Memorandum

Date: September 2, 2020

To: Randy Crowder
Charles County

From: Greg Hoffmann, P.E.
Hayden Smith
Melody Wu

Re: Precipitation Projections for Charles County
CIVE T580 Stormwater Planning in the Era of Climate Change

As a part of the Drexel University class CIVE T580, Stormwater Planning in the Era of Climate Change, Greg Hoffmann, Hayden Smith, and Melody Wu analyzed historical and projected future precipitation conditions for Charles County, Maryland. The methods used to develop preciptitation projections for 2050 and 2080 for the County are described below.

Existing Stormwater Management Practices in Charles County

Charles County is located in southern Maryland, on the eastern side of the Potomac River. With a 2010 population of 146,551, it is still a relatively rural county, but it has seen steady population growth in recent decades, with housing density increasing from 95 units per square mile in 2000 to 120 per square mile in 2010[1]. There is sufficient population and urbanized area that the County's Municipal Separate Storm Sewer System (MS4) has been regulated under the National Pollutant Discharge Elimination System (NPDES) permit system since 1997[2]. Its main areas of population and development are located in the northern part of the county, along the border with the more urban Prince George's County. The largest municipality in Charles County is Waldorf, an unincorporated community in the north with nearly half the county's population. The remaining areas of the County are lightly developed, consisting of small towns and villages and rural subdivisions. Much of the County's infrastructure was constructed prior to the 1987 Water Quality Act, which expanded the NPDES permit system to include MS4s and also

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[1] U.S. Census Bureau (2010). Profile of General Population and Housing Characteristics. Retrieved from https://factfinder.census.gov/faces/tableservices/jsf/pages/productview.xhtml?src=bkmk.

[2] KCI Technologies, Inc. 2016. Charles County Municipal Stormwater Restoration Plan. Prepared by KCI Technologies, Inc., Sparks, Maryland for Charles County Department of Planning and Growth Management, La Plata, Maryland. Dated June 2016.

established the Chesapeake Bay Program Office, which guides many of the water quality standards across Maryland[3].

The 2014 reissuance of the County's MS4 Permit expanded coverage of the permit to include the entire county, where it had previously been limited to the County Development District, comprised primarily of Waldorf. The Towns of Indian Head and La Plata are separate municipalities for the purpose of NPDES and other stormwater regulations, and so not covered by the County's Watershed Implementation Plans[4]. Other recent changes to stormwater management efforts in the County have included compliance with pollutant load limits from the Chesapeake Bay Total Maximum Daily Load (TMDL), restoration of previously untreated impervious surface, and expanded stormwater treatment options such as stream restoration and tree planting[5].

Charles County has experienced some friction in keeping pace with the changing regulatory landscape regarding stormwater infrastructure, initially asking for relief from the Maryland Department of the Environment's requirements that 20% of existing impervious surface be restored to the drainage capacity of forested land cover on the grounds that such a requirement exceeds the Maximum Extent Practicable (MEP) standard for the County[6]. While the County has thus far been able to meet the restoration requirements through a water quality pollutant credit trading program, Maryland's Phase III Watershed Implementation Plan (WIP) requires that any restoration requirements met by pollutant trading in the most recent NPDES permit phase will have to be met by physical retrofits in the subsequent MS4 permit phase, currently set to expire in 2024[7]. The Phase III WIP also promises an addendum in 2021 that will likely recommend

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[3] *Ibid*.
[4] *Charles County Watershed Implementation Plan* (2020). Port Tobacco River Conservancy. Retrieved from https://porttobaccoriver.org/about-the-port-tobacco-river/charles-county-md-watershed-implementation-plan/
[5] KCI Technologies, Inc. 2016. Charles County Municipal Stormwater Restoration Plan. Prepared by KCI Technologies, Inc., Sparks, Maryland for Charles County Department of Planning and Growth Management, La Plata, Maryland. Dated June 2016.
[6] Ball, Steven (2016). Re: Charles County NPDES MS4 Permit. Retrieved from https://mde.maryland.gov/programs/Water/StormwaterManagementProgram/Documents/Charles%20County%20FAP%20and%20WPRP%20Annual%20Report.pdf
[7] Maryland's Phase III Watershed Implementation Plan to Restore Chesapeake Bay by 2025 (2019). Retrieved from https://mde.maryland.gov/programs/Water/TMDL/TMDLImplementation/Documents/Phase%20III%20WIP

further changes to erosion and sediment control regulations based on climate change projections. By understanding how climate change is likely to impact the local precipitation regime, Charles County can better anticipate the changes that will be necessary to meet its regulatory obligations.

Understanding Sources of Uncertainty in Design Storm Modeling

While Charles County and the state of Maryland both recognize climate change as a threat to stormwater management and water quality goals, there are multiple vectors of uncertainty that make characterizing the magnitude and nature of climate risk challenging. With approximately 300 miles of shoreline, Charles County is vulnerable to sea level rise as well as precipitation regime change, which is the primary focus of this paper. Of particular concern in the region is changes in extreme precipitation events, with large storms expected to account for an increasing proportion of total precipitation in the Mid-Atlantic region[8]. Given finite resources for infrastructure upgrades and other climate adaptation initiatives, it is important for planners and other County officials to consider the range of possible future changes to local precipitation and understand the drivers of uncertainty that constrain these predictions[9].

In creating design storms for future stormwater management planning, there are three broad layers of uncertainty in predicting the impacts of climate change. The first layer is uncertainty regarding future emissions scenarios themselves, which has been widely discussed by the Intergovernmental Panel on Climate Change (IPCC) and other authorities. This uncertainty has been characterized by the IPCC using Representative Concentration Pathways (RCPs) since 2014[10]. The RCPs represent different trajectories for greenhouse gas concentrations throughout the 21st century and are named after the corresponding range of radiative forcing values in 2100. A successful implementation of the Paris Climate Agreement goal of limiting warming to

%20Report/Final%20Phase%20III%20WIP%20Package/Phase%20III%20WIP%20Document/Phase%20III%20WIP-Final_Maryland_8.23.2019.pdf

[8] Rockwell, Julia (2020). Stormwater Planning in the Era of Climate Change. Philadelphia Water Department.

[9] Chester, M et al. (2020). Keeping Infrastructure Reliable Under Climate Uncertainty. Nature, 10 pg. 482-490. https://doi.org/10.1038/s41558-020-0741-0

[10] **Hayhoe**, K., J. Edmonds, R.E. Kopp, A.N. LeGrande, B.M. Sanderson, M.F. Wehner, and D.J. Wuebbles, 2017: Climate models, scenarios, and projections. In: *Climate Science Special Report: Fourth National Climate Assessment, Volume I* [Wuebbles, D.J., D.W. Fahey, K.A. Hibbard, D.J. Dokken, B.C. Stewart, and T.K. May- cock (eds.)]. U.S. Global Change Research Program, Washington, DC, USA, pp. 133-160, doi: 10.7930/ J0WH2N54.

1.5°C corresponds to the lowest RCP of 1.9, while a “worst-case scenario” of increasing emissions throughout the century is represented by RCP8.5. Since the severity of climate change is determined by the concentration pathways of greenhouse gases, the emissions scenarios and related assumptions regarding feedback loops are fundamental to any predictions regarding future changes to precipitation regimes. In our analysis, we started with Global Climate Models representing RCP4.5 and RCP8.5, medium and a high-emissions scenarios, respectively.

The second layer of uncertainty in planning for climate change is created when attempting to downscale global change models to local conditions. Future temperatures, sea levels, precipitation regimes, and other climate variables are predicted by Global Climate Models (GCMs), but the spatial resolution of GCMs is too coarse to be useful and actionable without being adjusted to local conditions. Simple multiplication of local Intensity-Duration-Frequency (IDF) curves used in local stormwater planning, for instance, fails to account for year-to-year variability in precipitation and the possibility that precipitation changes will not be uniform across storm size or from season to season[11]. Variable outputs across different techniques for downscaling GCM precipitation forecasts to spatial and temporal scales usable for water resource planners add an additional layer of uncertainty in climate-aware stormwater planning.

The final layer of uncertainty in adapting design storms to global climate change predictions is found in modeling techniques themselves. Setting aside the challenges of predicting global climate change, defining local precipitation regimes and especially the time-distribution characteristics of rainfall in a given locality poses inherent challenges that city planners and engineers have been grappling with since the development of urban runoff models in the 1960’s [12]. Natural variability is a primary driver of year-to-year precipitation changes in the Mid-Atlantic region, with the El Niño-Southern Oscillation playing a particularly important role. While observed temperature changes over the past few decades are primarily anthropogenic, most observed precipitation changes in the region have been attributed to natural climate patterns[13].

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[11] Maimone, M., Malter, S., Rockwell, J., and Raj, V. (2019). Transforming Global Climate Model Precipitation Output for Use in Urban Stormwater Applications. *Journal of Water Resource Planning and Management* 145(6).

[12] Huff, F (1990). Time Distributions of Heavy Rainstorms in Illinois. *Illinois State Water Survey Campaign*. Circular 173.

[13] Najjar, R (2017). Climate change in the Mid-Atlantic Region. *Chesapeake Bay Program*. Retrieved from http://www.chesapeake.org/stac/presentations/280_Najjar%20Climate%20Mid-Atlantic_FINAL.pdf

Extreme weather events such as tropical cyclones are already an important, but difficult to predict, factor in Mid-Atlantic precipitation patterns, and there is still significant uncertainty regarding how anthropogenic climate change will impact tropical storms[14]. Differences in how the climate models characterize storm activity is one possible explanation for the increased variability in monthly precipitation projections compared to the annual totals, as described below.

Developing Delta Change Factors

In order to predict precipitation changes in Charles County over the rest of the century as a result of climate change, delta change factors (DCFs) were produced. To do this, the historically modeled precipitation from 20 global climate models (GCMs) and 2 different rainfall grids[15] were compared to observed historical data from 1971 - 2000 from Charles County[16]. Of the 40 combinations of GCM and rainfall grid, the 10 that best matched total rainfall from 1971 - 2000 were selected. The ten resulting GCMs are shown below, where 6 are METDATA gridded data and 4 are LIVNEH gridded data.

1. Bcc-csm1-1 (METDATA)
2. CCSM4 (METDATA)
3. CSIRO-Mk3-6-0 (METDATA)
4. GFDL-ESM2G (METDATA)
5. HadGEM2-ES365 (METDATA)
6. IPSL-CM5A-LR (METDATA)
7. CSIRO-Mk3-6-0 (LIVNEH)
8. GFDL-ESM2G (LIVNEH)
9. inmcm4 (LIVNEH)
10. MRI-CGCM3 (LIVNEH)

Using these 10 GCMs, monthly rainfall was projected for both medium and high emissions scenarios the 2020s (2010-2039), 2050s (2040-2069), and 2080s (2070-2099). This yielded a total of 720 potential DCFs (2 emissions scenarios X 3 time slices X 12 months X 10 GCMs = 720 DCFs). Each of the 720 DCFs were calculated through a percent change equation (Equation 1 below) where the future and historical values were found by averaging the monthly

[14] Geophysical Fluid Dynamics Laboratory (2020). Global Warming and Hurricanes: An Overview of Current Research Results. Retrieved from https://www.gfdl.noaa.gov/global-warming-and-hurricanes/
[15] University of California, Merced. "Design Your Own CSV File of MACA Point Data." *MACA Statistical Downscaling Method*. Retrieved from: climate.northwestknowledge.net/MACA/data_csv.php.
[16] National Oceanic and Atmospheric Administration. *Climate Explorer*. Retrieved from crt-climate-explorer.nemac.org/.

values for each time slice. The 2050s table of DCF's is shown as an example in Table 1 below. Similar tables were developed for the 2020s and 2080s.

$$DCF = 100 \times \frac{Future - Historical}{Historical} \quad \text{(Equation 1)}$$

Table 1: 2050s DCF's per month and RCP for the chosen 10 GCM's.

Month	TimeSlice	RCP	METDATA						LIVNEH			
			pr_bcc-csm1-1	pr_CCSM4	r_CSIRO-Mk3-6-(	pr_GFDL-ESM2G	_HadGEM2-ES3	r_IPSL-CM5A-LI	r_CSIRO-Mk3-6-	pr_GFDL-ESM2G	pr_inmcm4	pr_MRI-CGCM3
January	2050	4.5	-1.85	17.20	16.66	0.53	15.47	7.76	15.83	1.60	-6.20	21.75
January	2050	8.5	15.97	16.60	7.87	10.57	-0.26	16.58	8.19	3.68	-7.41	31.96
February	2050	4.5	5.91	21.84	16.31	15.99	27.92	31.23	14.36	9.67	4.84	24.59
February	2050	8.5	-0.97	16.94	4.80	26.73	27.92	36.70	7.02	16.79	-0.20	23.82
March	2050	4.5	10.43	26.06	-3.93	-0.67	6.77	-9.60	0.29	-3.08	9.64	5.97
March	2050	8.5	25.16	21.89	-0.42	1.46	8.59	-7.71	4.14	0.74	3.73	25.10
April	2050	4.5	15.51	13.75	22.18	7.30	26.86	5.34	13.33	7.61	8.96	-2.88
April	2050	8.5	21.75	23.12	17.54	11.40	13.33	-8.39	7.45	10.50	0.55	1.57
May	2050	4.5	18.56	1.52	27.78	11.20	4.81	9.15	21.98	12.03	6.03	0.03
May	2050	8.5	2.71	-6.18	28.45	6.81	-14.85	14.35	17.47	11.56	1.03	-10.89
June	2050	4.5	-4.57	13.42	22.39	10.08	4.71	-1.63	14.40	2.69	-11.64	-6.14
June	2050	8.5	3.89	11.37	6.43	-4.07	9.16	9.03	-1.44	-6.36	-8.28	-2.92
July	2050	4.5	-13.07	11.16	18.53	27.73	-1.54	10.79	15.16	22.60	17.50	-17.21
July	2050	8.5	-2.95	3.48	-2.35	22.24	-10.24	-6.73	6.29	20.39	21.57	-1.80
August	2050	4.5	-9.11	10.77	35.47	-8.59	15.09	22.39	29.36	-4.00	2.01	5.57
August	2050	8.5	-7.67	23.87	33.33	14.53	-9.49	1.31	33.93	12.73	11.46	-0.64
September	2050	4.5	-15.43	3.74	1.92	-2.73	11.50	12.61	12.90	3.54	-1.59	-0.88
September	2050	8.5	7.73	19.81	4.61	12.35	-3.54	-3.16	0.81	12.71	8.50	5.16
October	2050	4.5	21.71	7.30	25.44	28.67	0.14	-9.34	20.59	20.97	-0.06	29.51
October	2050	8.5	43.20	26.64	5.20	7.32	-7.27	-20.83	6.15	9.34	-14.83	14.34
November	2050	4.5	6.19	3.65	1.06	13.00	-10.54	-4.76	-1.86	13.99	-7.89	12.04
November	2050	8.5	15.06	30.50	29.69	8.57	-5.39	17.25	19.84	0.75	-8.58	16.76
December	2050	4.5	8.69	17.65	9.65	-7.69	13.55	-2.62	6.86	-9.39	-2.85	-7.01
December	2050	8.5	10.67	29.88	14.45	-4.05	25.77	0.68	11.42	-2.80	-16.73	11.08

Note:
Delta Change Factors were calculated using percent change between average monthly data between historical and GCM projected for each given time slice. The time slices are divided as follows: 2020's corresponds to 2010-2039, 2050's corresponds to 2040-2069, and 2080's corresponds to 2070-2099. Point location for historical and projected data are centered upon La Plata, a centralized town in Charles County. Rain gages around Charles County lacked consistent data between the historical time frame of 1971 to 2000. The chosen GCMs were determined to be best according to their correlation to historically observed data, which was pulled from Climate Explorer. These GCMs, 6 of which are METDATA gridded observation data and 4 of which are LIVNEH data, were pulled from climate.northwestknowledge.net/MACA.

To visually represent the delta change factors and how they predict precipitation changes in Charles County, a box and whisker plot was created for each time slice. Each month within the time slice has 2 boxes with 10 DCFs each at the different relative concentration pathways (RCPs) of 4.5 and 8.5, medium and high emission scenarios, respectively. These plots are shown in Figures 1, 2, and 3 below.

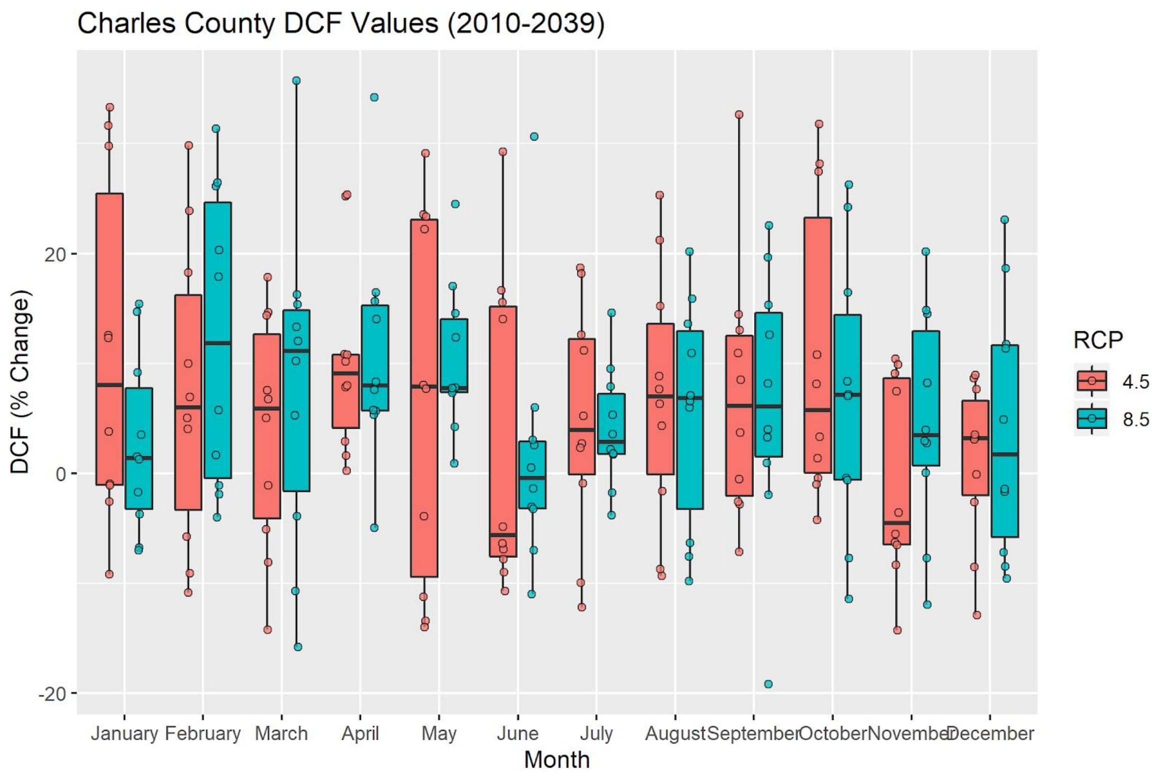

Figure 1: Delta Change Factors for precipitation in Charles County in the 2020s.

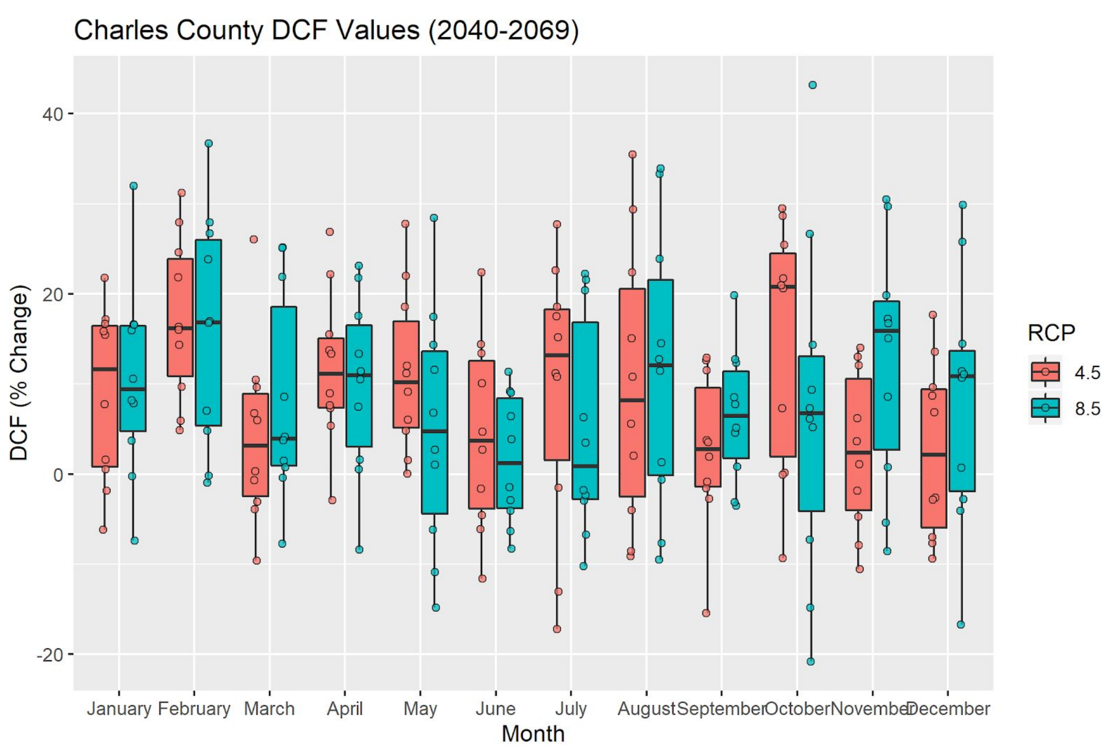

Figure 2: Delta Change Factors for precipitation in Charles County in the 2050s.

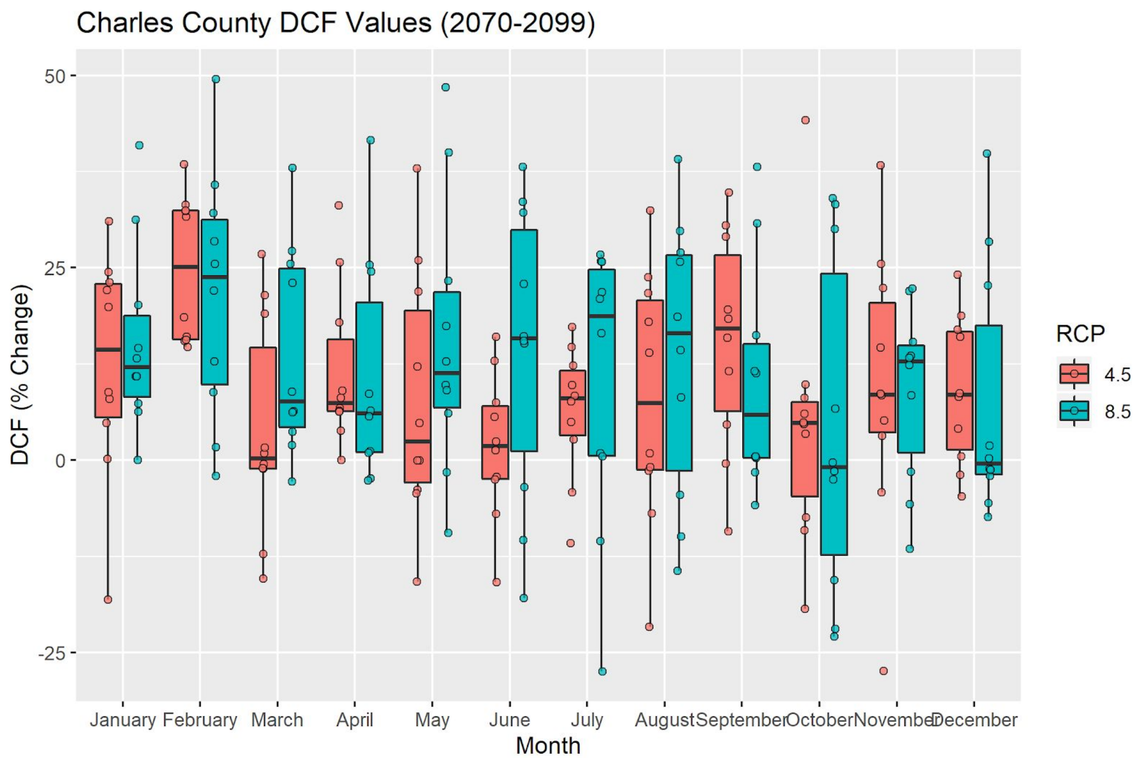

Figure 3: Delta Change Factors for precipitation in Charles County in the 2080s.

Analysis of DCFs and resulting box plots

Almost all box plot medians are greater than 0, indicating an increased precipitation per month in the time slices. Only June 2020s and October and December RCP 8.5 2080s show a negative change in precipitation. With only three outlying negative median values, amongst the 36 monthly medians, the projection of an increase in future precipitation is clear.

While the trend is toward an increase in precipitation, it is difficult to observe any notable differences in the projections for RCP 4.5 versus 8.5, and the trend in seasonality in the three time slices is also unclear. Thus, rather than focus on monthly values, the delta change factors were recalculated using the same information but instead focusing on total annual precipitation. Lastly, the 2020s data is less relevant due to its proximity to the historical time slice, so the final DCFs for the model focused on the 2050s and 2080s.

Final DCFs:

The final DCFs chosen were narrowed down to 4 total factors. As mentioned above, they were refined to total annual rather than monthly precipitation changes. They were also chosen only for the 2050s and 2080s and separated between RCPs 4.5 and 8.5. The actual factors were calculated by summing the total annual precipitation for each of the 10 GCMs. The median projected total precipitation among these was used in the percent change equation to find the annual DCFs. The resulting 4 factors are shown in Table 2 below.

Table 2: DCFs for time slices 2050s and 2080s at RCPs 4.5 and 8.5

	2050	2080
RCP 4.5	6.9%	7.8%
RCP 8.5	8.2%	9.6%

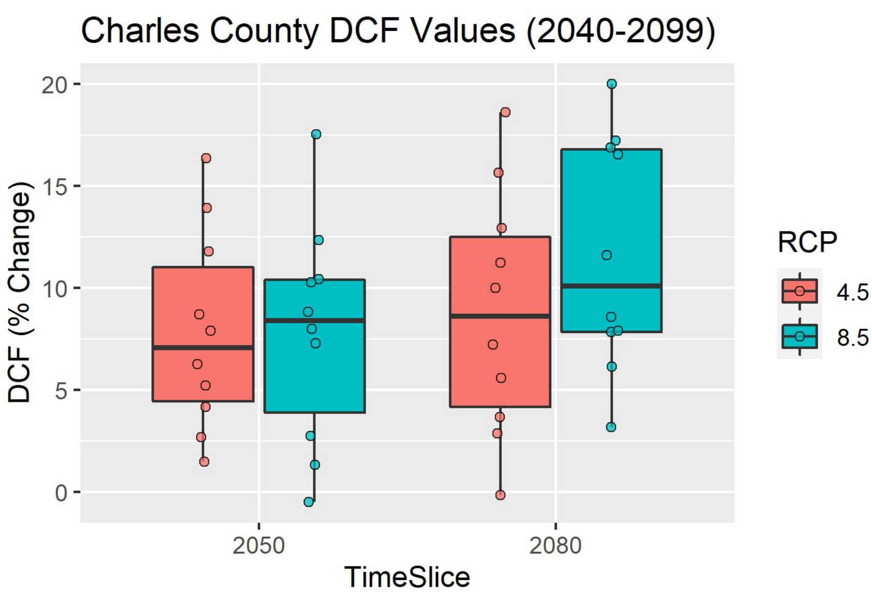

Figure 4: Annual Precipitation Delta Change Factors for 2050s and 2080s time slices

As shown in Table 2 and Figure 4, the impact of the two RCPs on resulting DCFs are much more noticeable annually than monthly. Furthermore, the impact shown by the median is much clearer when the data is not muddled from monthly variability.

Case Study: Waldorf Urban Redevelopment Corridor

The DCFs described above were used on an example site in Charles County to illustrate how they can be used to modify design storms and what the potential effects may be. The Waldorf Urban Redevelopment Corridor (WURC) is a heavily developed, 209-acre commercial area in Charles County, bounded by highway US 301 on the west and a railroad to the east. Due to these barriers, flat terrain, and poorly draining soils, the area is known to have drainage problems.

Figure 5. Aerial photograph of Waldorf Redevelopment Corridor.

A hydrologic model of a portion of the WURC was developed using WinTR-55 software, developed by the Natural Resources Conservation Service. Per instructions from Charles County, the 1-year, 2-year, 10-year, and 100-year storm events were modeled. Existing rainfall depths for these storms were found using the National Oceanic and Atmospheric Administration's Atlas 14 (See Table 3).

Table 3. Rainfall depths for Charles County

Storm Event	Rainfall Depth (inches)
1-year	2.66
2-year	3.23
10-year	5.01
100-year	8.65

To create a more manageable model, the southern 65 acres of the WURC was selected. As a comprehensive drainage plan for this area was not available, a few assumptions needed to be made in order to develop a hydrologic model. It was assumed that the entire 65 acres drains to the existing wooded wetland south of Bad Dog Alley along a flat, 0.5% slope flow path. Inputs to the model are provided below:

Land Cover

- 39.1 acres impervious cover
- 13.1 acres turf, D soils
- 7.4 acres forest, C soils
- 5.8 acres forest, D soils

Time of Concentration

14 minutes

Figure 6. Southern portion of WURC. 65-acre modeled area is highlighted in light blue. Assumed runoff flow path is shown in pink.

The model was run first using the existing rainfall data to estimate the expected runoff to the wetland using current design storms. Next, the design storms were increased by each of the four DCFs described above, and the model was re-run. Figure 7 below shows results for the

2-year storm. The existing design storm produced a peak flow of 138 cubic feet per second (cfs). The projected future storms produced peak flows of 151 to 157 cfs.

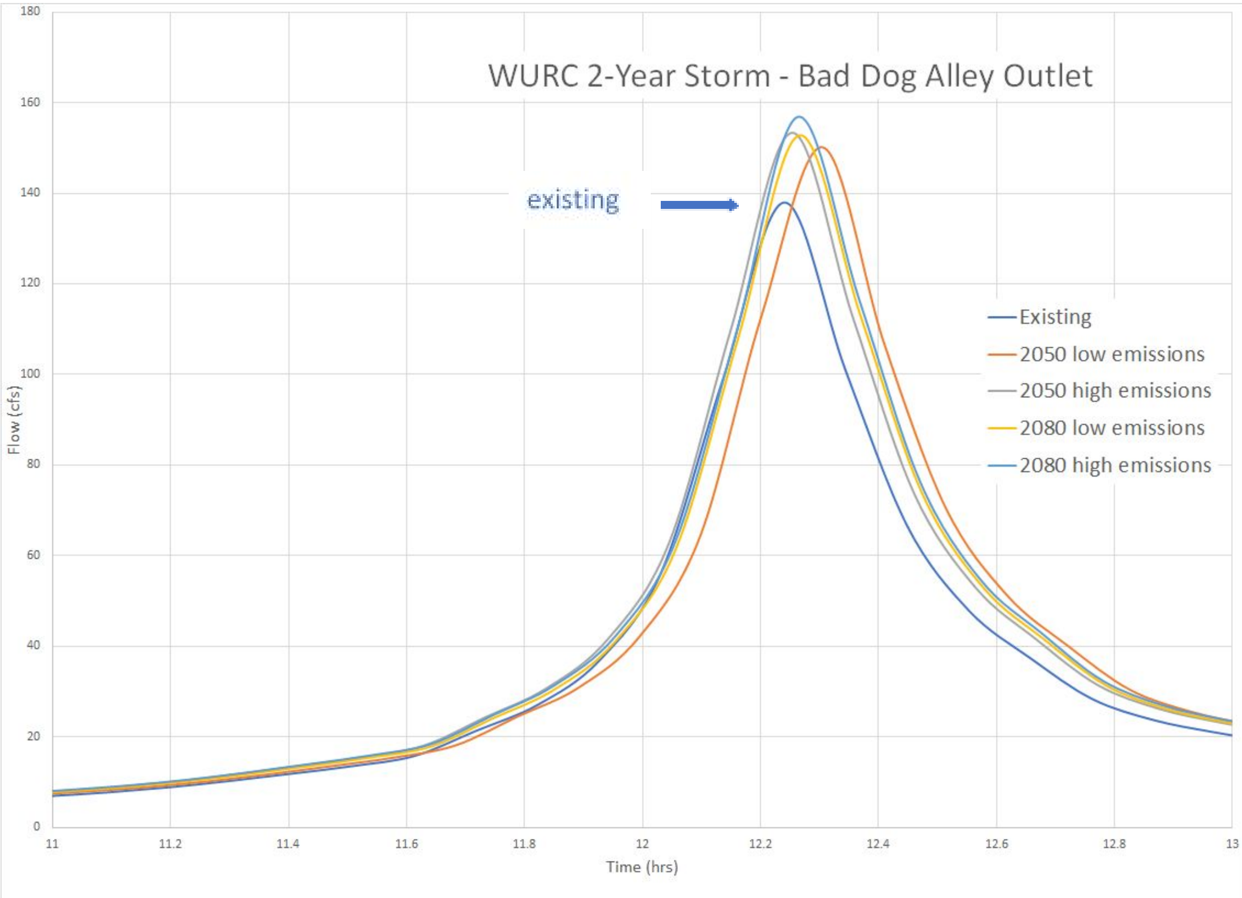

Figure 7. Modeled runoff for the 2-year storm for example area using existing and projected storm events.

Table 4 provides the peak flow results for all modeled storm events and all DCFs. It is worth noting that while the rainfall is projected to increase between 6.9% and 9.6%, the projected peak flows for the example area increase from 8.1% to 14.6%.

Table 4. Modeled peak flows and runoff for each storm event and climate projection.

WURC Bad Dog Alley Projected Flows										
	Existing Conditions		2050 Medium Emissions		2050 High Emissions		2080 Medium Emissions		2080 High Emissions	
Storm Event	Peak Flow (cfs)	Total Runoff (in)	Peak Flow (cfs)	Total Runoff (in)	Peak Flow (cfs)	Total Runoff (in)	Peak Flow (cfs)	Total Runoff (in)	Peak Flow (cfs)	Total Runoff (in)
1-yr	105	1.6	116	1.8	118	1.8	118	1.8	121	1.8

2-yr	138	2.1	151	2.3	153	2.3	153	2.3	157	2.4
10-yr	241	3.8	262	4.1	265	4.2	265	4.2	270	4.2
100-yr	451	7.3	485	7.9	492	8.0	490	8.0	500	8.1

Conclusions and Recommendations

Through this analysis, it has been estimated that annual runoff, and therefore Charles County design storms will increase by 6.9% - 8.2% by 2050 and 7.8% - 9.6% by 2080. By looking at the median values projected by a number of climate models, more extreme projections have essentially been factored out – both the high and the low. While the range of model projections illustrate how uncertain we are about future climate conditions, the majority of climate models project an increase in rainfall in the future. The median values calculated in this report represent the middle of the road of what is projected, and a good starting point for making changes to design storms. It is recommended that Charles County consider modifying its design storms to account for these projected increases. Given how close the projected percentages are, the specific scenario Charles County chooses is not the most important consideration; the fact that all of the projections represent an increase over existing conditions is.