DREXEL UNIVERSITY
College of
Engineering

Stormwater Planning in the Era of Climate Change

Prepared for Camden County (CCMUA), New Jersey

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Summary

The City of Camden is currently struggling with managing their stormwater systems and excessive precipitation intake. As time goes on, climate change intensifies and systems age, which leaves Camden needing to implement new ways to handle the intakes and flooding that occurs more than ever. This project is an attempt to provide Camden with future design storms that they can apply to their planning in order to ensure that extreme precipitation events no longer drastically impact suffering communities. This report is a detailed explanation of a downscaling approach of global climate models to create the design storms necessary to do so.

1. Camden City

The City of Camden currently struggles with major flooding issues due to its aged infrastructure and combined sewer systems outflows (CSO). Camden city has upwards of 30 CSOs, where 17% of the state lives within their limits. Due to this, the inherent health risks of spilled sewage steadily increase year by year since the amount and intensity of rainfall events are increasing. Roughly one inch of rainfall from every average storm causes massive damage and flooding to low lying areas, such as an area like Cramer Hill. These rains not only cause numerous infrastructure damages, but because CSOs furthermore pollute the flooded runoff and sewage waters into the city there are massive health concerns and property damages. Camden's CSO discharge is channeled to places such as the Delaware and Cooper River; unfortunately, Cooper river has recently been classified as a Class 1 River by the DEA. This new classification ranking makes the river a red zone for any CSO discharge, leading to a search for the use of a new outflow source.

The Camden County Municipal Authority (CCMUA) is currently planning and implementing to tackle these flooding issues affecting Camden and surrounding cities. Both budget constraints as well as a lack of collaborative effort from the state itself have been challenges faced during this process. Through a collaborative project approach called Camden Smart, CCMUA has begun working towards battling stormwater issues with the help of other local counties which lack state support to combat runoff damage. The Camden Smart (Stormwater Management and Resource Training) initiative is a collaborative effort between multiple counties in New Jersey to develop a comprehensive network of green stormwater infrastructure (GSI) projects within Camden. Since there is no current state precedent on making ways to fight stormwater issues, all lessons learned in the Camden Smart project are shared with other countries with the hope of encouraging the construction of more green stormwater infrastructures. While this approach is ad hoc and collaborative, the Camden Smart project has already begun multiple stormwater projects making steps towards reducing current runoff issues in Camden City.

When it comes to building new infrastructures as well as updating old ones, precautionary steps must be taken to ensure the investment is worth the time. Especially in regard to GSIs due to the fact that climate change is an ongoing, constantly changing challenge that cities are facing all around the world. CCMUA takes this into consideration by using a single storm model as a basis for all of their project plans and implementations. The storm model, known as their "Typical Storm" model, is based off of all of the rainfall events that occurred during the year 2014. The City's entire combined sewer system is based solely on the model; there are some challenges though. As of today, the model is not being updated with current precipitation data and cannot pinpoint the spot where flooding starts to occur within the city. Flooding is a problem that CCMUA is currently trying to find a way to engage the community in a way where they can identify flooded locations during or after storms. The storm model is also a very vague and basic representation of what could happen, lacking any strong or explicit details. It strictly focuses on the idea that CCMUA wants to capture 85% of the stormwater going through their systems. Since they can effectively apply this concept to the model, repercussions aren't held against them during an outlier storm that is more intense than the average one.

With all of the challenges and expectations CCMUA is faced with on a yearly basis, they have set some goals to achieve within the new future to furthermore improve the City of Camden and the surrounding areas. The most relevant goal would be to improve the public-to-stormwater utility communication. Neighborhoods and communities are those who are facing the challenges face to face, whether it be a power outage or extensive flooding during the storms. CCMUA wants the community engagement to be stronger to discuss and spread the word on current and future GSI projects occurring throughout the cities. In addition to that, they want to improve the climate change studies and the impact it has on their systems. Using 2014 data will not be the most ideal option for them as time goes on, and they are currently planning new ways to gather, analyze, and then implement the data into their stormwater management ways. Lastly, CCMUA wants to have a heat and power facility to rely on. When their buildings shut down due to power loss during storms, they can't pump anything. Having the heat and power system will help ensure that things will run more efficiently during and after powerful storms. A goal for this project is to assist CCMUA with their preparations for future storms by creating design storms that they can apply to their planning processes to ensure infrastructure can withstand the varying intensities.

As previously mentioned, it is expected that the rate of increasing rainfall amounts as well as the intensities to not diminish any time soon. Camden's low elevation conditions already put the county at high risk. With exacerbating circumstances, it is extremely imperative to assist Camden with their attempt to attack climate change. The approach taken to do such was to develop future design storms for Camden to use when designing future infrastructures to be able to perform efficiently when experiencing such precipitation events. With various data sources and methods, this process could be completed in a detail-oriented manner. However, like most heavily data-driven projects, many sources of error can occur when coming to conclusions. For one, this project does not go into depth with the rate of climate change and the individual factors that are responsible for contributing towards that. Changes with greenhouse gas (GHG) emissions, temperature fluctuations, and anthropogenic factors are just a fraction of the numerous factors that are not applied to this process of making design storms. When gathering data, only ten types of global climate models (GCMs) were utilized in hopes of retaining consistency throughout the project. Even though the goal was achieved in one sense, it still leads to uncertainty in another. Due to the fact that there are countless other reliable sources out there to use, there is no firm assumption that the data sources chosen perfectly reflects those that are available.

2. Precipitation Projections

The first task of this research project was to utilize historical and projected data collected from The Climate Explorer to create precipitation tables projecting future conditions. For the projected data, yearly precipitation levels as well as the amount of days Camden will experience a storm with precipitation values greater than one inch, two inches, and three inches were analyzed. Both the RCP 4.5 and 8.5 scenarios were also taken into consideration for this. The 4.5 RCP represents the stabilized GHG scenario, whereas the 8.5 RCP is the continuously increasing of GHG representation. Applying them both ensured that the models would be showing not only what is most likely to occur, but also what could occur if emission rates drastically increase over time. The data was also condensed and tabulated to focus on the 20's, 50's, and 80's time slices. To calculate how the values differ, a percent difference equation was applied between the historical data and projected data sets. The data sets being compared to the historical values were the following: minimum, maximum, and mean precipitation levels. These were represented as the low estimates, middle estimates, and high estimates, respectively. The percent difference for each of those categories were then averaged to get a single value for the time slice's estimates. Shown below in Tables 1 through 4 are the results.

Table 1 - Projected total annual precipitation change in Camden, New Jersey for the 20's, 50's, and 80's time slices

A. Precipitation Baseline for 30 year interval (1971-2000) 48.17 inches	RCP 4.5			RCP 8.5		
	Low Estimate	Middle Estimate	High Estimate	Low Estimate	Middle Estimate	High Estimate
2020	32.51	47.67	65.75	33.85	48.37	65.71
2050	32.68	48.38	67.74	34.07	48.97	66.47
2080	33.58	49.08	66.89	34.20	49.69	68.77
B. Precipitation Baseline for 30 year interval (1971-2000) 48.17 inches	Low Estimate	Middle Estimate	High Estimate	Low Estimate	Middle Estimate	High Estimate
2020	-8.21%	0.09%	7.66%	-4.93%	1.54%	8.78%
2050	-7.41%	2.43%	12.53%	-3.49%	3.67%	10.42%
2080	-4.86%	3.90%	11.11%	-3.11%	5.77%	14.24%

Notes: Based off of weighted RCP 4.5 and 8.5 data set for total annual precipitation amounts collected from Camden, NJ through the Climate Explorer site. This table covers the time period of

1971 to 2000. It includes the low estimate, high estimate, and the middle estimates. These estimates were based off of a minimum, maximum, and average rainfall data collection, respectively. The chart is based off of the difference calculated between the historical and projected days. Like any calculation, there are sources of error due to data collection, human error, or calculation rounding.

Table 2 - Projected precipitation change of days with rainfall greater than 1" in Camden, New Jersey for the 20's, 50's, and 80's time slices

A. Precipitation Baseline for 30 year interval (1971-2000) 7.45 days	RCP 4.5			RCP 8.5		
	Low Estimate	Middle Estimate	High Estimate	Low Estimate	Middle Estimate	High Estimate
2020	1.64	7.21	14.83	1.90	7.63	15.04
2050	1.77	7.55	15.71	2.06	8.08	15.42
2080	2.10	7.85	2.10	2.70	8.85	17.31
B. Precipitation Baseline for 30 year interval (1971-2000) 6.9 days	Low Estimate	Middle Estimate	High Estimate (90th Percentile)	Low Estimate	Middle Estimate	High Estimate
2020	-46.67%	-3.49%	16.20%	-37.70%	0.93%	21.09%
2050	-39.08%	4.24%	28.74%	-28.85%	11.51%	26.37%
2080	-27.47%	8.33%	28.36%	-6.90%	22.09%	41.91%

Notes: Based off of weighted RCP 4.5 and 8.5 data set for extreme precipitation events that exceeded 1" collected from Camden, NJ through the Climate Explorer site. This table covers the time period of 1971 to 2000. It includes the low estimate, high estimate, and the middle estimates. These estimates were based off of a minimum, maximum, and average rainfall data collection, respectively. The chart is based off of the difference calculated between the historical and projected days. Like any calculation, there are sources of error due to data collection, human error, or calculation rounding.

Table 3 - Projected precipitation change of days with rainfall greater than 2" in Camden, New Jersey, for the 20's, 50's, and 80's time slices

A. Precipitation Baseline for 30 year interval (1971-2000) 0.8 Days	RCP 4.5			RCP 8.5		
	Low Estimate	Middle Estimate	High Estimate	Low Estimate	Middle Estimate	High Estimate
2020	0.00	0.90	3.76	0.00	0.96	3.70
2050	0.00	0.94	3.95	0.00	1.05	3.84
2080	0.00	1.03	4.20	0.00	1.20	4.45
B. Precipitation Baseline for 30 year interval (1971-2000) 0.58 Days	Low Estimate	Middle Estimate	High Estimate	Low Estimate	Middle Estimate	High Estimate
2020	0.00%	26.16%	94.91%	0.00%	30.00%	91.75%
2050	0.00%	35.76%	108.07%	0.00%	51.11%	102.11%
2080	0.00%	48.71%	121.23%	0.00%	72.69%	134.21%

Notes: Based off of weighted RCP 4.5 and 8.5 data set for extreme precipitation events that exceeded 2" collected from Camden, NJ through the Climate Explorer site. This table covers the time period of 1971 to 2000. It includes the low estimate, high estimate, and the middle estimates. These estimates were based off of a minimum, maximum, and average rainfall data collection, respectively. The chart is based off of the difference calculated between the historical and projected days. Like any calculation, there are sources of error due to data collection, human error, or calculation rounding.

Table 4 - Projected precipitation change of days with rainfall greater than 3" in Camden, New Jersey, for the 20's, 50's, and 80's time slices

A. Precipitation Baseline for 30 year interval (1971-2000) 0.13 Days	RCP 4.5			RCP 8.5		
	Low Estimate	Middle Estimate	High Estimate	Low Estimate	Middle Estimate	High Estimate
2020	0.000	0.180	1.570	0.000	0.180	1.560
2050	0.000	0.200	1.700	0.000	0.200	1.570
2080	0.000	0.220	1.870	0.000	0.260	1.880
B. Precipitation Baseline for 30 year interval (1971-2000) 0.13 Days	Low Estimate	Middle Estimate	High Estimate	Low Estimate	Middle Estimate	High Estimate
2020	0.00%	14.31%	29.17%	0.00%	18.79%	31.94%
2050	0.00%	36.72%	41.94%	0.00%	34.48%	31.11%
2080	0.00%	50.17%	56.11%	0.00%	72.59%	56.39%

Notes: Based off of weighted RCP 4.5 and 8.5 data set for extreme precipitation events that exceeded 3" collected from Camden, NJ through the Climate Explorer site. This table covers the time period of 1971 to 2000. It includes the low estimate, high estimate, and the middle estimates. These estimates were based off of a minimum, maximum, and average rainfall data collection, respectively. The chart is based off of the difference calculated between the historical and projected days. Like any calculation, there are sources of error due to data collection, human error, or calculation rounding.

3. Delta Change Factors

To start the process of creating the design storms, historical and projected precipitation data sets had to be collected for Camden County to accurately downscale. Downscaling was applied since it is an effective way to relate the impact climate change has on a global and local scale. The Climate Explorer was utilized to obtain the yearly historical data, focusing on a baseline from 1971 to 2000. After that, projected precipitation as well as historical values were collected from The MACA Data Tool. For creating the design storms, both the 4.5 and 8.5 RCPs were applied again. Furthermore, the METDATA and Livneh data sets were selected for each of the RCPs, where Livneh data represents collected daily and monthly precipitation over the gridded area for Camden. Each of these sets consist of the ten global climate models chosen, leading one to have an overall total of 40 different data sets of projected precipitation.

In order to continue with the process of downscaling, the GCMs were analyzed and compared to each other to reduce the amount of data sets to work with as well as the level of uncertainty. The percent differences were calculated between the historical data obtained from The Climate Explorer and each individual GCM for the RCP 4.5 METDATA. When deciding on which models to eliminate, those with the highest percent difference were removed until only ten global climate models were left. Those ten GCMs[1] were then applied for the following remaining RCP scenarios: 4.5 Livneh, 8.5 Livneh, and 8.5 METDATA.

Following this process was to find the delta change factors (DCF) for the GCMs in comparison to the historical data from The MACA Data Tool. The 4.5 and 8.5 RCP METDATA GCMs were compared to the METDATA historical set, whereas the 4.5 and 8.5 RCP Livneh GCMs were compared to the Livneh historical set. In order to find the DCFs, as a percent, Equation 1 was applied to the values:

$$\frac{(Projected - Historical)}{Historical} \; x \; 100 \qquad (Equation\ 1)$$

A keynote to mention is that the MACA Data Tool released their data sets monthly, rather than yearly. Because of this, the historical and projected precipitation values had to be arranged and averaged by month to be compared to each other. Once this was accomplished, there were 36 monthly values for each of the projected GCMs. In addition to that, there were twelve monthly values for the historical data set. This led to an overall breakdown of the data set into three time periods as well, the 2020's, 2050's, and the 2080's. They accounted for the years 2009-2039, 2040-2069, and 2070 to 2099, respectively.

In order to visually represent the DCFs that have been calculated, boxplots were created for each of the time periods and are shown below. This assisted with the analyses on whether there were any similarities with the type of downscaling approaches applied with the GCMs as well as any seasonal distributions that occurred. Overall, the spring and early summer months tend to stay the most consistent with each other, whereas the end of summer through winter months fluctuate over each period. More importantly though, outliers within the data set can mislead a visual analysis since the programming used to create them regarded them as any other data set, rather than being extreme. As previously mentioned, this could be a factor leading to uncertainties when creating the modeled storms.

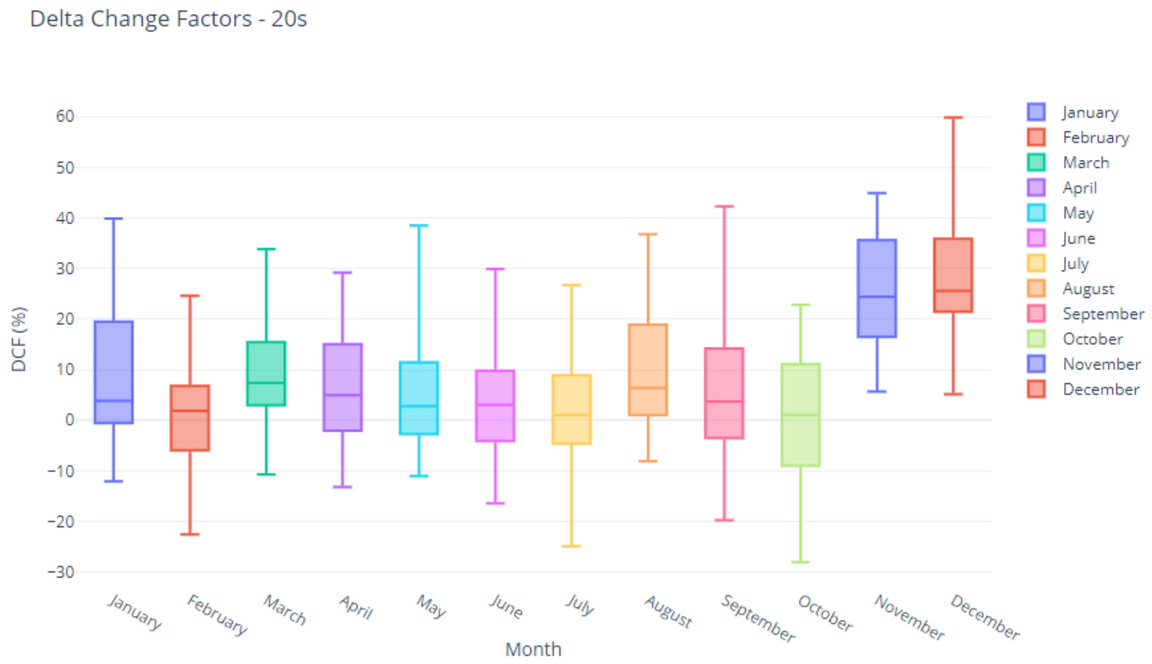

Figure 1 - Monthly delta change factors for the period of 2009-2039

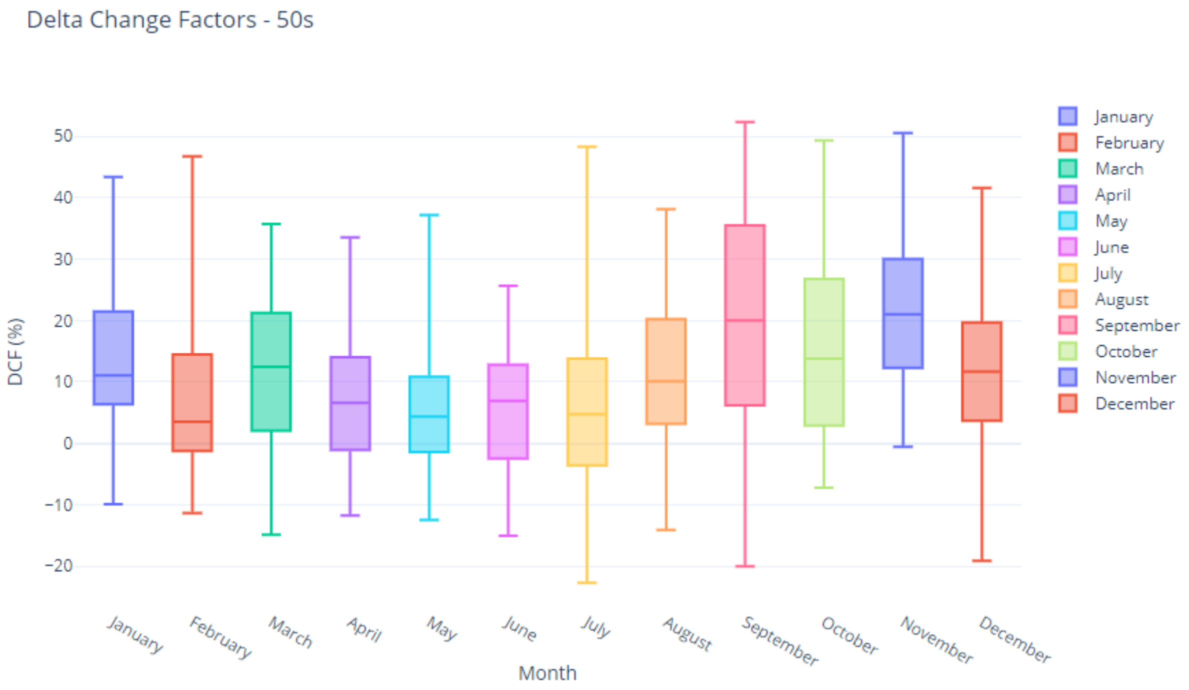

Figure 3 - Monthly delta change factors for the period of 2040-2069

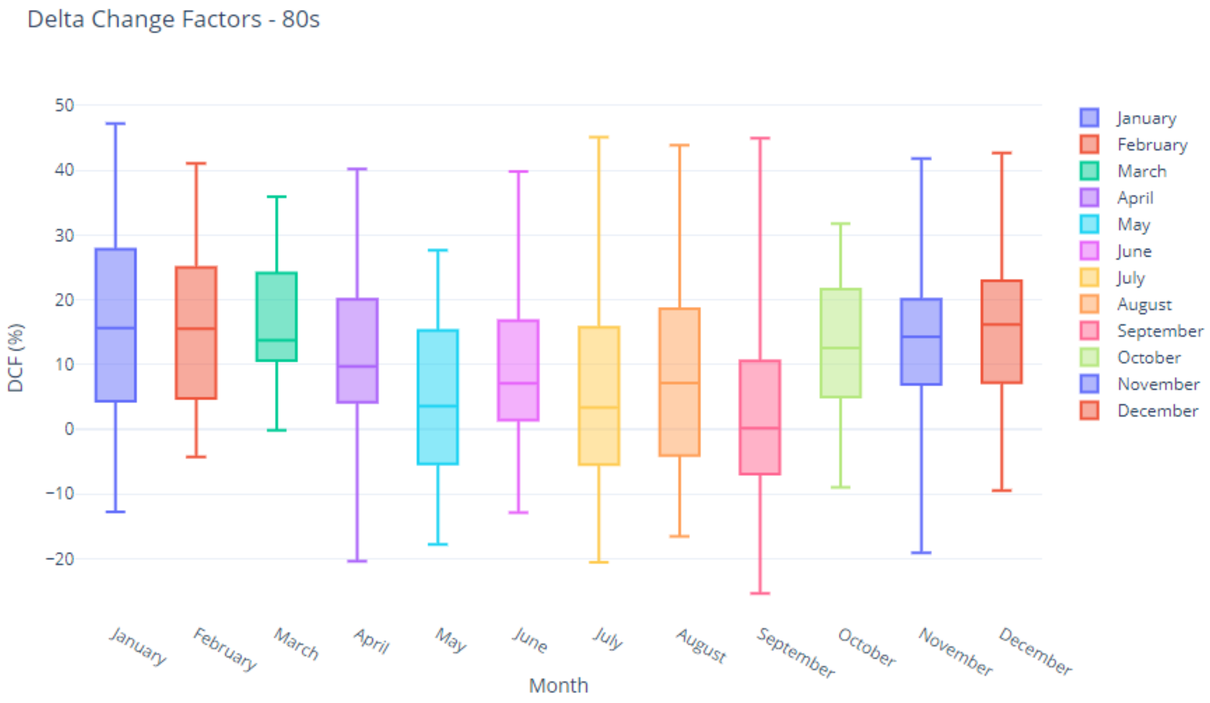

Figure 2 - Monthly delta change factors for the period of 2070-2099

Since there are countless DCFs to pick from when applying them to the designed storm, a method had to be applied in order to size down to a reasonable amount of DCFs to create a useful set of design storms. This was done by first going to Atlas16 and analyzing the seasonality analysis feature that was available. Shown below in Figure 4 is a bar graph provided by Atlas 14 representing such.

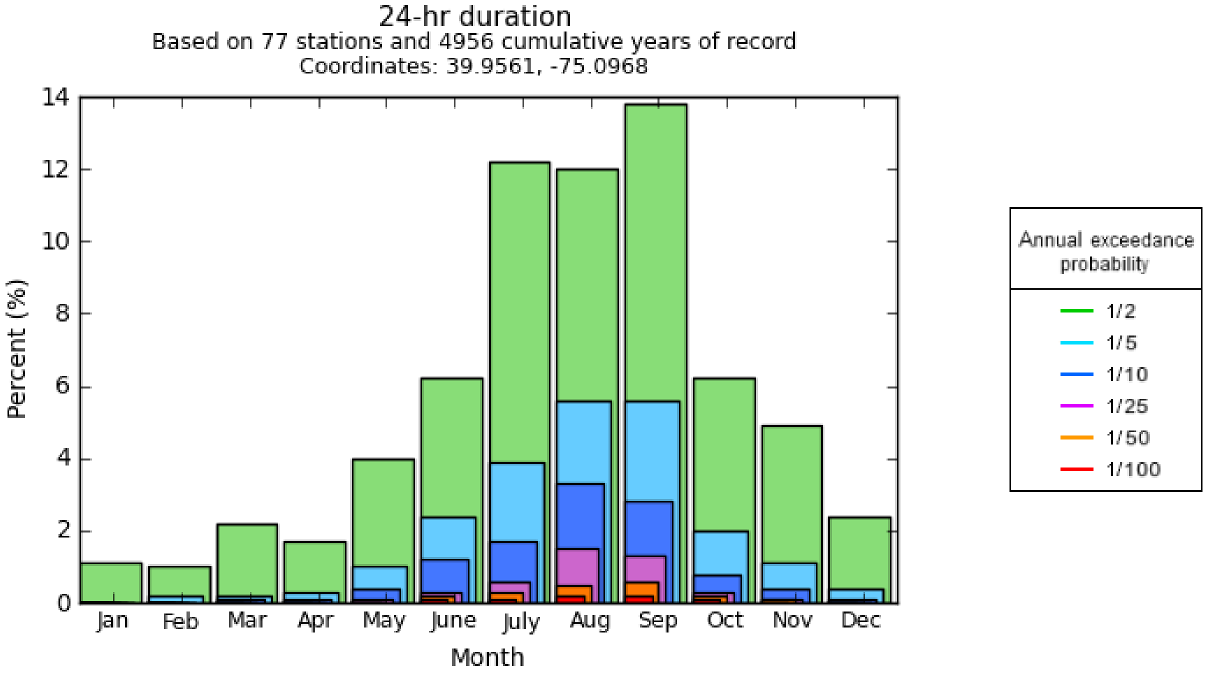

Figure 4 - Bar graph representing the seasonality distribution for Camden

Within the chart it can be seen that Atlas 14 provided numerous storm scenarios to focus on, located in the Annual Exceedance Probability box. The type of storms range from a two-year storm to a one hundred-year storm. The levels of percentages represent the individual months' probability of their 24-hour storm conditions exceeding the average rainfall amounts based off of previously collected storm data from surrounding stations. Clearly shown is the fact that the months July, August, and September have the highest percent of chance out of all months to exceed each type of storm event. Because of this, these three months were focused on when picking out delta change factors to apply to the future design storms. Each of the month's DCFs were averaged for all of the RCP scenarios, and the data was focused on the 50's and 80's time slices. These DCFs values are shown below (Table 5, Table 6,

Table 7, and

Table 8).

Table 5 - Average 8.5 METDATA delta change factors for the months of July, August, and September related to the time slices of the 50's and 80's

8.5 METDATA	July	August	September
50s	5.20	6.02	12.15
80s	2.79	0.46	-0.08

Table 6 - Average 4.5 METDATA delta change factors for the months of July, August, and September related to the time slices of the 50's and 80's

4.5 METDATA	July	August	September
50s	2.53	7.90	18.17
80s	2.21	4.52	2.35

Table 7 - Average 8.5 Livneh delta change factors for the months of July, August, and September related to the time slices of the 50's and 80's

8.5 Livneh	July	August	September
50s	7.85	12.60	22.48
80s	6.66	9.35	2.23

Table 8 - Average 4.5 Livneh delta change factors for the months of July, August, and September related to the time slices of the 50's and 80's

4.5 Livneh	July	August	September
50s	9.17	16.83	31.32
80s	13.85	15.36	13.59

Once these DCF values were collected, it was decided to average each month's individual yearly averages together to further lessen the amount of DCFs to factor into the future design storm process. These final delta change factor values are shown below in Table 9 and

Table 10 for the 50's and 80's, respectively. The delta change factors used for the future design storms are the following: 4.53, 6.19, 6.38, 7.42, 10.84, and 21.03.

Table 9 - Average delta change factor values that result in the final DCFs for July, August, and September for the 50's

Overall 50s Averages	July	August	September
4.5 Livneh	9.17	16.83	31.32
8.5 Livneh	7.85	12.60	22.48
4.5 METDATA	2.53	7.90	18.17
8.5 METDATA	5.20	6.02	12.15
Final DCFs	6.19	10.84	21.03

Table 10 - Average delta change factor values that result in the final DCFs for July, August, and September for the 80's

Overall 80s Averages	July	August	September
4.5 Livneh	13.85	15.36	13.59
8.5 Livneh	6.66	9.35	2.23
4.5 METDATA	2.21	4.52	2.35
8.5 METDATA	2.79	0.46	-0.08
Final DCFs	6.38	7.42	4.53

4. Case Study

4.1. Site

The site selected by CCMUA is one of the most flood-prone neighborhoods in the city of Camden. As a hotspot for street flooding, the study area was part of a larger project designed to improve the neighborhood flooding of 2010 and the city was interested to see how the design would cope with projected 2050s and 2080s precipitation. The area is within the combined sewershed upstream of the Cramer Hill neighborhood, NW Camden, and contains Von Nieda Park and Baldwin's Run drainage area. It is also home to CS-32, the largest CSO in the CCMUA sewer service area.

Figure 5 – Left: Cramer Hill Greater Area, Right: Case Study: Von Neida Park

4.2. H&H Modeling Decisions

PCSWMM Professional 2D was used to model stormwater runoff for the combined sewershed upstream of CS-32. The construction of the model was originally conducted through another collaborative research project between Drexel and CCMUA (credit: Joseph McGovern, MS student, with significant contributions from CDM Smith) to examine tidal boundary conditions, sanitary baseflow and evaporation.

The model assigned two subcatchments to the study area with the following attributes:

Table 11 – Properties of the drainage area within the study area

Total Area (ac)	Flow Length (ft)	Slope (%)	Imperv. (%)
17.96	249.947	0.3	12.5

Other attributes of the catchment areas varied depending on the precipitation depth for each design storm. The calibrated model[1] was mainly used to simulate CSO volumes at CS-32 outfall during specific design storms with the historical precipitation depth as well as the projected depths when DCFs percent increase are applied. The analysis is focused on CS-32 as this specific outfall is accountable for generating the most CSO in the area.

4.3. Simulation Decisions

To start simulating design storms for the site, the following procedure was taken:

1. Selection of:
    a. Return period
    b. Duration
    c. Total depth
2. Distribution of the selected depth of rain over the storm duration
    a. Time interval of one hour or less
3. Adding the cumulative precipitation quantities to the model
    a. Historical – Using Atlas 14 quantities
    b. Future – Multiplying Atlas 14 quantities by selected delta change factors

4.3.1. Design Storm Selection and Projection

The 2-year, 10-year, and 100-year return periods, using a 24-hour duration and 6 min interval are selected for the analysis and modeling. The 2-year storm indicates smaller, frequent storms. The 100-year return period represents high intensity but low probability unlike the 10-year return

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[1] The model calibration/validation was through synchronization with service area model developed by CDM Smith.

period. All design storms are distributed with a SCS Type II distribution. Consequently, projected design storm depths are calculated by applying the selected DCFs (% increase) to historical design storm depths that are gained from NOAA Atlas 14 using the following equation:

Projected Storm Depth = Historical Depth * [1 + (DCF / 100)]

The projected values for each design storm depth are demonstrated in the table below based on the two future time slices i.e. 2050s and 2080s:

Table 12 – Projected precipitation depth for 2050s and 2080s

Duration: 24-hr	Average recurrence interval (years)		
	2	10	100
Historical Depth (in)	3.28	4.89	7.93
2050 Projected Depth (DCF: 6.19%)	3.48	5.19	8.42
2050 Projected Depth (DCF: 10.84%)	3.64	5.42	8.79
2050 Projected Depth (DCF: 21.03%)	3.97	5.92	9.6
2080 Projected Depth (DCF: 6.19%)	3.49	5.2	8.44
2080 Projected Depth (DCF: 10.84%)	3.52	5.25	8.52
2080 Projected Depth (DCF: 21.03%)	3.43	5.11	8.29

The 3 selected design storms with 6 different DCFs for each event were simulated in PCSWMM and the total volume of CSO discharge per storm as well as water balance per storm are reported in the results section.

4.4. Modeling Results

The model was run multiple times to assess the total volume of CSO discharge per storm with different DCF scenarios. The summary of CS-32 outfall loading (discharge volume) with respect to projected design storm depths for 2050s and 2080s are presented below. With projected increase in precipitation, there will be associated increases in the volume CSO discharge. While this take away may seem intuitive, it is important to note a few key findings:

1. The worst-case future 2-yr storm still causes less CSO than today’s 10-yr storm. These two values are highlighted in the table.

2. Also notable is the observation that higher DCF (more increase in the precipitation depth) results in more CSO discharge regardless of the return period.

Table 13 – Projected precipitation depths and CSO (CS-32) discharge volumes

DCF (% increase)	2-yr		10-yr		100-yr	
	Precipitation Depth (in)	Total Volume 10^6 gal	Precipitation Depth (in)	Total Volume 10^6 gal	Precipitation Depth (in)	Total Volume 10^6 gal
Historical	3.28	21.07	4.89	37.35	7.93	69.30
DCF: 6.19	3.48	22.89	5.19	40.45	8.42	74.5
DCF: 10.84	3.64	24.61	5.42	42.72	8.79	78.33
DCF: 21.03	3.97	27.76	5.92	48.00	9.6	86.65
DCF: 6.38	3.49	22.98	5.2	40.38	8.44	74.79
DCF: 7.42	3.52	23.28	5.25	40.98	8.52	75.41
DCF: 4.53	3.43	22.39	5.11	39.46	8.29	73.06

Figure 6 visualizes the results exhibited in table 13 with the dots representing each DCF percent increase in precipitation. It also raises the question whether an increase in CSO is equivalent to increase in precipitation.

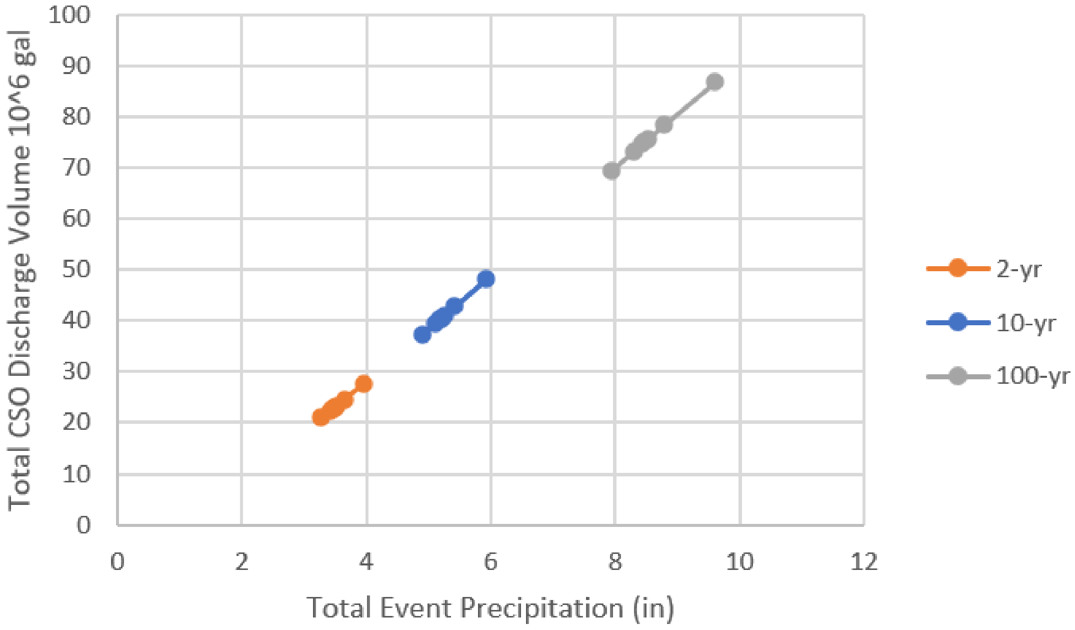

Figure 6 – Total CSO discharge volume for different precipitation depths (historical and projected) in each return period. P.S. for each return period a historical rainfall depth and 6 projected depths (6 DCFs) are considered. Each dot represents one design storm.

To further evaluate the relationship between the CSO discharge and precipitation depth, the projected design storm for each return period with the highest DCF, i.e. 21.03% increase in precipitation, was compared to the historical design storm. The results of this comparison are presented numerically in table 14 and with an intent to understand the trends in the numerical values, the bar chart is created. The chart in Figure 7 represents how the increase in the CSO discharge volume change with different design storm.

Table 14 – Maximum percent increase in CSO discharge volume in event precipitation

	2-yr			**10-yr**			**100-yr**		
	Precipitation Depth (in)	CSO Discharge Volume (10^6 gal)	CSO discharge volume % increase	Precipitation Depth (in)	CSO Discharge Volume (10^6 gal)	CSO discharge volume % increase	Precipitation Depth (in)	CSO Discharge Volume (10^6 gal)	CSO discharge volume % increase
Historical	3.28	21.073	31.76%	4.89	37.358	28.50%	7.93	69.304	25.03%
Projected with highest DCF: 21.03%	3.97	27.766		5.92	48.008		9.6	86.654	

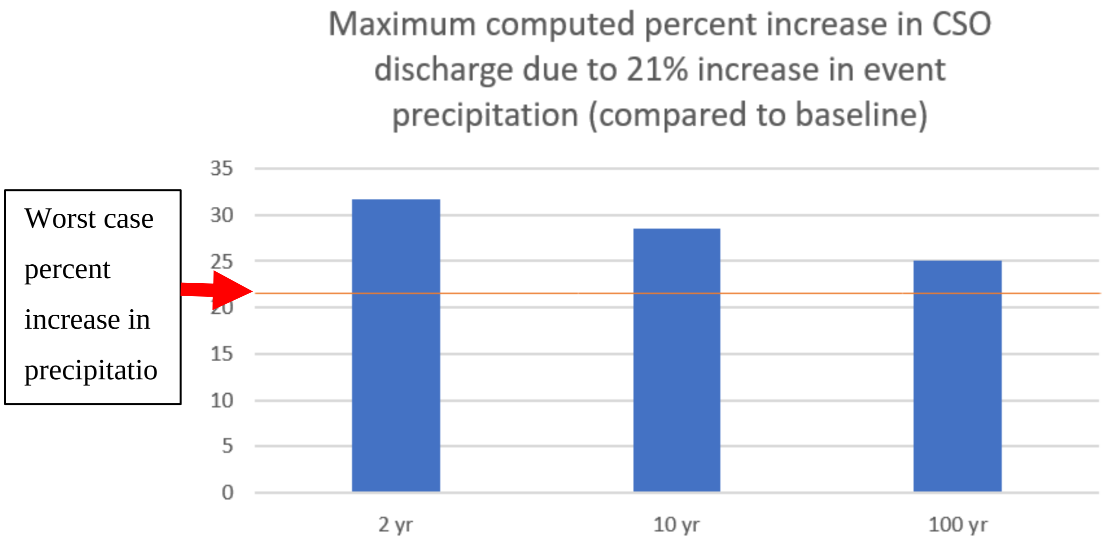

Figure 7 – Maximum CSO discharge increase in event

It is worth noting percentagewise, climate change will have a larger impact on CSOs occurring from smaller storms (e.g. there is already a lot of CSO due to today's 100-yr storm). This is supported through exploring the hydrologic water balance per storm.[2] In PCSWMM, the components of the water balance include initial storage, precipitation, infiltration loss, evaporation loss, surface runoff, and final storage. The water balance for the simulation period of the case study is reviewed using the Runoff Quantity Continuity summary displayed in the table below.

Table 15 – Water balance per storm

Runoff Quantity Continuity (in)	**2-yr Baseline**	**2-yr High Precipitation**	**10-yr Baseline**	**10-yr High Precipitation**	**100-yr Baseline**	**100-yr High Precipitation**
Total Precipitation	3.28	3.97	4.89	5.92	7.93	9.6
Evaporation Loss	0.035	0.035	0.036	0.037	0.039	0.041
Infiltration Loss	1.717	1.957	2.253	2.556	3.076	3.439
Surface Runoff	1.521	1.972	2.596	3.323	4.814	6.122
Final Storage	0.014	0.014	0.014	0.014	0.014	0.014
Continuity Error (%)	-0.007	-0.008	-0.009	-0.01	-0.013	-0.016

This breakdown of the water balance for the two design storms[3] in each return period is demonstrated in the following pie charts which yield some key findings:

1. Evaporation and storage are insignificant components of the water balance of the simulated storms.

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[2] Which is the equivalence between precipitation or other inputs, and the outflow of water through runoff, evapotranspiration, groundwater recharge, and stream flow.

[3] Historical and the highest projected precipitation depths.

2. Surface runoff is a larger percentage of larger storms than infiltration.
3. Climate change will have a more pronounced impact on the water balance of smaller events.

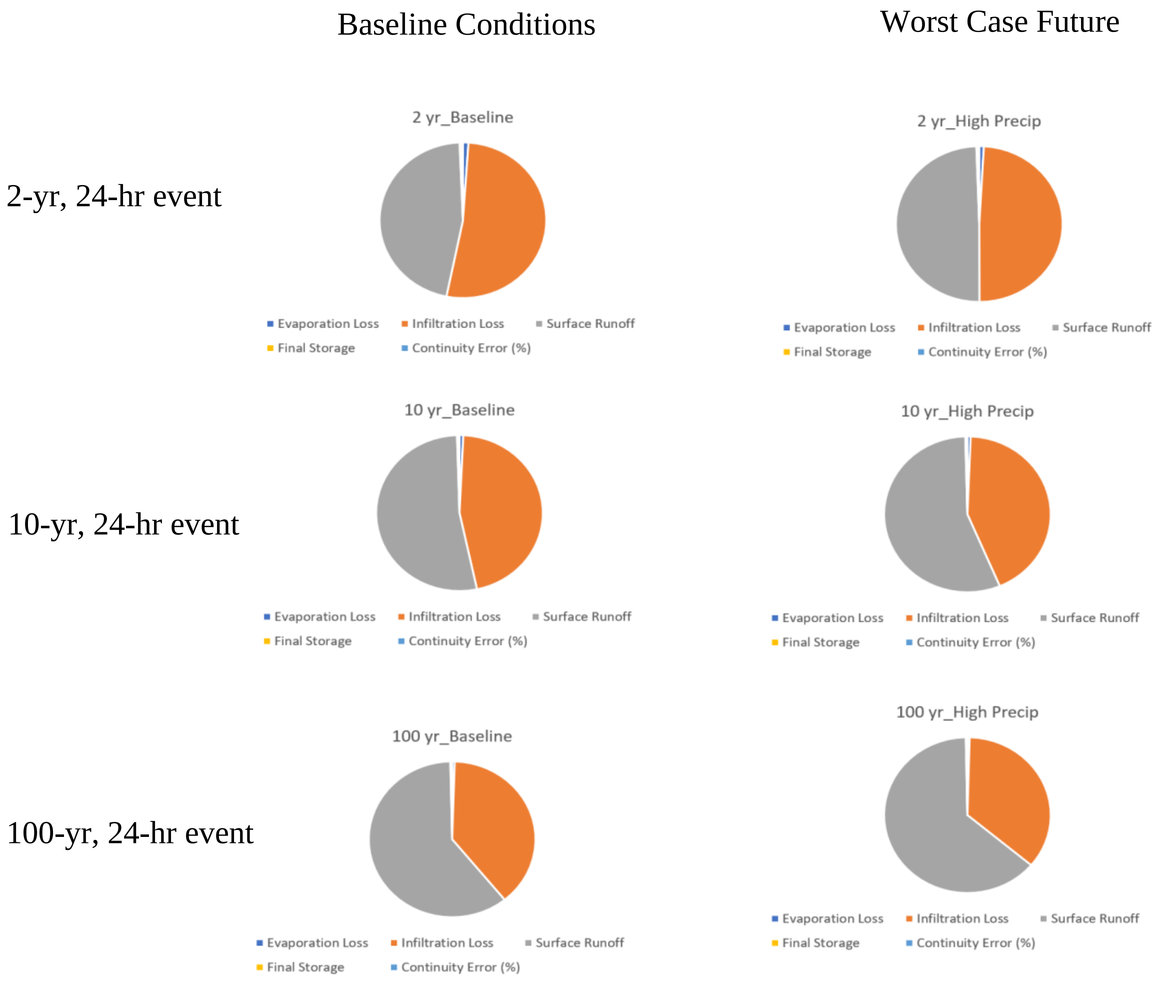

Figure 8 – Water balance breakdown

5. Conclusions and Next Steps

While there is a wide range of model projections, denoting uncertainty about future climate conditions, most climate models project an increase in rainfall. Through this analysis, as hoped, the DCF selection process provided range, more importantly with the intermediate values relating to August. It has been demonstrated that today's 2-yr, 10-yr, and 100-yr 24-hour storms already cause the system to overflow. Looking at the projected values pronounced more rain in the future will cause a larger volume of CSO discharge. However, for this sewer system, climate change will have a **greater** proportionate impact on the more frequently occurring (lower return period) storms as today's big storms already surcharge the system. It is recommended that CCMUA conduct some additional analyses with respect to the green infrastructure or cloudburst strategies that promote storage and investigate how much those adaptation strategies can mitigate the increased precipitation expected from climate change.

6. Notes

1 – The following are the 10 global climate models applied to the analysis: CNRM-CM5, inmcm4, NorESM1-M, bcc-csm1-1, BNU-ESM, MIROC-ESM, MIROC-ESM-CHEM, MRI-CGCM3, and IPSL-CM5A-MR, IPSL-CM5B-LR.

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