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Analysis of Climate Change Scenarios and Implications for Stormwater Management in Frederick, MD

BY:

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FOR:

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CIVET580 – STORMWATER PLANNING IN AN ERA OF CLIMATE CHANGE | DREXEL UNIVERSITY

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EXECUTIVE SUMMARY

In order to meet the objectives of the Drexel university course *Stormwater planning in the era of Climate Change*, our team performed an extreme precipitation study on behalf of the City of Frederick, MD located approximately fifty (50) miles north/northwest of the City of Baltimore. To begin the study, the team held an interview with three representatives of the subject community on Monday, July 6. This interview allowed our team to develop a clear understanding of the community's stormwater management needs and its current operational approach and design methods. Our team was also able to better understand the goals of the community for implementing climate change projections into its design methods and the obstacles experienced in these efforts. After completion of the interview, the team took the following steps to complete the study.

- The team was provided with the location of an area of interest to the community, which served as the focal point of this study. The site is a little more than five (5) acre s in area of which approximately sixty-seven (67) percent is impervious surfaces and is historically prone to flooding from runoff from the stockyards to the north and from Pine Avenue on the west. Based on 2012 topography, our team discovered that the site drained from northwest to southeast and that the site was on the downstream end of a 76-acre area that contributes to an existing storm sewer system discharging onto Carroll Creek. The team used the Curve Number Method to characterize the hydrologic response of the area.
- The team used an online tool called "The Climate Explorer" to evaluate the historical and projected climate trends for Frederick. At the request of the City, our team analyzed historical observations to supplement The Climate Explorer. The team formulated what amounted to a "virtual" rain gauge based on a conglomeration of historical data downloaded from multiple gauges located around both the City and County. This was necessary since no single station that had data coverage over the entire requested baseline period from 1971-2020.
- The team also downloaded historical modeled climate data from twenty (20) available global climate models (GCM's) through the online MACA tool and selected 10 GCMs for analysis based on how well the models replicated the average annual rainfall totals as seen from observed historical data. From these10 GCM models, the team extracted results from two emissions scenarios (RCP 4.5 and RCP 8.5) and two downscaling approaches to develop a range of monthly Delta Change Factors (DCF) values for five (5) time slices (2020, 2040, 2050, 2070, 2080). Our team selected three (3) DCFs per time slice based on the average median, 75th, and 90th percentiles of summertime (June - September) monthly DCF values calculated.
- These DCF values were used to adjust the historical rainfall depths for the 1, 10, and 100-year storm events. The resulting projected storm rainfall depths were used , along with the calculated hydrologic site parameters (Drainage Area, T_c, CN, etc.) and the NRCS type II distribution to formulate a hydrologic model (HEC-HMS) for the area contributing to the site to evaluate the projected 1-, 10-, and 100-year design storms at the City's request.

Based on the results of the analysis, the team was able to make several general observations.

1.) There is a large amount of variability in the projections of rainfall amounts made by the GCMs due to the variability of the GCMs and underlying assumptions and processes. The uncertainties increase by varying emissions scenarios (RCP 4.5 versus 8.5) and downscaling approach.
2.) Despite the high amount of variation in precipitation projections, on average, model results indicate that there is an increasing trend for annual and monthly precipitation amounts.
3.) The precipitation increases in monthly average rainfall are not constant throughout the year and tend to vary by season with winter and summer months showing the highest increase amounts.
4.) Seasonality analyses of historical precipitation records further show that there is a higher occurrence of storms of all frequencies in the summertime.
5.) The largest impacts from climate change and precipitation increases would be observed during the summer months.
6.) Climate projections will likely result in the shifting of the frequencies associated with certain rainfall depths causing higher rainfall to occur more frequently which will have implications to existing stormwater infrastructure performance and maintenance as well as to future infrastructure level of service and economic lifespan.

1.0 BACKGROUND

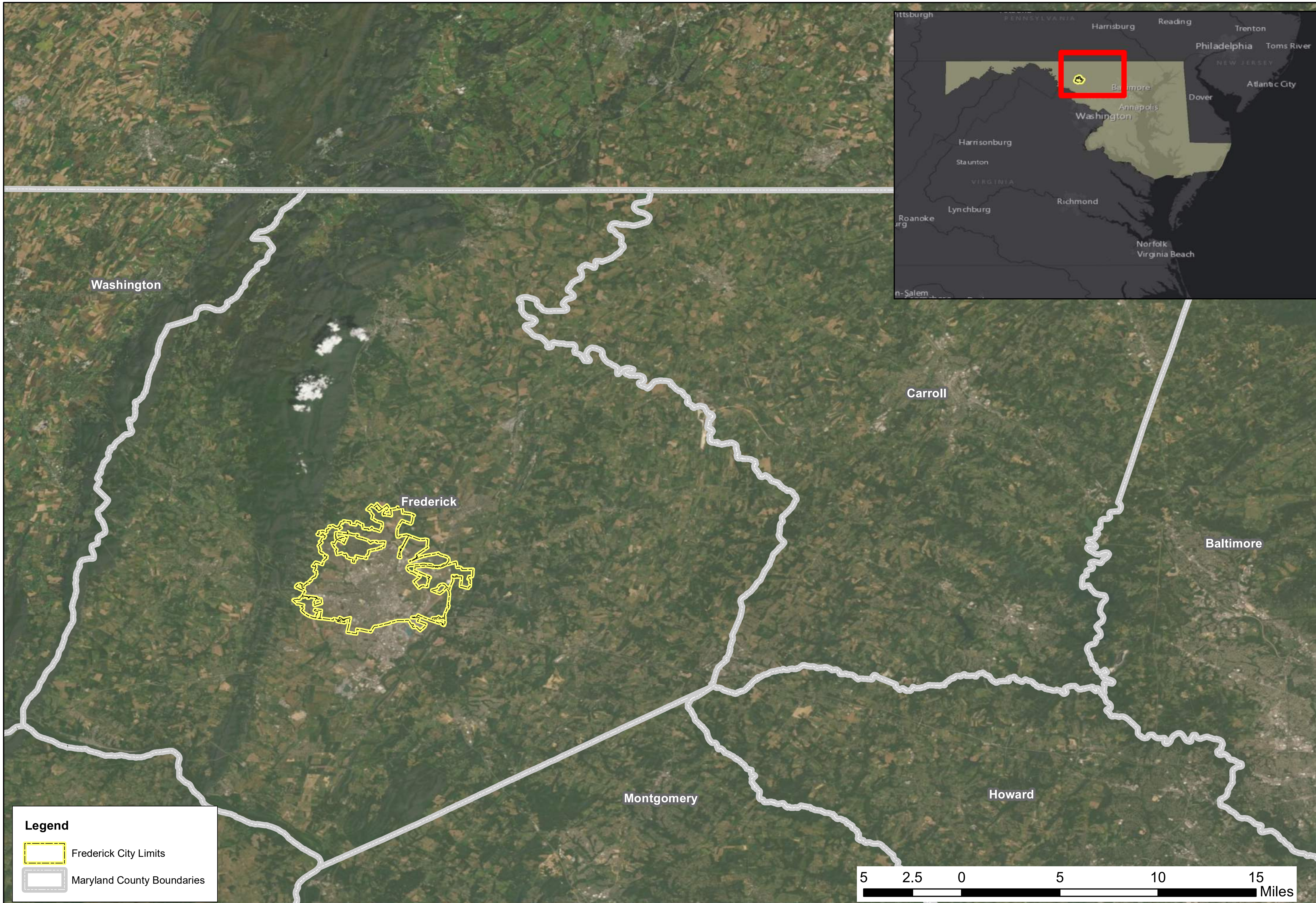
In order to meet the objectives of the Drexel university course *Stormwater planning in the era of Climate Change*, our team performed a precipitation study on behalf of the City of Frederick, MD located approximately fifty (50) miles north/northwest of the City of Baltimore and is located within Frederick County (See Figure 1). To begin the study, the team held an interview with three representatives of the subject community on Monday, July 6. This interview allowed our team to develop a clear understanding of the community's stormwater management needs as well as its current operational approach and design methods. It also allowed the team to fully document the goals of the community for implementing climate change projections into its design methods along with obstacles it has experienced in these efforts. Following completion of the interview, the team was provided with the location of an area of interest to the community, which served as the focal point of this study. The following sections describe the findings and results of the study along with key insights into the community's current needs, operational approach, and design methods as well as its goals for climate change implementation, the obstacles to reaching those goals and suggestions for overcoming those obstacles in the future.

2.0 CASE STUDY SITE

The focal site for this study is a site with an areas of a little more than five (5) acres, triangularly shaped, which the team chose to refer to as the Pine Avenue/East Church Street/County Lane Triangle (Triangle) for study purposes. It is located within the City of Frederick's corporate limits, and slightly south/southeast of the community center. It is bounded to the north/northwest by Pine Avenue, to the south/southeast by East Church Street, and to the north/northeast by County Lane. Of the total site area, approximately sixty-seven (67) percent, or three and a third ($3^1/_3$) acres is impervious surfaces.

The site contains multiple parcels consisting of single-family residential, light industrial, and institutional land uses. The primary discharge point for site runoff is located near the southeast corner and consists of an inlet, located at the intersection East Church Street and County Lane, that drains to an outfall located along the Carroll Creek. Other existing stormwater infrastructure adjacent to the site is found along Pine Ave between East 5th and East Church Streets and along East Church Street between Pine Avenue and County Lane. There is no other existing stormwater infrastructure located on the County Lane side of the Triangle.

The site is of interest to the community due to the issue of flooding regularly occurring in the area behind the residential properties located toward the southwest corner of the site along both Pine Avenue and East Church Street (See Figure 2). The primary cause of the flooding historically appears to be runoff from the stockyards located to the north and from the Pine Avenue side of the Triangle. Based on the current design criteria for the Maryland Department of the Environment (MDE) which is the basis for the design of stormwater infrastructure in Frederick, sites can be characterized by the Curve Number approach. Our team used a 2012 Digital Elevation Model (DEM) retrieved from MDiMAP which provided topographic source of data for drainage area delineation. Upon review of the topography around the site, our team realized that a much larger area (around 76 acres in total) contribute to the outlet of the storm sewer system that services the case study site. The site lies very close to the outlet of the system and is likely subject to overland flow from close to 70 acres upstream that may not be adequately captured by the existing storm system. Given that the primary concern for this site was the runoff in the back of the residential lots coming from the north and west which coincided with our observations of the topographic patterns that would govern overland flow in the area, our team decided to delineate a drainage area that would contribute to the storm sewer system outlet, including the requested site since this site will be affected by upstream runoff not directly related to the site itself. Figure 3 provides an overview of the drainage area delineated and the corresponding hydrologic parameters. The site had a weighted average curve number of 87 with an average percentage of impervious cover of 70%. The area is mostly developed already with concrete roads and storm sewer system with inlets and grates so a time of concentration of 10 minutes was calculated based on the TR-55 method which resulted in a lag time of 6 minutes.



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DATUM & COORDINATE SYSTEM: NAD83 State Plane (feet) Maryland

FILE NAME: Figure 1_VicinityMap

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CIVE T580: Stormwater Planning in an Era of Climate Change

Study Area - City of Frederick, MD

FIGURE 1

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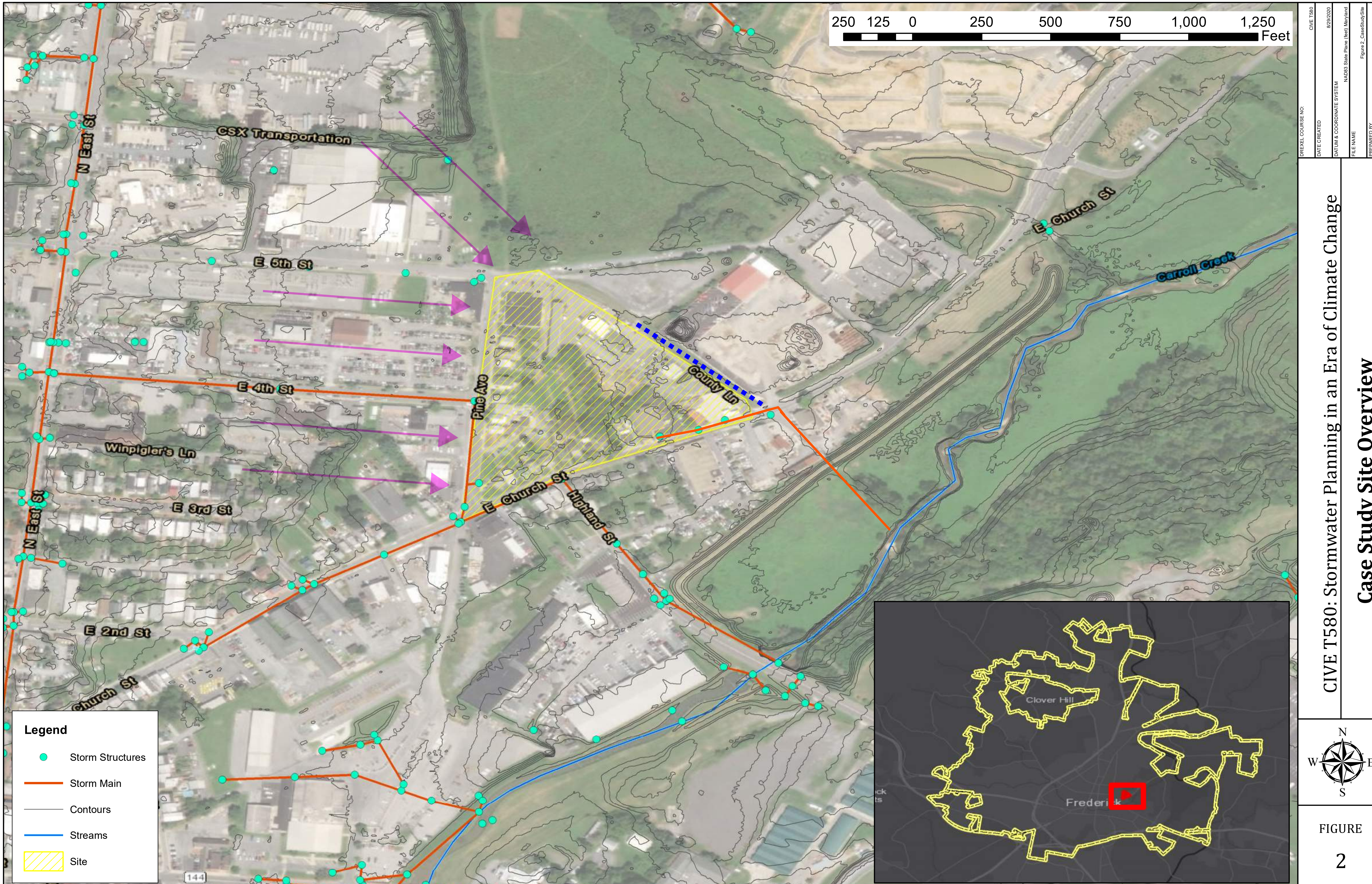

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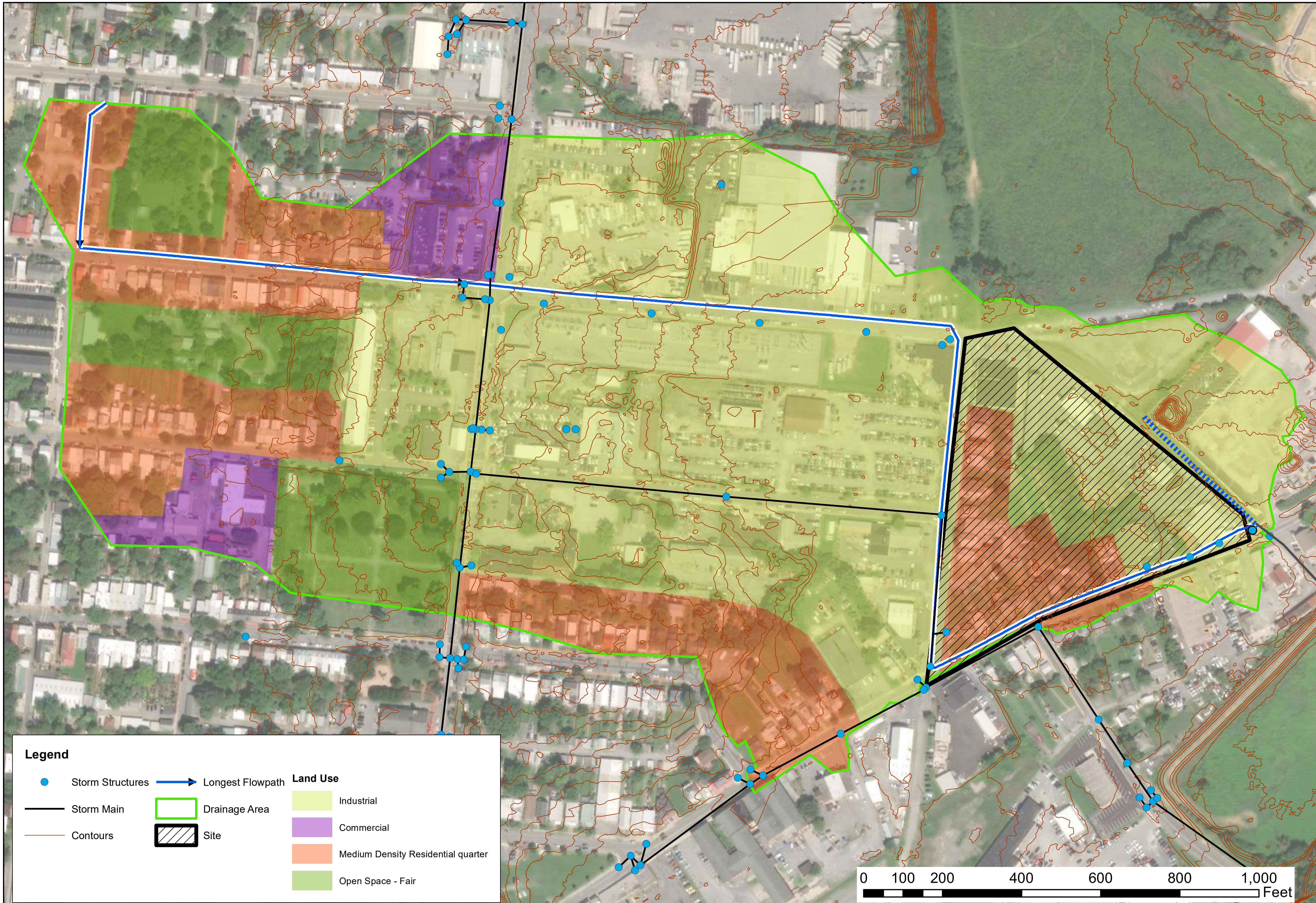

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Existing Hydrologic Conditions - Case Study Site

N W E S

FIGURE

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3.0 CLIMATE PROJECTIONS

3.1 THE CLIMATE EXPLORER

To get a starting idea of what the climate normals for Frederick are and what they could become in the future, our team used an online, publicly-available tool called "The Climate Explorer" which synthesizes climate normals from historical observations from gage data as well as basic statistics for climate projections from 35 global climate models (GCMs) and two emissions scenarios (RCP 4.5 and 8.5). The Climate Explorer reports climate normals from 1950 to 2006 and climate projections from 2006 to 2100. Additionally, The Climate Explorer also synthesizes the results of the 35 GCMs for the historical period of 1950 through 2006 which we will refer to as "historical modeled" results. As can be seen in Table 1, the GCM projections for historical periods do not exactly match the historical observations from gage records.

3.2 SUPPLEMENTAL GAGE ANALYSIS

For the purposes of this class, the period of 1971 through 2000 was chosen as a baseline for establishing what current climate normals are in each community. However, in conversation with City of Frederick (City) representatives, our team learned that the City had experienced a significant storm event during 2018 and that the City was desiring to also develop a baseline period which included this storm event from 2018. At the request of the community representatives, the team needed to evaluate the fifty (50) year baseline period from 1971-2020 to capture the two most significant recent storm events for the community. Since The Climate Explorer tool did not include climate averages for any years more recent than 2006 and the team was unable to find one single gage station that had data coverage over the entire desired baseline period, it was necessary for the team to utilize data averaged from a network of the available gauges to gain full coverage of the period. Our team formulated what amounted to a "virtual" rain gauge based on a conglomeration of historical data downloaded from a total of ten (10) gauges located at various points around both the City and County (See Figure 4) to supplement the data from The Climate Explorer for the missing years of 2007 through Summer of 2020. Table 1 summarizes the results for average annual and seasonal precipitation amounts for the historical baseline period of 1971 through 2000 from data retrieved from The Climate Explorer. It also includes the results for average annual and seasonal precipitation amounts for the historical baseline period of 1971 through 2020 based on data from The Climate Explorer and supplemented by data from our "virtual" gage analysis. Based on this analysis, the average annual precipitation using a baseline period of 1971-2000 is 42.8 inches a year whereas the average annual precipitation using a baseline period of 1971 – 2020 is 43.6 inches which shows a difference of 0.8 inches per year.

3.3 CITY OF FREDERICK IN THE FUTURE – AN OVERVIEW

In looking to the GCMs for future climate projections, it was important to determine what time periods were most relevant for the City in its planning needs. For the purposes of the class, standard 30-year time periods centered around the decades of 2020, 2050, and 2080. After conversations with City representatives, our team additionally included time periods centered around 2040s and 2070s to reflect 20-year and 50-year planning horizons for City infrastructure. Based on these five time periods, or time slices, our team analyzed the results from the climate projections from both RCP 4.5 and RCP 8.5 scenarios for the 35 GCMs. For each of the requested time slices centered around 2025, 2045, 2055, 2075, and 2085 both annual and seasonal totals were calculated for each of the emissions scenarios. Table 1 contains a summary of the minimum, mean, and maximum annual and seasonal precipitation amounts (in inches) from GCM results per time slice and emissions scenario. Table 2 summarizes these same results as percentage changes relative to the historical modeled baseline values. From these results, we observed that the percent changes in average annual and seasonal precipitation amounts increases with time and generally the results from models using emissions scenarios of RCP 8.5 have a higher percentage of increase in average precipitation amounts than results from models using RCP 4.5 emissions. Review of these results also showed that the models had a wide range of results showing minimum annual precipitation amounts that would result in decreases with respect to historical observed data and also maximum precipitation that would results in as high as 25% increase to historical observed data. This shows a wide range of variability in GCM results.

Table 1. Summary of Historical and Projected Precipitation Statistics for Frederick, MD

Table 1A: Historical and Projected Annual Precipitation Amounts, in inches

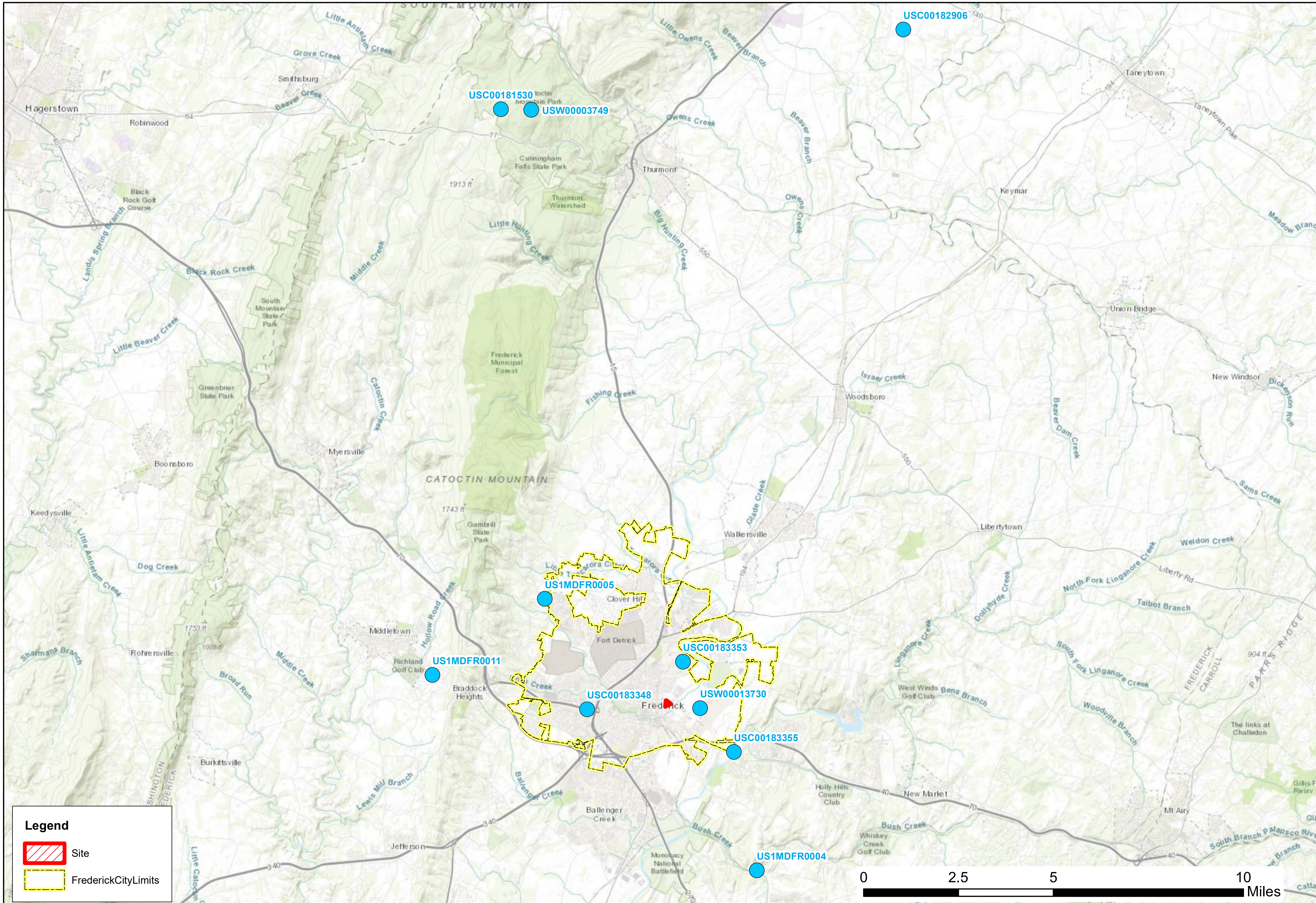
Historical				RCP 4.5				RCP 8.5			
Time Slice[1]	**Minimum**	**Average**	**Maximum**	**Time Slice[1]**	**Minimum[5]**	**Average**	**Maximum[5]**	**Time Slice[1]**	**Minimum[4]**	**Average**	**Maximum[5]**
Historical Modeled[2] Baseline 1 -1985	24.6	40.5	59.9	2025	24.1	42.6	69.6	2025	23.7	43.1	66.5
Historical Oberved[3] Baseline 1 -1985	32.4	42.8	66.8	2045	25.4	43.1	69.6	2045	24.6	43.7	68.4
Historical Oberved[4] Baseline 1 -1995	25.6	43.6	66.8	2055	25.1	43.9	71.1	2055	24.6	44.3	71.2
				2075	24.6	44.7	74.3	2075	24.2	45.5	73.3
				2085	22.7	44.3	74.3	2085	24.2	45.9	74.7

Table 1B: Historical and Projected Seasonal Precipitation Amounts, in inches

Winter	**Average**	**Winter**	**Minimum[7]**	**Average[7]**	**Maximum[7]**	**Winter**	**Minimum[7]**	**Average[7]**	**Maximum[7]**
Historical Oberved[6] Baseline	8.70	2025	2.2	9.2	20.0	2025	2.4	9.3	20.6
Spring		2050	2.3	9.6	21.5	2050	2.4	9.8	21.9
Historical Oberved[6] Baseline	11.10	2075	2.4	10.0	21.9	2075	2.3	10.5	23.4
Summer		**Spring**				**Spring**			
Historical Oberved[6] Baseline	10.80	2025	3.6	11.8	25.6	2025	3.4	12.1	25.6
Autumn		2050	3.6	12.2	26.6	2050	3.7	12.3	26.7
Historical Oberved[6] Baseline	10.40	2075	3.7	12.4	27.2	2075	3.6	12.6	27.3
		Summer				**Summer**			
		2025	2.9	11.2	28.5	2025	2.7	11.3	27.6
		2050	2.6	11.3	27.8	2050	2.7	11.4	28.3
		2075	2.8	11.7	28.2	2075	2.5	11.9	30.2
		Autumn				**Autumn**			
		2025	1.7	10.4	25.6	2025	1.7	10.3	26.9
		2050	1.7	10.4	26.2	2050	1.8	10.5	27.7
		2075	1.7	10.7	27.8	2075	1.6	10.5	28.1

Notes:

1. Time slice used for analysis is centered around the reported year, i.e., the reported year lies in the middle of the dataset.
2. From annual totals of historical model results for the period of 1971 - 2000 as downloaded from The Climate Explorer, accessed in the summer of 2020, for the City of Frederick, MD.
3. From observed annual precipitation totals for the period of 1971 - 2000 as compiled and downloaded through the Climate Explorer, accessed in the summer of 2020, for
4. From observed annual precipitation totals for the period 1971 -2005 as compiled and downlaoded through the Climate Explorer and supplemented with observed annual precipitation amounts for the years 2007 - 2020 based on a gage analysis for nearby active NCDC gages.
5. Minimum and Maximum values cited reflect the minimum / maximum annual precipitation within the time slice reported for any of the available 35 GCM's for a given RCP scenario.
6. From monthly averages of observed data as compiled and accessed through the Climate Explorer. Range of observed data is unknown and non-adjustable.
7. Season defined as: Winter- December, January, February; Spring - March, April, May; Summer - June, July, August; Autumn - September, october, November. Statistic reported is a result of the addition of the corresponding statistic of threemonths in the season based on projected precipitation montly totals (,i.e., the minimum value reported is the sum of monthly minimum precipitation amounts for the three months within each season for a given time slice and RCP scenario, the maximum value reported is the sum of the monthly maximum precipitation amounts for the three months.., the average value reported is the sum of the monthly average precipitation for the three months..)



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FILE NAME Figure 4_GageAnalysisMap
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Supplemental Gage Analysis Data

FIGURE

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Table 2. Summary of Historical and Projected Precipitation Changes for Frederick, MD

Table 2A: Projected Changes in Annual Precipitation Totals, % of Historical Modeled

Historical				RCP 4.5				RCP 8.5			
Time Slice[1]	Minimum (in)	Average (in)	Maximum (in)	Time Slice[1]	Minimum[5]	Average	Maximum[5]	Time Slice[1]	Minimum[4]	Average	Maximum[5]
Historical Modeled[2] Baseline 1 -1985	24.6	40.5	59.9	2025	-2%	5%	16%	2025	-4%	6%	11%
Historical Oberved[3] Baseline 1 -1985	32.4	42.8	66.8	2045	3%	6%	16%	2045	0%	8%	14%
Historical Oberved[4] Baseline 1 -1995	25.6	43.6	66.8	2055	2%	9%	19%	2055	0%	10%	19%
				2075	0%	11%	24%	2075	-2%	12%	22%
				2085	-8%	10%	24%	2085	-2%	13%	25%

Table 2B: Projected Changes in Seasonal Precipitation Totals, % of Historical Observed

Historical		RCP 4.5		RCP 8.5	
Winter	Average	**Winter**	Average[7]	**Winter**	Average[7]
Historical Oberved[6] Baseline	8.70	2025	6%	2025	7%
Spring		2050	11%	2050	13%
Historical Oberved[6] Baseline	11.10	2075	15%	2075	20%
Summer		**Spring**		**Spring**	
Historical Oberved[6] Baseline	10.80	2025	7%	2025	9%
Autumn		2050	10%	2050	11%
Historical Oberved[6] Baseline	10.40	2075	11%	2075	13%
		Summer		**Summer**	
		2025	3%	2025	5%
		2050	5%	2050	5%
		2075	8%	2075	10%
		Autumn		**Autumn**	
		2025	0.1%	2025	-1.0%
		2050	0%	2050	1%
		2075	3%	2075	1%

Notes:

1. Time slice used for analysis is centered around the reported year, i.e., the reported year lies in the middle of the dataset.
2. From annual totals of historical model results for the period of 1971 - 2000 as downloaded from The Climate Explorer, accessed in the summer of 2020, for the City of Frederick, MD.
3. From observed annual precipitation totals for the period of 1971 - 2000 as compiled and downloaded through the Climate Explorer, accessed in the summer of 2020, for the City
4. From observed annual precipitation totals for the period 1971 -2005 as compiled and downlaoded through the Climate Explorer and supplemented with observed annual precipitation amounts for the years 2007 - 2020 based on a gage analysis for nearby active NCDC gages.
5. Minimum and Maximum values cited reflect the minimum / maximum annual precipitation within the time slice reported for any of the available 35 GCM's for a given RCP scenario compared to the corresponding statistic during the baseline period for modeled historical results.
6. From monthly averages of observed data as compiled and accessed through the Climate Explorer. Range of observed data is unknown and non-adjustable.
7. Season defined as: Winter- December, January, February; Spring - March, April, May; Summer - June, July, August; Autumn - September, october, November. Statistic reported is a result of the addition of the corresponding statistic of three months in the season based on projected precipitation montly totals and compared to the average for the season from montly historical observed averages from The Climate Explorer (,i.e., the minimum value reported is the sum of monthly minimum precipitation amounts for the three months within each season for a given time slice and RCP scenario, the maximum value reported is the sum of the monthly maximum precipitation amounts for the three months.., the average value reported is the sum of the monthly average precipitation for the three months..)

4.0 METHODOLOGY FOR CASE STUDY

4.1 GENERAL APPROACH AND DATA SOURCES

The GCMs (global climate models) developed to model the effects of increasing greenhouse emissions on the world's climate use large grid cells for its computations of physical processes. The scale at which these computations happen does not allow for the raw results from these models to be useful without downscaling. There are many methods for downscaling which vary from statistical downscaling to dynamic downscaling. While dynamic downscaling may capture more complexities of the interactions of different climate variables and yield higher resolution data, it requires extensive computational power which was not available for the purposes and within the timeframe of this project. Statistical downscaling then provides a faster approach which yield results that are consistent with the observed natural relationships between various climate variables based in historical statistical distributions. While many variations of statistically based downscaling exist, the online MACA tool compiles and provides the public with access to already statistically-downscaled climate projection data for as far in the future as 2100. It also provides results for modeled historical periods as far back as 1950. Additionally, the MACA tool allows the user to select between two downscaling resolutions, namely the

LIVNEH and the METDATA, which provides flexibility to the user. Due to the MACA tool providing readily-available and easily-accessible downscaled data for 20 of the GCMs, our team used this available data to analyze the results from the GCMs and develop observations that could lead us to an estimate of expected change in climate variables, namely precipitation for our purposes.

Since there are 20 GCMs which are available for download through the MACA tool and they will all lead to different results, the first step would be to select models that may have a better performance in projecting future climate. Since the future is unknown and determining which models project the future best is not directly possible, the models were evaluated in their ability to project the climate of the past. The goal would be to select models that best capture the regional historical observations of rainfall depths with the assumption that these same models would continue to best capture the expected climate for the region in future times. After selecting the models, monthly model projections of precipitation amounts would be retrieved and analyzed by developing average monthly totals within each time slice. These monthly averages per selected model in each time slice would then be compared to the modeled historical results of the same model. This comparison would yield a Delta Change Factor (DCF) which captures the change expected and which is specific to that model and month. Namely, the DCF for a given month and model was calculated as:

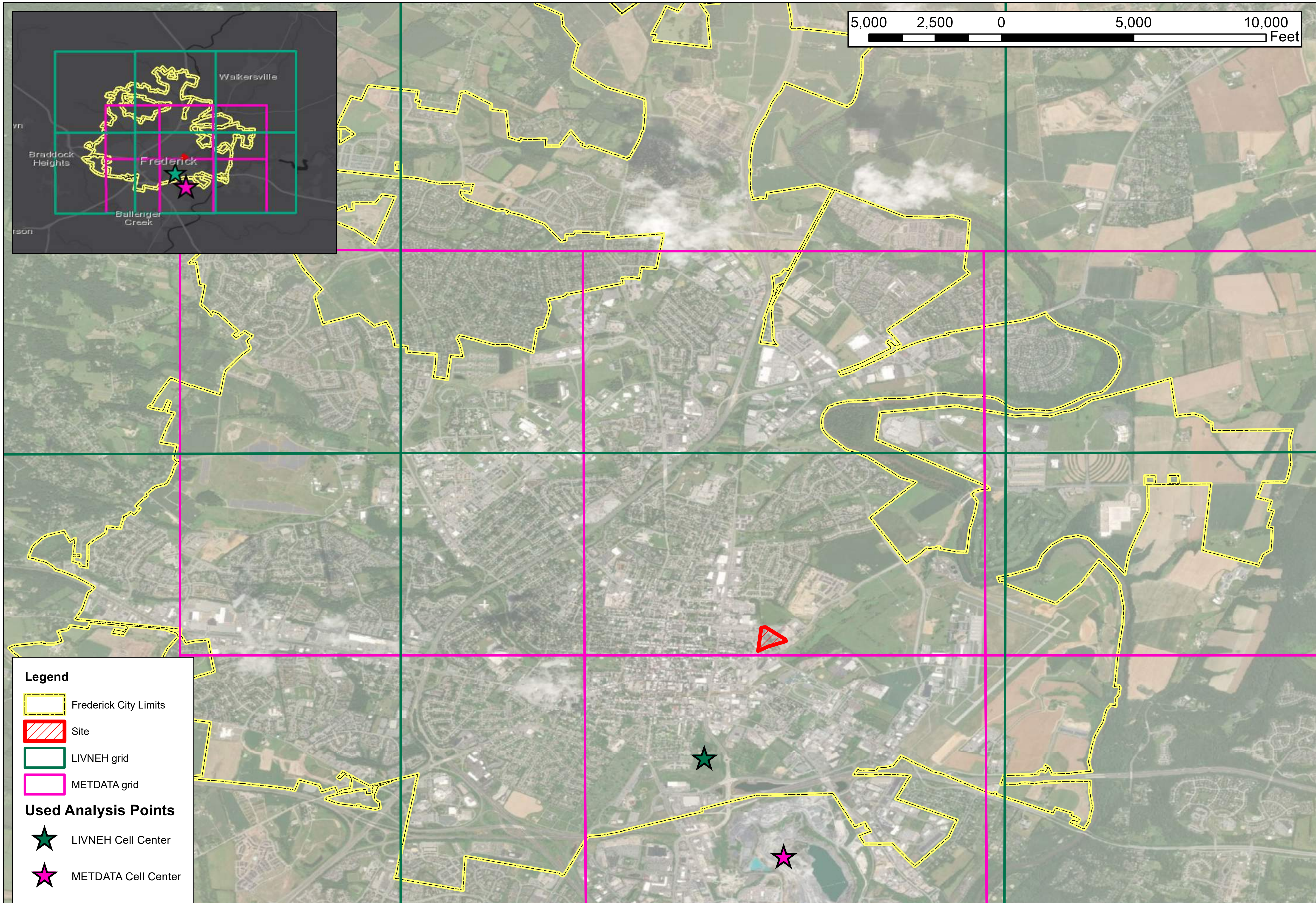
$$DCF = \frac{Projected\ monthly\ average\ rainfall\ depth}{Historical\ monthly\ average\ rainfall\ depth}$$

It is important to note that the DCF value is a ratio and not a percentage and any value over 1.00 represents expected increases in rainfall whereas any values less than 1.00 represent expected decreases in rainfall. Furthermore, any difference between the DCF and the value of 1.00 represent the percent change, e.g., a 1.03 DCF value represent a 3% increase in rainfall depth over historical modeled results. Given the possible combinations of emissions scenarios, GCM models, downscaling grid, and time slices, the total number of DCF values that can result from this approach can be large and our team would have to additionally develop a method for selecting DCF values that would be meaningful and useful for the municipality in its planning needs. Once DCF values are selected, these values would then be applied to (multiplied by) the current rainfall depths for the chosen frequency events as available through NOAA Atlas 14 for Frederick, MD. This would yield several projected rainfall depths associated with each frequency storm to be analyzed. Using these projected depths and site characteristics, our team then could develop runoff hydrographs for the case study site using hydrologic modeling software which would allow us to review and analyze the resulting peak flows and runoff values for historic and projected rainfall depths and derive observations.

4.2 SELECTING A FUTURE FOR FREDERICK'S STORMWATER PLANNING

In executing the approach described in section 4.1 for Frederick, MD. Our team made several assumptions and decisions along the way. This section summarizes not only the relevant data and calculations in support of the general approach, but also summarizes key assumptions or criteria used in this analysis. The first step in the process was to determine which GCM models would be most appropriate to use for Frederick. For the purposes of this analysis, “Frederick” is synonymous with the City of Frederick.

Results for the modeled historical period for the 20 available GCMs from the MACA tool were downloaded. Both the METDATA downscaled model results and the LIVNEH model results were downloaded and reviewed (). Average annual rainfall totals for the historical period for each model/downscaling method were calculated and compared with the historical observed average annual rainfall total. The historical observed average annual rainfall total (42.76”) was obtained from the Climate Explorer for the period of 1971 – 2000.



DREXEL COURSE NO:	CIVE T580
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DATUM & COORDINATE SYSTEM	NAD83 State Plane (feet) Maryland
FILE NAME	Figure 5_ClimateProjectionsAnalysis
PREPARED BY	Leslie Munoz

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Overview of Climate Projection Data

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FIGURE

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Table 3 summarizes the models that had the lowest combined difference with respect to the historical observed rainfall depth of 42.76" using both the LIVNEH and METDATA downscaled results. These models were then used to download the projected rainfall depths at a monthly scale for both LIVNEH and METDATA grids and both RCP 4.5 and RCP 8.5 emissions scenario. A total of 40 datasets for projected rainfall were downloaded (two downscaling methods, two emission scenarios, for each of the 10 GCM models).

Table 3. Summary of GCM Models Selected for Analysis in Frederick, MD

No.	Model Name	Selected (Y/N)
1	bcc-csm1-1	N
2	bcc-csm1-1-m	N
3	BNU-ESM	Y
4	CanESM2	Y
5	CCSM4	N
6	CNRM-CM5	N
7	CSIRO-Mk3-6-0	N
8	GFDL-ESM2G	N
9	GFDL-ESM2M	Y
10	HadGEM2-CC365	Y
11	HadGEM2-ES365	N
12	inmcm4	Y
13	IPSL-CM5A-LR	N
14	IPSL-CM5A-MR	N
15	IPSL-CM5B-LR	Y
16	MIROC5	Y
17	MIROC-ESM	Y
18	MIROC-ESM-CHEM	Y
19	MRI-CGCM3	N
20	NorESM1-M	Y

In conversations with City representatives, our team learned that 20-year and 50-year planning periods were most common and useful for stormwater planning in Frederick. So, our team also included two additional time slices (2040 and 2070) in our analysis to represent the changes that could be expected for any project that was being designed today (2020) with a lifetime of 20 and 50 years respectively. Each time slice consisted of a 30-year period of climate projection data centered around the decade reported.

For each time slice, average monthly rainfall depth values were calculated in each of the 40 available datasets. This yielded a total of 200 DCF values calculated for every month. A full summary of all the DCF values computed from these datasets is provided in Table 4 and Table 5. However, to make better sense of all the values and in an attempt to identify patterns and trends, our team dissected the data to analyze the results and determine if the variability seen in the results could be explained by the emissions scenario or downscaling method. Figure 6 on page 20 shows the distribution of the monthly DCF values based on emissions scenario and downscaling method. These boxplots were helpful in revealing some patterns and interesting observations. Based on the results, the distribution of DCFs in all boxplots showed DCF values lower than 1.00 for all months. Regardless of emission scenario or downscale grid, the GCM model results indicated that there could be a decrease in monthly rainfall in all months. However, the boxplots also showed that DCF monthly medians were above 1 for most months.

Table 4: Summary of DCF Calculation Results for RCP 4.5 Models

Time Slice	Month \ Model	RCP 4.5																								
		LIVNEH													METDATA												
		BNU-ESM	CanESM2	GFDL-ESM2M	HadGEM2-CC365	inmcm4	IPSL-CM5B-LR	MIROC5	MIROC-ESM	MIROC-ESM-CHEM	NorESM1-M	Avg	Min	Max	BNU-ESM	CanESM2	GFDL-ESM2M	HadGEM2-CC365	inmcm4	IPSL-CM5B-LR	MIROC5	MIROC-ESM	MIROC-ESM-CHEM	NorESM1-M	Avg	Min	Max
2020's (2010-2039)	1	1.11	1.14	0.95	1.19	0.84	1.00	1.22	1.08	0.87	1.32	1.07	0.84	1.32	1.08	1.10	1.00	1.21	0.82	0.98	1.29	1.05	0.91	1.28	1.07	0.82	1.29
	2	1.16	1.28	0.97	1.30	1.05	0.93	0.93	1.09	0.97	1.00	1.07	0.93	1.30	1.11	1.38	0.99	1.16	1.05	0.94	0.92	1.06	0.92	1.01	1.05	0.92	1.38
	3	1.13	1.01	1.03	1.00	1.10	0.98	1.05	0.99	0.95	1.00	1.02	0.95	1.13	1.16	1.10	1.03	1.01	1.10	0.96	1.09	1.01	1.01	1.04	1.05	0.96	1.16
	4	1.05	1.08	0.95	0.82	0.95	1.09	0.98	0.97	1.10	1.00	1.00	0.82	1.10	1.05	1.07	0.99	0.79	1.05	1.07	0.92	1.00	1.04	1.02	1.00	0.79	1.07
	5	1.08	1.01	1.05	1.11	0.99	0.95	1.20	0.89	1.13	0.91	1.03	0.89	1.20	0.99	1.07	1.12	1.08	1.06	1.02	1.17	0.95	1.10	0.94	1.05	0.94	1.17
	6	1.09	0.89	1.06	1.00	0.96	0.96	1.02	1.07	1.00	1.11	1.02	0.89	1.11	1.10	0.95	1.15	1.11	1.02	0.88	1.08	1.05	1.05	1.05	1.04	0.88	1.15
	7	1.10	1.01	1.04	1.15	1.00	0.88	1.27	1.07	0.88	0.93	1.03	0.88	1.27	1.07	1.06	1.06	1.10	1.10	0.88	1.13	1.10	0.90	0.98	1.04	0.88	1.13
	8	1.01	0.91	1.03	1.11	1.02	1.15	1.08	1.10	1.10	1.08	1.06	0.91	1.15	1.02	0.97	1.08	1.05	1.01	1.12	1.06	1.19	1.18	1.06	1.07	0.97	1.19
	9	0.95	0.79	1.20	1.01	1.00	0.96	1.09	0.98	1.04	1.03	1.00	0.79	1.20	0.91	0.82	1.12	1.05	1.05	0.96	1.08	0.84	1.07	0.98	0.99	0.82	1.12
	10	0.93	0.80	0.87	0.83	0.92	0.96	1.13	1.12	1.02	0.90	0.95	0.80	1.13	0.96	0.83	0.84	0.89	1.00	0.95	1.04	1.16	1.07	0.88	0.96	0.83	1.16
	11	1.04	0.81	1.14	1.06	0.95	0.99	1.11	0.99	1.00	1.10	1.02	0.81	1.14	1.06	0.77	1.17	1.04	0.92	0.95	1.12	1.08	0.98	1.13	1.02	0.77	1.17
	12	0.89	1.03	1.01	1.08	0.96	1.06	1.02	1.36	1.06	1.39	1.09	0.89	1.39	0.88	0.99	1.00	1.05	1.00	1.08	1.10	1.30	1.09	1.37	1.09	0.88	1.37
2040's (2030-2059)	1	1.13	1.04	1.02	1.27	0.86	1.08	1.24	1.18	0.97	1.34	1.11	0.86	1.34	1.11	1.03	1.07	1.30	0.86	1.01	1.28	1.12	0.97	1.26	1.10	0.86	1.30
	2	1.09	1.25	0.96	1.46	1.04	0.88	0.94	1.16	1.01	0.99	1.08	0.88	1.46	1.06	1.31	0.98	1.41	1.00	0.87	0.88	1.13	1.02	0.97	1.06	0.87	1.41
	3	1.05	1.08	0.99	1.02	1.13	0.99	1.03	1.03	1.00	1.10	1.04	0.99	1.13	1.04	1.13	1.02	1.01	1.18	0.99	1.04	1.07	1.05	1.13	1.07	0.99	1.18
	4	1.02	1.16	1.01	0.99	0.93	1.18	0.95	0.92	1.14	1.01	1.03	0.92	1.18	1.00	1.14	0.98	0.99	1.01	1.18	0.95	0.91	1.12	1.03	1.03	0.91	1.18
	5	1.02	0.98	1.09	0.97	1.03	1.05	1.21	0.94	1.11	1.05	1.05	0.94	1.21	0.98	1.00	1.09	0.96	1.09	1.07	1.22	1.01	1.06	1.08	1.06	0.96	1.22
	6	1.09	1.00	1.22	1.22	0.87	0.98	1.00	0.97	1.04	1.16	1.05	0.87	1.22	1.08	1.07	1.32	1.25	0.92	0.95	1.05	0.88	1.10	1.15	1.08	0.88	1.32
	7	1.11	0.99	0.97	1.08	1.06	1.00	1.33	1.00	1.07	0.96	1.06	0.96	1.33	1.08	1.07	0.98	1.01	1.10	0.98	1.16	0.98	1.11	1.00	1.05	0.98	1.16
	8	0.97	1.05	1.07	1.12	0.90	0.94	1.14	1.01	1.18	1.12	1.05	0.90	1.18	1.03	1.00	1.10	1.05	0.91	0.93	1.16	1.12	1.33	1.11	1.07	0.91	1.33
	9	1.03	0.89	1.26	1.02	1.00	0.97	1.04	1.07	0.89	0.95	1.01	0.89	1.26	1.02	0.83	1.22	1.01	1.05	0.99	1.02	0.92	0.83	0.92	0.98	0.83	1.22
	10	0.98	0.64	0.91	0.86	0.88	1.00	1.01	1.05	1.05	0.91	0.93	0.64	1.05	0.99	0.71	0.94	0.96	0.92	0.92	0.93	1.10	1.06	0.97	0.95	0.71	1.10
	11	1.12	0.73	1.25	0.95	0.94	0.96	1.16	0.95	1.02	1.07	1.01	0.73	1.25	1.13	0.71	1.32	0.97	0.93	0.87	1.14	0.98	0.99	1.10	1.02	0.71	1.32
	12	0.93	1.14	1.07	1.06	0.92	1.24	1.02	1.31	1.09	1.13	1.09	0.92	1.31	0.99	1.07	1.09	1.07	0.95	1.33	1.04	1.29	1.12	1.15	1.11	0.95	1.33
2050's (2040-2069)	1	1.04	1.06	1.02	1.28	0.93	1.12	1.29	1.17	0.95	1.34	1.12	0.93	1.34	1.03	1.08	1.04	1.26	0.91	1.09	1.29	1.13	0.96	1.30	1.11	0.91	1.30
	2	1.12	1.36	1.05	1.46	1.11	0.93	1.07	1.14	1.01	0.97	1.12	0.93	1.46	1.07	1.51	1.05	1.48	1.06	0.90	1.01	1.09	1.04	0.96	1.12	0.90	1.51
	3	0.97	1.12	0.98	0.97	1.10	1.02	1.00	1.09	1.02	1.11	1.04	0.97	1.12	1.00	1.18	0.98	0.93	1.15	1.02	1.06	1.12	1.07	1.17	1.07	0.93	1.18
	4	1.03	1.23	1.05	1.04	1.01	1.16	0.95	1.05	1.12	0.99	1.06	0.95	1.23	1.03	1.20	0.98	1.05	1.06	1.16	0.97	1.02	1.09	0.99	1.05	0.97	1.20
	5	1.01	1.08	1.10	0.95	1.04	1.01	1.21	0.82	1.06	1.07	1.04	0.82	1.21	1.01	1.08	1.09	0.96	1.02	1.03	1.15	0.89	1.00	1.09	1.03	0.89	1.15
	6	1.09	1.14	1.34	1.19	0.95	1.02	0.94	0.92	1.05	1.22	1.09	0.92	1.34	1.10	1.11	1.38	1.20	0.99	1.03	0.97	0.89	1.09	1.19	1.09	0.89	1.38
	7	1.02	1.04	0.92	1.03	1.09	0.95	1.32	0.92	1.11	0.99	1.04	0.92	1.32	1.03	1.09	0.94	1.06	1.15	0.96	1.15	0.89	1.14	1.05	1.05	0.89	1.15
	8	1.01	1.17	1.11	1.10	1.13	0.93	1.16	0.97	1.00	1.15	1.07	0.93	1.17	1.10	1.16	1.18	1.10	1.14	0.90	1.17	1.08	1.16	1.22	1.12	0.90	1.22
	9	1.07	0.99	1.18	0.86	0.97	0.98	1.08	1.06	0.98	0.89	1.01	0.86	1.18	1.06	0.90	1.17	0.84	0.98	1.04	1.10	0.93	0.92	0.86	0.98	0.84	1.17
	10	0.94	0.73	1.04	0.84	0.93	0.93	1.11	1.11	1.10	0.94	0.97	0.73	1.11	0.97	0.78	1.05	0.91	0.97	0.84	1.07	1.15	1.06	1.01	0.98	0.78	1.15
	11	1.26	0.80	1.22	0.93	1.02	0.95	1.07	0.91	1.06	1.05	1.03	0.80	1.26	1.23	0.80	1.29	0.93	1.01	0.89	1.02	0.85	1.10	1.09	1.02	0.80	1.29
	12	0.88	1.12	1.07	1.21	0.95	1.20	1.02	1.26	1.14	1.05	1.09	0.88	1.26	0.94	1.09	1.09	1.26	0.95	1.35	1.05	1.24	1.16	1.13	1.13	0.94	1.35
2070's (2060-2089)	1	1.07	1.21	1.02	1.15	0.88	1.16	1.25	1.05	1.01	1.33	1.11	0.88	1.33	1.07	1.17	1.00	1.18	0.85	1.20	1.35	1.06	1.06	1.30	1.12	0.85	1.35
	2	1.11	1.41	1.11	1.30	1.18	1.09	1.01	1.02	1.10	0.97	1.13	0.97	1.41	1.07	1.52	1.10	1.33	1.21	1.07	0.97	0.95	1.16	1.00	1.14	0.95	1.52
	3	1.02	1.09	1.05	1.03	1.20	0.94	1.01	1.02	1.14	1.08	1.06	0.94	1.20	1.07	1.16	1.04	1.05	1.22	0.91	1.03	1.04	1.20	1.11	1.08	0.91	1.22
	4	1.14	1.29	1.07	1.07	1.05	1.19	1.13	1.14	1.12	1.01	1.12	1.01	1.29	1.12	1.31	1.04	1.04	1.12	1.10	1.13	1.17	1.10	1.01	1.11	1.01	1.31
	5	1.02	1.03	0.99	1.09	0.99	0.92	1.02	0.80	1.04	1.03	0.99	0.80	1.09	1.02	1.06	0.96	1.00	0.92	0.95	0.93	0.89	0.99	1.05	0.98	0.89	1.06
	6	1.07	1.13	1.22	0.87	0.98	1.03	0.96	0.95	1.09	1.19	1.05	0.87	1.22	1.05	1.09	1.32	0.93	0.98	1.04	0.96	0.98	1.14	1.08	1.06	0.93	1.32
	7	1.04	1.19	0.91	1.06	1.04	0.92	1.34	0.94	1.10	1.06	1.06	0.91	1.34	1.13	1.19	0.85	1.01	1.12	0.92	1.25	1.02	1.16	1.16	1.08	0.85	1.25
	8	1.04	1.13	1.20	0.94	1.13	1.01	1.14	0.93	0.88	1.09	1.05	0.88	1.20	1.10	1.09	1.22	0.91	1.06	1.02	1.14	1.02	0.98	1.24	1.08	0.91	1.24
	9	1.01	0.88	1.35	0.94	1.00	0.92	1.19	1.14	1.03	0.87	1.03	0.87	1.35	0.93	0.85	1.24	1.04	1.14	1.07	1.14	1.02	1.04	0.86	1.03	0.85	1.24
	10	0.97	0.65	0.98	1.02	0.96	0.96	1.00	1.09	1.15	0.99	0.98	0.65	1.15	0.99	0.67	0.92	1.10	0.97	0.90	0.96	1.12	1.10	0.97	0.97	0.67	1.12
	11	1.22	0.77	1.15	0.97	0.88	1.09	1.04	0.84	1.17	1.04	1.02	0.77	1.22	1.24	0.78	1.22	0.86	0.88	1.16	0.99	0.83	1.16	1.09	1.02	0.78	1.24
	12	0.95	1.10	0.99	1.16	0.95	1.15	1.17	1.33	1.07	1.06	1.09	0.95	1.33	0.91	1.06	0.98	1.25	0.98	1.29	1.24	1.32	1.05	1.12	1.12	0.91	1.32
2080's (2070-2099)	1	1.14	1.18	1.05	1.16	0.84	1.09	1.25	1.05	1.07	1.20	1.10	0.84	1.25	1.13	1.20	1.04	1.23	0.83	1.09	1.35	1.05	1.08	1.14	1.11	0.83	1.35
	2	1.08	1.39	1.21	1.23	1.23	1.16	1.03	1.03	1.25	0.92	1.15	0.92	1.39	1.05	1.44	1.21	1.15	1.33	1.17	1.04	0.96	1.30	0.94	1.16	0.94	1.44
	3	1.00	1.08	1.12	1.04	1.20	1.02	1.10	1.09	1.16	1.08	1.09	1.00	1.20	1.01	1.14	1.13	1.07	1.24	1.00	1.08	1.11	1.17	1.07	1.10	1.00	1.24
	4	1.15	1.25	1.14	1.01	0.97	1.20	1.07	1.09	1.19	1.03	1.11	0.97	1.25	1.09	1.24	1.14	0.95	0.99	1.12	1.07	1.12	1.17	1.03	1.09	0.95	1.24
	5	1.04	1.01	1.02	1.04	0.97	0.98	0.99	0.99	1.03	1.05	1.01	0.97	1.05	1.01	1.02	1.04	0.96	0.94	0.99	0.93	1.02	1.02	1.08	1.00	0.93	1.08
	6	1.02	1.08	1.14	0.90	0.93	1.14	1.02	0.98	1.13	1.15	1.05	0.90	1.15	1.06	1.09	1.20	0.92	0.93	1.10	1.05	0.95	1.20	1.10	1.06	0.92	1.20
	7	1.06	1.21	1.06	1.09	1.07	0.88	1.35	1.15	1.13	1.13	1.11	0.88	1.35	1.10	1.21	0.97	1.01	1.11	0.86	1.24	1.20	1.21	1.25	1.11	0.86	1.25
	8	1.00	1.15	1.22	0.96	0.98	1.05	1.06	0.99	0.92	1.11	1.04	0.92	1.22	0.99	1.12	1.24	0.97	0.89	1.07	1.06	1.06	1.02	1.17	1.06	0.89	1.24
	9	1.03	0.92	1.35	0.99	0.96	0.99	1.21	1.07	0.92	0.89	1.03	0.89	1.35	0.97	0.99	1.26	1.08	1.15	1.13	1.09	0.97	0.93	0.86	1.04	0.86	1.26
	10	1.05	0.59	0.88	0.91	0.89	0.92	0.87	1.03	1.19	1.02	0.93	0.59	1.19	1.08	0.63	0.85	0.97	0.89	0.91	0.84	1.09	1.20	1.02	0.95	0.63	1.20
	11	1.05	0.75	1.20	0.91	0.76	1.13	1.03	0.95	1.18	1.07	1.00	0.75	1.20	1.05	0.75	1.21	0.80	0.74	1.19	1.03	1.01	1.11	1.12	1.00	0.74	1.21
	12	0.99	1.13	1.05	1.23	0.97	1.19	1.19	1.32	1.05	1.06	1.12	0.97	1.32	0.96	1.07	1.07	1.28	1.01	1.29	1.27	1.27	1.01	1.10	1.13	0.96	1.29

Table 5: Summary of DCF Calculation Results for RCP 8.5 Models

Time Slice	Month \ Model	RCP 8.5																									
		LIVNEH													METDATA												
		BNU-ESM	CanESM2	GFDL-ESM2M	ladGEM2-CC36	inmcm4	IPSL-CM5B-LR	MIROC5	MIROC-ESM	IROC-ESM-CHE	NorESM1-M	avg	Min	Max	BNU-ESM	CanESM2	GFDL-ESM2M	ladGEM2-CC36	inmcm4	IPSL-CM5B-LR	MIROC5	MIROC-ESM	IROC-ESM-CHE	NorESM1-M	avg	Min	Max
2020's (2010-2039)	1	1.01	0.96	1.12	1.33	0.86	1.00	1.14	1.00	0.95	1.41	1.08	0.86	1.41	1.00	0.94	1.19	1.33	0.90	0.97	1.11	0.98	1.01	1.41	1.08	0.90	1.41
	2	1.00	1.12	1.04	1.28	1.05	1.07	0.94	1.01	1.07	0.95	1.05	0.94	1.28	0.97	1.20	1.04	1.18	1.12	1.05	0.89	0.96	1.09	1.03	1.05	0.89	1.20
	3	1.01	0.96	1.05	0.91	1.17	1.05	1.07	0.99	1.07	0.98	1.03	0.91	1.17	1.02	1.06	1.09	0.94	1.19	0.97	1.13	0.98	1.20	1.01	1.06	0.94	1.20
	4	1.15	0.98	1.11	1.05	1.02	0.93	1.19	1.13	1.12	1.02	1.07	0.93	1.19	1.15	0.95	1.09	1.01	1.06	0.91	1.21	1.14	1.11	0.99	1.06	0.91	1.21
	5	0.97	1.11	1.08	0.94	1.02	0.93	1.07	0.91	1.09	1.04	1.02	0.91	1.11	0.99	1.20	1.07	0.97	0.98	0.95	1.02	0.99	1.06	1.01	1.02	0.95	1.20
	6	0.94	0.97	1.20	1.16	0.93	1.01	1.02	0.98	1.05	1.07	1.03	0.93	1.20	0.90	1.02	1.18	1.20	1.06	0.97	1.06	0.97	1.02	1.08	1.05	0.90	1.20
	7	1.11	0.89	0.94	1.26	0.97	0.88	1.50	1.04	1.09	1.02	1.07	0.88	1.50	0.98	0.98	0.95	1.27	1.12	0.95	1.38	1.06	1.13	1.02	1.08	0.95	1.38
	8	1.09	1.03	1.03	1.10	1.05	1.04	1.11	0.96	1.00	1.10	1.05	0.96	1.11	1.09	1.08	1.04	1.01	1.04	1.01	1.10	1.08	1.08	1.15	1.07	1.01	1.15
	9	0.92	0.91	1.14	1.00	1.12	0.94	1.12	1.02	1.14	0.97	1.03	0.91	1.14	0.88	0.89	1.12	0.99	1.24	1.04	1.13	0.89	1.07	1.01	1.03	0.88	1.24
	10	0.96	0.74	0.87	0.93	0.81	0.98	1.11	1.04	1.21	0.77	0.94	0.74	1.21	0.96	0.80	0.90	1.00	0.83	0.99	1.05	1.05	1.21	0.79	0.96	0.79	1.21
	11	0.99	1.02	1.13	0.97	0.92	0.91	1.07	0.94	1.01	1.08	1.00	0.91	1.13	0.99	1.06	1.14	0.84	0.91	0.84	1.07	1.06	0.96	1.08	1.00	0.84	1.14
	12	0.98	0.98	1.07	1.12	1.11	1.04	1.09	1.24	1.09	1.28	1.10	0.98	1.28	1.02	1.00	1.13	1.18	1.16	1.10	1.17	1.19	1.05	1.30	1.13	1.00	1.30
2040's (2030-2059)	1	1.03	0.96	1.10	1.25	0.84	1.14	1.21	1.01	0.95	1.33	1.08	0.84	1.33	1.04	0.97	1.14	1.32	0.86	1.10	1.16	1.04	1.03	1.30	1.10	0.86	1.32
	2	1.07	1.35	1.10	1.26	1.03	1.23	0.99	1.07	1.17	0.96	1.12	0.96	1.35	1.07	1.35	1.10	1.16	1.04	1.18	0.89	1.03	1.22	0.99	1.10	0.89	1.35
	3	1.05	1.12	1.08	0.91	1.09	1.00	1.18	1.09	1.15	1.07	1.07	0.91	1.18	1.11	1.26	1.11	0.92	1.11	0.98	1.22	1.11	1.27	1.10	1.12	0.92	1.27
	4	1.18	1.07	1.08	0.97	1.02	1.05	1.00	1.05	1.23	1.03	1.07	0.97	1.23	1.16	1.08	1.09	0.94	1.06	1.03	0.97	1.12	1.25	1.01	1.07	0.94	1.25
	5	1.00	1.07	1.10	0.91	1.10	0.99	1.04	0.90	1.06	1.03	1.02	0.90	1.10	1.09	1.18	1.13	0.91	1.08	1.01	1.01	1.00	1.02	1.01	1.04	0.91	1.18
	6	0.94	0.96	1.10	1.23	0.89	0.90	0.92	0.91	1.08	1.14	1.01	0.89	1.23	0.98	1.02	1.11	1.24	1.06	0.89	0.92	0.95	1.06	1.11	1.03	0.89	1.24
	7	0.97	0.91	0.97	1.10	1.16	0.79	1.48	0.96	0.98	1.15	1.05	0.79	1.48	1.01	0.95	0.98	1.13	1.25	0.88	1.30	0.94	1.07	1.19	1.07	0.88	1.30
	8	1.05	1.18	1.07	1.03	1.20	1.11	0.97	1.01	0.98	1.23	1.08	0.97	1.23	1.00	1.38	1.02	0.96	1.14	1.13	0.96	1.10	1.02	1.24	1.10	0.96	1.38
	9	0.91	0.92	1.12	1.16	0.99	1.05	1.11	1.04	1.03	0.91	1.02	0.91	1.16	0.93	0.92	1.06	1.23	0.95	1.13	1.14	0.89	1.02	0.94	1.02	0.89	1.23
	10	1.01	0.75	0.92	1.01	0.83	0.88	1.11	1.04	1.15	0.89	0.96	0.75	1.15	1.05	0.78	1.00	1.07	0.89	0.85	1.08	1.04	1.17	0.89	0.98	0.78	1.17
	11	0.94	0.93	1.09	1.01	0.92	0.97	0.92	0.88	1.00	1.10	0.98	0.88	1.10	0.96	0.95	1.10	0.93	0.93	0.91	0.86	0.94	1.03	1.17	0.98	0.86	1.17
	12	1.01	1.00	1.07	1.24	0.90	1.04	1.00	1.22	1.16	1.05	1.07	0.90	1.24	1.02	0.99	1.11	1.37	0.86	1.11	1.02	1.21	1.13	0.99	1.08	0.86	1.37
2050's (2040-2069)	1	1.08	1.03	1.13	1.33	0.89	1.25	1.26	0.96	0.99	1.27	1.12	0.89	1.33	1.06	1.02	1.16	1.35	0.91	1.21	1.27	0.94	1.05	1.29	1.13	0.91	1.35
	2	1.19	1.48	1.09	1.17	0.98	1.20	1.11	1.07	1.26	0.98	1.15	0.98	1.48	1.21	1.53	1.09	1.16	0.97	1.15	1.05	1.01	1.33	0.98	1.15	0.97	1.53
	3	1.13	1.16	1.21	0.92	1.06	0.96	1.22	1.17	1.15	1.14	1.11	0.92	1.22	1.21	1.26	1.20	0.89	1.05	0.97	1.19	1.20	1.22	1.16	1.13	0.89	1.26
	4	1.17	1.07	1.05	0.97	0.98	1.12	1.02	1.12	1.26	0.97	1.07	0.97	1.26	1.14	1.05	1.08	0.90	0.98	1.07	0.98	1.16	1.24	0.94	1.05	0.90	1.24
	5	0.99	1.11	1.10	0.93	1.03	0.94	1.09	0.91	1.03	1.06	1.02	0.91	1.11	1.04	1.16	1.11	0.90	1.06	0.98	1.04	0.99	1.04	1.03	1.03	0.90	1.16
	6	1.03	1.00	1.10	1.15	0.88	0.89	1.05	0.75	1.07	1.17	1.01	0.75	1.17	1.04	1.04	1.11	1.25	1.01	0.87	1.02	0.80	1.08	1.15	1.04	0.80	1.25
	7	1.06	0.96	1.06	1.13	1.27	0.84	1.55	0.92	1.07	1.08	1.09	0.84	1.55	1.11	1.00	1.04	1.09	1.29	0.86	1.34	0.91	1.10	1.12	1.09	0.86	1.34
	8	1.05	1.12	1.14	0.94	1.10	1.12	1.12	0.90	0.87	1.26	1.06	0.87	1.26	1.07	1.21	1.09	0.90	1.05	1.09	1.06	0.94	0.96	1.23	1.06	0.90	1.23
	9	0.89	1.07	1.29	0.99	1.00	0.98	1.08	1.01	0.94	0.92	1.02	0.89	1.29	0.86	1.12	1.16	1.08	0.98	1.06	1.10	0.82	0.95	0.92	1.01	0.82	1.16
	10	0.95	0.76	0.91	0.85	0.80	0.97	1.01	1.01	1.04	1.00	0.93	0.76	1.04	0.98	0.76	0.99	0.90	0.84	0.92	0.93	1.05	1.03	1.00	0.94	0.76	1.05
	11	1.01	0.82	1.20	1.05	0.94	0.96	1.00	0.93	1.08	1.06	1.01	0.82	1.20	1.02	0.83	1.21	1.01	0.95	0.89	0.96	0.98	1.19	1.15	1.02	0.83	1.21
	12	1.04	1.12	1.05	1.31	0.82	1.11	1.07	1.26	1.20	1.20	1.12	0.82	1.31	1.04	1.10	1.02	1.41	0.79	1.23	1.16	1.23	1.23	1.24	1.14	0.79	1.41
2070's (2060-2089)	1	1.04	1.15	1.08	1.40	1.01	1.30	1.27	1.16	1.11	1.41	1.19	1.01	1.41	0.99	1.17	1.19	1.41	1.07	1.27	1.28	1.09	1.17	1.40	1.20	0.99	1.41
	2	1.20	1.41	1.03	1.19	1.01	1.17	1.14	1.11	1.18	0.95	1.14	0.95	1.41	1.09	1.55	1.03	1.30	0.99	1.21	1.10	1.07	1.19	0.99	1.15	0.99	1.55
	3	1.17	1.14	1.26	0.96	1.07	1.10	1.16	1.19	1.10	1.18	1.13	0.96	1.26	1.25	1.21	1.19	0.95	1.10	1.12	1.11	1.19	1.11	1.20	1.14	0.95	1.25
	4	1.22	1.11	1.15	1.04	1.07	1.18	1.05	1.16	1.33	0.89	1.12	0.89	1.33	1.21	1.07	1.11	0.96	1.05	1.14	1.04	1.18	1.30	0.87	1.09	0.87	1.30
	5	1.18	1.14	1.01	1.07	1.00	1.01	1.10	0.99	1.07	1.04	1.06	0.99	1.18	1.16	1.16	1.01	1.01	1.01	1.02	1.00	1.03	1.07	1.00	1.05	1.00	1.16
	6	1.09	1.00	1.13	1.14	0.95	0.97	1.10	0.81	1.02	1.13	1.03	0.81	1.14	1.13	0.96	1.18	1.26	0.96	0.92	1.17	0.78	1.07	1.04	1.05	0.78	1.26
	7	1.09	1.04	0.97	1.10	1.13	0.87	1.64	0.99	1.06	1.01	1.09	0.87	1.64	1.17	1.10	1.01	1.13	1.27	0.79	1.43	0.96	1.06	1.13	1.10	0.79	1.43
	8	1.14	1.11	1.28	0.87	1.03	0.94	1.11	0.84	0.84	1.24	1.04	0.84	1.28	1.23	1.12	1.25	0.81	0.98	0.93	1.06	0.92	0.95	1.25	1.05	0.81	1.25
	9	0.98	1.04	1.23	0.88	0.90	0.95	0.99	1.00	0.93	0.98	0.99	0.88	1.23	0.94	1.04	1.16	0.91	0.89	1.04	0.98	0.84	0.95	0.98	0.97	0.84	1.16
	10	1.01	0.64	0.91	0.96	0.66	1.06	0.99	0.98	1.06	0.98	0.93	0.64	1.06	1.11	0.65	0.96	0.99	0.71	0.98	0.91	1.06	1.10	0.98	0.94	0.65	1.11
	11	1.11	0.95	1.30	1.15	0.93	1.03	1.04	1.06	1.10	1.08	1.08	0.93	1.30	1.15	0.97	1.34	1.09	0.94	0.96	0.97	1.11	1.11	1.09	1.07	0.94	1.34
	12	0.93	1.19	1.27	1.47	0.96	1.26	1.10	1.42	1.03	1.21	1.18	0.93	1.47	0.91	1.16	1.25	1.48	1.01	1.28	1.23	1.37	1.11	1.34	1.21	0.91	1.48
2080's (2070-2099)	1	1.10	1.19	1.06	1.49	0.94	1.26	1.22	1.25	1.15	1.43	1.21	0.94	1.49	1.05	1.20	1.15	1.49	0.98	1.29	1.22	1.25	1.16	1.37	1.22	0.98	1.49
	2	1.15	1.37	1.14	1.24	1.17	1.19	1.09	1.14	1.22	0.89	1.16	0.89	1.37	1.02	1.39	1.17	1.35	1.17	1.22	1.10	1.10	1.19	0.94	1.16	0.94	1.39
	3	1.11	1.16	1.22	1.02	1.13	1.11	1.15	1.12	1.09	1.25	1.14	1.02	1.25	1.21	1.21	1.16	1.04	1.19	1.11	1.11	1.13	1.10	1.28	1.15	1.04	1.28
	4	1.28	1.08	1.15	1.08	1.10	1.18	1.09	1.14	1.37	0.99	1.15	0.99	1.37	1.27	1.06	1.11	1.02	1.13	1.18	1.07	1.14	1.40	0.98	1.14	0.98	1.40
	5	1.20	1.06	0.94	1.13	1.17	1.11	1.02	1.06	1.07	1.02	1.08	0.94	1.20	1.16	1.05	0.92	1.08	1.12	1.11	0.94	1.12	1.02	0.97	1.05	0.92	1.16
	6	1.05	0.90	1.15	1.02	0.98	0.99	0.96	0.98	1.03	1.04	1.01	0.90	1.15	1.12	0.85	1.18	1.02	1.02	0.98	1.04	0.93	1.03	0.97	1.01	0.85	1.18
	7	1.09	1.08	0.89	0.95	1.10	0.81	1.54	1.07	0.95	1.25	1.07	0.81	1.54	1.18	1.12	0.96	0.98	1.27	0.77	1.40	1.01	0.98	1.32	1.10	0.77	1.40
	8	1.21	1.19	1.18	0.98	1.09	0.85	1.16	0.82	0.85	1.37	1.07	0.82	1.37	1.25	1.30	1.16	0.89	1.00	0.87	1.10	0.88	0.90	1.41	1.07	0.87	1.41
	9	0.98	1.04	1.02	1.13	0.99	0.97	1.10	1.01	0.98	0.96	1.02	0.96	1.13	0.96	0.96	1.01	1.15	0.97	1.12	1.15	0.84	1.03	0.97	1.02	0.84	1.15
	10	1.08	0.67	0.95	1.23	0.75	1.06	0.99	0.84	1.12	1.06	0.98	0.67	1.23	1.20	0.68	0.92	1.23	0.82	1.00	0.98	0.95	1.18	1.05	1.00	0.68	1.23
	11	0.97	1.03	1.26	1.23	0.94	1.22	1.08	1.07	1.01	1.07	1.09	0.94	1.26	1.01	0.99	1.31	1.20	0.93	1.17	0.97	1.14	1.01	1.12	1.08	0.93	1.31
	12	0.92	1.22	1.19	1.41	0.94	1.34	1.10	1.34	1.15	1.21	1.18	0.92	1.41	0.84	1.23	1.20	1.41	1.00	1.40	1.22	1.26	1.16	1.31	1.20	0.84	1.41

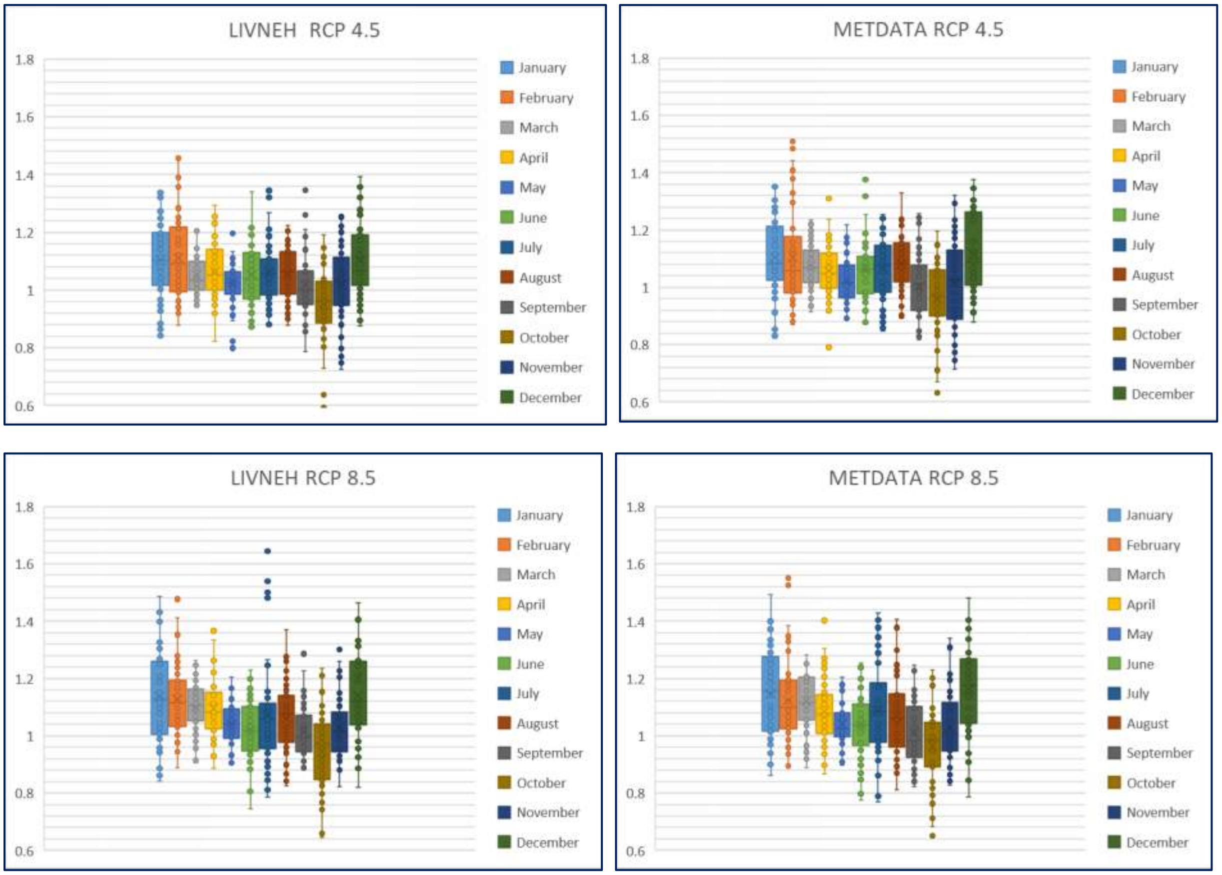

Figure 6. Boxplots of the Calculated DCF Values by Emissions Scenario and Downscaling Method

Additionally, it was visible that regardless of emission scenario or downscaling method, the variability in DCF values had a wide range with decreases of 30% and increases of up to about 70%. This variability seemed to be greater with the RCP 8.5 for several months although the trend was not applicable to all months. Additionally, in looking at the medians of the monthly DCF values, our team identified a seasonal trend with winter and summer median DCFs being higher than fall and the lowest DCF median occurring in October in a consistent manner.

Based on these observations, our team decided to inquire into the seasonality of historical rainfall events. NOAA Atlas 14 included a seasonality evaluation within the rainfall analysis (Figure 7). Based on this seasonality analysis, it was apparent that while high frequency events (e.g., 2-year) happened in all months of the year. However, less frequent /heavier rainfall events seemed to mostly occur within the summer months of June through September and as the 100-year event is approached, the occurrence of rainfall events seems to be exclusively seen within this June through September timeframe. While DCF values that were calculated seemed to be highest in winter and summer, only the summer months had historically seen large rainfall events that had the potential to overwhelm stormwater infrastructure. With this in mind, increases in monthly precipitation during the summer had a larger potential to impact the community than even large increases in precipitation during the winter months. Our team then concluded that any projected climate change would have the most impact on the community during summer and so decided to use DCFs that would capture the expected rainfall changes for the summer months.

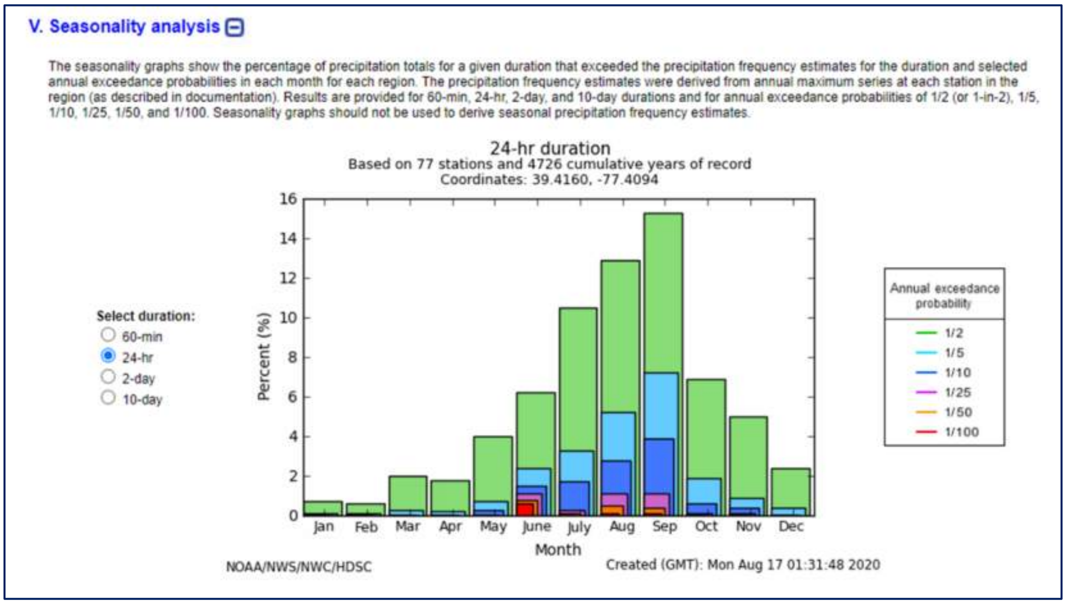

Figure 7. NOAA Atlas 14 Seasonality Analysis for Frederick, MD

For each time slice, our team ran statistic on the monthly DCFS. We calculated the 25th, 50th, 75th, and 90th percentiles of each monthly results and averaged these statistics for the months of June through September. This yielded a total of four DCF values that would be representative of the 25th, 50th, 75th, and 90th percentiles of the summer months. After calculating these time-slice specific DCFs, our team noticed that a majority of the 25th percentile average DCFs were values slightly below 1.00. Given that rainfall decreases are much less likely to have any negative impacts to the existing stormwater infrastructure than rainfall increases, our team discarded the 25th percentile average DCFs. By determining 3 representative DCF values per time slice (Table 6), our team was able to create projected rainfall events. These projected rainfall events were created by applying the selected DCF values to the historical rainfall depths associated with the frequency storms of interest (1, 10, and 100-year). Review of the selected DCF values show that the projected storms would reflect an increase in rainfall depths between 3% and 21%. A total of 36 projected storm depths were developed to be used in the case study (Table 7). On the low end, the projected storm events showed an increase in rainfall depth as little as 0.08 inches and as high as 0.53" for the 1-year storm. For the 100-year storm, the projected storm events have an increase in rainfall depths from 0.24 inches to 1.65 inches with respect to existing rainfall depths from NOAA Atlas 14, volume 2.

Table 6. Summary of Selected DCFs for Case Study Analysis

Frequency \ DCF	Existing	2040s			2050s			2070s			2080s		
	1.00	1.03	1.10	1.19	1.05	1.12	1.19	1.04	1.11	1.21	1.04	1.14	1.20

Note: DCF values resported in this table area a ratio of the projected rainfall to the historical modeled rainfall, e.g., a DCF of 1.03 means a 3% increase over historical modeled conditions.

Table 7. Summary of Historical and Projected Rainfall Amounts for Case Study

Frequency \ Rainfall	Existing (in)	2040s			2050s			2070s			2080s		
1-year	2.55	2.63	2.81	3.03	2.67	2.85	3.04	2.65	2.83	3.08	2.66	2.91	3.07
10-year	4.64	4.78	5.11	5.52	4.86	5.19	5.53	4.83	5.15	5.61	4.84	5.30	5.58
100-year	7.89	8.13	8.69	9.38	8.26	8.83	9.41	8.20	8.77	9.54	8.23	9.01	9.49

Notes:
1. Existing conditions are a reflection of NOAA Atlas 14, volume 2 rainfall frequency analysis for Frederick, MD
2. Rainfall Projections are the result of mulitplying the existing rainfall amounts by the DCF values selected for each time slice.

5.0 CASE STUDY AND RESULTS

5.1 HYDROLOGIC MODELING METHODOLOGY

Once we had developed our projected storm depths for Frederick, our team was ready to create scenarios to be modeled to obtain peak runoff rates and total runoff volumes based on our case study site and associated parameters. Our team decided to use the USACE's HEC-HMS program, version 4.5 (Figure 8). This hydrologic software can model hydrologic processes based on several available methods of loss estimation, rainfall distributions, and rainfall transform. A HEC-HMS model consist of at least three basic components: a basin model, a meteorological model, and a time control. Our team developed a basin model with one subbasin using the parameters previously calculated. This basin model included one subbasin only with loss parameters associated with the curve number approach. The model included a total of 39 meteorological models: 3 existing (1, 10, and 100-year) and 36 projected (4 time slices, 3 frequencies, and 3 DCFs per time slice). These meteorological models used only a total rainfall depth value along with an NRCS Type 2 rainfall distribution which is already embedded into the modeling software. The last component was a time control which governs the modeling time step as well as the simulation duration. Our team chose a fifteen-minute time step with a total simulation time of 36 hours. The one basin model was paired with the time control and the 39 meteorological models for a total of 39 simulations.

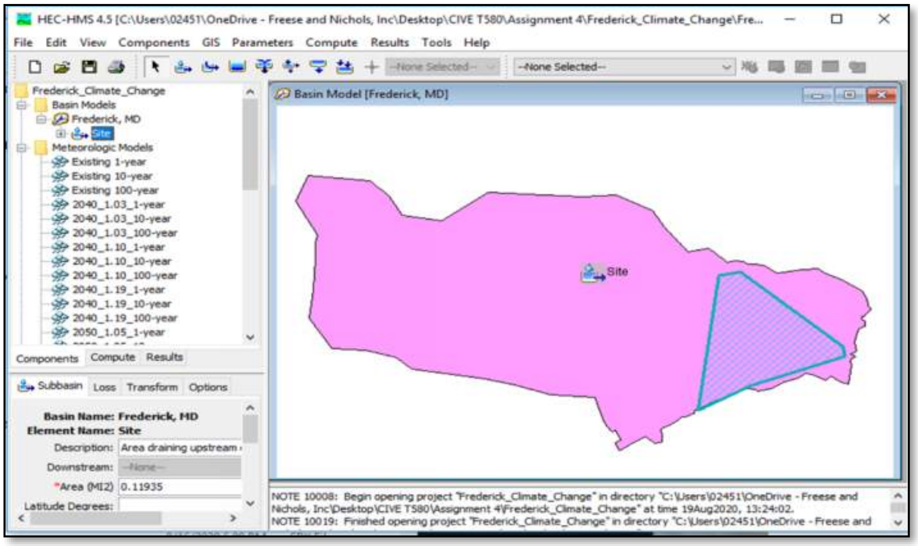

Figure 8. Overview of HEC-HMS Model Developed

5.2 HYDROLOGIC MODELING RESULTS

Executing the 39 simulations in the HEC-HMS model yielded 39 runoff hydrographs associated with the area contributing to the case study site. The results for peak runoff and runoff volume resulting from the modeled subbasin for the 39 storms are summarized in Table 8 and Table 9, respectively, on the following page. Review of the results show that the projected storm depths yield as little as 6 cubic-feet-per second (cfs) of increase in peak flow rates for the 1-year storm event and as much as 117 cfs of increase in peak flow rates for the 100-year storm event. In terms of runoff volume, the projected storms yielded increases of as little as 0.5 acre-feet for the 1-year storm event to as much as 10.4 acre-feet of increase for the 100-year storm event. These increases have implications for infrastructure design, particularly for volume control of extreme precipitation events and floodplain management.

Table 8. Summary of Peak Flow Results (in cfs) for Scenario Modeling

DCF / Frequency	Existing	2040s			2050s			2070s			2080s		
	1.00	1.03	1.10	1.19	1.05	1.12	1.19	1.04	1.11	1.21	1.04	1.14	1.20
1-year	159.57	165.2	178.0	193.6	168.0	180.8	194.3	166.6	179.4	197.1	167.3	185.0	196.4
10-year	308.59	318.6	342.3	371.6	324.4	348.0	372.3	322.2	345.1	378.1	322.9	355.9	375.9
100-year	541.16	558.3	598.3	647.5	567.6	608.3	649.6	563.3	604.0	658.9	565.4	621.1	655.3

Notes:
1. Existing conditions are a reflection of NOAA Atlas 14, volume 2 rainfall frequency analysis for Frederick, MD
2. DCFs reported are a ratio with respect to the existing precipitation amounts (i.e., 1.03 = 3% higher than existing)

Table 9. Summary of Results for Runoff Volumes (ac-ft)

Frequency \ DCF	Existing	2040s			2050s			2070s			2080s		
	1.00	1.03	1.10	1.19	1.05	1.12	1.19	1.04	1.11	1.21	1.04	1.14	1.20
1-year	13.9	14.4	15.5	16.9	14.7	15.8	16.9	14.6	15.6	17.2	14.6	16.1	17.1
10-year	26.8	27.7	29.8	32.3	28.2	30.3	32.4	28.0	30.0	32.9	28.1	31.0	32.7
100-year	47.3	48.8	52.3	56.7	49.6	53.2	56.9	49.2	52.8	57.7	49.4	54.3	57.4

Notes:
1. Existing conditions are a reflection of NOAA Atlas 14, volume 2 rainfall frequency analysis for Frederick, MD
2. DCFs reported are a ratio with respect to the existing precipitation amounts (i.e., 1.03 = 3% higher than existing)

While the absolute increases in peak flow rates and runoff volumes are significant by themselves, our team additionally also looked at what these increases represented in term of percent changes from the existing rainfall depths for Frederick. Table 10 and Table 11 summarize the results from the 39 simulations in terms of percent changes with respect to the results from the existing rainfall depths. Review of the results in terms of percent changes revealed that the expected increases are approximately the same as the percent increase applied to the rainfall depths through the DCF. For example, where a DCF value of 1.03 was applied, approximately a 3% increase in peak flows and volumes was observed. Although the percent increases in peak flows and volumes were not identical to the percent increase in rainfall applied by the DCF value, it was within a couple of percentage points at most. This trend was consistent in both peak flow rates and runoff volumes. Another interesting observation is that the percent changes in peak flow rates and runoff volumes have a slight negative relationship with the storm return period. As the storm return period increases, the percent changes decrease. So, for example, the percent change for the 100-year storm event is lower than the percent change for the 10-year storm event, which is in turn lower than the 1-year storm event.

Table 10. Summary of Projected Percent Changes in Peak Flow Results

Frequency \ DCF	2040s			2050s			2070s			2080s		
	1.03	1.10	1.19	1.05	1.12	1.19	1.04	1.11	1.21	1.04	1.14	1.20
1-year	4%	12%	21%	5%	13%	22%	4%	12%	24%	5%	16%	23%
10-year	3%	11%	20%	5%	13%	21%	4%	12%	23%	5%	15%	22%
100-year	3%	11%	20%	5%	12%	20%	4%	12%	22%	4%	15%	21%

Notes:
1. Existing conditions are a reflection of NOAA Atlas 14, volume 2 rainfall frequency analysis for Frederick, MD

Table 11. Summary of Projected Percent Changes in Runoff Volumes

Frequency \ DCF	2040s			2050s			2070s			2080s		
	1.03	1.10	1.19	1.05	1.12	1.19	1.04	1.11	1.21	1.04	1.14	1.20
1-year	3%	11%	21%	5%	13%	21%	4%	12%	23%	5%	16%	23%
10-year	3%	11%	21%	5%	13%	21%	4%	12%	23%	5%	15%	22%
100-year	3%	11%	20%	5%	13%	20%	4%	12%	22%	5%	15%	21%

Notes:
1. Existing conditions are a reflection of NOAA Atlas 14, volume 2 rainfall frequency analysis for Frederick, MD

While tabular representations of the hydrograph results were useful for comparison, our team has additionally provided a graphical representation of the simulations in Figure 9 on the following page. The figure shows the family of simulation results for the 1-year storm event at the bottom, 10-year storm event in the middle, and the 100-year storm event at the top of the graph. The graph includes the minimum and maximum peak runoff value for every family of storms. The minimum value reported corresponds to the results associated with the existing rainfall depths for each frequency event. The maximum value reported corresponds to the results from the projected storm event with the highest DCF applied (1.21) for each frequency event.

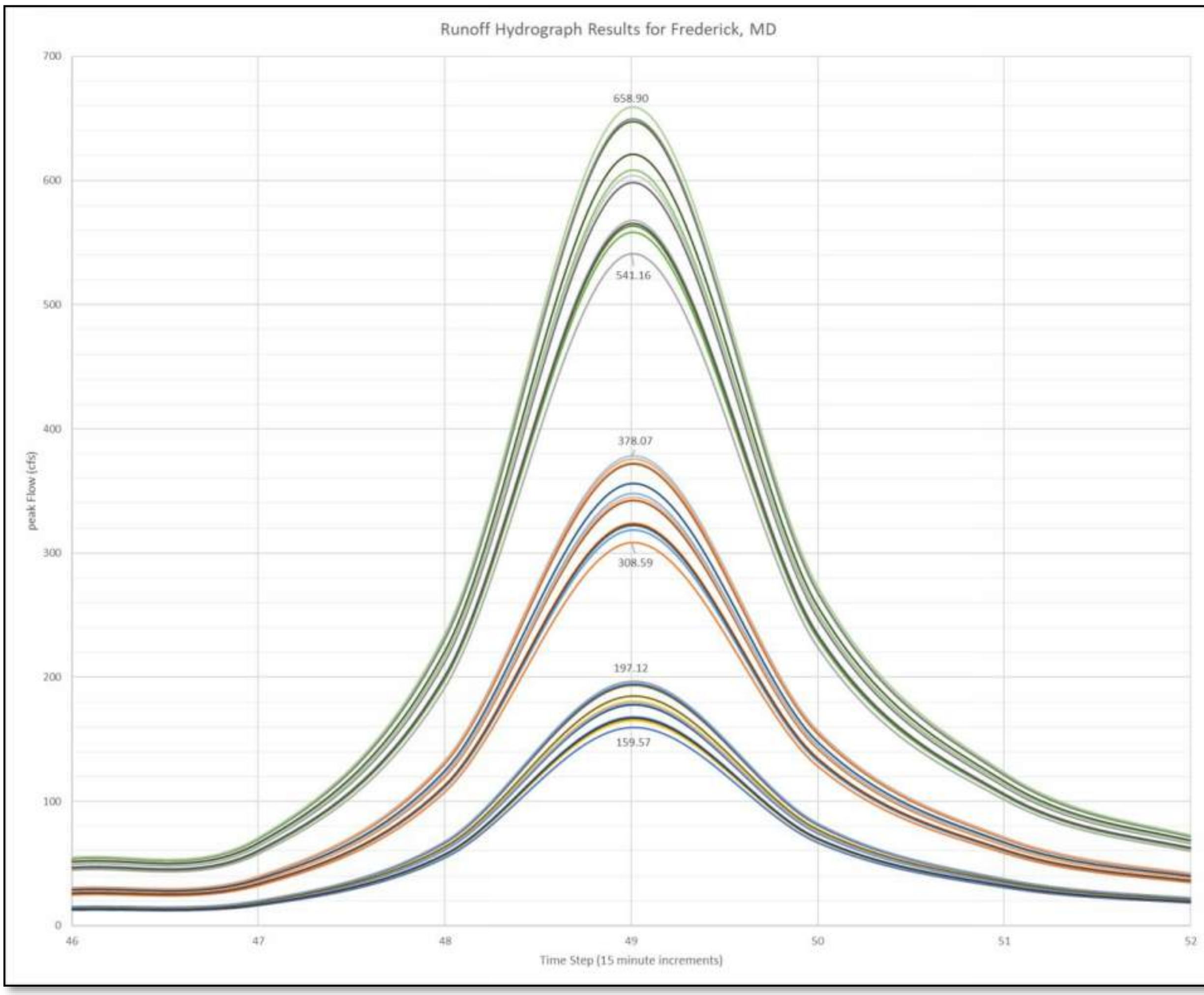

Figure 9. Ensemble of Hydrograph Results from Scenario Modeling

6.0 IMPLICATIONS FOR FREDERICK

In reviewing the results of the hydrologic model, our team became curious as to how these projected increases in precipitation amounts (rainfall depths) compared to existing rainfall depths associated with the frequency analysis presented in NOAA Atlas 14, volume 2. Relating the projected rainfall depths to existing frequency storm events with similar rainfall depths can help the City in communicating the range of changes to other community members and allow others to interpret a percent change value into a relatable storm that may have occurred in the community or in the reader's past experiences. From this exercise, which is summarized in Table 12, our team discovered that our highest projected rainfall depths resulted in rainfall depths that have historically occurred less frequently than the return periods our team used in the analysis. For example, the maximum projected 1-year storm event resulted in rainfall depths of 3.08 inches. This depth of rainfall is higher than the depth of rainfall associated with the 2-year storm event based on NOAA's frequency analysis of historical observed data. This means that what the residents of Frederick consider a 2-year storm could become more frequent. While this may have implications for water quality feature design, inlet design, and design of Best Management Practices (BMPs), the City could adopt changes now to adapt for the future. However, Table 12 also indicates that what our team projected as the high end for the 100-year storm event had a rainfall depth of 9.54 inches which is higher than the rainfall depth associated with a 200-year storm event by roughly 0.4 inches. This could have implications for the extents of the floodplains within the City, and in specific for the site that was chosen for our case study as it sits within the floodplain for Carroll Creek. It additionally has implications for existing flood reduction projects and any volume control of extreme events.

Table 12. Comparison of Projected Rainfall Depths and Rainfall Depths from NOAA Atlas 14 Rainfall Frequency Analysis

Projected Return Period	Max Projected Precipitation (in)	Current Precipitation (in)	Current Return Period
1-yr	3.08	3.07	2-yr
10-yr	5.61	4.64 - 5.77	10-yr to 25-yr
100-yr	9.54	9.18 - 11.2	200-yr to 500-yr

While the projected increases have general implications, these implications should be considered with respect to the current design criteria used by the City of Frederick. The City of Frederick heavily relies on the guidance provided by the Maryland Department of the Environment (MDE). Many of the requirements included in MDE's Stormwater Design Manual are based on rainfall depths and volumes that are associated with particular frequency events that capture the level of service that is expected for a given stormwater feature. As higher rainfall depths become more and more common, these requirements and criteria will need to be updated if the same level of service is expected. Stormwater planning and design rely on

MDE requirements such as the water quality volume (based on capturing 90% of the average rainfall in a year). As rainfall averages increase, the current requirement will not be able to achieve the same treatment goals. Other requirements such as the site recharge volume is based on the average annual groundwater recharge based on site soil type divided by the average annual rainfall depth. As annual rainfall depth increases, use of the current soil specific recharge factors in the Design Manual will likely result in higher groundwater recharge rates. Higher groundwater recharge rates may result in higher stream baseflows which would impact channel capacities. If this is not desired, the soil specific recharge rates may need to be revised and lowered.

Additionally, channel protection volume requirements are based on 1-year rainfall depths and associated peak flow rates. These rainfall depths will likely need to be updated or a lower level of protection should be expected as the design 1-year storm event starts occurring more frequently. Overbank flood protection volume that includes peak flow rate control by matching pre-development peaks uses the 2 or 10-year frequency storms as a design parameter. Design calculations to meet this requirement will need to use updated rainfall depths or the City could expect a lower level of service. Lastly, the extreme flood volume requirement uses the 100-year storm to design any ponds and other storage components. Given the projected higher occurrence of today's 100-year storm event, the rainfall depths used for pond design should be updated or a lower level of protection should be accepted. This component may have an additional impact on increasing the 100-year floodplains that exists today or achieving an ultimate 100-year floodplain sooner than anticipated. Furthermore, design frequencies for inlets and storm sewer pipes are typically frequent storms such as the 2 or 5-year events. However, as rainfall depths increases and become more frequent, the possibility of existing infrastructure to meet its capacity or surcharge will be greater , so that surcharges and ponding at inlets will likely increase if design standards are not updated.

For new stormwater infrastructure, more frequent use and potentially more frequent surcharge may also mean an increase in maintenance needs and associated costs and/or potentially a shorter infrastructure lifespan than designed. It will likely also mean more complaints of nuisance flooding at minimum and potentially new areas becoming affected by channel-related flooding. If the City desires to bring the projected level of service back in line with current design expectations, proactive planning efforts must be undertaken. It may be decided by the City and the community, however, that a higher level of risk (or lower level of protection) is acceptable given other social and economic considerations.

7.0 CONCLUDING REMARKS

Based on the information gathered from The Climate Explorer and the MACA tool for climate projections for the City of Frederick, our team made some observations. First, there is a large amount of variability in the projections of rainfall amounts made by the GCMs. The variability exists with the GCMs and underlying assumptions and processes and more variability is introduced by varying emissions scenarios (RCP 4.5 versus 8.5) and downscaling approach. This wide variability is exemplified by models showing projected average monthly precipitation amounts that are as low as 40% lower than historical records and as high as 65% higher than historical records. Second, despite the high amount of variation in precipitation projections, on average, model results indicate that there is an increasing trend for annual and monthly precipitation amounts. Third, these precipitation increases in monthly average rainfall are not constant throughout the year. Model results indicate that projected increases tend to vary by season with winter and summer months showing the highest increase amounts. Fourth, seasonality analyses of historical precipitation records further show that there is a higher occurrence of storms of all frequencies in the summertime. However, high-frequency / less intense storms still occur throughout the year whereas low-frequency storms / more extreme storms happen almost exclusively in the summer months. Fifth, the largest impacts from climate change and precipitation increases would be observed during the summer months. Sixth, from our team's analysis on projected storms at the case study site, climate projections will likely result in the shifting of the frequencies associated with certain rainfall depths causing higher rainfall to occur more frequently which will have implications to existing stormwater infrastructure performance and maintenance as well as to future infrastructure level of service and economic lifespan.

Based on our analysis, our team learned that the projections for future climate are highly variable when it comes to precipitation estimates. The GCMs will not provide one unique answer for any community looking to plan for a future with more extremes. However, it does provide possibilities of future climate scenarios to inform communities on the degree of change that can be used for guiding conversations about planning for the future. Ultimately, each City and its residents must decide what an appropriate level of risk and protection is for their community. However, the City of Frederick must consider the uncertainty regarding the future climate and have the appropriate conversations with its community members to adequately plan for future possibilities. It must additionally consider where existing stormwater infrastructure is already undersized or underperforming and how increases in precipitation may have a more noticeable impact to these locations and the associated storm sewers and / or channel systems and its nearby residents.

The approach and findings summarized in this document should provide the City with one tool to start conversations by providing context and ranges of the current state of climate projections for Frederick. However, the analysis our team undertook represents only one approach in an emerging field of study and research and the specific values selected for the case study may or may not reflect Frederick's actual future. However, not planning for climate change also has a cost and the community needs to be aware of that as well. Our team hopes that this document may serve to communicate the need for planning for the future, but this document should not be considered as a definitive conclusion on Frederick's approach to stormwater planning for its community.

APPENDIX A – Supporting Calculations

Submitted in Digital (*.xlsx) Format Only

APPENDIX B – Digital Data

Copy of Final Class PowerPoint Presentation
Copy of HEC-HMS v4.5 Hydrologic Model