4.93
6-hr	2.47	3.23	3.73	4.39	4.86	5.33	6.34
12-hr	2.99	3.92	4.59	5.47	6.15	6.84	8.45
24-hr	3.47	4.60	5.45	6.58	7.48	8.40	10.65
2-day	4.02	5.32	6.25	7.50	8.43	9.39	11.62
3-day	4.25	5.62	6.60	7.90	8.87	9.86	12.16
4-day	4.48	5.91	6.94	8.30	9.32	10.36	12.78
7-day	5.17	6.74	7.88	9.34	10.39	11.56	14.02

Figure 3-5. Updated Baseline IDF Curves for Montgomery County



Notes:
-PDS, converted from AMS
-Based on analysis of 24-hour precipitation data; other durations converted using ratios from NOAA Atlas 14.

4. Projected Future IDF Curves

4.1 Projected Future Climate Background

There are multiple accepted sources of climate change projections. Both the Mid-Atlantic Regional Integrated Sciences and Assessments (MARISA) and SimCLIM, two robust sources for future climate change projections, were discussed in a workshop setting with County staff. MARISA is a free public web tool that provides climate change projections at the County level[1]. The MARISA program provides a variety of tools for climate analysis and projections. A full comparison of MARISA and SimCLIM extreme precipitation projection methods is provided in Table 4-1.

[1] https://www.midatlanticrisa.org/

Table 4-1. Comparison of MARISA and SimCLIM

Attribute	MARISA	SimCLIM
Availability	Public web tool	Proprietary software
Climate Science	AR5	AR5 and AR6
Return Periods	2-year through 100-year	2-year through 1000-year
Percentiles	10, 25, 50, 75, or 90th	All
Planning Horizons	2020-2070 [2045] and 2050-2100 [2075] only	Any between present and 2100
GHG Scenarios	RCP 4.5 and RCP 8.5 only	SSP1-1.9 ,SSP1-2.6, SSP2-4.5, SSP3-7.0, and SSP5-8.5
Downscaling method	Two downscaling methods used: dynamic and statistical	Ensemble of GCMs is pattern downscaled
Data Resolution	County Level	0.25-degree grid (13 miles)
Baseline	1950-1999	2005
Robust and acceptable science	Yes	Yes

While both MARISA and SimCLIM provide reasonable climate projections for the region, MARISA has several limitations which SimCLIM does not, including:

- Only provides climate change percentages for the future years 2045 and 2075, with each representing mid-point of a 50 year climate period (2020-2070 and 2050-2100, respectively).
- Uses climate science that is outdated after new climate science and models were released in 2021 (AR5 versus AR6).
- Contains a limited number of climate model scenarios to choose from (only RCP4.5 and 8.5, not the newer greenhouse gas scenarios in AR6).

Based on the above limitations of MARISA, it was selected by the County to use SimCLIM.

SimCLIM is a computer software system for examining the effects of climate variability and change over time and space, developed by CLIMsystems (CLIMsystems 2018a, 2018b)[2]. SimCLIM integrates historical observations with complex arrays of data and general circulation model (GCM) results to assess the impacts of climatic variability, change, and extreme climatic events on natural and constructed systems as user-selectable target years.

The SimCLIM system allows the generation of site-specific, climate-change-perturbed, historical time series that can be used as input to hydrologic, ecosystem, and any number of climate-driven natural resource models. The system supports analysis of historical and projected changes in extreme values such as precipitation intensity, duration and frequency, and using the GEV distribution.

SimCLIM uses Intergovernmental Panel on Climate Change (IPCC)-sanctioned Sixth Assessment Report (AR6) (IPCC, 2021) and Coupled Model Intercomparison Project Phase 6 (CMIP6) GCMs. SimCLIM uses a pattern downscaling approach to increase the spatial resolution of the GCM projections.

SimCLIM uses the IPCC-sanctioned shared socioeconomic pathway (SSP) greenhouse gas (GHG) scenarios as input to GCM model results, allowing a full exploration of boundaries of projected changes in extreme precipitation. To facilitate GCM boundaries, SimCLIM supports “ensemble” analysis, which means that a group of user-defined GCMs can be run and exceedance probabilities determined to assess risk. Because there is a range of results from the ensemble analysis, values are expressed in terms of nonexceedance

[2] https://www.climsystems.com/simclim/

percentiles. For example, for a given SSP there are 24 GCMs available, so these can be summarized based on median and upper bound as the 50 percent nonexceedance and 90 percent nonexceedance. To illustrate, SSP5-8.5 50th Percentile and SSP5-8.5 90th Percentile refer to the median (50 percent nonexceedance) and an upper bound based on not exceeding 90 percent of a 24-member ensemble of GCM model results for the SSP5-8.5 emissions scenario.

The climate modeling reflected in AR6 is based on five SSP scenarios that describe five alternative trajectories for future GHG emissions, listed in Table 4-2. Two of these scenarios, that is SSP1-1.9 and SSP1 2.6, anticipate rapid decarbonization, leading to net removal of GHGs from the atmosphere during the second half of this century. These contrast with scenarios SSP3-7.0 and SSP5-8.5, which anticipate continued growth in emissions until at least the latter part of this century. An intermediate GHG scenario, SSP2-4.5, assumes carbon dioxide emissions will continue at approximately present levels until 2050, then decrease but do not reach net zero by 2100.

Table 4-2. Shared Socioeconomic Pathway Overview

SSP	Description
SSP5-8.5	Fossil Fuel Driven
SSP3-7.0	Regional Rivalry
SSP2-4.5	Middle of the Road
SSP1-2.6	Sustainable development
SSP1-1.9	Ambitious sustainability

4.2 Montgomery County Future Climate Selections

The future climate analysis was completed for the following parameters:

- Planning Time Horizons: 2050 and 2100
- GHG scenarios: SSP2-4.5 and SSP5-8.5
- General Circulation Model (GCM) Summaries: 50 percent nonexceedance and 90 percent nonexceedance

These parameters were selected after review and discussion in a workshop setting with County staff. The near-term (2050) and long-term (2100) planning horizons were selected based on the likely service life of infrastructure assets, which typically range from 20 to 30 years for electrical and mechanical systems such as motors and pumps, and heating/cooling systems, to 50 to 100 years for structural systems, such as critical buildings, or below ground utilities such as concrete storm drains. The 2050 and 2100 years are only used as general indicators used for scenario planning purposes.

The general circulation models used in this analysis, as well as the extreme value analysis methodology are outlined in Attachment 4 and Attachment 5.

4.3 Projected Future Climate IDF Curves

The Updated Baseline IDF curves were used as the starting point for projected future IDF curves. Future IDF percent change factors from SimCLIM were applied to the updated baseline IDF curves developed using L-Moments and presented in Table 4-3. The percent change in event depth for SSP2-4.5 50th Percentile, SSP2-4.5 90th Percentile, SSP5-8.5 50th Percentile, and SSP5-8.5 90th Percentile for both 2050 and 2100 are presented on Figure 4-1.

The percent increase for each future climate scenario was then applied to the updated baseline IDF curve. Full IDF curve information for varying return periods and event lengths is presented numerically in Table 4-3 and Table 4-4 for SSP5-8.5 50th percentile for the years 2050 and 2100, respectively. For tables of percent change and 24-hour event depths at varying return periods for all eight future climate scenarios see Attachment 6.

The future climate scenarios recommended for modeling are the 10-, 25-, 50-, 100-, and 500-year return periods for the year 2050 SSP5-8.5 50th percentile and the year 2100 SSP5-8.5 50th percentile (total of 10 scenarios).

Figure 4-1. Projected Percent Change in 100-Year, 24-Hour Depth

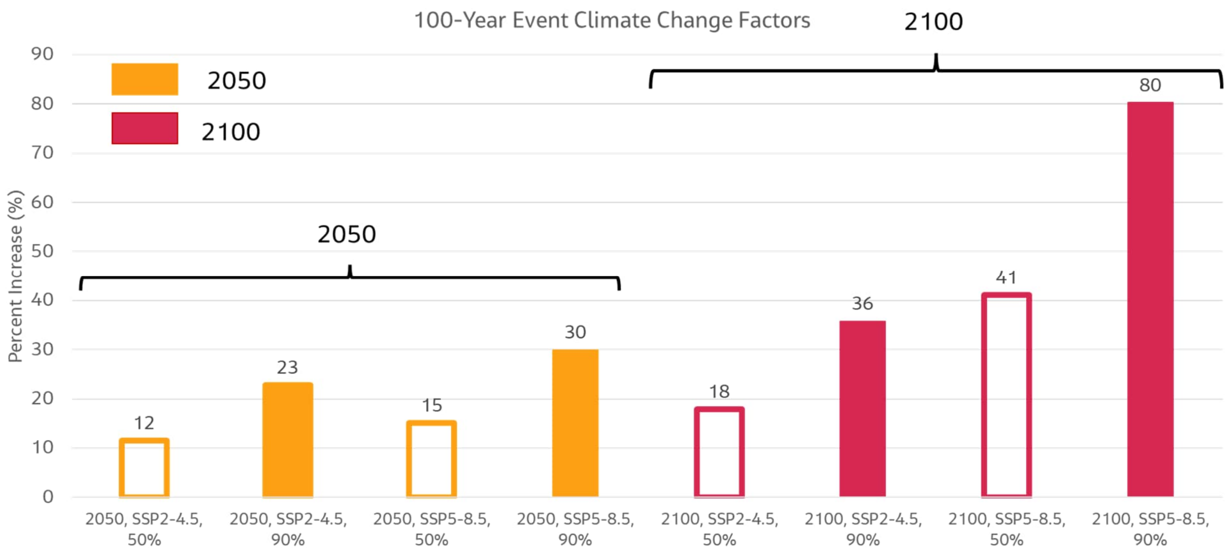


Table 4-3. Future Climate SSP5-8.5 2050, 50th Percentile Event Depths at Varying Durations (depth in inches)

SSP5-8.5 2050, 50th Percentile	2-Year	5-Year	10-Year	25-Year	50-Year	100-Year	500-Year
5-min	0.50	0.63	0.71	0.78	0.83	0.86	0.90
10-min	0.80	1.01	1.13	1.25	1.32	1.36	1.42
15-min	1.01	1.28	1.43	1.58	1.66	1.73	1.79
30-min	1.39	1.83	2.08	2.35	2.51	2.65	2.86
60-min	1.75	2.33	2.71	3.12	3.40	3.65	4.11
2-hr	2.04	2.74	3.20	3.74	4.13	4.47	5.18
3-hr	2.18	2.93	3.44	4.04	4.48	4.88	5.73
6-hr	2.67	3.58	4.19	4.98	5.56	6.13	7.38
12-hr	3.23	4.36	5.15	6.20	7.04	7.86	9.82
24-hr	3.75	5.11	6.12	7.46	8.56	9.66	12.38
2-day	4.34	5.91	7.02	8.50	9.64	10.80	13.51
3-day	4.59	6.23	7.41	8.95	10.15	11.35	14.13
4-day	4.84	6.56	7.80	9.41	10.66	11.92	14.85
7-day	5.58	7.49	8.85	10.59	11.89	13.30	16.30

Table 4-4. Future Climate SSP5-8.5 2100, 50th Percentile Event Depths at Varying Durations (depth in inches)

SSP5-8.5 2100, 50th Percentile	2-Year	5-Year	10-Year	25-Year	50-Year	100-Year	500-Year
5-min	0.57	0.74	0.84	0.94	1.01	1.06	1.12
10-min	0.91	1.19	1.35	1.50	1.61	1.67	1.77
15-min	1.14	1.50	1.70	1.90	2.03	2.12	2.23
30-min	1.57	2.14	2.48	2.83	3.05	3.25	3.55
60-min	1.97	2.73	3.22	3.75	4.14	4.47	5.10
2-hr	2.30	3.21	3.80	4.51	5.02	5.48	6.43
3-hr	2.46	3.43	4.09	4.86	5.46	5.99	7.11
6-hr	3.01	4.19	4.98	5.99	6.78	7.52	9.16
12-hr	3.65	5.10	6.13	7.47	8.57	9.65	12.20
24-hr	4.23	5.98	7.28	8.98	10.42	11.85	15.37
2-day	4.90	6.92	8.36	10.23	11.74	13.25	16.78
3-day	5.18	7.30	8.82	10.78	12.36	13.92	17.55
4-day	5.46	7.68	9.28	11.32	12.99	14.62	18.45
7-day	6.30	8.77	10.53	12.75	14.48	16.31	20.24

5. Historical Rainfall Event Analysis

Four historical events were characterized for consideration for use in modeling. These include:

- September 1, 2021
- September 10, 2020
- August 7, 2019
- July 8, 2019

For the September 2020, August 2019, and July 2019 events, stations across the County were examined to determine which subdaily gages within the MesoWest network captured the events. Quality control was performed on the data, and precipitation records were used to plot the event and determine the event size. Two stations were analyzed for each of these three events.

For the September 2021 event, precipitation information for the Twinbrook Community Recreation Center Station was extracted from *Twinbrook / Rockcrest Watershed September 1st, 2021 Flood Study at Rock Creek Woods Apartments* (Montgomery County Department of Transportation 2022) The data from this report uses the Twinbrook Community Recreation Center gage, which is a third-party gage not available on publicly available gage networks. For this reason, data from this gage are only available for the September 2021 event.

Historical flooding complaints were analyzed based on event date and complaint location for the September 2021, September 2020, August 2019 and July 2019 events, as an indication of spatial variability of flooding issues associated with heavy precipitation (Figure 5-1).

Information on historical event data used to analyze the four flooding events is provided in Table 5-1 and a map of precipitation stations used for analysis on Figure 5-2.

The following two historical events are recommended for modeling:

- September 10, 2020 using DW9421 Silver Spring gage data
- July 8, 2019 using Ten Mile Creek Precipitation Gage Near Clarksburg 2SW gage data

These two events had rainfall corresponding to large return intervals and received complaint calls within the County. They also represent events both in the southeast and northwest of the County. The Twinbrook Community Recreation Center gage also has a large return interval, but there are only 4 hours of data available. A temporal view of these events is shown on Figure 5-3 through Figure 5-9. Corresponding return intervals at various durations for each event are shown in Table 5-2 through Table 5-8.

Figure 5-1. Locations of Flooding Complaints for Selected Rainfall Events

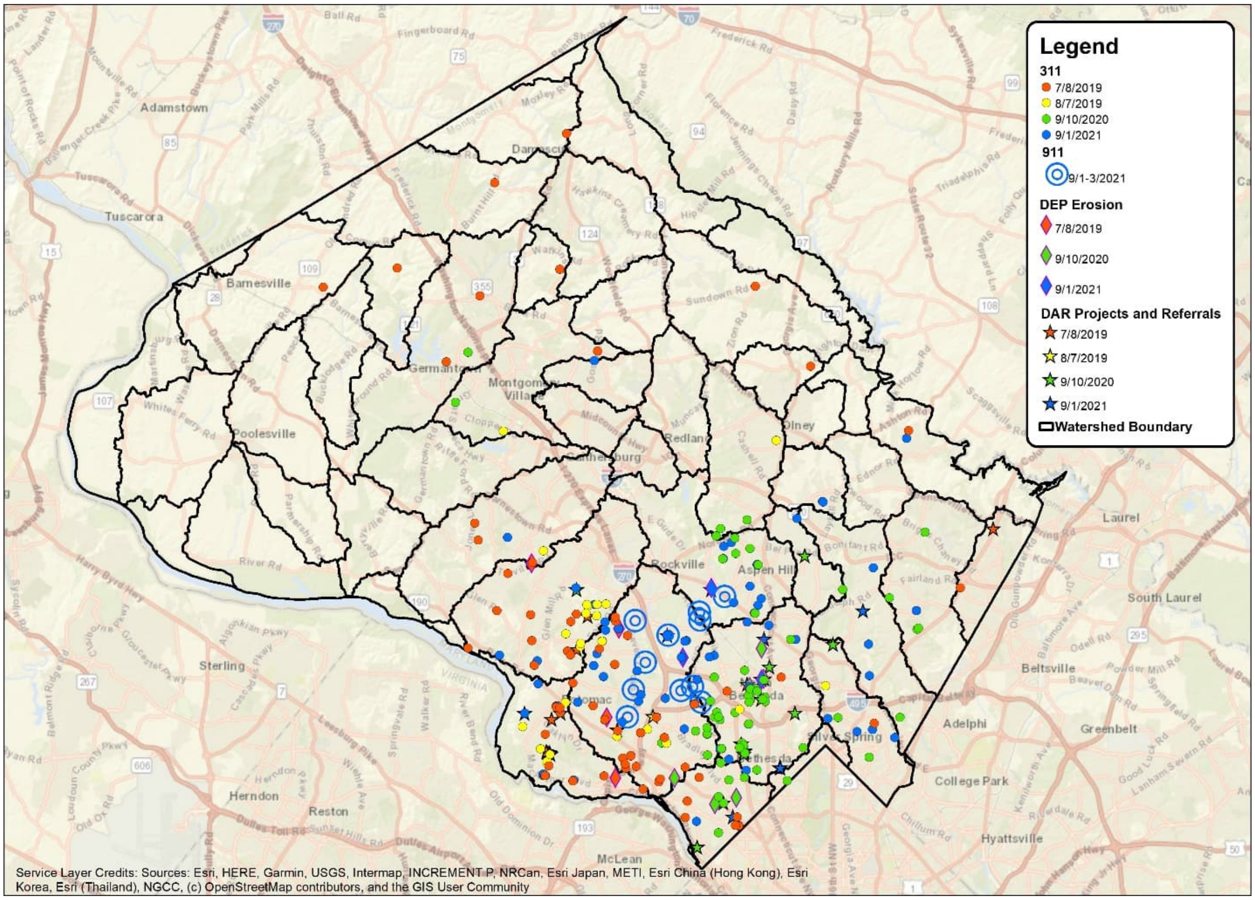


Table 5-1. Historical Event Stations

Station ID	Station Name	Network	Time Interval
AS787	KB3HHA-13 Germantown	APRSWXNET/ CWOP	5-minute
TMPM2	Ten Mile Creek Precip Gage Near Clarksburg 2SW[a]	HADS	15-minute
D9421	DW9421 Silver Spring	APRSWXNET/ CWOP	15-minute
E7774	EW7774 North Bethesda	APRSWXNET/ CWOP	5-minute or 3-minute (depending on date)
N/A	Twinbrook Community Recreation Center	Records extracted from report[b]	5-minute

[a] Ten Mile Creek Precip Gage Near **Clarksville** 2SW appears to be erroneously named and will be referred to as Ten Mile Creek Precipitation Gage Near **Clarksburg** 2SW in this TM.

[b] Source: Montgomery County Department of Transportation 2022

Figure 5-2. Historical Event Stations

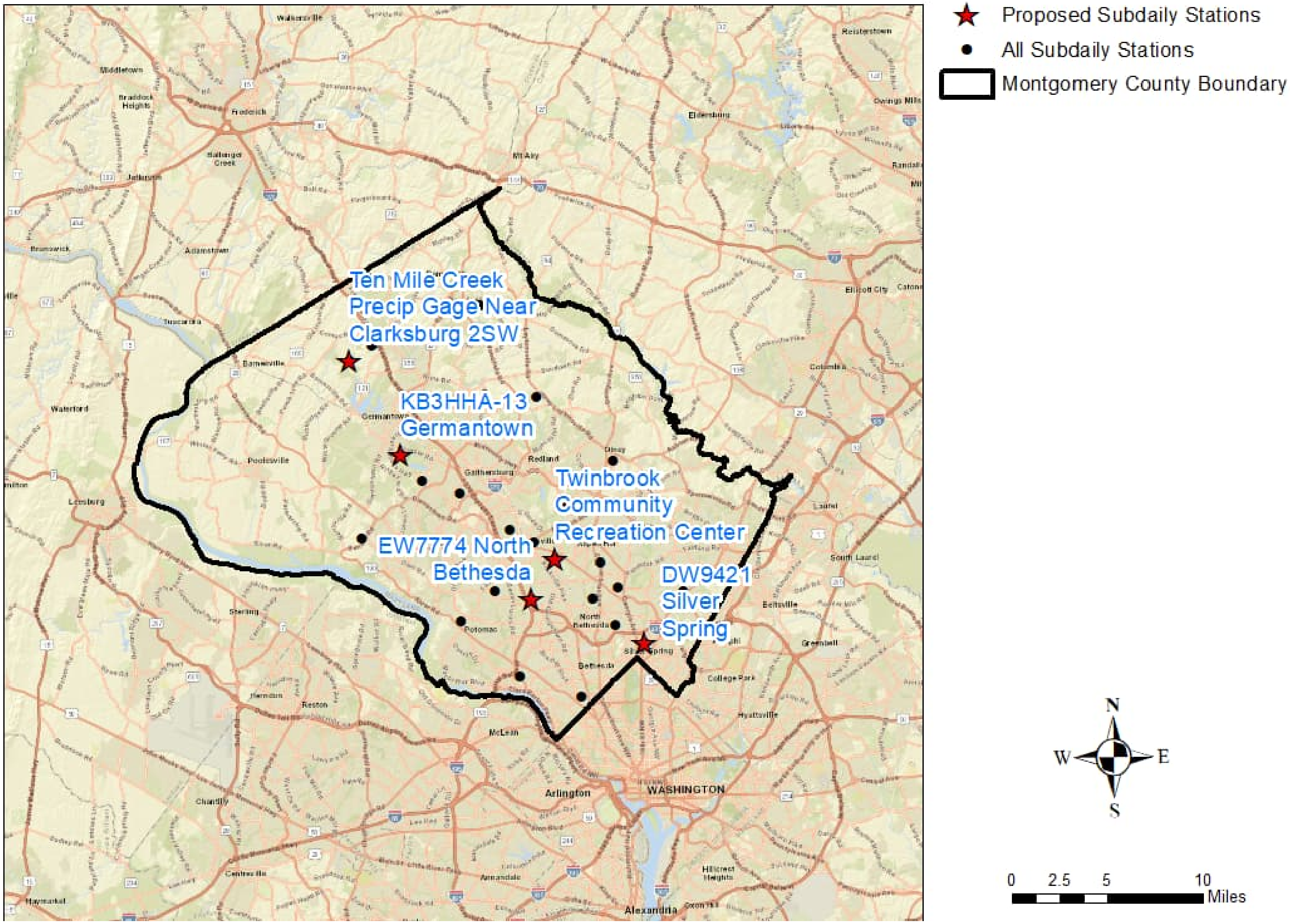


Figure 5-3. September 1, 2021 at Twinbrook Community Recreation Center

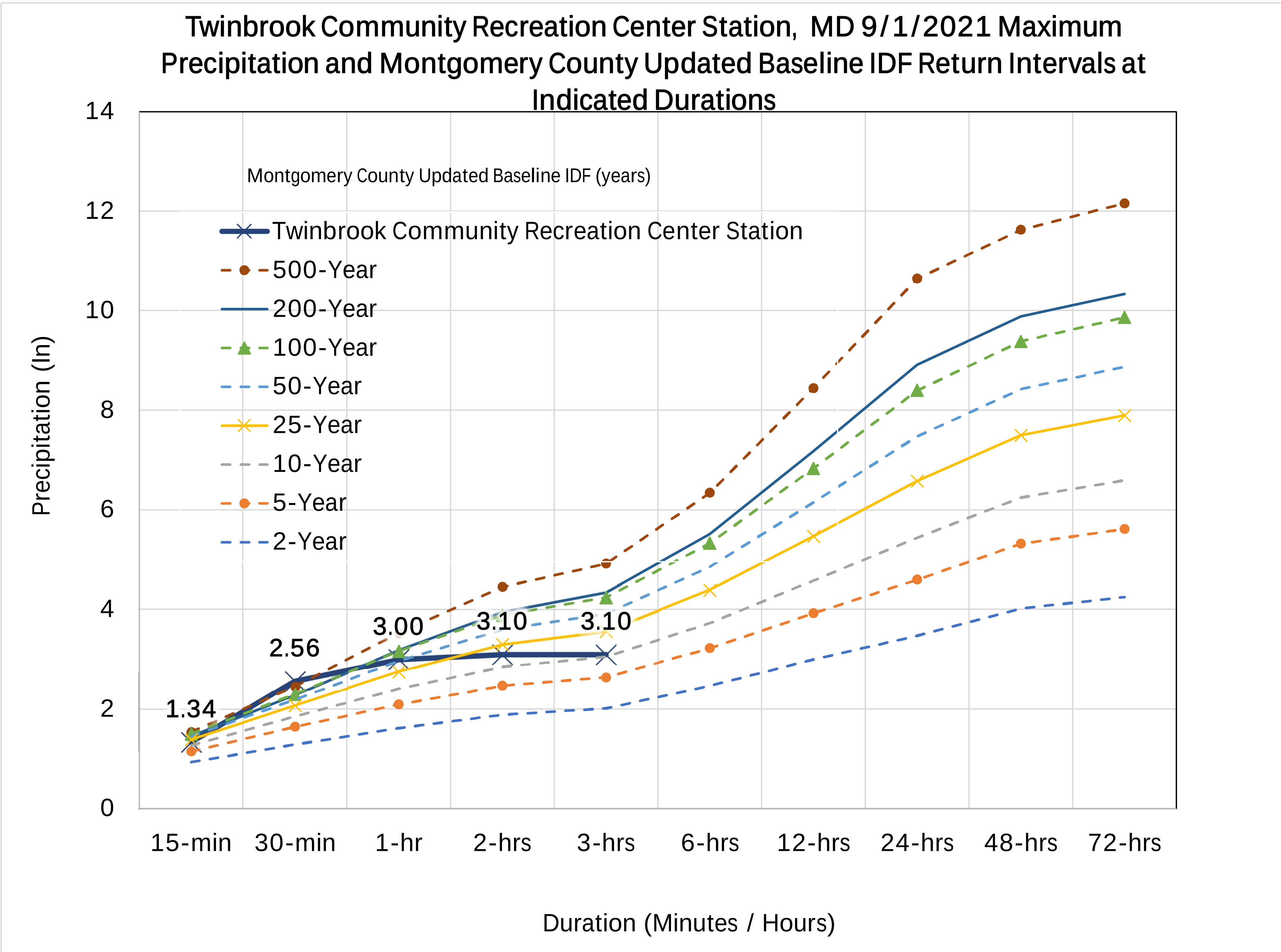


Table 5-2. September 1, 2021 at Twinbrook Community Recreation Center

September 1, 2021		
Duration	Depth at Twinbrook Community Recreation Center (inches)	Return Interval
15-min	1.34	10-Year
30-min	2.56	500-Year
1-hr	3.00	50-Year
2-hr	3.10	10-Year
3-hr	3.10	10-Year
6-hr	NA[a]	NA[a]
12-hr	NA[a]	NA[a]
24-hr	NA[a]	NA[a]

[a] Gage data only available for 4-hour time span for this event.

Figure 5-4. September 10, 2020 at DW9421 Silver Spring (Recommended for Modeling)

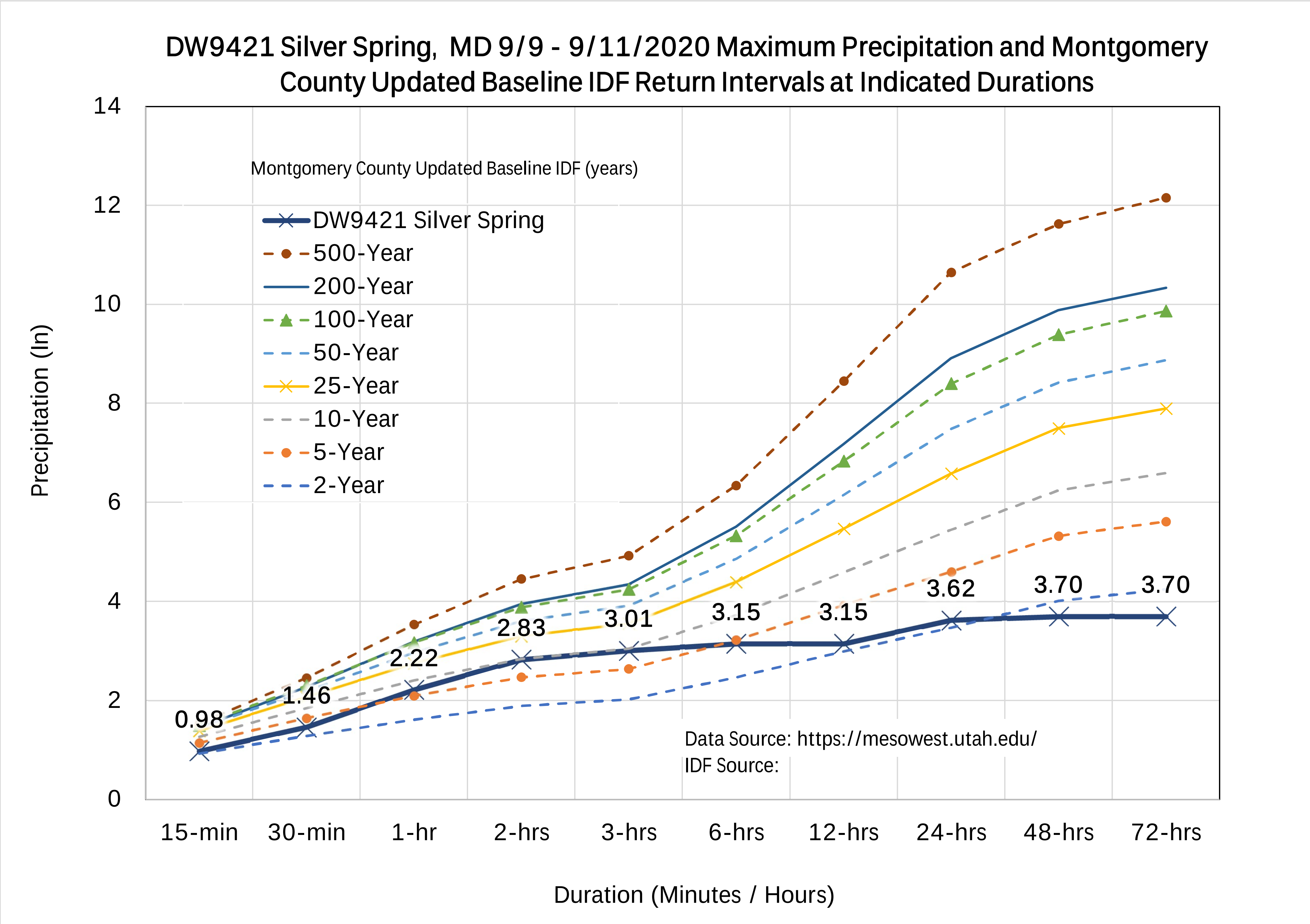


Table 5-3. September 10, 2020 at DW9421 Silver Spring (Recommended for Modeling)

September 10, 2020		
Duration	Depth at DW9421 Silver Spring (inches)	Return Interval
15-min	0.98	2-Year
30-min	1.46	2-Year
1-hr	2.22	5-Year
2-hr	2.83	5-Year
3-hr	3.01	5-Year
6-hr	3.15	2-Year
12-hr	3.15	2-Year
24-hr	3.62	2-Year

Figure 5-5 September 10, 2020 at EW7774 North Bethesda

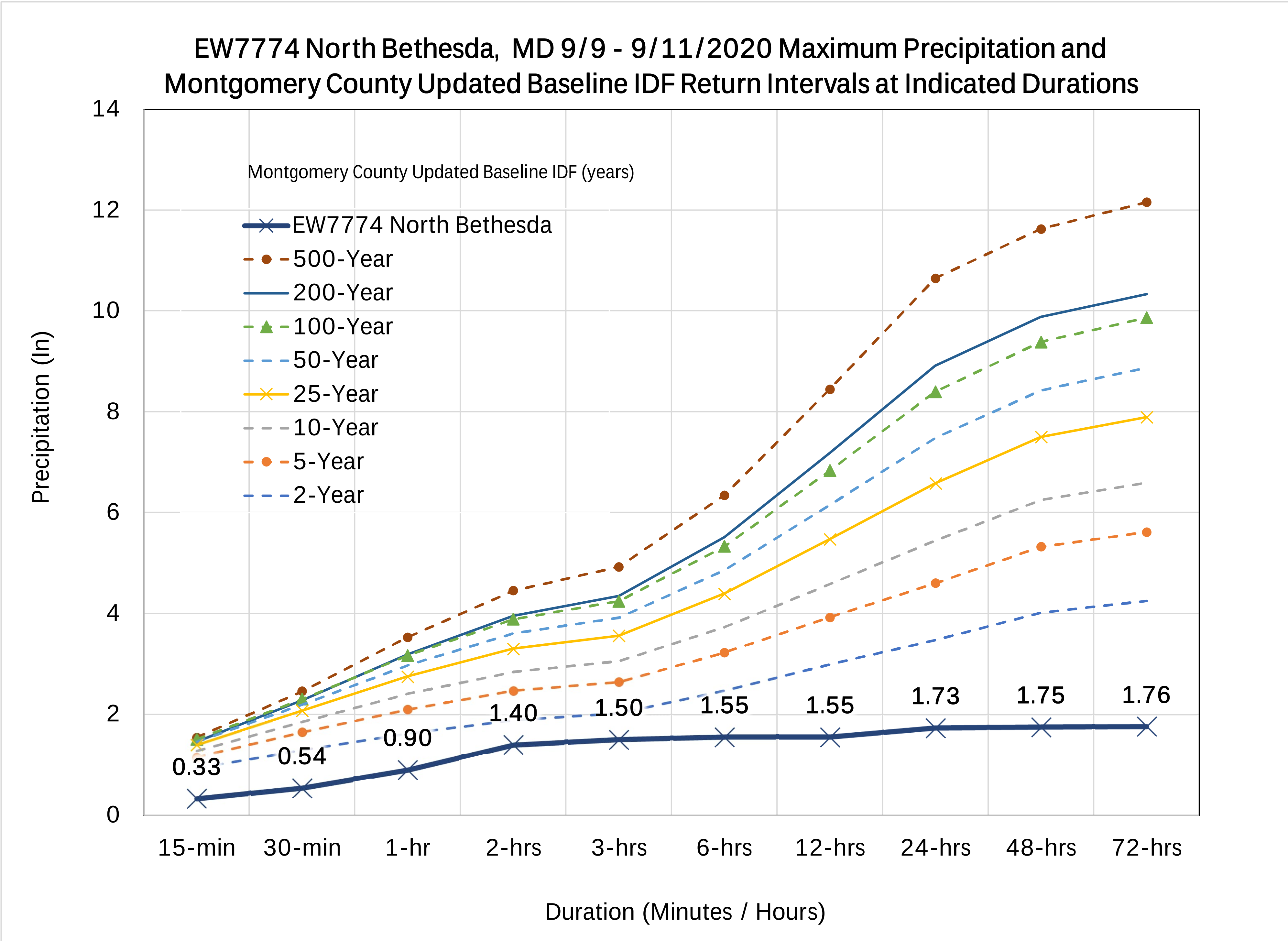


Table 5-4. September 10, 2020 at EW7774 North Bethesda

September 10, 2020		
Duration	Depth at EW7774 North Bethesda (inches)	Return Interval[a]
15-min	0.33	≤2-Year
30-min	0.54	≤2-Year
1-hr	0.9	≤2-Year
2-hr	1.4	≤2-Year
3-hr	1.5	≤2-Year
6-hr	1.55	≤2-Year
12-hr	1.55	≤2-Year
24-hr	1.73	≤2-Year

[a]≤ = less than or equal to

Figure 5-6. August 7, 2019 at KB3HHA-13 Germantown

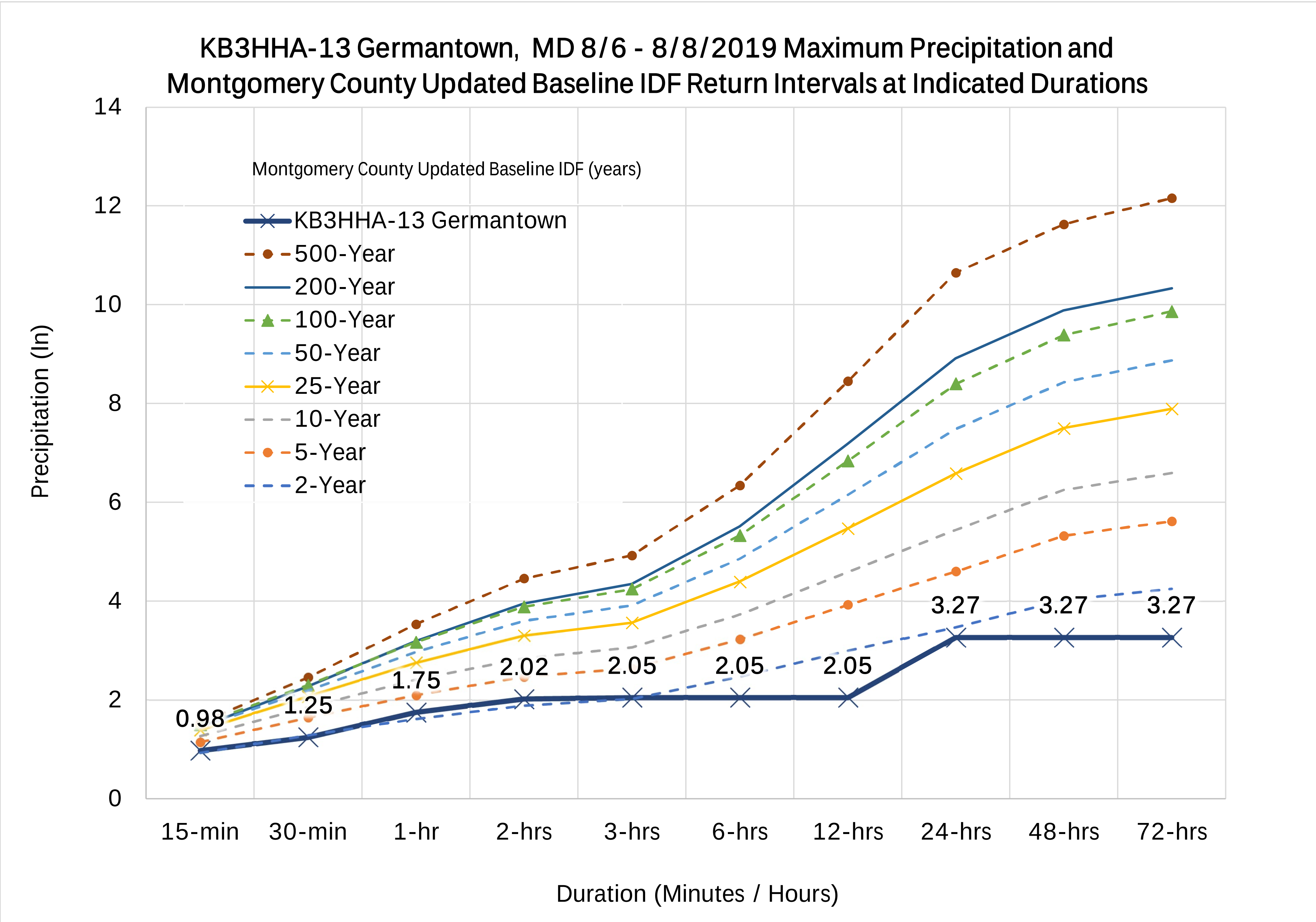


Table 5-5. August 7, 2019 at KB3HHA-13 Germantown

August 7, 2019		
Duration	Depth (inches) at KB3HHA-13 Germantown (inches)	Return Interval[a]
15-min	0.98	2-Year
30-min	1.25	≤2-Year
1-hr	1.75	2-Year
2-hr	2.02	2-Year
3-hr	2.05	2-Year
6-hr	2.05	≤2-Year
12-hr	2.05	≤2-Year
24-hr	3.27	≤2-Year

[a]≤ = less than or equal to

Figure 5-7. August 7, 2019 at EW7774 North Bethesda

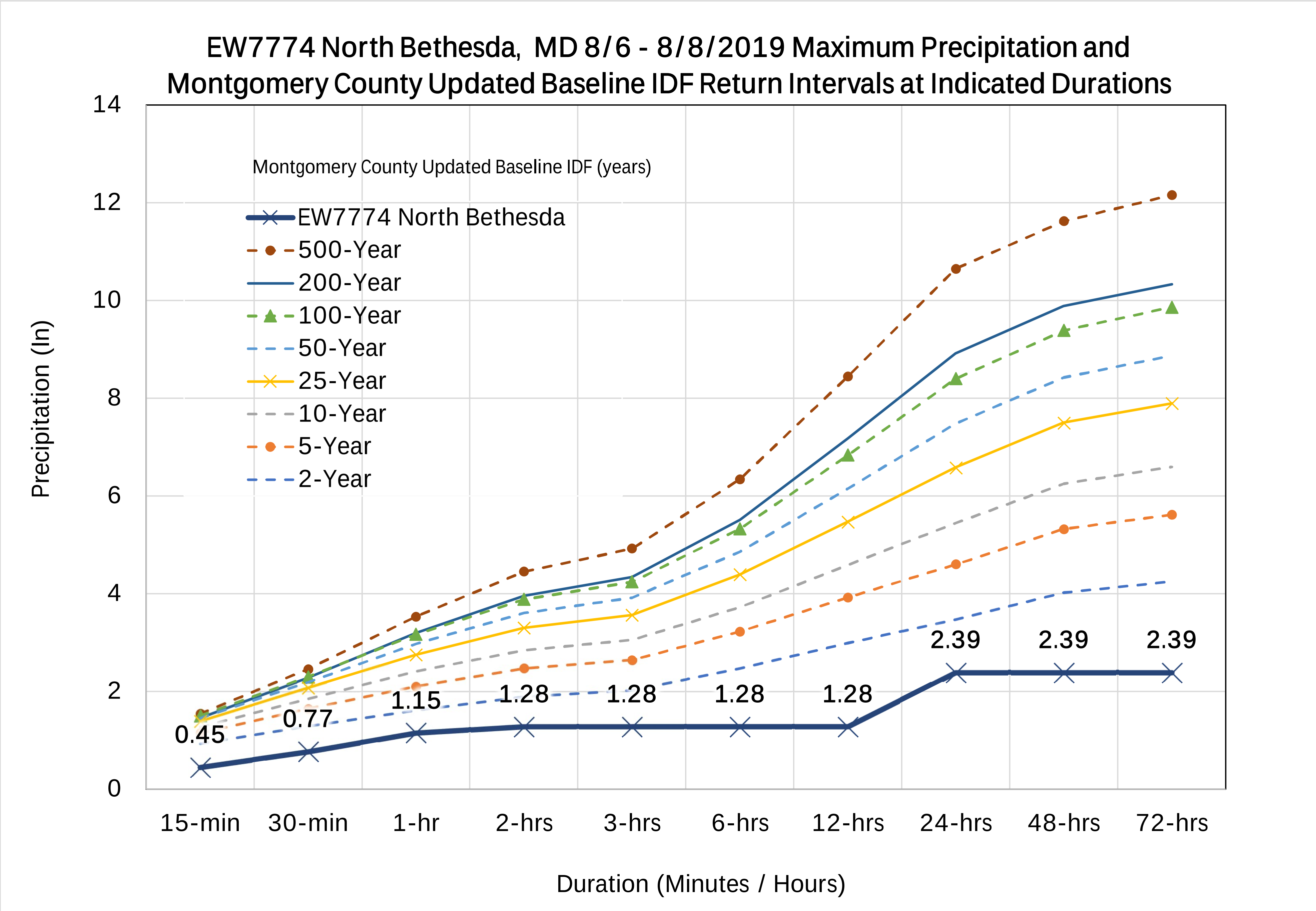


Table 5-6. August 7, 2019 at EW7774 North Bethesda

August 7, 2019		
Duration	Depth at EW7774 North Bethesda (inches)	Return Interval[a]
15-min	0.45	≤2-Year
30-min	0.77	≤2-Year
1-hr	1.15	≤2-Year
2-hr	1.28	≤2-Year
3-hr	1.28	≤2-Year
6-hr	1.28	≤2-Year
12-hr	1.28	≤2-Year
24-hr	2.39	≤2-Year

[a]≤ = less than or equal to

Figure 5-8. July 8, 2019 at EW7774 North Bethesda

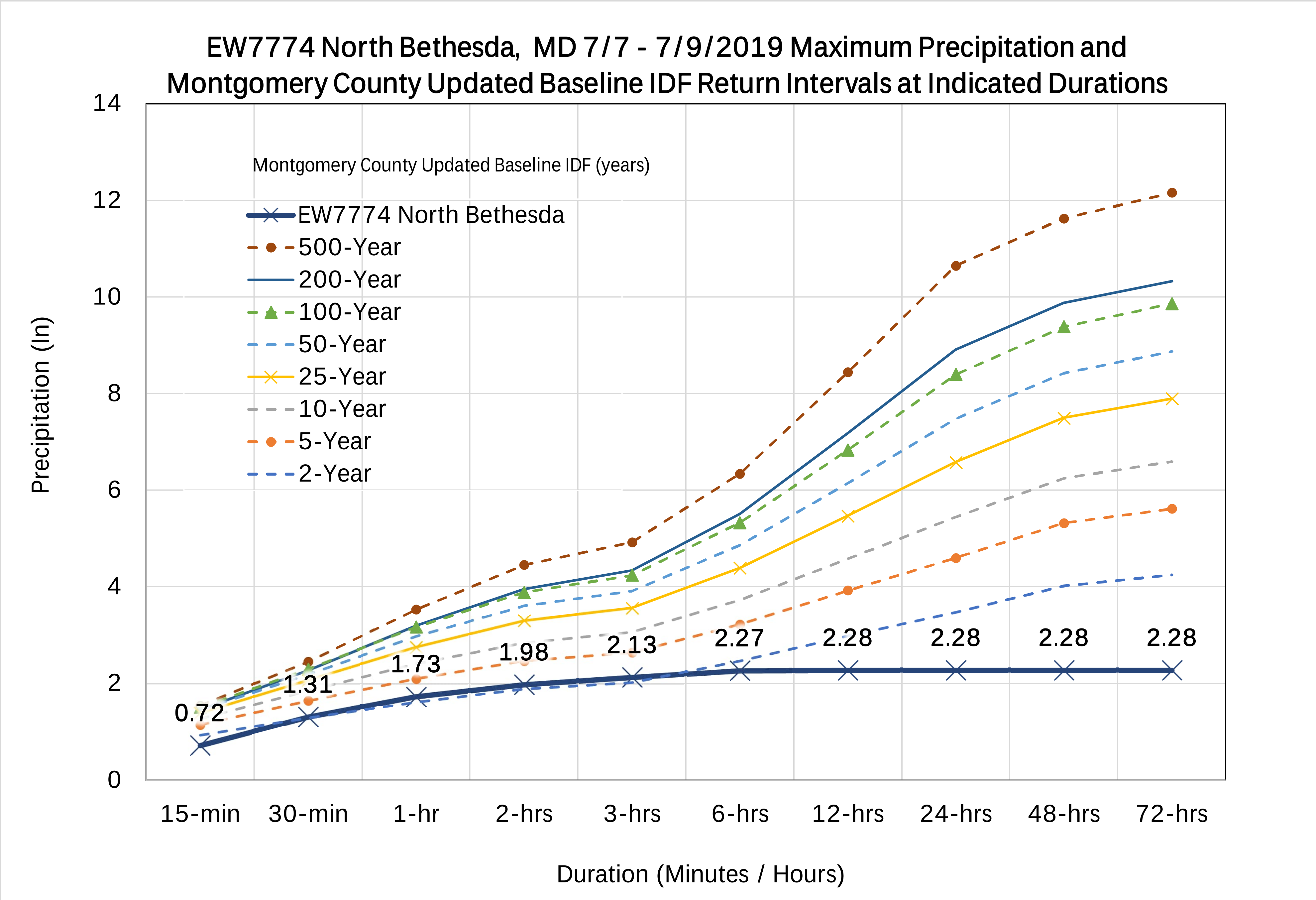


Table 5-7. July 8, 2019 at EW7774 North Bethesda

July 8, 2019		
Duration	Depth at EW7774 North Bethesda (inches)	Return Interval[a]
15-min	0.72	≤2-Year
30-min	1.31	2-Year
1-hr	1.73	2-Year
2-hr	1.98	2-Year
3-hr	2.13	2-Year
6-hr	2.27	2-Year
12-hr	2.28	≤2-Year
24-hr	2.28	≤2-Year

[a]≤ = less than or equal to

Figure 5-9. July 8, 2019 at Ten Mile Creek Precip Gage Near Clarksburg 2SW (Recommended for modeling)

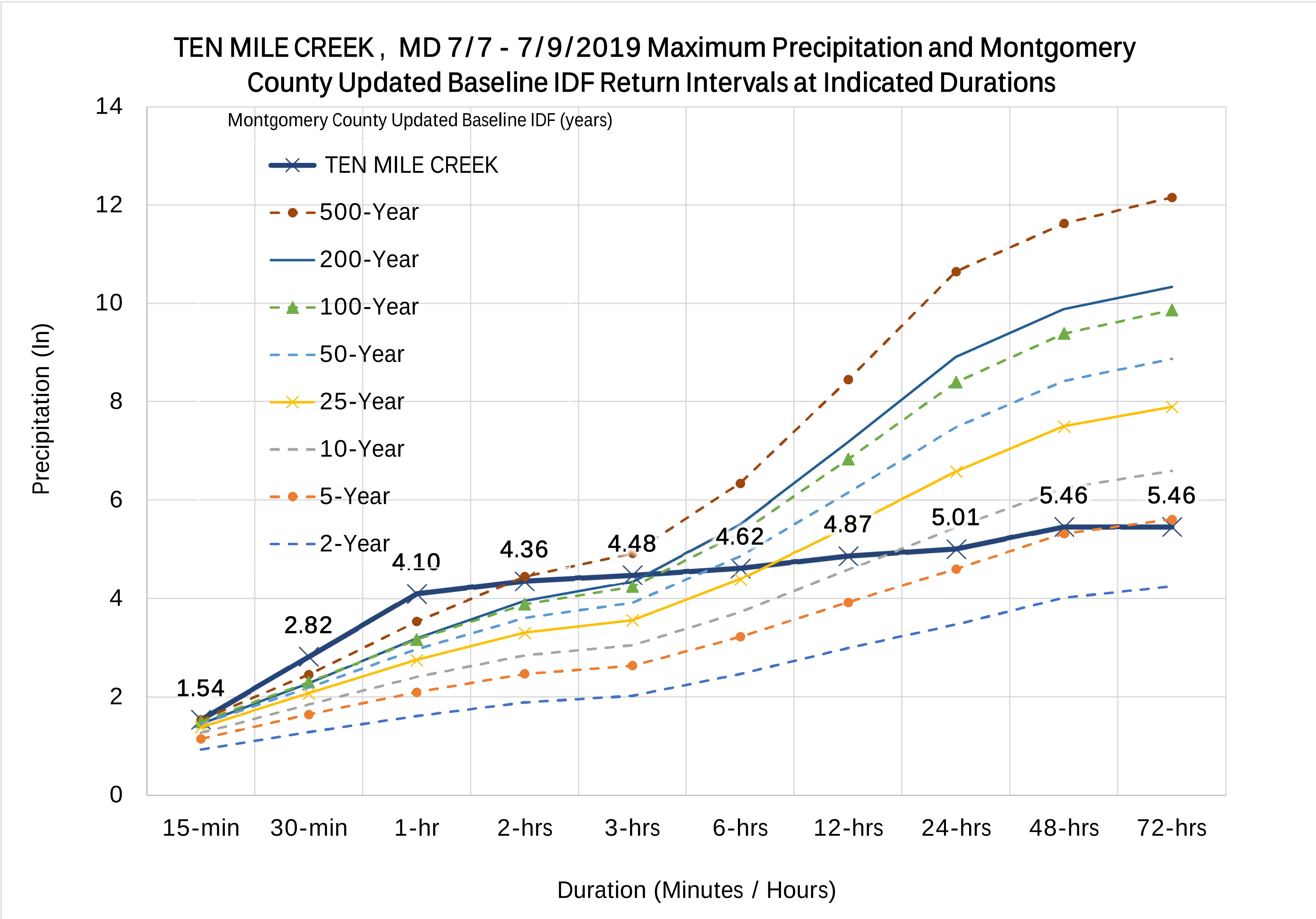


Table 5-8. July 8, 2019 at Ten Mile Creek Precip Gage Near Clarksburg 2SW (Recommended for modeling)

July 8, 2019		
Duration	Depth at Ten Mile Creek Precip Gage Near Clarksburg 2SW (inches)	Return Interval
15-min	1.54	500-Year
30-min	2.82	500-Year
1-hr	4.1	500-Year
2-hr	4.36	200-Year
3-hr	4.48	200-Year
6-hr	4.62	25-Year
12-hr	4.87	10-Year
24-hr	5.01	5-Year

6. Synthetic Temporal Rainfall Distributions

Synthetic distributions are commonly used for “design storms” in H&H modeling. These provide a standardized distribution of an event’s total rainfall across the time period of the event, which is different than an observed historical event.

Three synthetic distributions were considered for use in Montgomery County: SCS Type II, NOAA Atlas 14 Region C and Alternating Block. SCS Type II is currently being used by the County. This distribution is overly conservative (higher intensity) at short durations, and only requires the 24-hour depth to generate. Although this is a commonly used distribution, it is recommended by the National Engineering Handbook (United States Department of Agriculture, 2019) that its use be discontinued in areas where NOAA Atlas 14 data are available (Bonnin et al. 2006). The NOAA Atlas 14 distribution curves are more location specific than SCS Type II. The County falls within Region C. These distributions use a ratio of the 60-minute to 24-hour event (based on the 25-year event) and only require a 24-hour depth to generate. The alternating block distribution requires a higher resolution of IDF information to generate and varies based on return interval, unlike the other two distributions. Within the alternating block distribution curve, events are nested within each other (for example, the 15-minute event is nested within the 1-hour event, then within the 6-hour event). This means that ‘slices’ of the center of the curve can be used to simulate shorter event durations.

A comparison of maximum depths and associated return periods for three synthetic events using the 10-year, 24-hour event and two historical events is presented numerically in Table 6-1 and Table 6-2.

Figure 6-1 shows a temporal distribution of the same events and distributions.

Figure 6-2 and Figure 6-3 show depths at various time intervals, as well as a dimensionless ratio compared to the alternating block IDF at the same time intervals. The alternating block distribution is recommended for modeling purposes because this distribution varies based on return interval, is not overly conservative at shorter durations, and it contains short duration events nested within each 24-hour event.

Table 6-1. Maximum Depths (inches) at Varying Durations for Three 10-Year, 24-Hour Synthetic Events and Two Historical Events

Duration	10-Year SCS Type II	10-Year NOAA Atlas 14 Region C	10-Year Alt Block	Event 1 Sept. 2020 Silver Spring	Event 2 July 2019 Ten Mile Creek
5-min	0.67	0.57	0.63	-	-
10-min	1.15	0.92	1.01	-	-
15-min	1.4	1.1	1.3	1.0	1.5
30-min	2.1	1.6	1.9	1.5	2.8
60-min	2.4	2.1	2.4	2.2	4.1
2-hr	2.9	2.8	2.8	2.8	4.4
3-hr	3.2	3.2	3.1	3.0	4.5
6-hr	3.8	3.9	3.7	3.2	4.6
12-hr	4.6	4.6	4.6	3.2	4.9
24-hr	5.4	5.4	5.4	3.6	5.0

Table 6-2. Equivalent Return Periods (years) at Varying Durations for Three Synthetic Events and Two Historical Events

Duration	10-Year SCS Type II	10-Year NOAA Atlas 14 Region C	10-Year Alt Block	Event 1 Sept. 2020 Silver Spring	Event 2 July 2019 Ten Mile Creek
5-min	19	5	10	-	-
10-min	47	5	10	-	-
15-min	37	5	10	3	>500
30-min	25	5	10	3	>500
60-min	11	5	10	7	>500
2-hr	13	10	10	10	443
3-hr	15	14	10	9	271
6-hr	13	13	10	5	37
12-hr	10	10	10	3	15
24-hr	10	10	10	2	7

> = greater than

Figure 6-1. 10-Year, 24-Hour Design Storm Comparison

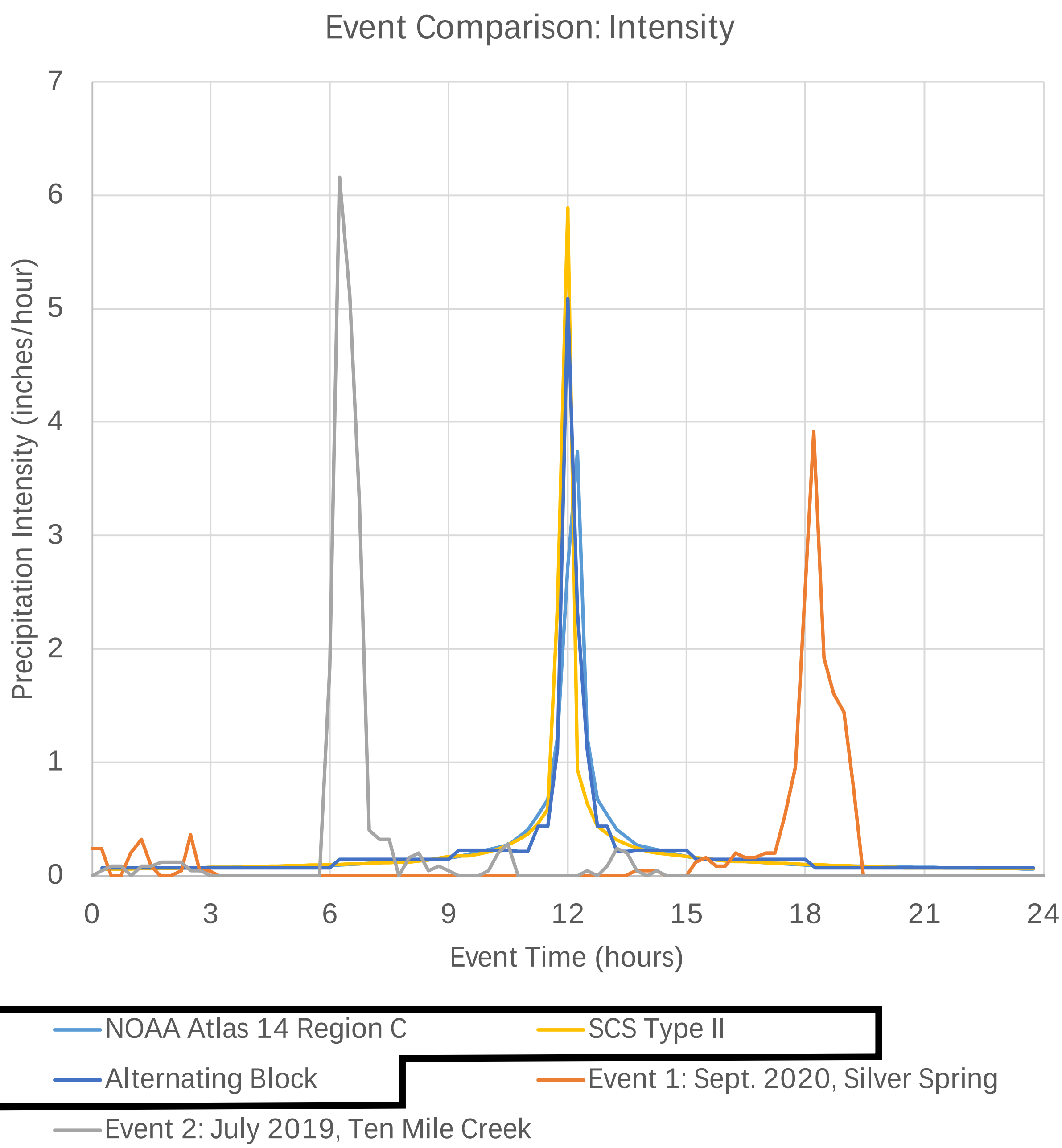


Figure 6-2. Precipitation Depth at Various Durations for the 10-Year, 24-Hour Storm

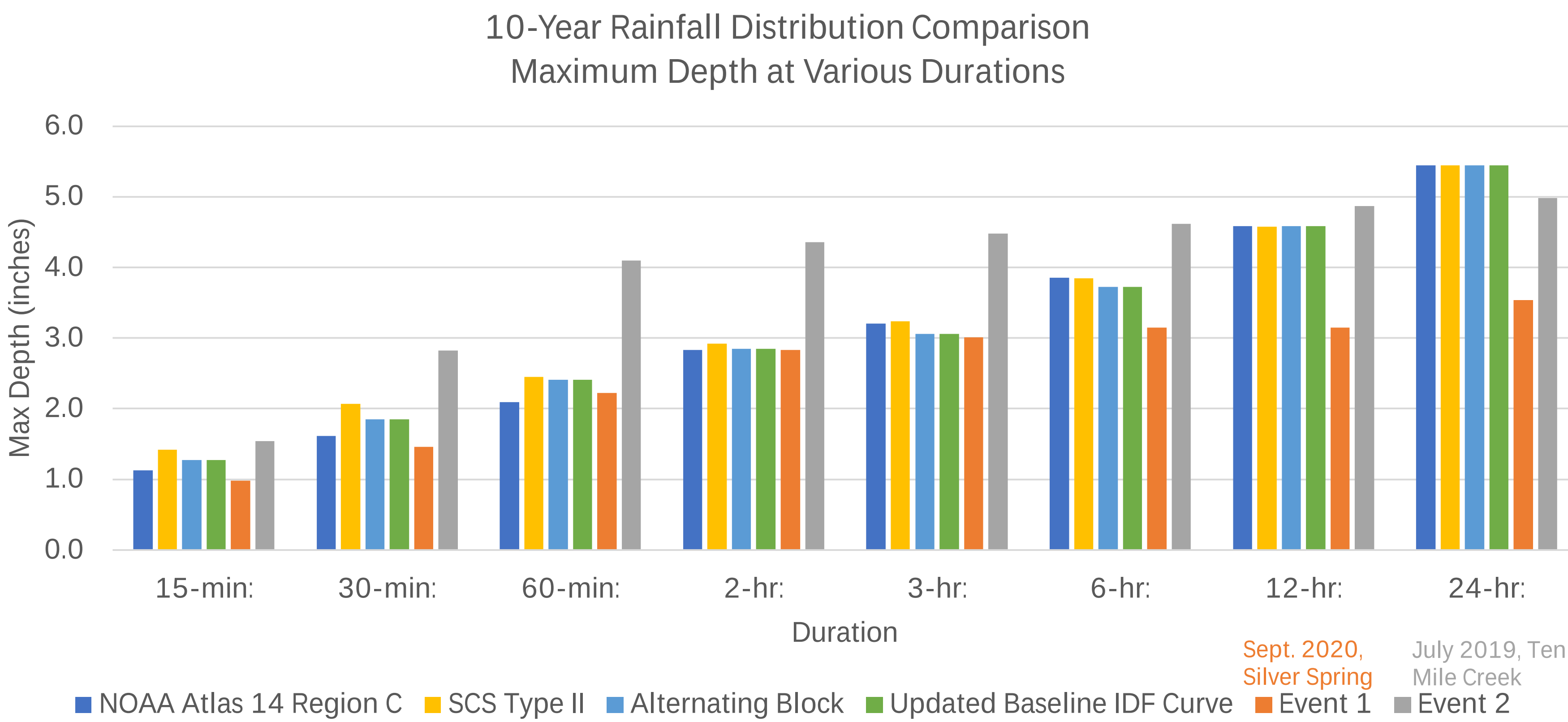
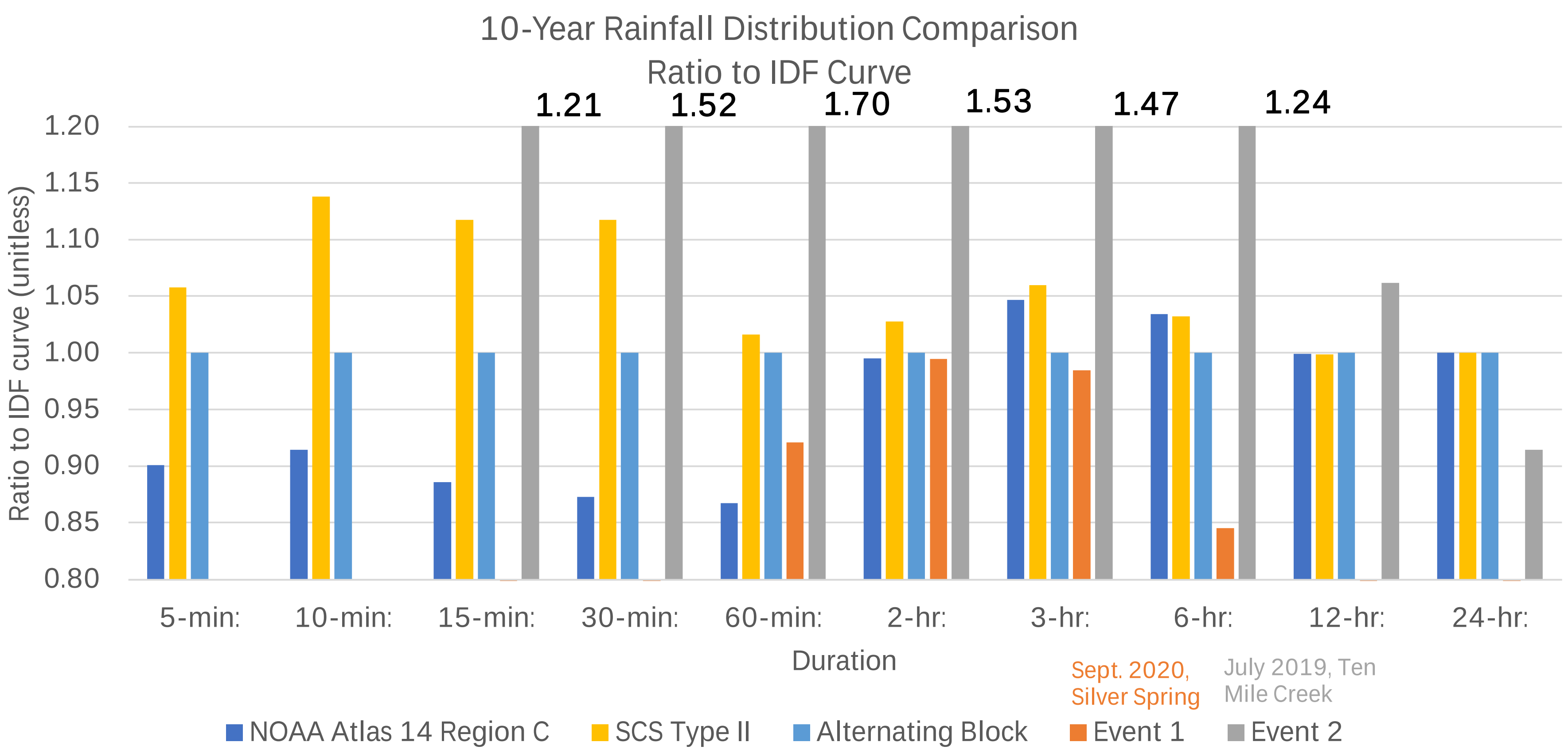


Figure 6-3. Ratio to IDF at Various Durations for the 10-Year, 24-Hour Storm



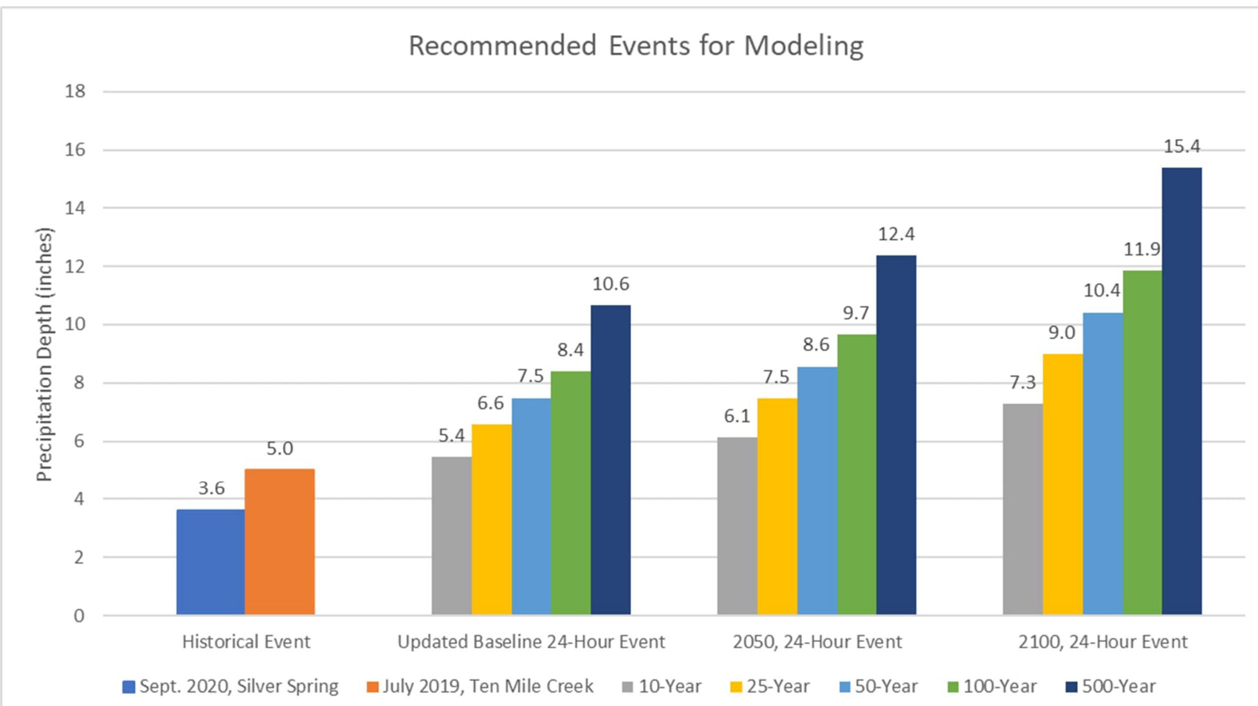
7. Modeling Recommendations

The following recommendations are made for modeling in Task W-3:

- Two observed historical events:
  - September 10, 2020 at DW9421 Silver Spring gage
  - July 8, 2019 at Ten Mile Creek Precip Gage Near Clarksburg 2SW gage
- Five updated baseline scenarios: 10-, 25-, 50-, 100-, and 500-year return periods
- Ten future climate scenarios based on the SSP5-8.5, 50th Percentile projections:
  - 2050, for the 10-, 25-, 50-, 100-, and 500-year return periods
  - 2100, for the 10-, 25-, 50-, 100-, and 500-year return periods
- Use Alternating Block Synthetic Distribution

Note that these recommendations are subject to change during modeling. The 17 events recommended for modeling are shown on Figure 7-1. Attachment 7 contains 15-minute time series for these events.

Figure 7-1. Events Recommended for Hydrologic and Hydraulic Modeling and Flood Risk Assessments, Future Events are SSP5-8.5 Climate Scenario



8. References

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United States Department of Agriculture. 2019. Part 630 Hydrology National Engineering Handbook. Chapter 4, Storm Rainfall Depth and Distribution. 210–630–H., Amend. 88. August. https://directives.sc.egov.usda.gov/OpenNonWebContent.aspx?content=43924.wba

Attachment 1. Annual Maximum Series and Partial Duration Series

Attachment 1. Annual Maximum Series and Partial Duration Series

National Oceanic and Atmospheric Administration (NOAA) developed Atlas 14 intensity, duration, and frequency (IDF) curves separately for annual maxima series (AMS) and partial duration series (Bonnin et al. 2006). AMS and PDS precipitation depths are generally similar for low frequency events (greater than 10-year return period); for more frequent events (less than 10-year return period), PDS precipitation depths are higher than AMS. Analysis that uses more frequent events should use PDS values as a more realistic representation of these types of events. Final results for the analysis in this technical memorandum are presented as PDS depths. However, because direct comparison between updated baseline IDF curves and NOAA Atlas 14 is best conducted using AMS, and in order to maintain consistency with future IDF curves developed using SimCLIM and AMS methods, all updated and future IDF curve analysis was conducted as AMS, and then converted to PDS. Conversion of AMS IDF curves to PDS IDF curves (as opposed to direct calculation of PDS curves) was performed in later volumes of NOAA Atlas 14; for instance, Volume 9 converts AMS to PDS using the Langbein formula (Perica et al. 2013).

For this analysis, AMS statistics were converted to PDS statistics using ratios of PDS to AMS from Atlas 14 Volume 2, specific to individual stations, durations, and frequency, as shown for 24-hour durations in the table herein. PDS to AMS ratios are generally similar for all stations, and for all durations (the 2-year 5-minute PDS to AMS ratio is similar to the 2-year 7-day ratio).

PDS to AMS Ratios – Dalecarlia Reservoir

Return Period	2-Year	5-Year	10-Year	25-Year	50-Year	100-Year	200-Year	500-Year	1000-Year
1-hr, PDS/AMS Ratio	1.0882	1.0220	1.0141	1.0039	1.0035	1.0032	1.0057	1.0051	1.0046
24-hr, PDS/AMS Ratio	1.0890	1.0226	1.0104	1.0033	1.0042	1.0048	1.0041	1.0084	1.0072

References

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Attachment 2. L-Moments Regional Method

Attachment 2. L-Moments Regional Method

Regional flood frequency analysis involves augmenting at-site data with data from other sites with similar probability distributions. The procedure for regional flood frequency analysis involves the following: (1) screening of data, (2) partitioning of data into homogeneous subregions, and (3) fitting probability distributions to data within each subregion. These tasks involve subjective and objective decisions regarding outliers, heterogeneity, and goodness-of-fit. The L-Moments package (Hosking, 1996; Hosking and Wallis, 1997) provides convenient routines for screening, clustering, and frequency analysis of regional data sets based on the L-Moments method. L-Moments have been shown in various Monte Carlo studies to outperform other estimation methods, such as the method of moments and method of maximum likelihood, in terms of bias and robustness. The L-Moments package (Hosking, 1996) was used to perform the frequency analysis of the precipitation data in this study.

The annual maximum precipitation data for various durations were fitted to selected frequency distributions, using L-Moments to estimate the distribution parameters. In the L-Moments method, a regional frequency curve is obtained by averaging the slopes of the station frequency curves in a given homogeneous region. L-Moments are analogous to ordinary moments in that the purpose is to summarize theoretical probability distributions and observed samples. Because L-Moments are computed as linear combinations of the ranked observations (instead of squaring and cubing the observations), they are subject to less variability in small samples than ordinary moments (Hosking, 1990).

The sample L-Moments or sample L-Moments ratios needed to describe the frequency distributions and apply various statistical tests incudes:

l1 = first L-Moment, measure of location (mean)

l2 = second L-Moment, measure of scale (dispersion)

l2/l1 = L coefficient of variation (L-CV)

l3 = third L-Moments

l4 = fourth L-Moments

l3/l2 = measure of skewness (L-Skewness)

l4/l2 = measure of kurtosis (L-Kurtosis)

Regionalization involves forming clusters of subregions from the entire data set based on site characteristics. The primary goal is to choose site characteristics that best capture the relevant indicators upon which climatological homogeneity can be predicated.

After the initial formation of subregions, the next goal is to determine that the sites within the tentative subregions can reasonably be assumed to be homogeneous. The L-Moments package incorporates three tests for homogeneity:

- H1: The weighted standard deviation of the sample L-CVs
- H2: The average distance from the site to the regional average on a graph of L-CV vs. L-Skewness
- H3: The average distance from the site to the regional average on a graph of L-Skewness vs. L-Kurtosis

These compare the between-site variations in sample L-Moments for sites in a subregion. The use of only one of the three options is often adequate. A subregion is acceptably homogeneous if H is less than 1, likely heterogeneous if H is greater than 1, and most likely heterogeneous if H is greater than 2. These thresholds are based on expert judgment but are not definitive. Several adjustments are required when a given subregion is not homogenous. The options include moving sites between subregions, deleting sites from the data set, subdividing subregions, and merging subregions. The three tests noted were used in defining homogeneous regions for this analysis.

Fitting Frequency Distributions

Given homogeneous regions, the objective is to find the regional frequency distributions that, on average, describe the observations at each site. The L-Moments package fits sample data to the following three-parameter (location, scale, and skewness) frequency distributions

- Generalized Logistic
- Generalized Extreme Value
- Generalized Normal
- Pearson Type III
- Generalized Pareto

The goodness-of-fit is quantified using test statistics internal to the L-Moments package at a 90-percent confidence level (implying only a 10 percent chance of choosing an erroneous distribution). More details on the goodness-of-fit test are provided by Hosking (1990), Hosking (1996), and Hosking and Wallis (1997).

References

Hosking. 1990. "L-Moments: Analysis and Estimation of Distributions Using Linear Combinations of Order Statistics", Research Report, IBM Research Division, Yorktown Heights, NY.

Hosking, J.R.M. 1996. "Fortran Routines for Use with the Method of L-Moments," Research Report, IBM Research Division, Yorktown Heights, NY.

Hosking, J.R.M., and J. R. Wallis. 1997. *Regional Frequency Analysis, An Approach Based on L Moments.* Cambridge University Press, Cambridge, U.K.

Attachment 3. Results of XTEST Station Discordancy and Heterogeneity Test

Attachment 3. Results of XTEST Station Discordancy and Heterogeneity Test

Discordancy is used to assist in identifying those sites whose L-Moments ratios (variability, skewness, and kurtosis) are markedly different relative to L-Moments ratios for the stations used in the analysis. The discordancy value is a measure of data quality and homogeneity that can be used to identify stations containing questionable data.

The following results were generated by the L-Moments XTEST software. They show the results of the station discordancy test for each of the six stations used for the IDF analysis. Hosking and Wallis (1997) suggest the formula D(I) ≤ (N-1)/3 provides the threshold for a discordancy based on the number of stations used for the analysis (N).

Solving the equation for the nine stations used in this project yields a threshold value of 2.67, which is higher than the discordancy station values shown in the XTEST analysis, meaning that all stations passed.

Montgomery County Nine Stations

Site	N	Name	L-CV	L-SKEW	L-KURT	D(I)
1	67	BOYDS 2 NW, MD US	0.2112	0.2776	0.2627	1
2	50	BRIGHTON DAM, MD US	0.255	0.1385	0.2939	0.65
3	78	DALECARLIA RESERVOIR, DC US	0.2145	0.2016	0.1409	0.95
4	47	DAMASCUS 3 SSW, MD US	0.1867	0.0915	0.1993	0.61
5	48	POTOMAC FILTER PLANT, MD US	0.2756	0.1483	0.3172	1.06
6	70	ROCKVILLE 1 NE, MD US	0.2706	0.113	0.2236	1.16
7	66	WASHINGTON DULLES INTERNATIONAL AIRPORT, VA US	0.2326	0.3619	0.2497	1.29
8	74	NATIONAL ARBORETUM DC, DC US	0.2312	0.2141	0.1742	0.62
9	19	SHARPSBURG 5, MD US	0.1546	0.0151	0.1315	1.65

WEIGHTED MEANS 0.2312 0.1938 0.2224
PARAMETERS OF REGIONAL KAPPA DISTRIBUTION 0.9277 0.2171 -0.1938 -1.0000

Heterogeneity Results

A project area is acceptably homogeneous if H less than 1, likely heterogeneous if H greater than 1, and most likely heterogeneous if H greater than 2. Each of the H values are less than 1, so the subregion selected for this analysis is most acceptably homogeneous.

***** HETEROGENEITY MEASURES *****
(NUMBER OF SIMULATIONS = 1000)

OBSERVED S.D. OF GROUP L-CV = 0.0306
SIM. MEAN OF S.D. OF GROUP L-CV = 0.0243
SIM. S.D. OF S.D. OF GROUP L-CV = 0.0067
STANDARDIZED TEST VALUE H(1) = 0.94

OBSERVED AVE. OF L-CV / L-SKEW DISTANCE = 0.0792
SIM. MEAN OF AVE. L-CV / L-SKEW DISTANCE = 0.0666
SIM. S.D. OF AVE. L-CV / L-SKEW DISTANCE = 0.0162
STANDARDIZED TEST VALUE H(2) = 0.78

OBSERVED AVE. OF L-SKEW/L-KURT DISTANCE = 0.0996
SIM. MEAN OF AVE. L-SKEW/L-KURT DISTANCE = 0.0828
SIM. S.D. OF AVE. L-SKEW/L-KURT DISTANCE = 0.0194
STANDARDIZED TEST VALUE H(3) = 0.87

***** GOODNESS-OF-FIT MEASURES *****
(NUMBER OF SIMULATIONS = 1000)

GEN. LOGISTIC L-KURTOSIS= 0.198 Z VALUE= -2.46
GEN. EXTREME VALUE L-KURTOSIS= 0.160 Z VALUE= -4.20
GEN. NORMAL L-KURTOSIS= 0.152 Z VALUE= -4.56
PEARSON TYPE III L-KURTOSIS= 0.135 Z VALUE= -5.34
GEN. PARETO L-KURTOSIS= 0.074 Z VALUE= -8.14

PARAMETER ESTIMATES FOR DISTRIBUTIONS ACCEPTED AT THE 90% LEVEL

WAKEBY 0.124 6.735 12.834 0.375 0.036

QUANTILE ESTIMATES

	0.010	0.020	0.050	0.100	0.200	0.500	0.900	0.950	0.990	0.999
WAKEBY	0.191	0.251	0.396	0.552	0.703	0.912	1.550	1.836	2.529	3.594

Reference

Hosking, J.R.M., and J. R. Wallis. 1997. *Regional Frequency Analysis, An Approach Based on L Moments.* Cambridge University Press, Cambridge, U.K.

Attachment 4. SimCLIM Daily General Circulation Models

Attachment 4. SimCLIM Daily General Circulation Models

24 SimCLIM daily general circulation models were used for precipitation intensity, duration, and frequency (IDF) estimates.

Number	Name
1	ACCESS-CM2
2	AWI-CM-1-1-MR
3	BCC-CSM2-MR
4	CanESM5
5	CMCC-CM2-SR5
6	CMCC-ESM2
7	CNRM-CM6-1
8	CNRM-CM6-1-HR
9	CNRM-ESM2-1
10	EC-Earth3
11	EC-Earth3-Veg
12	FGOALS-g3
13	GFDL-ESM4
14	HadGEM3-GC31-LL
15	IPSL-CM6A-LR
16	KACE-1-0-G
17	KIOST-ESM
18	MIROC-ES2L
19	MIROC6
20	MPI-ESM1-2-HR
21	MPI-ESM1-2-LR
22	MRI-ESM2-0
23	NESM3
24	UKESM1-0-LL

Attachment 5. Daily GCM Extreme Value Analysis Methodology

Attachment 5. Daily GCM Extreme Value Methodology

General Circulation Models Pattern Preparation

The following method is used to analyze climate change impact on extreme precipitation events, using daily general circulation model (GCM outputs at their original spatial resolution (that is, not downscaled). The steps of such a method are as follows:

1. Build a Generalized Extreme Value (GEV) distribution for one GCM baseline period (1981 to 2000 or 1980 to 1999) daily data, and calculate its extreme precipitation intensity values for seven selected return periods (2-, 5-, 10-, 25-, 50-, 100-, and 500-year).
2. Build GEV distribution for the above GCM based on its future daily data (2050 and 2100). Select two emissions scenarios (shared socioeconomic pathways [SSPs]) SSP2-4.5 and SSP5-8.5 available from Intergovernmental Panel on Climate Change Sixth Assessment Report (IPCC 2021) data archive. Calculate its extreme precipitation intensity values for the selected return periods as baseline period.
3. Calculate the difference in percentage of the extreme precipitation intensity values of between baseline and each future period.
4. Calculate the annual global average mean temperature change between the future periods and its baseline for the above GCM.
5. Normalize the extreme precipitation changes by using linear least square regression method using following equation:

$$\Delta V_{ij}^{'} = \frac{\sum_{y=1}^{m} \Delta T_y \cdot \Delta V_{yij}}{\sum_{y=1}^{m} (\Delta T_y)^2}$$

$\Delta V'_{ij}$ the normalized change value a grid cell (*i*) and return period (*j*); ΔV_{yij} is the change percentage for ΔT_y for global mean temperature change for future period *y*; *m* is the number of future sample periods used.

A bilinear interpolation method is used to obtain a finer scale extreme precipitation change pattern at the required spatial resolution. Applying the change pattern generated from daily GCM data for extreme precipitation event analysis for the study region is done in the following way:

1. Build GEV distribution from data of the study region and calculate the extreme precipitation values for selected return periods.
2. Extract the change pattern values from global change patterns generated in Step 6 of the GEV process.
3. Obtain the global average mean temperature change for the selected study time slices (2050, 2100) and greenhouse gas (GHG) emission scenarios (SSP2-4.5 and SSP5-8.5) in midclimate sensitivity from SimCLIM.
4. Calculate the extreme precipitation values by calculating the change patterns with global mean temperature using following equation.

$P_1 = P_o \cdot (1+\Delta P/100 x \Delta GMT_1)$

P_1 and P_0 represent the future and baseline extreme precipitation; ΔP is the change percentage generated from GCM data; ΔGMT, the scalar, is the change of global mean temperature increase in a future time slice.

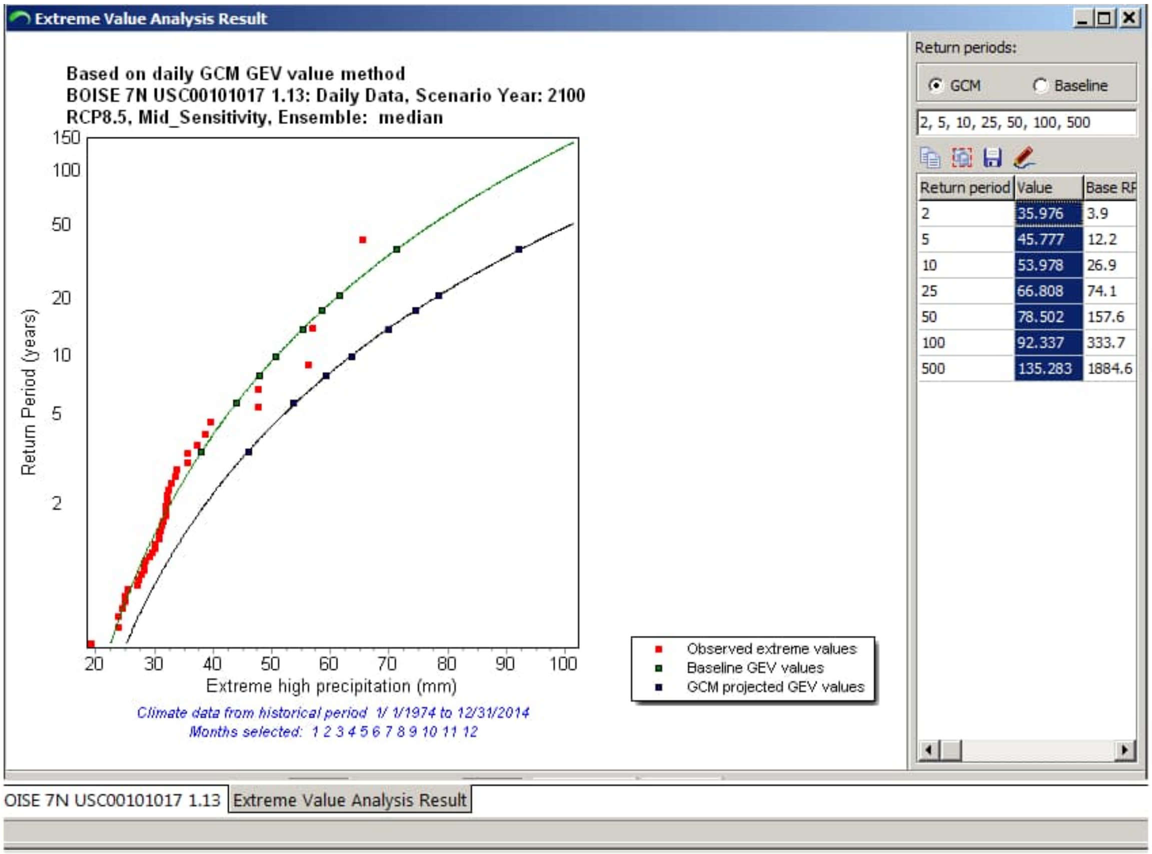
Generalized Extreme Value Process

The following steps assume that the local to global relationships previously outlined have been performed:

1. From the observed time series, extract the yearly maxima.
2. Fit a GEV curve.
3. The curve gives the extreme values for defined return periods (2-, 5-, 10-, 25-, 50-, 100-, and 500-year).
4. From the GCMs that produce daily projections, global patterns were extracted that contain the normalized (percent change per degree of global warming) change in the extreme event for these 11 return periods.
5. The model (or ensemble) change (from the normalized value, times the global mean temperature increase from the combination of SSP, climate sensitivity and year) is applied to the extreme values of the fitted curve (from Step 2).
6. A new curve is fitted to these (climate changed) extremes.

An example of the GEV process is shown herein with the following details:

- The red dots (in both graphs) are the observations (the highest value from each year).
- The green line is the GEV curve fitted through these observations (thus corresponding to the baseline - no climate change).
- The green dots correspond to the extreme values from the curve for the 11 specific return periods.
- The blue dots correspond to the climate changed extremes for these return periods (constructed from the normalized patterns for the 30 models) (the blue dots are the climate changed green dots).
- The blue line corresponds to the GEV curve fitted through these blue dots.



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Attachment 6. Projected Future Climate Percent Change and 24-Hour Event Depths

Attachment 6. Projected Future Climate Percent Change and 24-Hour Event Depths

	Percent Change From Updated Baseline								
Return Period (years)	Updated Baseline (inches)	2050, SSP2-4.5, 50%	2050, SSP2-4.5, 90%	2050, SSP5-8.5, 50%	2050, SSP5-8.5, 90%	2100, SSP2-4.5, 50%	2100, SSP2-4.5, 90%	2100, SSP5-8.5, 50%	2100, SSP5-8.5, 90%
2	3.47	6.1%	13.9%	8.0%	18.1%	9.5%	21.6%	21.9%	45.3%
5	4.60	8.4%	11.2%	11.0%	14.7%	13.1%	17.5%	30.0%	41.4%
10	5.45	9.4%	12.0%	12.4%	15.8%	14.7%	18.7%	33.7%	44.9%
25	6.58	10.2%	14.2%	13.4%	18.5%	15.9%	22.0%	36.5%	52.0%
50	7.48	11.0%	18.6%	14.4%	24.3%	17.1%	28.9%	39.3%	66.1%
100	8.40	11.5%	22.8%	15.1%	30.0%	17.9%	35.8%	41.1%	80.3%
500	10.65	12.4%	35.8%	16.3%	47.6%	19.3%	57.7%	44.4%	126.8%

	Depth in inches (Values in PDS converted from AMS)								
Return Period (years)	Updated Baseline	2050, SSP2-4.5, 50%	2050, SSP2-4.5, 90%	2050, SSP5-8.5, 50%	2050, SSP5-8.5, 90%	2100, SSP2-4.5, 50%	2100, SSP2-4.5, 90%	2100, SSP5-8.5, 50%	2100, SSP5-8.5, 90%
2	3.47	3.7	4.0	3.8	4.1	3.8	4.2	4.2	5.0
5	4.60	5.0	5.1	5.1	5.3	5.2	5.4	6.0	6.5
10	5.45	6.0	6.1	6.1	6.3	6.2	6.5	7.3	7.9
25	6.58	7.3	7.5	7.5	7.8	7.6	8.0	9.0	10.0
50	7.48	8.3	8.9	8.6	9.3	8.8	9.6	10.4	12.4
100	8.40	9.4	10.3	9.7	10.9	9.9	11.4	11.9	15.1
00	10.65	12.0	14.5	12.4	15.7	12.7	16.8	15.4	24.1

Attachment 7. Time Series of Scenarios Recommended for Modeling

Attachment 7. Time Series of Scenarios Recommended for Modeling (depth in inches)

Time (hours)	Updated Baseline, 10-yr	Updated Baseline, 25-yr	Updated Baseline, 50-yr	Updated Baseline, 100-yr	Updated Baseline, 500-yr	2050-High-50th_10- yr	2050-High-50th_25yr	2050-High-50th_50yr	2050-High-50th_100yr	2050-High-50th_500yr	2100-High-50th_10yr	2100-High-50th_25yr	2100-High-50th_50yr	2100-High-50th_100yr	2100-High-50th_500yr
0.25	0.017902	0.023152	0.027708	0.032591	0.045849	0.020112	0.026246	0.031701	0.0375	0.053299	0.023934	0.031598	0.038608	0.04599	0.066192
0.5	0.017902	0.023152	0.027708	0.032591	0.045849	0.020112	0.026246	0.031701	0.0375	0.053299	0.023934	0.031598	0.038608	0.04599	0.066192
0.75	0.017902	0.023152	0.027708	0.032591	0.045849	0.020112	0.026246	0.031701	0.0375	0.053299	0.023934	0.031598	0.038608	0.04599	0.066192
1	0.017902	0.023152	0.027708	0.032591	0.045849	0.020112	0.026246	0.031701	0.0375	0.053299	0.023934	0.031598	0.038608	0.04599	0.066192
1.25	0.017902	0.023152	0.027708	0.032591	0.045849	0.020112	0.026246	0.031701	0.0375	0.053299	0.023934	0.031598	0.038608	0.04599	0.066192
1.5	0.017902	0.023152	0.027708	0.032591	0.045849	0.020112	0.026246	0.031701	0.0375	0.053299	0.023934	0.031598	0.038608	0.04599	0.066192
1.75	0.017902	0.023152	0.027708	0.032591	0.045849	0.020112	0.026246	0.031701	0.0375	0.053299	0.023934	0.031598	0.038608	0.04599	0.066192
2	0.017902	0.023152	0.027708	0.032591	0.045849	0.020112	0.026246	0.031701	0.0375	0.053299	0.023934	0.031598	0.038608	0.04599	0.066192
2.25	0.017902	0.023152	0.027708	0.032591	0.045849	0.020112	0.026246	0.031701	0.0375	0.053299	0.023934	0.031598	0.038608	0.04599	0.066192
2.5	0.017902	0.023152	0.027708	0.032591	0.045849	0.020112	0.026246	0.031701	0.0375	0.053299	0.023934	0.031598	0.038608	0.04599	0.066192
2.75	0.017902	0.023152	0.027708	0.032591	0.045849	0.020112	0.026246	0.031701	0.0375	0.053299	0.023934	0.031598	0.038608	0.04599	0.066192
3	0.017902	0.023152	0.027708	0.032591	0.045849	0.020112	0.026246	0.031701	0.0375	0.053299	0.023934	0.031598	0.038608	0.04599	0.066192
3.25	0.017902	0.023152	0.027708	0.032591	0.045849	0.020112	0.026246	0.031701	0.0375	0.053299	0.023934	0.031598	0.038608	0.04599	0.066192
3.5	0.017902	0.023152	0.027708	0.032591	0.045849	0.020112	0.026246	0.031701	0.0375	0.053299	0.023934	0.031598	0.038608	0.04599	0.066192
3.75	0.017902	0.023152	0.027708	0.032591	0.045849	0.020112	0.026246	0.031701	0.0375	0.053299	0.023934	0.031598	0.038608	0.04599	0.066192
4	0.017902	0.023152	0.027708	0.032591	0.045849	0.020112	0.026246	0.031701	0.0375	0.053299	0.023934	0.031598	0.038608	0.04599	0.066192
4.25	0.017902	0.023152	0.027708	0.032591	0.045849	0.020112	0.026246	0.031701	0.0375	0.053299	0.023934	0.031598	0.038608	0.04599	0.066192
4.5	0.017902	0.023152	0.027708	0.032591	0.045849	0.020112	0.026246	0.031701	0.0375	0.053299	0.023934	0.031598	0.038608	0.04599	0.066192
4.75	0.017902	0.023152	0.027708	0.032591	0.045849	0.020112	0.026246	0.031701	0.0375	0.053299	0.023934	0.031598	0.038608	0.04599	0.066192
5	0.017902	0.023152	0.027708	0.032591	0.045849	0.020112	0.026246	0.031701	0.0375	0.053299	0.023934	0.031598	0.038608	0.04599	0.066192
5.25	0.017902	0.023152	0.027708	0.032591	0.045849	0.020112	0.026246	0.031701	0.0375	0.053299	0.023934	0.031598	0.038608	0.04599	0.066192
5.5	0.017902	0.023152	0.027708	0.032591	0.045849	0.020112	0.026246	0.031701	0.0375	0.053299	0.023934	0.031598	0.038608	0.04599	0.066192
5.75	0.017902	0.023152	0.027708	0.032591	0.045849	0.020112	0.026246	0.031701	0.0375	0.053299	0.023934	0.031598	0.038608	0.04599	0.066192
6	0.017902	0.023152	0.027708	0.032591	0.045849	0.020112	0.026246	0.031701	0.0375	0.053299	0.023934	0.031598	0.038608	0.04599	0.066192
6.25	0.035803	0.044956	0.053684	0.062692	0.08763	0.040225	0.050962	0.06142	0.072133	0.10187	0.047869	0.061356	0.074804	0.088464	0.126512
6.5	0.035803	0.044956	0.053684	0.062692	0.08763	0.040225	0.050962	0.06142	0.072133	0.10187	0.047869	0.061356	0.074804	0.088464	0.126512
6.75	0.035803	0.044956	0.053684	0.062692	0.08763	0.040225	0.050962	0.06142	0.072133	0.10187	0.047869	0.061356	0.074804	0.088464	0.126512
7	0.035803	0.044956	0.053684	0.062692	0.08763	0.040225	0.050962	0.06142	0.072133	0.10187	0.047869	0.061356	0.074804	0.088464	0.126512
7.25	0.035803	0.044956	0.053684	0.062692	0.08763	0.040225	0.050962	0.06142	0.072133	0.10187	0.047869	0.061356	0.074804	0.088464	0.126512
7.5	0.035803	0.044956	0.053684	0.062692	0.08763	0.040225	0.050962	0.06142	0.072133	0.10187	0.047869	0.061356	0.074804	0.088464	0.126512
7.75	0.035803	0.044956	0.053684	0.062692	0.08763	0.040225	0.050962	0.06142	0.072133	0.10187	0.047869	0.061356	0.074804	0.088464	0.126512
8	0.035803	0.044956	0.053684	0.062692	0.08763	0.040225	0.050962	0.06142	0.072133	0.10187	0.047869	0.061356	0.074804	0.088464	0.126512
8.25	0.035803	0.044956	0.053684	0.062692	0.08763	0.040225	0.050962	0.06142	0.072133	0.10187	0.047869	0.061356	0.074804	0.088464	0.126512
8.5	0.035803	0.044956	0.053684	0.062692	0.08763	0.040225	0.050962	0.06142	0.072133	0.10187	0.047869	0.061356	0.074804	0.088464	0.126512
8.75	0.035803	0.044956	0.053684	0.062692	0.08763	0.040225	0.050962	0.06142	0.072133	0.10187	0.047869	0.061356	0.074804	0.088464	0.126512
9	0.035803	0.044956	0.053684	0.062692	0.08763	0.040225	0.050962	0.06142	0.072133	0.10187	0.047869	0.061356	0.074804	0.088464	0.126512
9.25	0.055797	0.069232	0.078795	0.090509	0.118319	0.062688	0.078482	0.090149	0.104139	0.137546	0.074601	0.094488	0.109793	0.127717	0.170818

Time (hours)	Updated Baseline, 10-yr	Updated Baseline, 25-yr	Updated Baseline, 50-yr	Updated Baseline, 100-yr	Updated Baseline, 500-yr	2050-High-50th_10- yr	2050-High-50th_25yr	2050-High-50th_50yr	2050-High-50th_100yr	2050-High-50th_500yr	2100-High-50th_10yr	2100-High-50th_25yr	2100-High-50th_50yr	2100-High-50th_100yr	2100-High-50th_500yr
9.5	0.055797	0.069232	0.078795	0.090509	0.118319	0.062688	0.078482	0.090149	0.104139	0.137546	0.074601	0.094488	0.109793	0.127717	0.170818
9.75	0.055797	0.069232	0.078795	0.090509	0.118319	0.062688	0.078482	0.090149	0.104139	0.137546	0.074601	0.094488	0.109793	0.127717	0.170818
10	0.055797	0.069232	0.078795	0.090509	0.118319	0.062688	0.078482	0.090149	0.104139	0.137546	0.074601	0.094488	0.109793	0.127717	0.170818
10.25	0.055797	0.069232	0.078795	0.090509	0.118319	0.062688	0.078482	0.090149	0.104139	0.137546	0.074601	0.094488	0.109793	0.127717	0.170818
10.5	0.055797	0.069232	0.078795	0.090509	0.118319	0.062688	0.078482	0.090149	0.104139	0.137546	0.074601	0.094488	0.109793	0.127717	0.170818
10.75	0.053007	0.064737	0.077929	0.089678	0.11758	0.059554	0.073386	0.089158	0.103184	0.136687	0.070871	0.088353	0.108586	0.126545	0.16975
11	0.053007	0.064737	0.077929	0.089678	0.11758	0.059554	0.073386	0.089158	0.103184	0.136687	0.070871	0.088353	0.108586	0.126545	0.16975
11.25	0.108804	0.137566	0.158455	0.179356	0.230723	0.122242	0.155945	0.181289	0.206367	0.268215	0.145471	0.18775	0.220792	0.25309	0.333094
11.5	0.108804	0.137566	0.158455	0.179356	0.230723	0.122242	0.155945	0.181289	0.206367	0.268215	0.145471	0.18775	0.220792	0.25309	0.333094
11.75	0.278986	0.339868	0.389644	0.433445	0.536874	0.31344	0.385275	0.445792	0.498721	0.624116	0.373004	0.463852	0.54293	0.611634	0.775085
12	1.272174	1.391842	1.454672	1.504601	1.544067	1.429287	1.577792	1.664291	1.731194	1.794978	1.700897	1.899586	2.02694	2.123142	2.22917
12.25	0.58029	0.679737	0.737727	0.797139	0.914017	0.651956	0.77055	0.844033	0.917189	1.062545	0.775848	0.927705	1.027948	1.124843	1.319566
12.5	0.278986	0.339868	0.389644	0.433445	0.536874	0.31344	0.385275	0.445792	0.498721	0.624116	0.373004	0.463852	0.54293	0.611634	0.775085
12.75	0.108804	0.137566	0.158455	0.179356	0.230723	0.122242	0.155945	0.181289	0.206367	0.268215	0.145471	0.18775	0.220792	0.25309	0.333094
13	0.108804	0.137566	0.158455	0.179356	0.230723	0.122242	0.155945	0.181289	0.206367	0.268215	0.145471	0.18775	0.220792	0.25309	0.333094
13.25	0.053007	0.064737	0.077929	0.089678	0.11758	0.059554	0.073386	0.089158	0.103184	0.136687	0.070871	0.088353	0.108586	0.126545	0.16975
13.5	0.053007	0.064737	0.077929	0.089678	0.11758	0.059554	0.073386	0.089158	0.103184	0.136687	0.070871	0.088353	0.108586	0.126545	0.16975
13.75	0.055797	0.069232	0.078795	0.090509	0.118319	0.062688	0.078482	0.090149	0.104139	0.137546	0.074601	0.094488	0.109793	0.127717	0.170818
14	0.055797	0.069232	0.078795	0.090509	0.118319	0.062688	0.078482	0.090149	0.104139	0.137546	0.074601	0.094488	0.109793	0.127717	0.170818
14.25	0.055797	0.069232	0.078795	0.090509	0.118319	0.062688	0.078482	0.090149	0.104139	0.137546	0.074601	0.094488	0.109793	0.127717	0.170818
14.5	0.055797	0.069232	0.078795	0.090509	0.118319	0.062688	0.078482	0.090149	0.104139	0.137546	0.074601	0.094488	0.109793	0.127717	0.170818
14.75	0.055797	0.069232	0.078795	0.090509	0.118319	0.062688	0.078482	0.090149	0.104139	0.137546	0.074601	0.094488	0.109793	0.127717	0.170818
15	0.055797	0.069232	0.078795	0.090509	0.118319	0.062688	0.078482	0.090149	0.104139	0.137546	0.074601	0.094488	0.109793	0.127717	0.170818
15.25	0.035803	0.044956	0.053684	0.062692	0.08763	0.040225	0.050962	0.06142	0.072133	0.10187	0.047869	0.061356	0.074804	0.088464	0.126512
15.5	0.035803	0.044956	0.053684	0.062692	0.08763	0.040225	0.050962	0.06142	0.072133	0.10187	0.047869	0.061356	0.074804	0.088464	0.126512
15.75	0.035803	0.044956	0.053684	0.062692	0.08763	0.040225	0.050962	0.06142	0.072133	0.10187	0.047869	0.061356	0.074804	0.088464	0.126512
16	0.035803	0.044956	0.053684	0.062692	0.08763	0.040225	0.050962	0.06142	0.072133	0.10187	0.047869	0.061356	0.074804	0.088464	0.126512
16.25	0.035803	0.044956	0.053684	0.062692	0.08763	0.040225	0.050962	0.06142	0.072133	0.10187	0.047869	0.061356	0.074804	0.088464	0.126512
16.5	0.035803	0.044956	0.053684	0.062692	0.08763	0.040225	0.050962	0.06142	0.072133	0.10187	0.047869	0.061356	0.074804	0.088464	0.126512
16.75	0.035803	0.044956	0.053684	0.062692	0.08763	0.040225	0.050962	0.06142	0.072133	0.10187	0.047869	0.061356	0.074804	0.088464	0.126512
17	0.035803	0.044956	0.053684	0.062692	0.08763	0.040225	0.050962	0.06142	0.072133	0.10187	0.047869	0.061356	0.074804	0.088464	0.126512
17.25	0.035803	0.044956	0.053684	0.062692	0.08763	0.040225	0.050962	0.06142	0.072133	0.10187	0.047869	0.061356	0.074804	0.088464	0.126512
17.5	0.035803	0.044956	0.053684	0.062692	0.08763	0.040225	0.050962	0.06142	0.072133	0.10187	0.047869	0.061356	0.074804	0.088464	0.126512
17.75	0.035803	0.044956	0.053684	0.062692	0.08763	0.040225	0.050962	0.06142	0.072133	0.10187	0.047869	0.061356	0.074804	0.088464	0.126512
18	0.035803	0.044956	0.053684	0.062692	0.08763	0.040225	0.050962	0.06142	0.072133	0.10187	0.047869	0.061356	0.074804	0.088464	0.126512
18.25	0.017902	0.023152	0.027708	0.032591	0.045849	0.020112	0.026246	0.031701	0.0375	0.053299	0.023934	0.031598	0.038608	0.04599	0.066192
18.5	0.017902	0.023152	0.027708	0.032591	0.045849	0.020112	0.026246	0.031701	0.0375	0.053299	0.023934	0.031598	0.038608	0.04599	0.066192
18.75	0.017902	0.023152	0.027708	0.032591	0.045849	0.020112	0.026246	0.031701	0.0375	0.053299	0.023934	0.031598	0.038608	0.04599	0.066192
19	0.017902	0.023152	0.027708	0.032591	0.045849	0.020112	0.026246	0.031701	0.0375	0.053299	0.023934	0.031598	0.038608	0.04599	0.066192

Time (hours)	Updated Baseline, 10-yr	Updated Baseline, 25-yr	Updated Baseline, 50-yr	Updated Baseline, 100-yr	Updated Baseline, 500-yr	2050-High-50th_10- yr	2050-High-50th_25yr	2050-High-50th_50yr	2050-High-50th_100yr	2050-High-50th_500yr	2100-High-50th_10yr	2100-High-50th_25yr	2100-High-50th_50yr	2100-High-50th_100yr	2100-High-50th_500yr
19.25	0.017902	0.023152	0.027708	0.032591	0.045849	0.020112	0.026246	0.031701	0.0375	0.053299	0.023934	0.031598	0.038608	0.04599	0.066192
19.5	0.017902	0.023152	0.027708	0.032591	0.045849	0.020112	0.026246	0.031701	0.0375	0.053299	0.023934	0.031598	0.038608	0.04599	0.066192
19.75	0.017902	0.023152	0.027708	0.032591	0.045849	0.020112	0.026246	0.031701	0.0375	0.053299	0.023934	0.031598	0.038608	0.04599	0.066192
20	0.017902	0.023152	0.027708	0.032591	0.045849	0.020112	0.026246	0.031701	0.0375	0.053299	0.023934	0.031598	0.038608	0.04599	0.066192
20.25	0.017902	0.023152	0.027708	0.032591	0.045849	0.020112	0.026246	0.031701	0.0375	0.053299	0.023934	0.031598	0.038608	0.04599	0.066192
20.5	0.017902	0.023152	0.027708	0.032591	0.045849	0.020112	0.026246	0.031701	0.0375	0.053299	0.023934	0.031598	0.038608	0.04599	0.066192
20.75	0.017902	0.023152	0.027708	0.032591	0.045849	0.020112	0.026246	0.031701	0.0375	0.053299	0.023934	0.031598	0.038608	0.04599	0.066192
21	0.017902	0.023152	0.027708	0.032591	0.045849	0.020112	0.026246	0.031701	0.0375	0.053299	0.023934	0.031598	0.038608	0.04599	0.066192
21.25	0.017902	0.023152	0.027708	0.032591	0.045849	0.020112	0.026246	0.031701	0.0375	0.053299	0.023934	0.031598	0.038608	0.04599	0.066192
21.5	0.017902	0.023152	0.027708	0.032591	0.045849	0.020112	0.026246	0.031701	0.0375	0.053299	0.023934	0.031598	0.038608	0.04599	0.066192
21.75	0.017902	0.023152	0.027708	0.032591	0.045849	0.020112	0.026246	0.031701	0.0375	0.053299	0.023934	0.031598	0.038608	0.04599	0.066192
22	0.017902	0.023152	0.027708	0.032591	0.045849	0.020112	0.026246	0.031701	0.0375	0.053299	0.023934	0.031598	0.038608	0.04599	0.066192
22.25	0.017902	0.023152	0.027708	0.032591	0.045849	0.020112	0.026246	0.031701	0.0375	0.053299	0.023934	0.031598	0.038608	0.04599	0.066192
22.5	0.017902	0.023152	0.027708	0.032591	0.045849	0.020112	0.026246	0.031701	0.0375	0.053299	0.023934	0.031598	0.038608	0.04599	0.066192
22.75	0.017902	0.023152	0.027708	0.032591	0.045849	0.020112	0.026246	0.031701	0.0375	0.053299	0.023934	0.031598	0.038608	0.04599	0.066192
23	0.017902	0.023152	0.027708	0.032591	0.045849	0.020112	0.026246	0.031701	0.0375	0.053299	0.023934	0.031598	0.038608	0.04599	0.066192
23.25	0.017902	0.023152	0.027708	0.032591	0.045849	0.020112	0.026246	0.031701	0.0375	0.053299	0.023934	0.031598	0.038608	0.04599	0.066192
23.5	0.017902	0.023152	0.027708	0.032591	0.045849	0.020112	0.026246	0.031701	0.0375	0.053299	0.023934	0.031598	0.038608	0.04599	0.066192
23.75	0.017902	0.023152	0.027708	0.032591	0.045849	0.020112	0.026246	0.031701	0.0375	0.053299	0.023934	0.031598	0.038608	0.04599	0.066192
24	0.017902	0.023152	0.027708	0.032591	0.045849	0.020112	0.026246	0.031701	0.0375	0.053299	0.023934	0.031598	0.038608	0.04599	0.066192

Time (hours)	July 2019 at Ten Mile Creek (depth in inches)	Sept 2020 at Silver Springs (depth in inches)
0.25	0.02	0.01
0.5	0.36	0.05
0.75	0.06	0
1	0	0
1.25	0	0
1.5	0	0
1.75	0.01	0.01
2	0	0.01
2.25	0	0
2.5	0	0
2.75	0	0.02
3	0	0.01
3.25	0	0.01
3.5	0	0
3.75	0	0
4	0	0
4.25	0	0
4.5	0	0
4.75	0	0
5	0	0.04
5.25	0	0
5.5	0	0
5.75	0	0
6	0	0
6.25	0	0
6.5	0	0
6.75	0	0
7	0	0
7.25	0	0.06
7.5	0	0.06
7.75	0	0
8	0	0
8.25	0	0.05
8.5	0	0.08
8.75	0	0.02
9	0	0
9.25	0	0
9.5	0	0.01
9.75	0	0.09

Time (hours)	July 2019 at Ten Mile Creek (depth in inches)	Sept 2020 at Silver Springs (depth in inches)
10	0	0.01
10.25	0	0.01
10.5	0	0
10.75	0	0
11	0	0
11.25	0	0
11.5	0	0
11.75	0	0
12	0	0
12.25	0	0
12.5	0	0
12.75	0	0
13	0	0
13.25	0	0
13.5	0	0
13.75	0	0
14	0	0
14.25	0	0
14.5	0	0
14.75	0	0
15	0	0
15.25	0	0
15.5	0	0
15.75	0	0
16	0	0
16.25	0	0
16.5	0	0
16.75	0	0
17	0	0
17.25	0	0
17.5	0	0
17.75	0	0
18	0	0
18.25	0	0
18.5	0	0
18.75	0	0
19	0	0
19.25	0	0
19.5	0	0

Time (hours)	July 2019 at Ten Mile Creek (depth in inches)	Sept 2020 at Silver Springs (depth in inches)
19.75	0	0
20	0	0
20.25	0	0
20.5	0	0
20.75	0	0
21	0	0.01
21.25	0	0.01
21.5	0	0.01
21.75	0	0
22	0	0
22.25	0	0
22.5	0	0.03
22.75	0	0.04
23	0	0.02
23.25	0	0.02
23.5	0	0.05
23.75	0	0.04
24	0.03	0.04
24.25	0	0.05
24.5	0	0.05
24.75	0	0.13
25	0	0.24
25.25	0	0.98
25.5	0	0.48
25.75	0	0.4
26	0	0.36
26.25	0	0.19
26.5	0	0
26.75	0	0
27	0	0
27.25	0	0
27.5	0	0
27.75	0	0
28	0	0
28.25	0	0
28.5	0	0
28.75	0	0
29	0.01	0
29.25	0.02	0

Time (hours)	July 2019 at Ten Mile Creek (depth in inches)	Sept 2020 at Silver Springs (depth in inches)
29.5	0.02	0
29.75	0	0
30	0.02	0
30.25	0.02	0
30.5	0.03	0
30.75	0.03	0
31	0.03	0
31.25	0.01	0
31.5	0.01	0
31.75	0	0
32	0	0
32.25	0	0
32.5	0	0
32.75	0	0
33	0	0
33.25	0	0
33.5	0	0
33.75	0	0
34	0	0
34.25	0	0
34.5	0	0
34.75	0.46	0
35	1.54	0
35.25	1.28	0
35.5	0.82	0
35.75	0.1	0
36	0.08	0
36.25	0.08	0
36.5	0	0
36.75	0.04	0
37	0.05	0
37.25	0.01	0
37.5	0.02	0
37.75	0.01	0
38	0	0
38.25	0	0
38.5	0	0
38.75	0.01	0
39	0.05	0

Time (hours)	July 2019 at Ten Mile Creek (depth in inches)	Sept 2020 at Silver Springs (depth in inches)
39.25	0.07	0
39.5	0	0
39.75	0	0
40	0	0
40.25	0	0
40.5	0	0
40.75	0	0
41	0	0
41.25	0.01	0
41.5	0	0
41.75	0.02	0
42	0.06	0
42.25	0.05	0
42.5	0.01	0
42.75	0	0
43	0.01	0