September 2nd, 2020

City of Takoma Park Public Works Department
31 Oswego Avenue
Silver Spring, MD 20910

Attention: Daryl Braithwaite; Ali Khalilian; Kate Semmens

Subject: Takoma Park Stormwater Plan/Climate Change Final Report

Dear Daryl Braithwaite:

Attached to this document you will find the completed final report written by Cassidy Bornemann, Andrew Keenan, and John Kij on behalf of Doctor Franco Montalto's CIVE-T580 Stormwater Plan/Climate Change class and Drexel University. The results of the research conducted and summary of the services provided are detailed below in the report. The raw data used for this report are available upon request.

As previously outlined in the MOU, this project was conducted by students as part of an academic learning endeavor and therefore, Drexel makes no representations or warranties regarding the information found in the following report.

On behalf of Drexel, we would like to thank the City of Takoma Park's Public Works Department for this opportunity to work with you. If there are any questions in regard to this report, please contact the undersigned.

Sincerely:

Cassidy Bornemann

Andrew Keenan

John Kij

Prepared for:

Takoma Parks Public Works
31 Oswego Ave
Silver Spring, MD 20910

STORMWATER PLANNING UNDER CLIMATE CHANGE REPORT

Prepared by:

Drexel University
3141 Chestnut Street
Philadelphia, PA 19104

2 September 2020

Contents

1.0 Introduction

The following report has been prepared by Cassidy Bornemann, Andrew Keenan, and John Kij for the City of Takoma Park Public Works Department. This report is intended to show the methodology and results associated with an exercise in climate change analysis and modeling. The data presented in this report has been taken from publicly available sources and was further analyzed by the group to form predictions of precipitation changes that may occur in the City of Takoma Park.

The data in this report was taken from a variety of sources included but not limited to NOAA's Climate Explorer, the University of California Merced's MACA tool, and NOAA's Atlas 14. Data taken from each of these sources will be further explained in the subsequent sections of this report. Results and conclusions drawn from this exercise include a set of delta change factors and a case study of an area of concern in the City of Takoma Park.

2.0 Project Description

Drexel University has signed a MOU with the City of Takoma Park to have a group of students research and analyze the projected effects climate change will have on the City. By analyzing the available data on climate change it is expected that the group will be able to form predictions for the City on what the general consensus is between different global change models. From here, the City will be able to use this information as they wish while adhering to the MOU.

2.1 City Background

The City of Takoma Park is located in Montgomery County, Maryland and is a MS4 jurisdiction. The City's stormwater group is housed within the Public Works Department and has a relatively low budget of roughly $700,000 per year for capital projects, payroll, and maintenance. The City currently does not use any specific precipitation models and relies on the State standards for water quality and stormwater design. Being a MS4 jurisdiction, the majority of the stormwater group's projects are related to adhering with the State's guidelines.

Takoma Parks has not experienced any major storms of note over the last few years, but has been experiencing an increase in the frequency of flash rain events. These storm events cause localized flooding in several roadways and other low lying areas. To date, these flooding events have not caused severe property damage nor have obstructed traffic flow. The flooding is typically due to minor obstructions in their stormwater system. The City of Takoma Park does not view these flood events as a major concern at the time but rather an issue that should be considered in future designs.

Currently, Takoma Park has three major concerns in regard to stormwater in the City. Their main concerns are managing and maintaining their existing stormwater infrastructure, identifying future needs for the City in regard to stormwater management, and meeting the state requirement to treat 20% of existing impervious area within the City limits.

2.2 Analysis Goals

The goals for this project are primarily centered around developing a standardized and easily understandable method to show the effects climate change is expected to have on the City of Takoma Park. As the City's stormwater requirements are closely tied to the State's guidelines the flexibility the City currently has to modify its requirements are limited. However, as conditions permit the City has required additional stormwater measures on top of the State's baseline. For example, in low lying areas where flooding has been a known issue the City may require the developer design to the 20-year storm rather than the State's required 10-year storm. By developing new design storms with climate change accounted for the City will be able to better prepare for future conditions, especially in flood-prone areas throughout the City.

The full analysis of data will include two representative concentration paths (RCP) values; one of 4.5 and one of 8.5. The RCP values of 8.5 and 4.5 have been established to represent different emission scenarios with 8.5 being considered the scenario if emissions continue on the track they currently are on with minimal to no improvement. An RCP of 4.5 represents a scenario where emissions continue to rise for the next two decades but begin to fall following that.

3.0 Data Analysis Methodology

The data used throughout this report was downloaded from various publicly available sources. All data references can be found in the *References* section of the report.

3.1 Mean Annual Changes

Historical and projected precipitation data was downloaded from Climate Explorer in order to construct tables characterizing variability for three future planning periods (2020's, 2050's, and 2080's) in relation to the baseline (historical) data.

The data was compiled into an excel spreadsheet, where the baseline for the total annual precipitation was determined by averaging the precipitation data between 1970 and 2000. The maximum, minimum and average projected annual precipitation was then determined for each future planning period for an RCP of 4.5 and an RCP of 8.5.

To determine the change in the number of days with precipitation above 1", 2", and 3", a baseline was found for each by averaging the number of days matching the criteria between 1970 and 2000. The maximum, minimum, and average projected days with more than 1", 2", and 3", were then determined for each future planning period and for each RCP. The baseline was then subtracted from each scenario's minimum, average, and maximum projected precipitation to determine the change.

To determine the change in total monthly precipitation, the historical monthly precipitation was subtracted from the predicted monthly values for each RCP corresponding to the future period. The total seasonal precipitation was then determined by adding the values determined for each month corresponding to the season (such as adding all the minimum values for 2025's RCP 4.5 of March, April, and May for the 2025 RCP 4.5 spring minimum).

3.2 Global Change Model Ranking

In order to determine the appropriate delta change factors to use, the proper global change models (GCMs) were first selected. The first step of the analysis was to identify which GCMs most accurately represent observed precipitation data for the City of Takoma Park. Historical modeled data, from 1970-2000, for 20 GCMs was exported from the MACA tool for two different data sets (LIVNEH and METDETA). The two data sets represent different levels of accuracy for the area surrounding Takoma Park. The result of this produced 40 different data sets that could be compared to observed precipitation data[2]. Observed precipitation data was taken from Climate explorer for the period 1970-2000[1]. By taking the modeled past from the GCMs and comparing those values to observed precipitation data it is possible to determine which GCMs are the most accurate for Takoma Park.

All data sets were assigned a correlation value through an Excel analysis and from there the correlation values for each GCM (two datasets) were averaged together to determine a single correlation value for each GCM. The 10 most accurate GCMs were chosen and used for the DCF calculations.

3.3 Delta Change Factors

Delta change factors (DCF) represent a quantitative change from the current conditions to future conditions. DCFs can be broken down into both additive and multiplicative to represent different data sets. For example, temperature changes typically utilize additive change factors whereas precipitation changes use multiplicative factors. Below is the equation used to calculate the DCF:

$$DCF = 100 * \frac{Future - Historical}{Historical}$$

For the purpose of this exercise, multiplicative DCFs were calculated using data collected from the 10 selected global change models (GCMs). Historical modeled rainfall data from 1970 to 2000 was used as the historical data for the calculation. The data was averaged by month for the 30 years to determine the "historical" input by month for the DCF equation. Future projected data for the 10 selected GCMs was used to create 40 separate data sets (10 GCMs, 2 datasets and 2 RCPs) for the "future" input by month for the DCF equation. Thus, 40 monthly DCFs were generated for each of the chosen future time periods (2010-2039, 2040-2069, and 2070-2099).

4.0 Analysis Results

4.1 Mean Annual Changes

Table 1 below shows the annual precipitation change found using Climate Explorer for the 2020s, 2050s, and 2080s (these periods represent 2010-2039, 2040-2069, and 2070-2099, respectively). Tables 2 through 4 show the change in number of days with 1, 2 and 3 inches of rainfall, respectively. Overall, the tables show that the mean annual precipitation (in.) and the days with more than 1" and 2" of rainfall are expected to rise above the baseline for both low emission scenarios (RCP 4.5) and high emission scenarios (RCP 8.5). Table 5 displays the seasonal variation in precipitation.

Table 1: Annual precipitation changes based on low and high emission scenarios for the 2020s, 2050s, and 2080s.

Total Annual Precip						
43.5 in, Baseline (1970-2000)						
	RCP 4.5 (Low Emissions)			RCP 8.5 (High Emissions)		
Period	Min	Ave	Max	Min	Ave	Max
2020s	-18.9	0.3	24.0	-20.2	0.8	25.7
2050s	-19.1	1.5	27.4	-18.1	2.1	28.6
2080s	-20.7	2.0	35.2	-17.4	3.6	33.0

Table 2: Number of days with Precipitation Above 1"

Number of Days with Precipitation Above 1"						
5.9 days, Baseline (1970-2000)						
	RCP 4.5 (Low Emissions)			RCP 8.5 (High Emissions)		
	Min	Ave	Max	Min	Ave	Max
2020s	-5.7	0.0	10.9	-5.3	0.3	12.9
2050s	-5.5	0.5	13.7	-5.4	1.0	13.3
2080s	-5.5	0.8	14.3	-5.3	1.8	13.7

Table 3: Number of days with Precipitation Above 2"

Number of Days with Precipitation Above 2"						
0.5 days, Baseline (1970-2000)						
	RCP 4.5 (Low Emissions)			RCP 8.5 (High Emissions)		
	Min	Ave	Max	Min	Ave	Max
2020s	-0.5	0.1	3.7	-0.5	0.1	4.1
2050s	-0.5	0.2	4.1	-0.5	0.2	5.3
2080s	-0.5	0.2	4.0	-0.5	0.5	5.3

Table 4: Number of days with Precipitation Above 3"

Number of Days with Precipitation Above 3"						
0.1 days, Baseline (1970-2000)						
	RCP 4.5 (Low Emissions)			RCP 8.5 (High Emissions)		
	Min	Ave	Max	Min	Ave	Max
2020s	-0.1	0.0	2.2	-0.1	0.0	1.8
2050s	-0.1	0.0	1.8	-0.1	0.0	2.0
2080s	-0.1	0.0	2.6	-0.1	0.0	3.1

Table 5: Annual precipitation changes by season.

Total Seasonal Precip			RCP 4.5 (Low Emissions)			RCP 8.5 (High Emissions)		
Season	Baseline Precip (in)		Min	Ave	Max	Min	Ave	Max
Spring	11.0	2025	-7.6	0.9	15.1	-7.7	1.1	15.1
		2050	-7.6	1.1	16.1	-7.5	1.3	16.0
		2075	-7.5	1.3	16.6	-7.6	1.5	16.7
Summer	11.6	2025	-8.6	0.3	19.4	-8.6	0.5	18.0
		2050	-8.7	0.5	17.9	-8.8	0.6	18.3
		2075	-8.6	0.9	18.6	-9.0	1.1	20.2
Fall	10.5	2025	-8.9	0.0	15.7	-8.9	0.0	17.3
		2050	-8.9	0.0	16.3	-8.7	0.2	18.1
		2075	-8.9	0.3	17.6	-9.0	0.1	18.1
Winter	8.9	2025	-6.8	0.7	12.1	-6.6	0.7	12.6
		2050	-6.7	1.0	13.5	-6.5	1.2	14.0
		2075	-6.5	1.4	13.9	-6.6	1.9	15.5

As shown in Table 5 there is a fairly significant range of values for the change in seasonal precipitation. Values range from nearly -100% to 100%. This large range is based on all GCMs incorporated in the Climate Explorer being used to determine these values. Had the GCMs been analyzed for their accuracy in relation to historical data for the City of Takoma Park this range of values would likely be much smaller.

4.2 Global Change Model Ranking

As mentioned above, the GCMs were ranked based on correlation values between the projected historical precipitation data and the historical observed precipitation data that was acquired from the MACA tool[2]. The selected models are listed below in Table 6:

Table 6: Selected GCMs.

Selected Models
pr_bcc-csm1-1-m_
pr_CNRM-CM5_
pr_CSIRO-Mk3-6-0_
pr_GFDL-ESM2M_
pr_GFDL-ESM2G_
pr_inmcm4_
pr_IPSL-CM5B-LR_
pr_MIROC-ESM_
pr_MIROC-ESM-CHEM_
pr_MRI-CGCM3_

4.3 Delta Change Factors

Table 7, 8, and 9 below display the range of monthly delta change factors for 2010-2030, 2040-2069, and 2070-2099, respectively. Figures 1, 2, and 3 illustrate the range of monthly delta change factors for 2010-2039, 2040-2069, and 2070-2099, respectively. As can be seen from these tables and figures, there is a high level of variability for DCFs throughout each month, for each time slice. However, this variability is not uniform seasonally, as the absolute range and relative skew of the DCFs varies by month. Additionally, this monthly variability changes between time slices.

With this level of variability, proper selection of DCFs for design considerations is challenging. Despite some GCMs better representing the observed conditions than others, at this time there is no evidence to indicate one GCM is more likely to occur than another. Thus, it becomes difficult to dismiss even some of the extreme GCMs (and therefore DCFs) as outliers. However, by looking at a larger quantity of DCFs, this does provide some guidance in where GCMs and assumptions converge, or at least are heavily concentrated.

Table 7: Monthly delta change factors for 2010-2039.

Month	Max	95th	75th	Mean	Median	25th	5th	Min
1	39%	31%	14%	6%	1%	-4%	-8%	-13%
2	29%	21%	10%	5%	5%	-3%	-10%	-12%
3	25%	21%	10%	5%	6%	-3%	-10%	-14%
4	24%	15%	10%	6%	7%	-1%	-6%	-7%
5	25%	23%	12%	2%	3%	-7%	-17%	-20%
6	21%	18%	2%	-2%	-2%	-8%	-14%	-24%
7	16%	15%	9%	2%	5%	-5%	-13%	-18%
8	21%	14%	10%	4%	4%	-2%	-7%	-14%
9	34%	21%	12%	6%	5%	-1%	-5%	-18%
10	34%	26%	17%	7%	6%	-3%	-13%	-15%
11	25%	19%	6%	2%	2%	-3%	-15%	-15%
12	30%	23%	13%	5%	4%	-3%	-10%	-13%

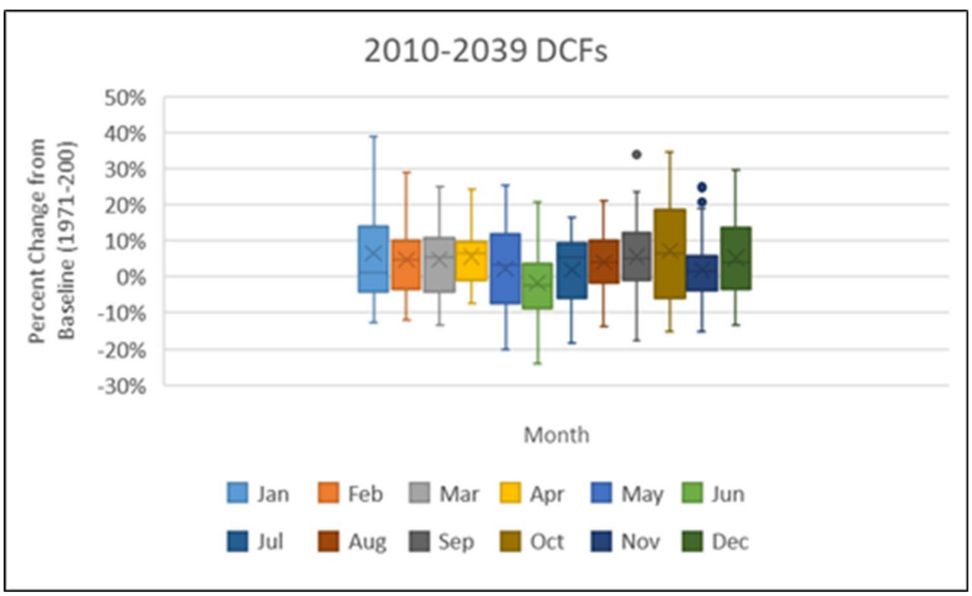

Figure 1: Box Plot of monthly delta change factors for 2010-2039.

Table 8: Monthly delta change factors for 2040-2069.

Month	Max	95th	75th	Mean	Median	25th	5th	Min
1	42%	38%	19%	11%	8%	1%	-7%	-11%
2	32%	30%	18%	10%	8%	3%	-5%	-7%
3	27%	20%	15%	8%	6%	0%	-4%	-7%
4	31%	20%	11%	7%	8%	1%	-4%	-9%
5	29%	23%	8%	2%	4%	-7%	-17%	-22%
6	41%	28%	6%	-1%	-2%	-10%	-21%	-27%
7	24%	21%	12%	2%	-1%	-7%	-14%	-21%
8	43%	34%	13%	6%	7%	-4%	-14%	-15%
9	45%	34%	12%	6%	2%	-2%	-9%	-10%
10	44%	41%	22%	10%	6%	0%	-12%	-21%
11	30%	24%	17%	8%	13%	-4%	-11%	-12%
12	31%	24%	18%	10%	13%	2%	-11%	-20%

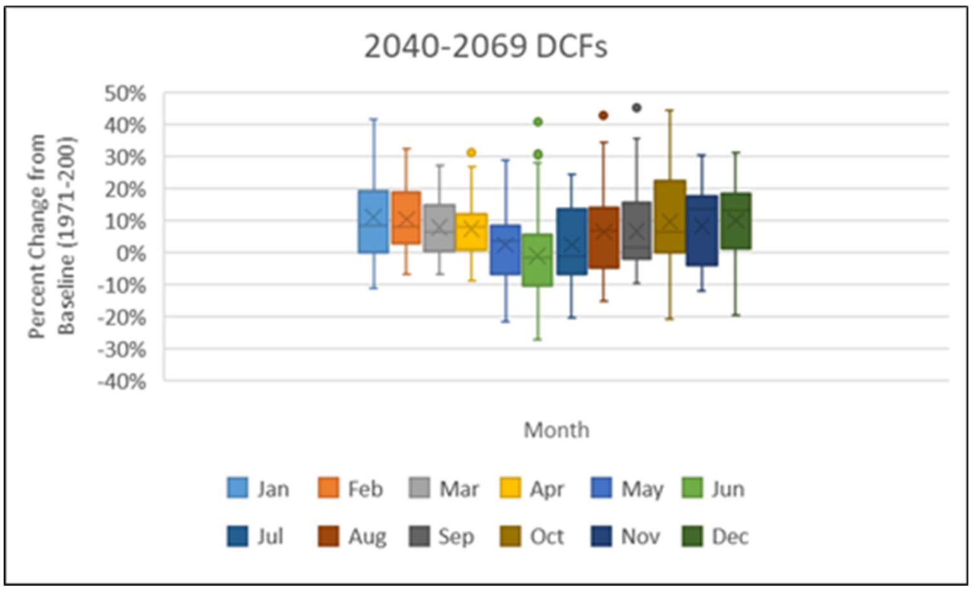

Figure 2: Box Plot of monthly delta change factors for 2040-2069.

Table 9: Monthly delta change factors for 2070-2099.

Month	Max	95th	75th	Mean	Median	25th	5th	Min
1	48%	46%	27%	16%	12%	5%	-8%	-17%
2	40%	37%	23%	16%	19%	11%	-6%	-10%
3	43%	31%	20%	12%	9%	2%	-2%	-10%
4	39%	27%	14%	9%	10%	2%	-6%	-8%
5	41%	33%	15%	5%	3%	-5%	-19%	-22%
6	40%	21%	11%	3%	1%	-8%	-15%	-18%
7	37%	26%	14%	5%	3%	-4%	-14%	-23%
8	39%	29%	14%	4%	-1%	-5%	-21%	-22%
9	39%	33%	13%	4%	0%	-6%	-14%	-22%
10	53%	38%	9%	4%	2%	-11%	-20%	-25%
11	40%	22%	15%	9%	11%	7%	-13%	-31%
12	42%	34%	23%	15%	17%	5%	-3%	-6%

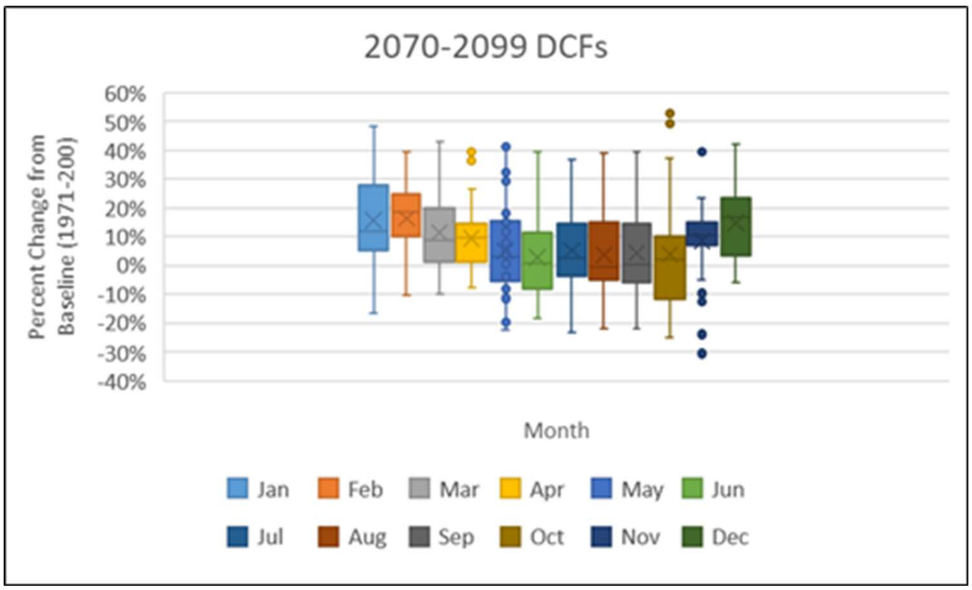

Figure 3: Box Plot of monthly delta change factors for 2070-2099.

Another way to help understand the variability in DCFs, and thus sources of uncertainty, is to isolate the distinct variables of the DCFs for comparison. As an example, one can isolate the data sets (LIVNEH or METDATA) and GCMs associated with each RCP, such that the range of DCFs within each RCP can be compared, in order to understand to what extent RCP selection influences the DCF variability. The same can be done for the data sets and GCMs. This process was completed for a cold weather and warm weather month (January and July, respectively) for the time slices of 2010-2039 and 2070-2099, as shown in Figure 4, in order to highlight some of the differences inherent in seasonal and temporal selections. While this is neither a statistical or comprehensive approach to understanding variability, it does provide a visual aid which is readily understood. As can be seen in Figure 4, the difference that the DCFs range between the data sets (METDATA vs LIVNEH) are minor, though METDATA tends to have a larger upper and lower bound of DCF, with the average skewing higher. With minor exceptions, RCP 8.5 DCFs skew higher than RCP 4.5, though the overall range between the two RCPs is not drastically different. Within a given month and time slice, a large part of the variability is driven by the individual GCM utilized. The variability between GCMs is not constant between months of time slices however, indicating that not just GCM selection, but the point in time in which it is being evaluated, drives the variability of DCFs here.

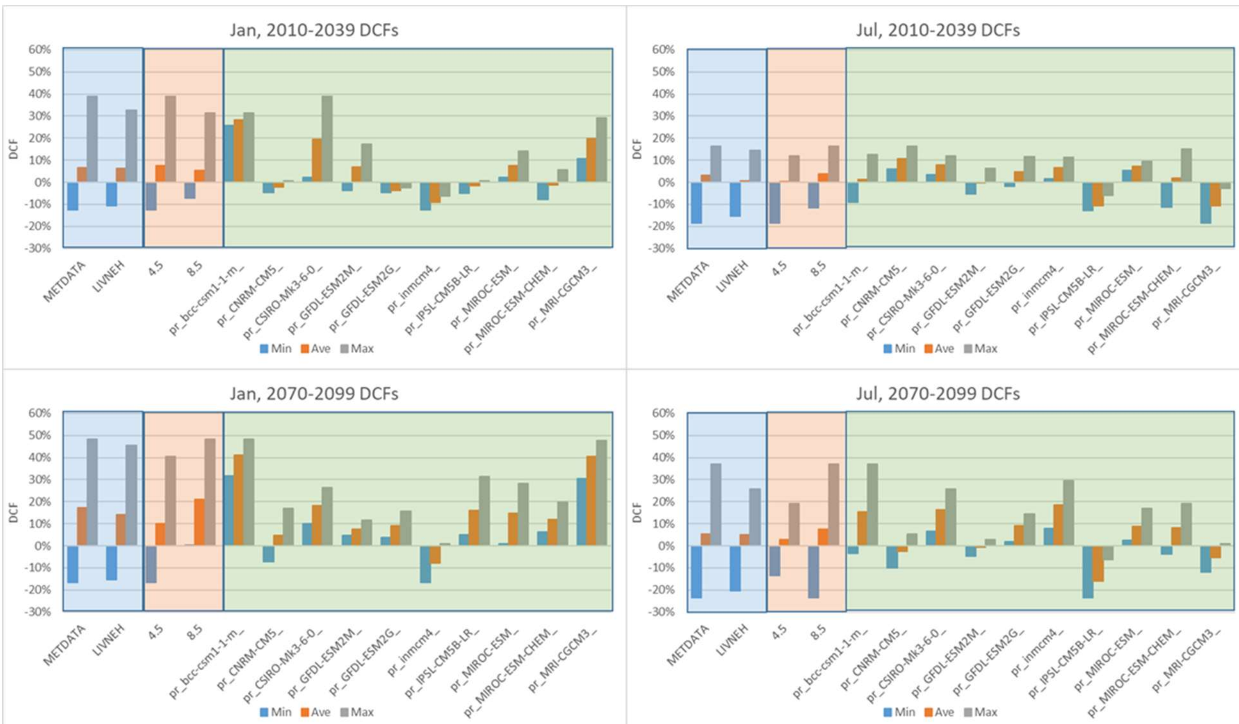

Figure 4: Factors of DCF Variability.

5.0 Adjusted Design Storms

One purpose of generating DCFs is to allow easy adjustment of existing design criteria for climate change considerations. For stormwater management, design storms, often dictated by local or state agencies, are one of the design considerations most impacted by climate change. For Takoma Park, the 2-Yr 24 Hour, 10-Yr 24 Hour, and 100-Yr 24 Hour design storms are common design criteria[4], and the impacts of climate change are explored further for these storms. In order to scale the design storms relevant to the City, DCF's representing a plausible range of change were selected. The DCFs shown in Table VI show DCFs selected to represent a potential low, median, and high scenario for the periods 2040-2069 and 2070-2099. The low represents the minimum DCF of all those calculated for that time period, while the high represents the maximum DCF calculated for that time period. The median represents the median of all DCFs calculated for that time period.

While the selected DCFs do not necessarily represent the most prudent design considerations, namely for the high scenario, they do illustrate the full range of variability which is likely possible for this area. Thus, if the low and high scenarios do not present any challenges to existing infrastructure, the system may be considered resilient to worst case scenarios for climate change. However, should the extreme values presented in the low or high scenarios pose potential risks, further analysis is needed to understand what level or risk the City should consider.

Table 11 shows the design storms of interest adjusted based on the selected DCFs noted in Table 10. While Takoma Park follows the MD Stormwater Design Manual for design storm standards, the design storms are based on county level data from 2000[4]. The most recent Atlas 14 update includes design storm data specific to the Takoma Park area, which may be more indicative of actual storm depths for the noted return periods5. Thus, design storms from both the MD Stormwater Design Manual and Atlas 14 are provided in Table 11.

Table 10: Selected DCFs.

Period	2040-2069			2070-2099		
Scenario	Low	Median	High	Low	Median	High
Assumption	Min of Jun	Med of All	Max of Sep	Min of Nov	Med of All	Max of Oct
DCF	-27%	6%	45%	-31%	8%	53%

Table 11: Design Storm Adjustments.

Source, Location, Year	Storm	Storm Depth (in)	2040-2069			2070-2099		
			Low	Median	High	Low	Median	High
Atlas 14, Takoma Park, 2004	2-Yr, 24 Hour	3.19	2.32	3.38	4.63	2.21	3.44	4.88
	10-Yr, 24 Hour	4.90	3.57	5.19	7.12	3.40	5.28	7.49
	100-Year, 24-Hour	8.46	6.16	8.96	12.29	5.87	9.12	12.94
MD Manual, Montgomery County, 2000	2-Yr, 24 Hour	3.20	2.33	3.39	4.65	2.22	3.45	4.89
	10-Yr, 24 Hour	5.10	3.71	5.40	7.41	3.54	5.50	7.80
	100-Year, 24-Hour	7.20	5.24	7.62	10.46	4.99	7.76	11.01

DCFs can be used to scale not just the storm depth, but the entire temporal profile of a storm. Figure 5, Figure 6, and Figure 7 show the current and adjusted temporal distributions of the Atlas 14 2-Yr 24 Hour, 10-Yr 24 Hour, and 100-Yr 24 Hour design storms, respectively. It was assumed that the DCF would apply uniformly across the entire storm duration. A third quartile design storm from Atlas 14 was utilized for the intensity profile. This storm represents one in which the majority of the rainfall occurs during the third quarter of the storm (hours 14-19 for a 24 hour storm).

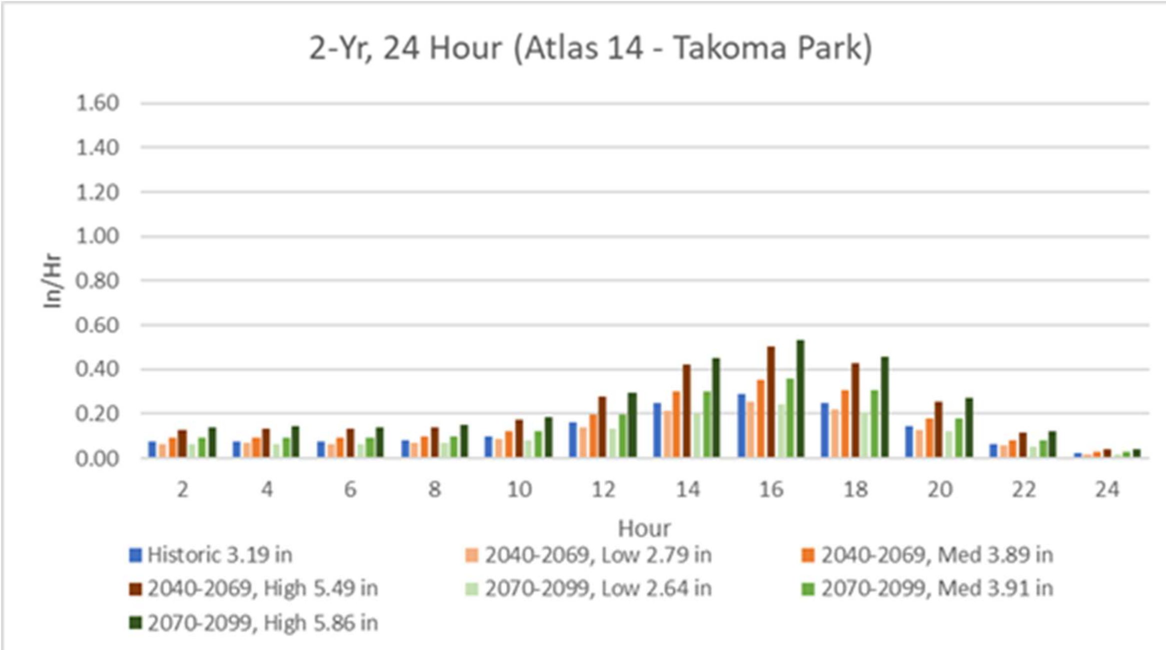

Figure 5: Temporal Distribution of 2-YR, 24 Hour design storm for Takoma Park, MD.

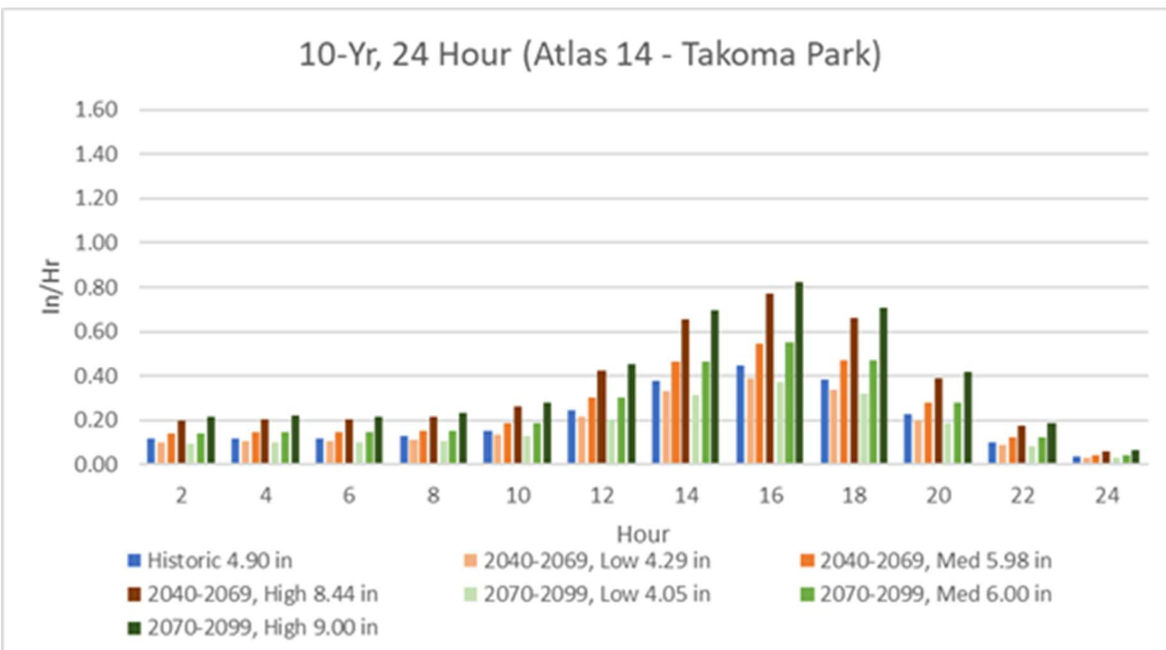

Figure 6: Temporal Distribution of 10-YR, 24 Hour design storm for Takoma Park, MD.

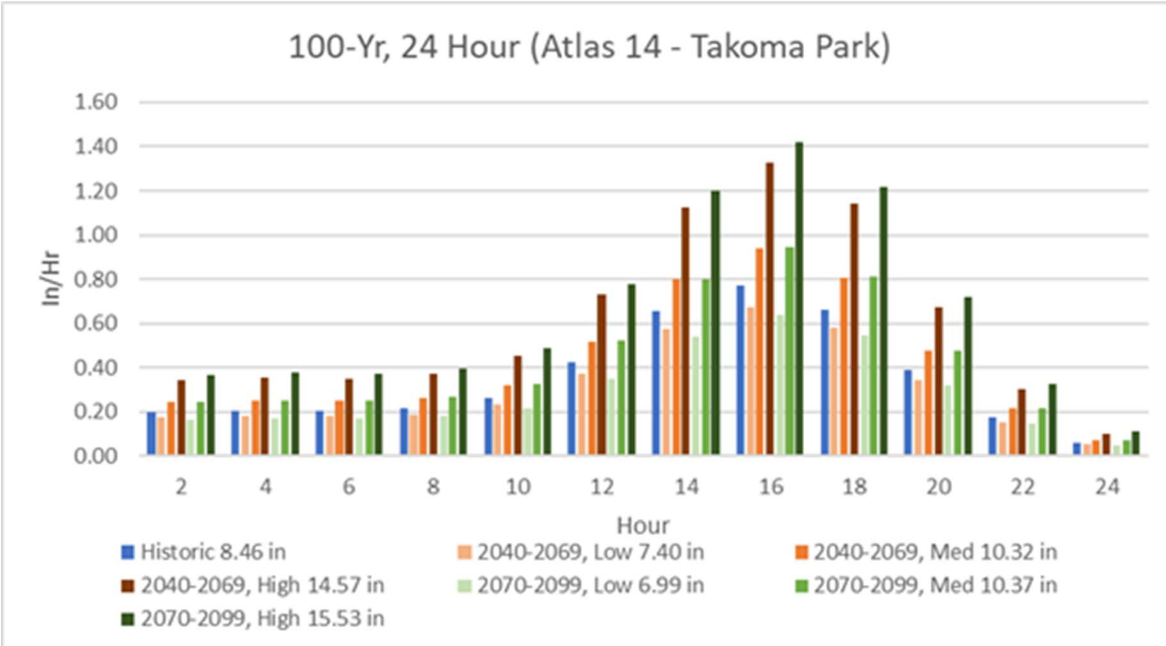

Figure 7: Temporal Distribution of 100-YR, 24 Hour design storm for Takoma Park, MD.

6.0 Case Study

In order to demonstrate the impacts of climate change, a small stormwater modeling case study was conducted for an area of interest to the City. The case study site selected by the City is the intersection of 2nd Avenue and Allegheny Avenue, as this site experiences minor flooding due to being located at a low point in the area. An aerial image of the site can be seen below in Figure 8.

Figure 8: Google Maps view of modeled site.

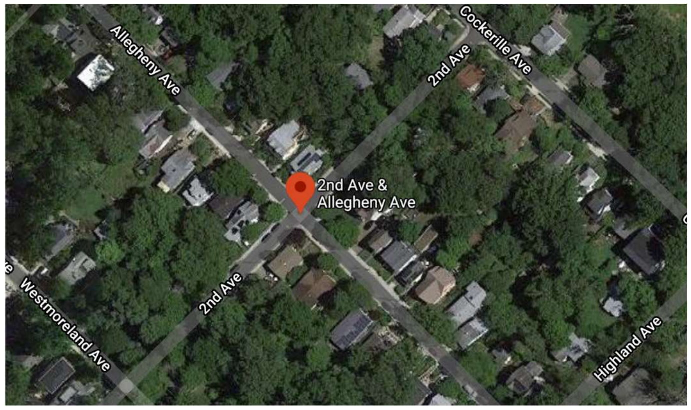

Figure 9: Google Aerial view of modeled site.

A simplified stormwater model was created in EPA's Storm Water Management Model (SWMM) software for the site as well as the upstream areas which would likely contribute to the flooding in this area. As shown in Figure 10, the City delineated the site area and contributing area with a small and large radius from the intersection of 2nd Ave and Allegheny Ave, respectively. Using elevation data, a more focused contributing area was selected for modeling, as highlighted in blue in Figure 10. The total modeled area was divided into a total of 24 subcatchments, with characteristics such as slope, previous area, flow path length, etc. specific to each subcatchment. The model is thus able to simulate the anticipated volume of rainfall and surface runoff generated by this total area for a given design storm. It was beyond the scope of this study to include the complete conveyance system that supports this area. Instead, it was assumed that runoff would flow to a downstream subcatchment, until ultimately reaching the site subcatchment, at which point flow exists the system via an outfall node. Additionally, calibration of the model based on observed conditions was not possible for this study, and thus there is additional uncertainty inherent in the modeling results.

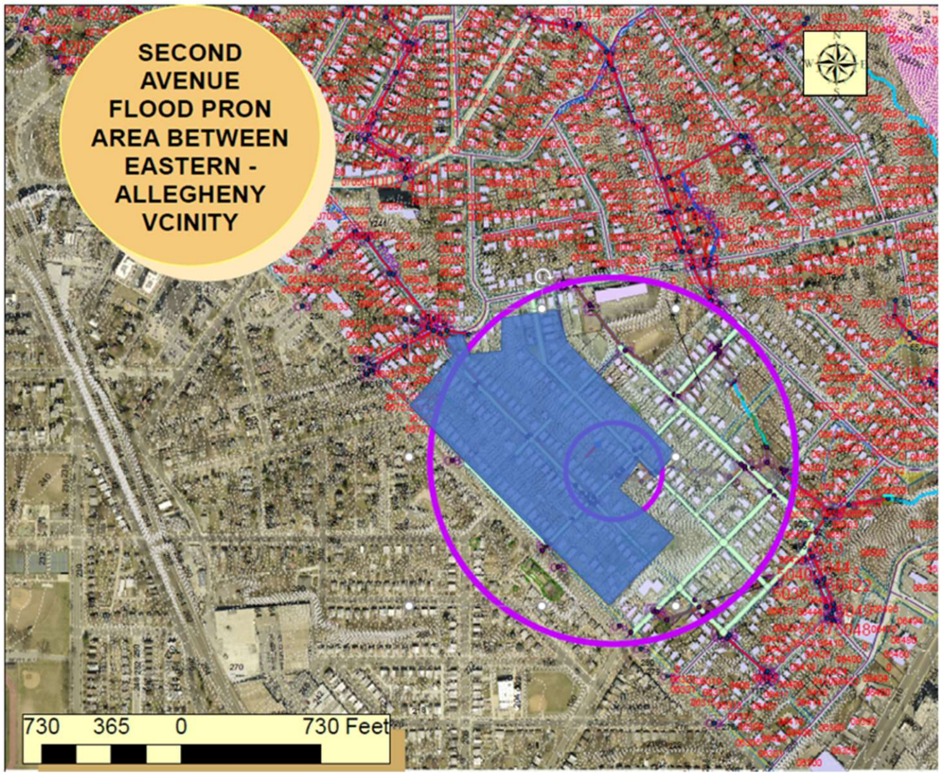

Figure 10: Case Study Modeled Area.

Scenarios for fifteen design storms of interest were created, consisting of the "Atlas 14" 2-Yr 24 Hr, 10-Yr 24 Hr, and 100-Yr 24 Hr design storms as of present, as well as design storms adjusted with the 2040-2069 and 2070-2099 Median and High DCFSs, as previously summarized in Table VII. The low scenario DCFs were excluded from the modeling case study as these values all represented a reduction in total precipitation from existing design storms, and thus do not provide meaningful insight to future flooding concerns.

Table 12 provides a summary of the modeling results for each scenario. While these results are not representative of actual surface runoff and flooding conditions, due to the lack of conveyance system modeling and calibration, they do provide a realistic look at the total volumetric rainfall and runoff potential for the areas which may contribute to runoff flowing to the site. This can provide some insight to the relative impacts of climate change and the extent to which existing design criteria may be inadequate for future conditions.

Table 12: Stormwater Modeling Case Study Results

Scenario	Total Precipitation (in.)	Total Precipition (ac-ft)	Surface Runoff (in)	Surface Runoff (ac-ft)	Surface Runoff Change from Baseline (%)
2-Yr, 24 Hr	3.19	6.19	1.24	2.40	0.0%
2-Yr, 24 Hr, 2040-2069 Median	3.38	6.56	1.32	2.56	6.5%
2-Yr, 24 Hr, 2040-2069 High	4.63	8.99	1.90	3.68	53.0%
2-Yr, 24 Hr, 2070-2099 Median	3.44	6.68	1.35	2.62	8.8%
2-Yr, 24 Hr, 2070-2079 High	4.88	9.47	2.01	3.91	62.5%
10-Yr, 24 Hr	4.90	9.51	2.02	3.93	0.0%
10-Yr, 24 Hr, 2040-2069 Median	5.19	10.07	2.16	4.20	6.9%
10-Yr, 24 Hr, 2040-2069 High	7.12	13.81	3.12	6.05	54.1%
10-Yr, 24 Hr, 2070-2099 Median	5.28	10.26	2.21	4.29	9.2%
10-Yr, 24 Hr, 2070-2079 High	7.49	14.54	3.31	6.42	63.6%
100-Yr, 24 Hr	8.46	16.42	3.81	7.39	0.0%
100-Yr, 24 Hr, 2040-2069 Median	8.96	17.39	4.07	7.90	6.9%
100-Yr, 24 Hr, 2040-2069 High	12.29	23.85	5.88	11.41	54.4%
100-Yr, 24 Hr, 2070-2099 Median	9.12	17.71	4.16	8.07	9.2%
100-Yr, 24 Hr, 2070-2079 High	12.94	25.11	6.24	12.12	63.9%

As shown in Table 12, for each design storm, selecting a high scenario (rather than median) is responsible for greater change in total precipitation and surface from the baseline than selecting the time slice of 2070-2099 (rather than 2040-2069. This is an indication that, while future conditions may increase the expected rainfall amount, and thus there is DCF variability related to selection of a planning horizon, selection of GCM is largely driving variability.

7.0 Conclusion and Recommendations

While climate change is what seems to be an evolving topic, global change models have been established and refined to best represent predictions in everything from precipitation to temperature changes. This report primarily focused on precipitation changes and how it has the potential to impact stormwater management. The main goal of this exercise was to develop a standardized and easily understandable method for quantifying the impacts of climate change on the city of Takoma Park. By determining new design storms that can be used in future design applications, this goal was met by the project team.

While results of this exercise are specific to the area of Takoma Park, MD and its immediate surroundings, the image below shows that similar precipitation increases are expected for the cities surrounding Takoma Park:

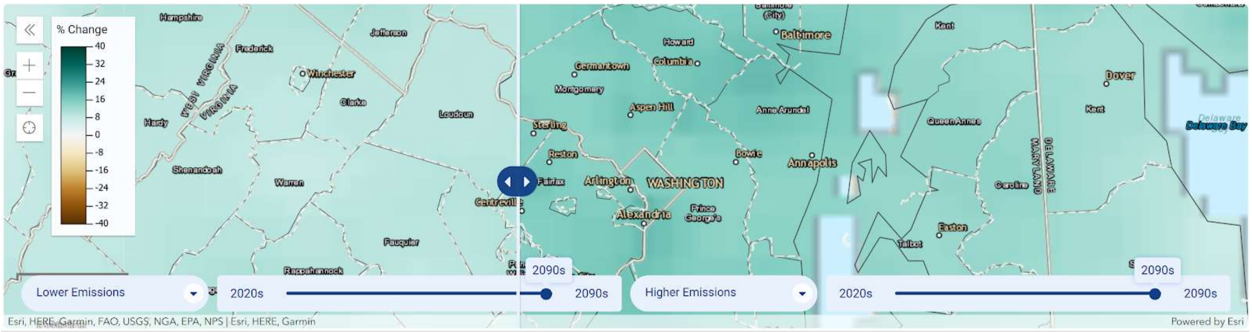

Figure 11: Map of the City of Takoma Park and surrounding areas and the projected annual precipitation increase based on an RCP of 8.5 (Climate Explorer).

Based on the knowledge gained throughout this exercise, the project team believes the revised design storms will provide an appropriate order of magnitude to drive further investigation into the effects climate change will have on the City. While the City of Takoma Park must meet the minimum design criteria the State of Maryland has set forth, it would likely be beneficial to determine design storms specific to the City that incorporate predictions based on climate change.

Additionally, the City should pursue updating any existing stormwater models with design storms adjusted for climate change. If the City does not already have a comprehensive stormwater model, including the entire stormwater system, this should be created in order to identify localized areas of the conveyance system which may be prone to backups and flooding as a result of climate change.

Finally, it should be noted that neither the DCFs selected for the case study, nor the GCMs selected to generate them, represent the only possible outcome for climate change. As has been seen through several of the analysis results, there are many assumptions and thus, uncertainty with climate change projections and DCF calculations. However, understanding the relative impacts of climate change and the order or magnitude on which they exist still provide value for planning and decision making. Rather than allowing the DCFs presented here to drive specific design criteria adjustments, this work should be used to facilitate a dialogue with regulators, customers, and other shareholders about the potential challenges climate change will pose, as well as potential mitigations which can be achieved with support from those engaged.

8.0 References

[1]*Climate Explorer,* crt-climate-explorer.nemac.org/.

[2]Google. Google Maps. https://www.google.com/maps.

[3]*MACA Statistical Downscaling Method,* climate.northwestknowledge.net/MACA/data_csv.php.

[4]*Maryland Stormwater Design Manual , Volumes I and II.* Maryland Department of the Environment. (2000). https://mde.maryland.gov/programs/water/StormwaterManagementProgram/Pages/stormwater_design.aspx.

[5]US Department of Commerce, N. O. A. A. (2005, November 7). HDSC/OWP. https://www.nws.noaa.gov/oh/hdsc/index.html.