Preparing for Increases in Extreme Precipitation Events in Local Planning and Policy on Maryland's Eastern Shore

A report by the Eastern Shore Land Conservancy on behalf of the Eastern Shore Climate Adaptation Partnership

January, 2020

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[1]This report was commissioned by the Eastern Shore Land Conservancy on behalf of the Eastern Shore Climate Adaptation Partnership (ESCAP). The main body of the report was written by Eastern Shore Land Conservancy coastal resilience intern Michelle Charochak and edited by coastal resilience program manager Jim Bass. Precipitation research was conducted by Dr. Kaye Brubaker and Joseph Eisenstadt at the University of Maryland.
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Cover photo: David Harp, Chesapeake Photos

I - Executive Summary

Flooding, coastal or otherwise, is not a new phenomenon on the Eastern Shore of Maryland. However, as the climate continues to warm, extreme precipitation events are likely to become more frequent. The risk of flood damage will increase as floodplains continue to expand, underground aquifers become full, and waterways breach their banks. Research conducted for this report by Dr. Kaye Brubaker at the University of Maryland shows increases in precipitation depth and intensity over the entire Eastern Shore for all examined durations and average return periods. The implications for the Eastern Shore are increased volume of rain-induced, inland (pluvial) flooding and faster rise of flood waters. Anticipated sea-level rise and coastal or storm-surge flooding will exacerbate the effect of pluvial flooding by suppressing the gradients that would allow flood waters to run off.

In short, climate change is driving precipitation patterns on the Eastern Shore to the extreme. The region can expect more rain to fall harder as time goes on, exacerbating existing vulnerabilities to flooding across the region.

Potential strategies were gathered and evaluated for local jurisdictions to reduce flood risks and improve stormwater management practices. The recommendations that were prioritized by ESLC during the study include:

1. Upgrade infrastructure to reflect future precipitation estimates
2. Utilize hybrid green-gray infrastructure
3. Implement stormwater utility
4. Adopt Executive Order criteria into development standards
5. Create recovery plans which prioritize flood mitigation and future flood risk
6. Restore unutilized agricultural land to natural ecosystem
7. Prepare plans for future funding and grant opportunities

Flood risk is changing across the Eastern Shore. The strategies included in this report will help communities build a greater margin of safety against extreme precipitation events. While these types of storms are not anything residents of the Eastern Shore have not dealt with before, as they become more frequent they will become more destructive. Now is the time to build in the protections that the Eastern Shore requires to weather new climate risks.

II - Introduction

The purpose of this report is to identify and illustrate risk associated with the increasing frequency of extreme precipitation events on Maryland's Eastern Shore, and to provide guidance to local governments seeking to incorporate evolving flood and stormwater risk into local plans and decision-making. Extreme precipitation refers to an episode of abnormally high rainfall. The word "extreme" may vary depending on location, season, and length of historical record. These events are defined as days with precipitation in the top one percent of days with precipitation (U.S. Global Change, 2019). The fundamental intent underlying all elements of this report is a science-to- solutions process, drawing on multiple disciplines to inform a broad and interconnected array of findings and recommendations based on scientific and policy-based research informed by local subject-matter experts.

The data contained in this report is an innovative look at the impacts of extreme precipitation on Maryland's Eastern Shore in the coming years. By using downscaled model analysis data produced by the North American Regional Climate Change Assessment Program (NARCCAP), this analysis provides critical new information to planners and decision makers by anticipating precipitation scenarios.

Upon publication of this report, jurisdictions participating in the Eastern Shore Climate Adaptation Partnership (ESCAP) will be informed and empowered to have more substantial conversations and planning initiatives involving planning and zoning, floodplain management, economic development, emergency management, housing, public health, transportation, and more. By utilizing a science-to- solutions approach, local decision makers will be empowered by rich, complex information distilled into simple messages and tangible recommendations. These recommendations will help foster change that will protect Eastern Shore communities for years to come.

ESCAP communities are the primary audience for this report. ESCAP is a network of county and municipal government staff working in collaboration with representatives of state government, academic institutions, and not-for-profit organizations to understand, plan for, and reduce the costs associated with changing climate.

The scope of work for this project was designed to advance priorities stated by multiple ESCAP jurisdictions in their official planning documents and vulnerability assessments. By identifying and aggregating needs across the region, this project demonstrates ESCAP's ability to provide data analysis and guidance products more cost-efficiently than jurisdictions could acquire individually.

III - Background

Heavy downpours have been consistently increasing across the region, especially the last 50 years. These rainfall events have become more frequent while the amount of rain falling has also increased. Historical rainfall records and future rainfall projections are predicting heavier and more regular storms for the east coast specifically. Current flood plans, however, only reflect what has been calculated based on historical record, not taking current changing climate conditions into consideration. This, combined with the usual approach of adapting to the impacts of heavy rainfall after the event has occurred, is making communities more vulnerable to extreme precipitation events.

Extreme precipitation events have substantial impacts on both the environment and society. During the 20th century, floods caused more loss of life and property damage than any other natural disaster in the United States. Flooding also brings a host of public health concerns such as increased rates of waterborne disease and mold contamination. Increase in extreme precipitation events, combined with changes in land use, have led to an increase in freshwater flooding across the northeast. A higher rate of flood damage has occurred due to the increase in impermeable surfaces in watersheds and development in flood-prone areas. As infrastructure and development continue to expand, stormwater runoff has increased, escalating erosion and leading to prominent flooding issues.

With heavy rainfall comes flooding, and on the Eastern Shore extreme precipitation events are becoming more intense in both depth and intensity. Across the region Dr. Brubaker's research shows significant increase in the volume of precipitation experienced in a 1-hour rain event and a moderate increase in the volume of precipitation experienced in a 24-hour rain event. The largest increases appear toward the southern end of the ESCAP region, roughly in the center of Dorchester County. These findings highlight the need for a modification in stormwater management and flood protection practices across the region.

Flooding on the Eastern Shore

Maryland's Eastern Shore is naturally vulnerable to elevated water levels and heavy rainstorms. Sitting on the Chesapeake Bay and housing numerous tributaries, the region has low-lying areas that are exposed to both coastal and riverine flooding. Climate change is exacerbating environmental conditions and increasing the risk of these natural hazards.

A flood is defined by Merriam-Webster as any high flow, overflow, or inundation by water that causes or threatens damage. Floods are caused or amplified by both weather and human related factors. There are multiple types of flooding and most of them are experienced on the Eastern Shore.

Riverine flooding is the most common flood event, where a body of water exceeds its normal holding capacity. This type of flooding typically occurs following high amounts of precipitation over an extended period of time, causing a river to 'burst its banks'. This localized flooding causes considerable amount of damage and threatens safety of residents in the immediate area. Communities located in flat regions surrounding rivers require strong defense mechanisms in order for them to be resilient against these river floods.

Flash flooding, caused by heavy and sudden rainfall, will become more frequent as we observe increases in extreme precipitation events. Flash floods occur when the ground cannot absorb water as quickly as it falls and usually subside quickly. However, these floods have the potential to be fast- moving and dangerous when they occur. The danger of flash flood events can be largely mitigated by avoiding the overdevelopment of floodplains and the implementation of high quality drainage systems which use natural features for absorbance while conveying floodwaters away from at-risk populations and infrastructure in environmentally-friendly ways. This can be accomplished through resident participation and proper infrastructure planning.

Groundwater floods are common on the Eastern Shore where high water tables are experienced throughout the region. As rain falls over an extended period of time, the ground becomes so saturated that it can no longer absorb water. When this occurs, water rises above the ground's surface and causes flooding. This category of flooding can last for weeks or even months.

Urban and suburban flooding occurs when excessive runoff and inadequate drainage to sewer systems, rivers, lake, and streams in developed areas leads to flooding. The influx of development has magnified the impacts of stormwater runoff due to the increase in impervious area across the Eastern Shore. Impervious pavement and developed areas hinder waters ability to enter the ground, leading to water-covered streets and neighborhoods.

Lastly, coastal flooding is an occurrence that residents of the Eastern Shore experience frequently. More often than not, coastal communities bear the brunt of severe storms, especially those that have gathered strength over the oceans. With severe storms come high winds and storm surges, flooding the areas closest to the water. High winds also increase wave energy which digs away at coastlines, causing coastal erosion and uprooting the ecosystems that call them home. Extreme weather and high tides cause a rise in sea levels, usually leaving low-lying seaside areas vulnerable to impending waters.

Most communities on the Eastern Shore utilize FEMA Flood Zone maps in order to plan for potential flooding events. Currently, floodplain management practices are providing protection for today's 1% or 0.2% chance flood. A 1% flood equates to the term 100-year flood, but this term has been found to be dangerously inaccurate. A 100-year flood does not necessarily mean that the event is only likely to happen once every 100 years, but instead that it has a 1% chance of happening any year. Similarly, the term 500-year flood event is being replaced with 0.2% chance flood, as this more accurately describes the likelihood of the flood event occurring. Relatively limited damage is caused by today's 1% and 0.2% chance floods, both in terms of impacted structures and property value lost. However, a tipping point is being approached, which will fundamentally change the way local governments manage their floodplain.

IV - Science to Solutions Process

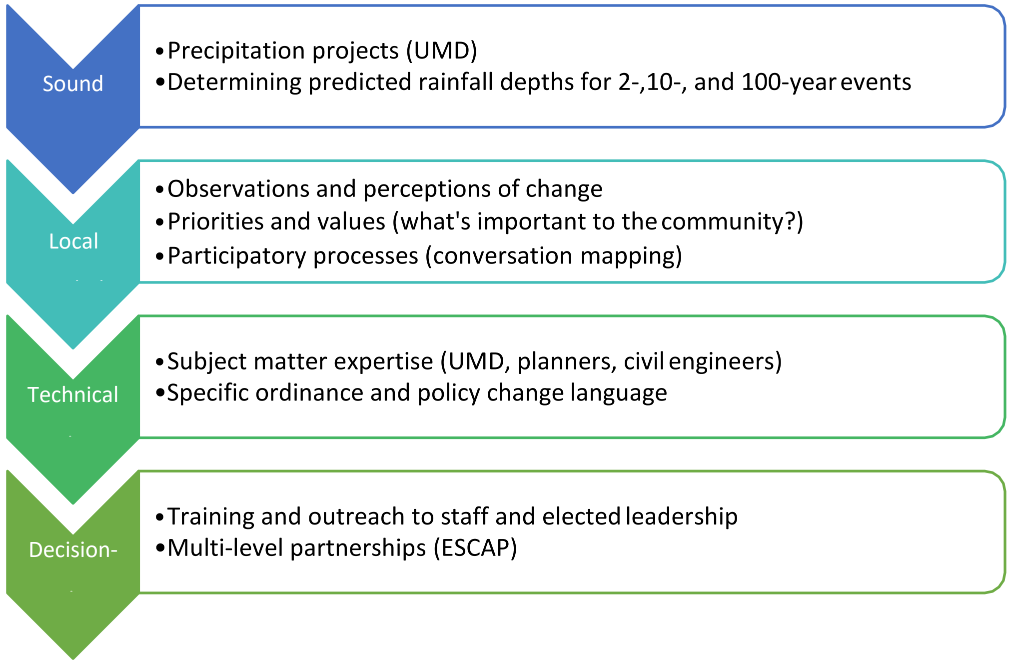
Science to Solutions background

The goal of the science to solutions process is to implement decisions at the local level, which are built soundly upon scientific data via a three-step process.

Step one involves taking data from scientists and applying a local filter in order to verify or "ground truth" the data's relevance. The filtering process involves knowledgeable voices at the local level who can paint a picture of the community. The goal is to have a thorough understanding not only of the data being used, but how it will be applied in context.

Step two is to translate this filtered science into technical guidance. Subject-matter experts ensure that the data is applied properly to the needs of the community. Guidance may include draft codes, specific ordinances, policy change language, implementation recommendations, and case studies.

Finally, step three is to act upon the newly developed technical guidance. By filtering and translating, communities can undertake new or expanded actions which are rooted in science and have been developed based on local context.



The science of extreme precipitation

Research concerning precipitation patterns on Maryland's Eastern Shore was conducted by Dr. Kaye Brubaker and research assistants in the Department of Civil & Environmental Engineering at the University of Maryland College Park. Dr. Brubaker and her team answered two research questions during the course of the project:

1. Are the regional patterns of extreme precipitation changing?
2. How might extreme precipitation change in the future?

On the Eastern Shore of Maryland, the extreme flood control criteria are defined as preventing the post development two-year 24-hour storm peak discharge rate from exceeding the pre-development peak discharge rate. The intent of this criteria is to (MDE et al., 2000):

1. Prevent flood damage from large storm events
2. Maintain the boundaries of the pre-development 100-year Federal Emergency Management and/or locally designated floodplain
3. Protect the physical integrity of best management practice structures

This has been done by either creating stormwater storage to handle 100-year floods or by reserving the floodplain through review of development by designated authorities. The rainfall depths associated with these 2-, 10-, and 100-year, 24-hour storm events can be found in Table 1 below and maps listed in Appendix I. Notable trends in this data include:

1. Overall increase in precipitation depth and intensity
2. Greater relative increase for shorter, more intense precipitation events
3. Greater relative increase for locations further south in the study area

Table 1: Predicted Rainfall Depths* Associated with the 2-,10- and 100-year, 24-hour Storm Events, for Mid-21st Century, Selected Eastern Shore Locations

(AEP = annual exceedance probability)

	Precipitation Depth [inches]		
	2-yr 24-hr (50% AEP)	**10-yr 24-hr (10% AEP)**	**100-yr 24-hr (1% AEP)**
Cambridge	3.8	5.9	10.1
Centreville	3.6	5.5	9.2
Denton	3.6	5.6	9.9
Easton	3.7	5.8	10.0
Elkton	3.8	5.7	9.3

The rainfall depths associated with these 2-, 10-, 25-, and 100-year, 1-hour storm events can be found in Table 2 below and maps also listed in Appendix I.

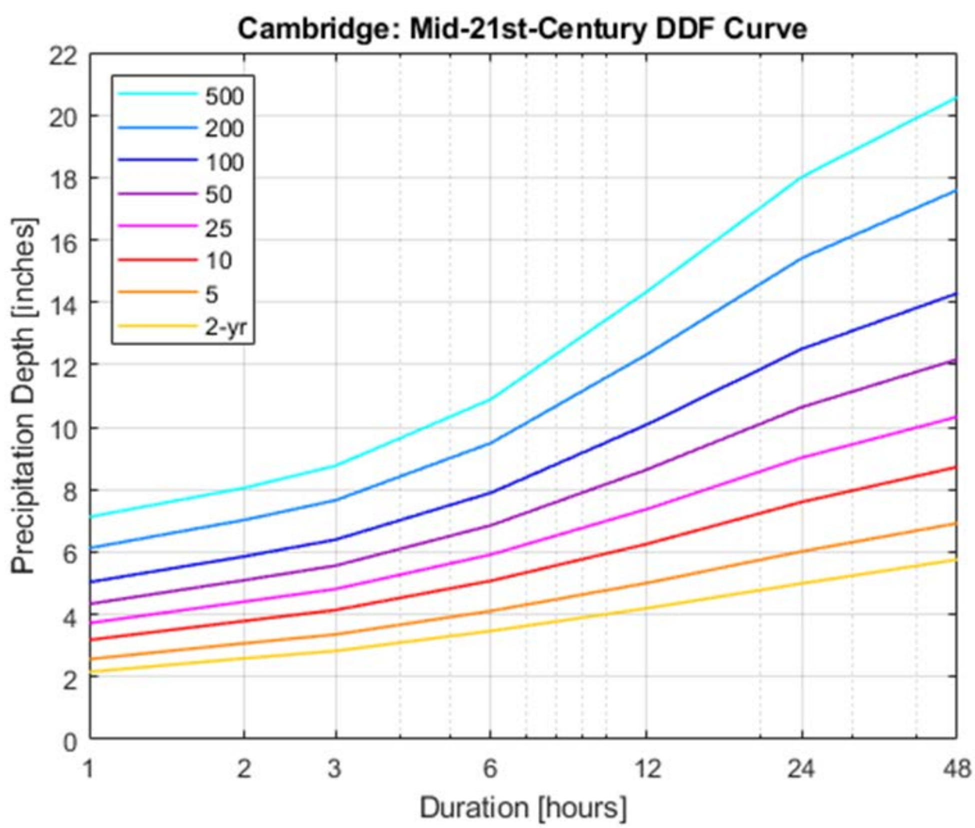
Table 2: Predicted Rainfall Depths* Associated with the 2-,10-, 25- and 100-year, 1-hour Storm Events, for Mid-21st Century, Selected Eastern Shore Locations

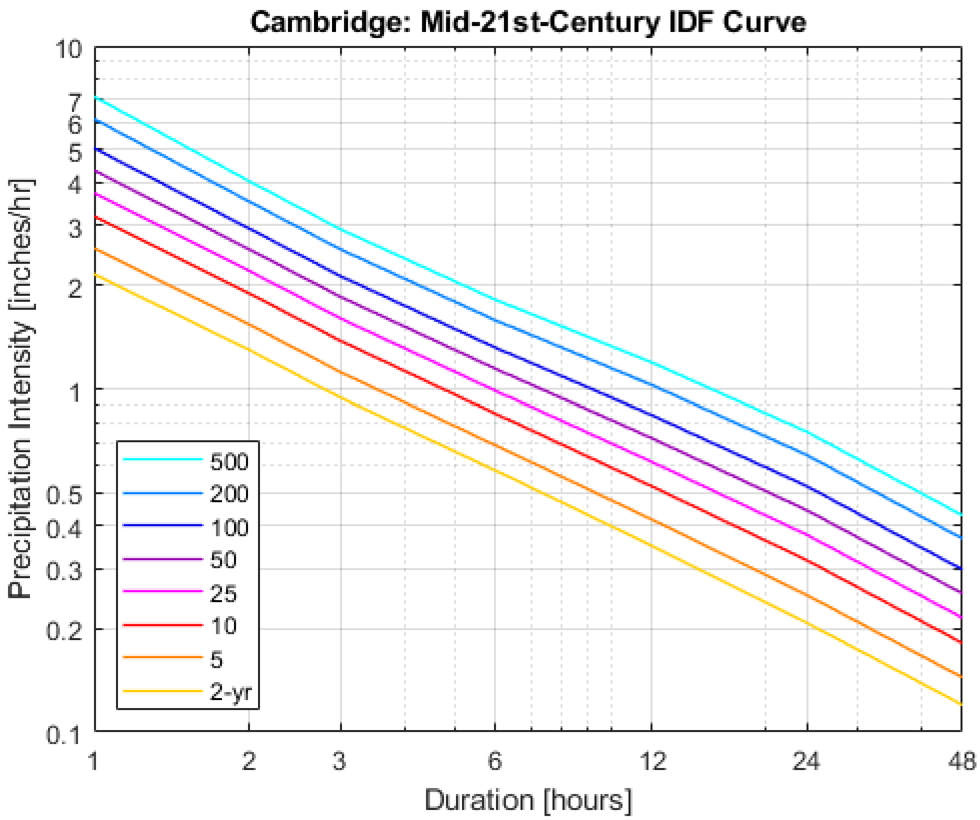
	Precipitation Depth [inches]			
	2-yr 1-hr (50% AEP)	**10-yr 1-hr (10% AEP)**	**25-yr 1-hr (4% AEP)**	**100-yr 1-hr (1% AEP)**
Cambridge	1.7	2.6	3.3	4.5
Centreville	1.6	2.3	2.8	3.5
Denton	1.6	2.4	2.8	3.7
Easton	1.6	2.5	3.0	4.0
Elkton	1.6	2.3	2.7	3.3

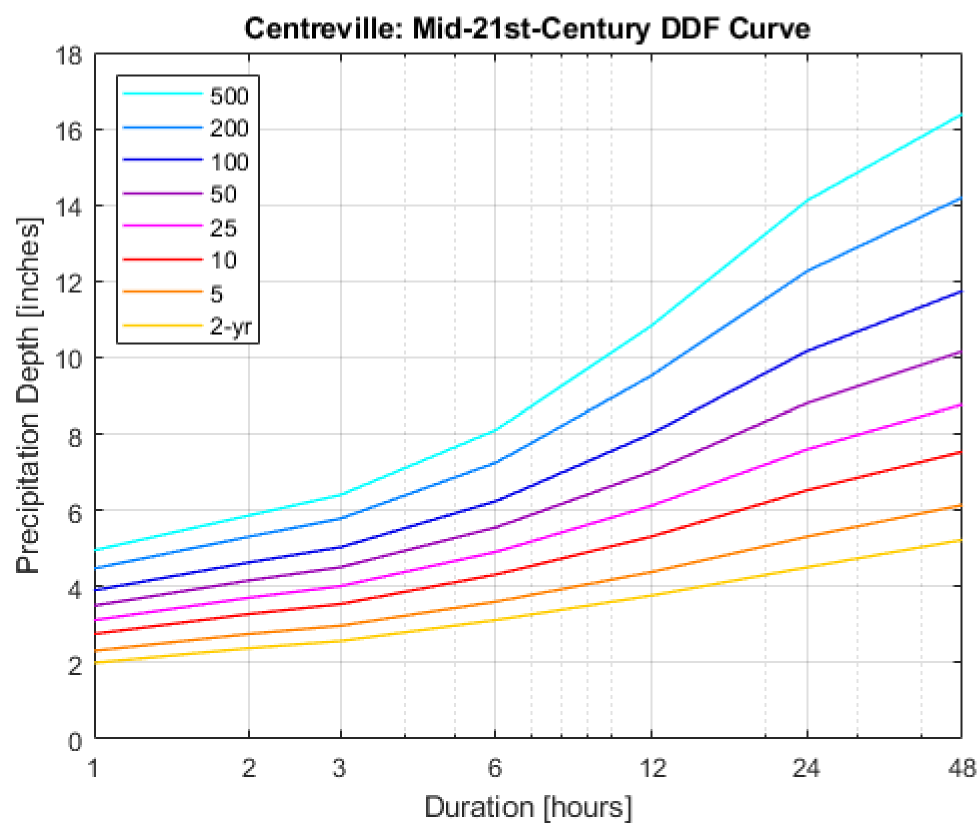
Records were obtained in order to test for trends and determine if change is happening on the Eastern Shore in comparison to what NOAA data has anticipated. Precipitation estimates used in the research are the average of values derived by frequency analysis of 30-year (2040-2070) model outputs of five regional-global model pairs in the North American Regional Climate Change Assessment Project (NARCCAP) (Mearns et al. 2007, updated 2014).

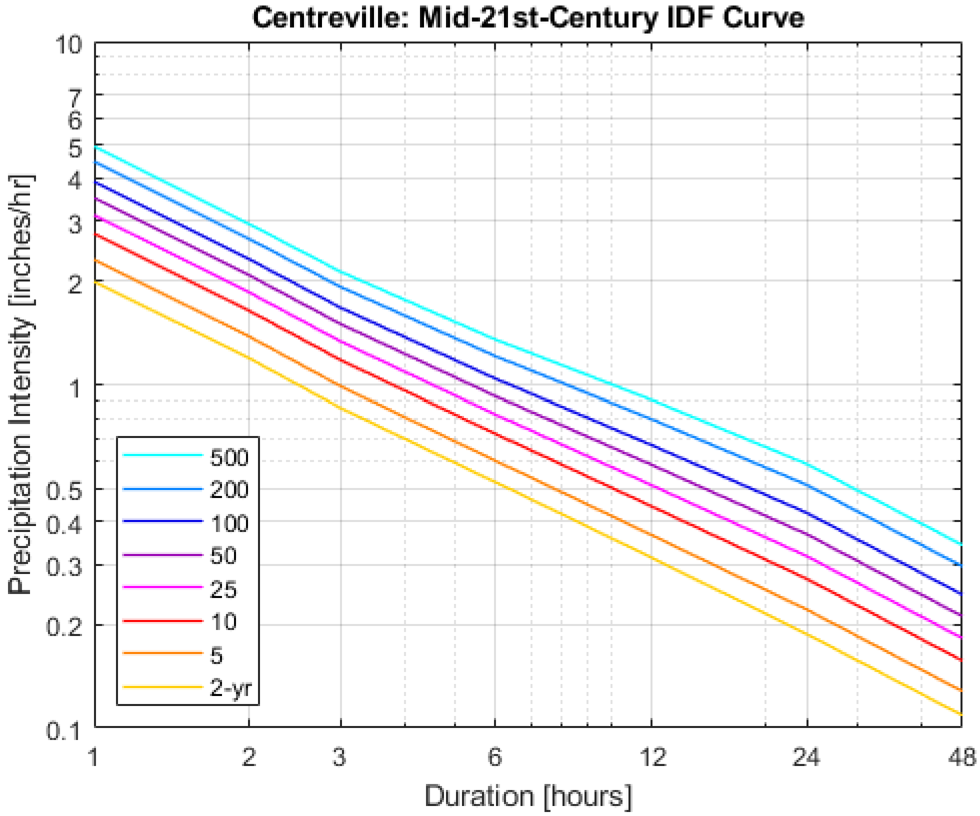
In order to answer the research questions, consistency tests were completed in order to compare the published NOAA Atlas 14 depth-duration frequency curves (DDFs) for precipitation events to precipitation records and their calculated estimates. Intensity-duration frequency curves (IDFs) and DDFs were used when performing probabilistic tests for consistency of intense storm occurrences against NOAAs study sites. IDFs relate to rainfall intensity with its duration and frequency of occurrence while DDFs describe rainfall depth as a function of duration given return periods. Short duration storm events are typically measured based on intensity rather than depth, however both curves use the same method for derivation (Koutsoyiannis et al., 1998). These curves are important for design purposes in water management. Statistics provide information in order to construct sewage and stormwater systems and determine the required capacities necessary for infrastructure to prevent flooding.

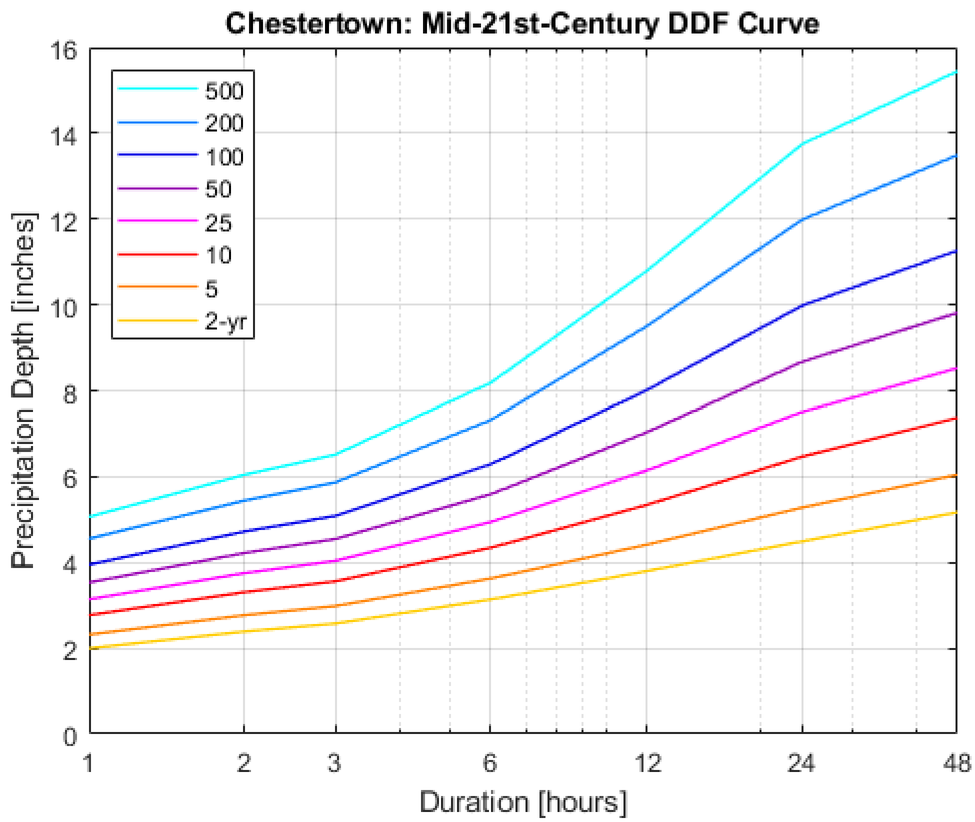
Below are the predictions for mid-century precipitation frequency from the average of five model pairs in the NARCCAP data. Each Regional model provides results on an approximately 50x50 kilometer grid. Dr. Brubaker and her team calculated DDFs and IDFs at each model grid point. They were then interloped to a finer grid to match gridded data retrieved from NOAA Atlas 14 online. The DDFs were calculated for the following selected communities: Cambridge, Centreville, Chestertown, Denton, Easton, and Elkton. The graphs illustrate these communities based on their longitude and latitude points on the finer grid.

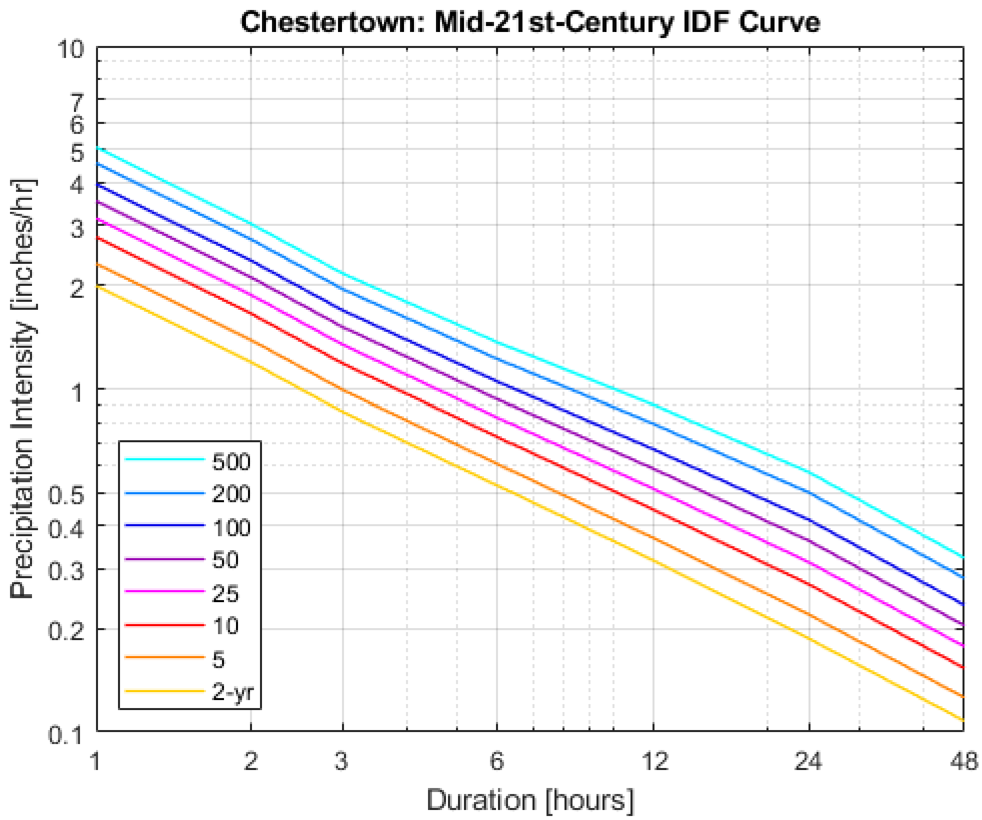



Cambridge: Mid-21st-Century IDF Curve
Precipitation Intensity [inches/hr]
Duration [hours]
10
7
6
5
4
3
2
1
0.5
0.4
0.3
0.2
0.1
1
2
3
6
12
24
48
500
200
100
50
25
10
5
2-yr

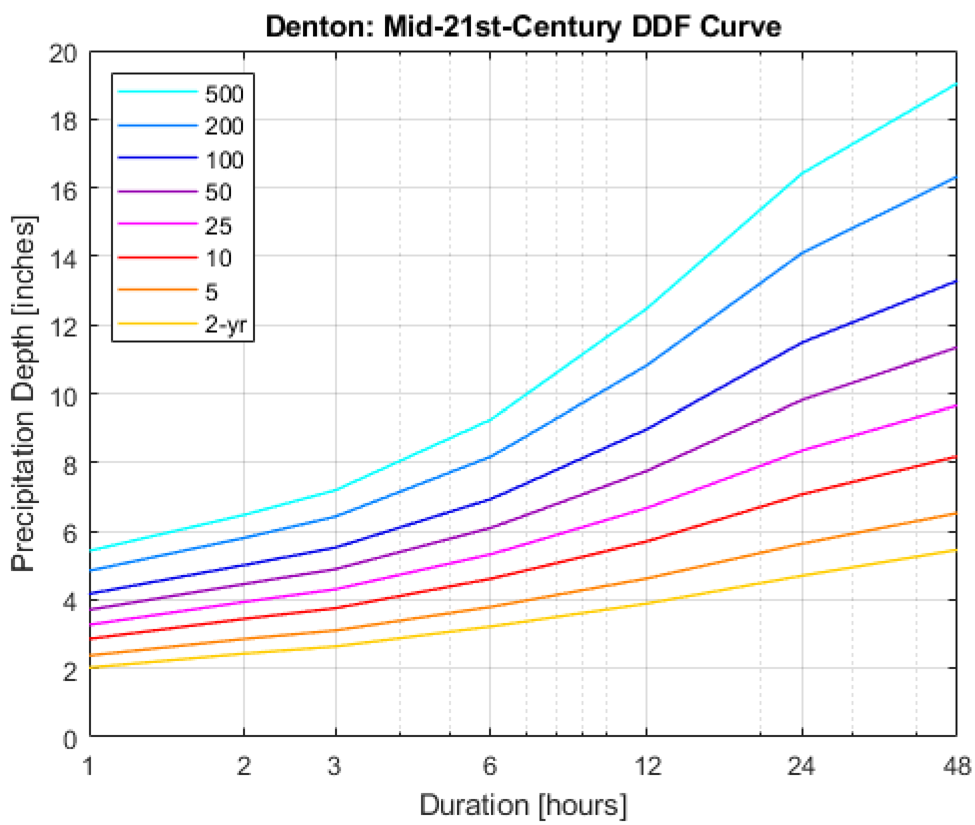

Centreville: Mid-21st-Century DDF Curve
Precipitation Depth [inches]
Duration [hours]
18
16
14
12
10
8
6
4
2
0
1
2
3
6
12
24
48
500
200
100
50
25
10
5
2-yr


Centreville: Mid-21st-Century IDF Curve
Precipitation Intensity [inches/hr]
Duration [hours]
10
7
6
5
4
3
2
1
0.5
0.4
0.3
0.2
0.1
1
2
3
6
12
24
48
500
200
100
50
25
10
5
2-yr

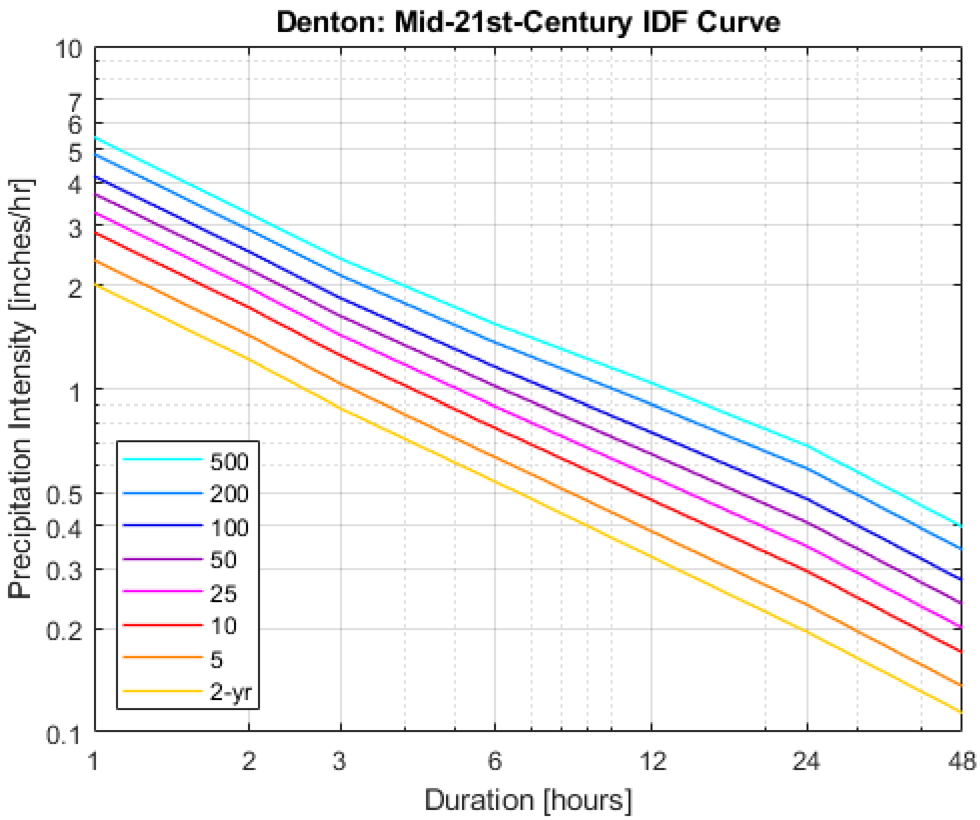

Chestertown: Mid-21st-Century DDF Curve
Precipitation Depth [inches]
Duration [hours]
16
14
12
10
8
6
4
2
0
1
2
3
6
12
24
48
500
200
100
50
25
10
5
2-yr

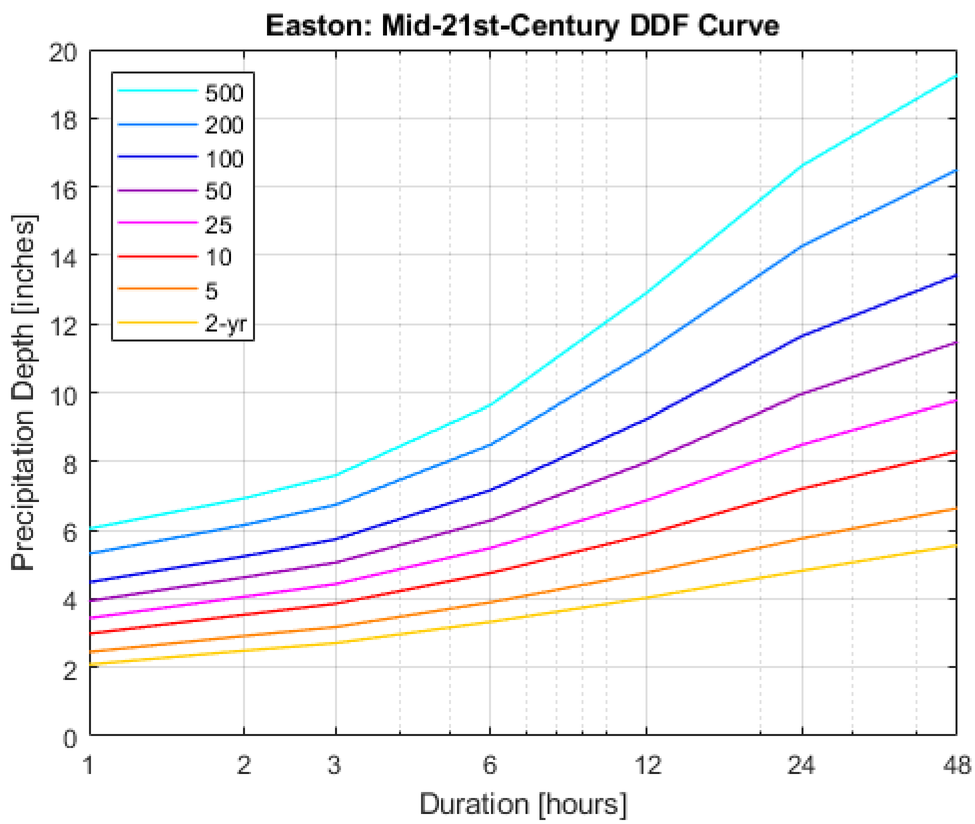


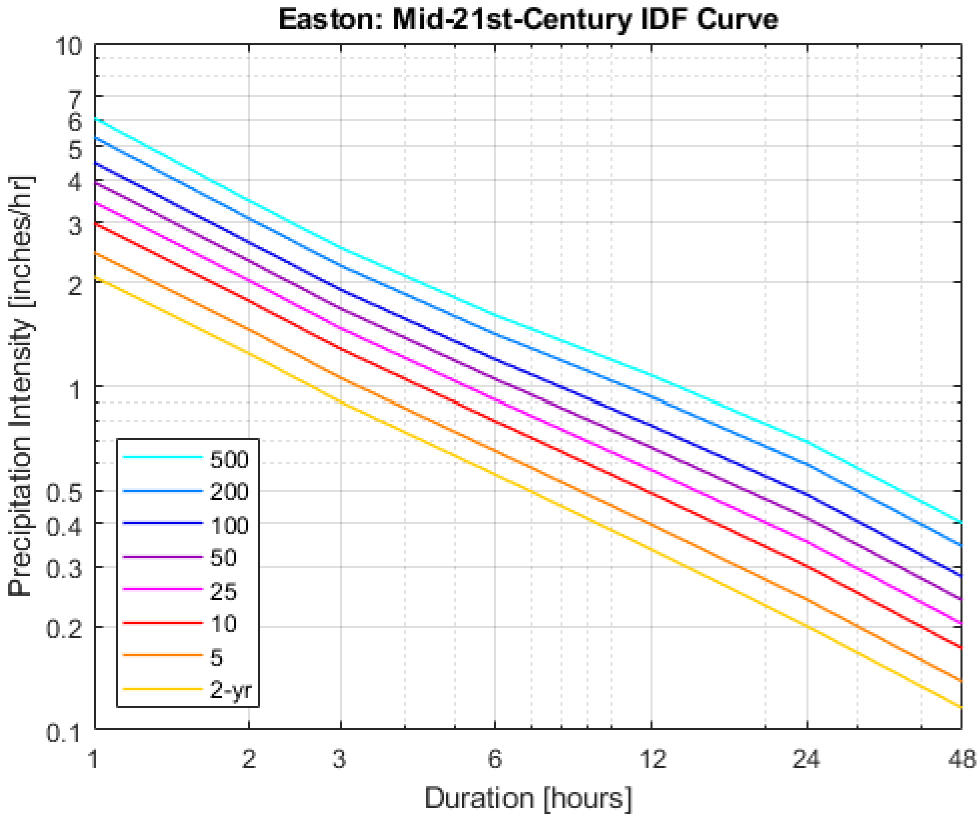
Chestertown: Mid-21st-Century IDF Curve
Precipitation Intensity [inches/hr]
10
7
6
5
4
3
2
1
0.5
0.4
0.3
0.2
0.1
Duration [hours]
1
2
3
6
12
24
48
500
200
100
50
25
10
5
2-yr

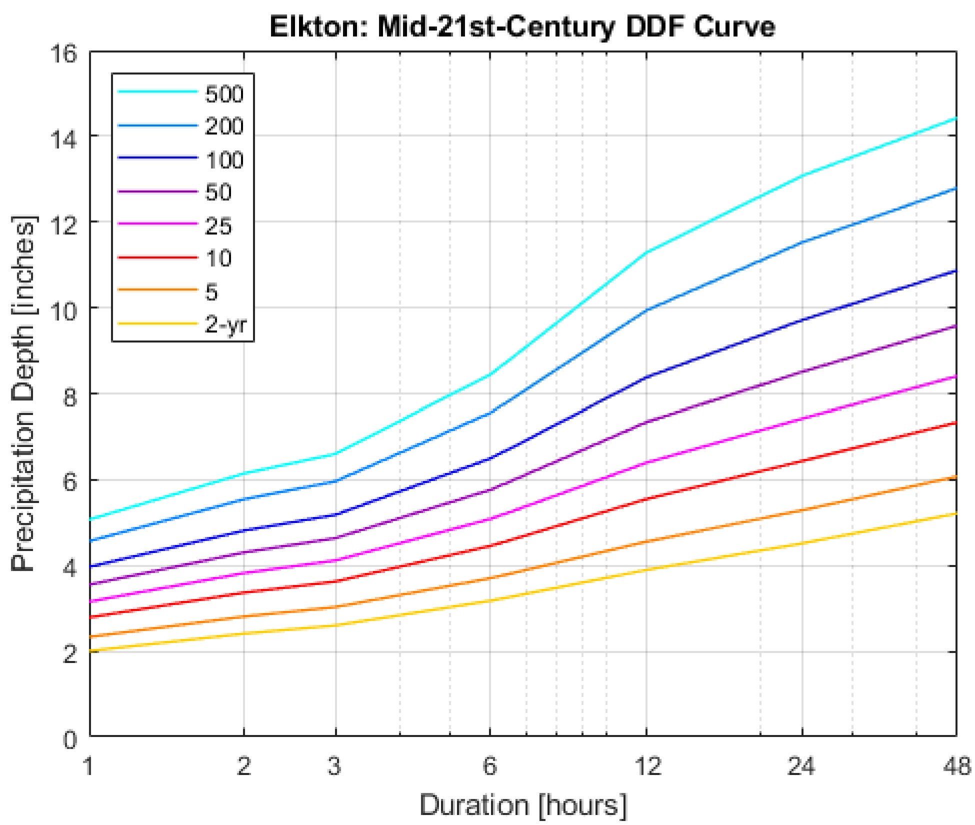


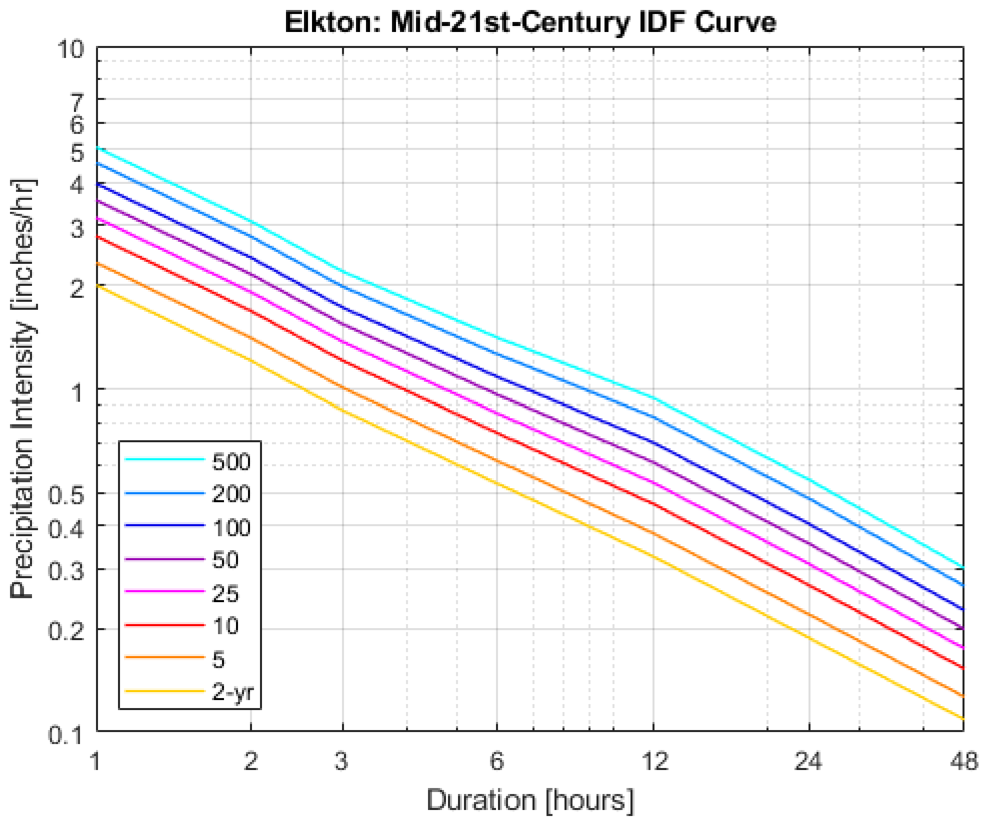
Denton: Mid-21st-Century DDF Curve
Precipitation Depth [inches]
20
18
16
14
12
10
8
6
4
2
0
Duration [hours]
1
2
3
6
12
24
48
500
200
100
50
25
10
5
2-yr


Denton: Mid-21st-Century IDF Curve
Precipitation Intensity [inches/hr]
Duration [hours]
500
200
100
50
25
10
5
2-yr


Easton: Mid-21st-Century DDF Curve
Precipitation Depth [inches]
Duration [hours]
500
200
100
50
25
10
5
2-yr


Easton: Mid-21st-Century IDF Curve
Precipitation Intensity [inches/hr]
10
7
6
5
4
3
2
1
0.5
0.4
0.3
0.2
0.1
1
2
3
6
12
24
48
Duration [hours]
500
200
100
50
25
10
5
2-yr


Elkton: Mid-21st-Century DDF Curve
Precipitation Depth [inches]
16
14
12
10
8
6
4
2
0
1
2
3
6
12
24
48
Duration [hours]
500
200
100
50
25
10
5
2-yr



The precipitation data from the University of Maryland presented above and in Appendices I and II clearly indicate that climate change is increasing the volume and intensity of rainfall on the Eastern Shore. This trend will continue well into the future. Coupled with rising sea level rates of roughly two feet by 2050 and six feet by 2100 (Bass et al., 2018) it is imperative that the region take steps today to mitigate and adapt to the flood risks projected for the future. To this end, ESLC has developed planning recommendations for use by local and state government and other key leaders. The recommendations presented below, as well as the associated evaluative criteria, should be considered by all communities on the Eastern Shore for the protection of private property, public infrastructure, and life safety. By making investments today in climate adaptation efforts, communities can save many times over on the cost of maintenance and disaster recovery for years to come.

V - Extreme Precipitation Policy Recommendations

Policy Option 1: Upgrade Infrastructure to Reflect Future Precipitation Estimates

Communities are typically connected to a stormwater system, whether it is through underground pipes, downspouts, culverts, storm drains, or gutters. All of these are utilized to transport stormwater from where it lands during a precipitation event into a body of water. These hard systems capture water and everything else it touches such as, gasoline, trash, and motor oil, as it moves along until it reaches a waterway.

Municipalities across the country are planning or have begun upgrading and expanding water treatment systems in order to meet the demands of increased stormwater flows. Upgrading, rebuilding, or expanding stormwater systems accordingly will increase systems capacity throughout the region while the frequency of extreme precipitation events continues to rise. Construction of new tunnel systems to control overflows and rehabilitate pumping stations can help communities meet the new expectations of stormwater flow.

In Minneapolis, city records state that the storm sewer system currently in place was designed to bear a 2-year storm event (Thoreen & Osborn, 2018). A series of studies were completed in order to determine what steps were necessary in order to reduce flooding and prepare for changing conditions. Studies suggested the need for upsized piping throughout the study area as well as the need for new stormwater retention facilities throughout the system. The city broke the study area into quadrants and determined which upgrades to implement through a needs-based process. It was deemed that a mix of both gray and green options were necessary in order to best improve resilience in developed areas. The underground, gray systems required the most attention in order to best maintain and utilize the existing water quality treatment stations. Construction of the gray infrastructure projects were coordinated alongside city departments in order to synchronize construction projects and minimize impacts (Thoreen & Osborn, 2018). Some common upgrades that occurred were:

- Replace existing storm drain pipe system (12-inch pipe) with 24-inch pipe
- Installment of underground stormwater retention system
- Upsize existing or install storm pipe (Sizing examples – 18-inch, 24-inch, 30-inch, 34-inch)
- Install backflow preventers
- Upsize existing 12-inch pipe to double barreled 30-inch storm pipe

Minor infrastructure adjustments were also made utilizing green infrastructure to offer more natural strategies to take some of the strain off of the stormwater systems. Rain gardens, curb cuts, swales, tree boxes, and wetlands serve as both aesthetic improvements while helping to address localized stormwater challenges (Thoreen & Osborn, 2018).

Similarly, in the small town of Mission Hills, Kansas, a stormwater open channel and stormwater pipe system master plan was adopted in order to preserve the community and retain stormwater (Harper, 2017). However, in addition to underground stormwater systems, Mission Hills utilizes aboveground retaining walls, open channel systems, and stream buffers. Some common upgrades that were made include:

- Realigning channels through rock grade controls in the form of rock riffles
- Pedestrian bridge improvements and height upgrades across channels
- Channel restoration and grading to decrease bank erosion and provide stability
- Stream banks that were graded were restored with native vegetation

Many municipalities on the Eastern Shore have systems built with the carrying capacity to handle stormwater volumes associated with 100-year storms. Upgrading or upsizing pipes to handle additional water in higher frequency storm events will help to minimize on-street flooding. This is of particular importance for communities such as Cambridge, where patterns of intensity will be disproportionally significant compared to elsewhere in the region. A basic example is that many pipes now are 18”, and a 24” pipe would have the ability to carry more water. While this comes with additional costs, it has the high potential to save communities money in the long run (Jett, B. personal communication, June 2019).

It is also important to note that the Eastern Shore has many unincorporated areas that are not connected to bigger sewer or water systems. These residents are also susceptible to flooding and other impacts related to increases in extreme precipitation events. Homeowners with their own septic and well systems need to be considered when taking infrastructure upgrades into consideration.

Policy Option 2: Utilize Hybrid Green-Gray Infrastructure

Hard and soft infrastructure, more commonly referred to as gray and green, are the two most common forms of infrastructure utilized in stormwater management. Gray infrastructure refers to any human-engineered system for water sources such as pipelines, berms, levees, dikes, or seawalls. Gray is the traditional option and plays a key role in collecting, conveying, or storing stormwater until it is ready to be discharged into a body of water. Much of the gray infrastructure utilized in municipalities across the United States was implemented anywhere from 25-100 years ago and needs to be updated in order to meet the demands of population increase and urbanization, as well as changes in precipitation patterns (Terraza, 2013).

Green infrastructure is defined as the "strategic use of networks of natural lands, working landscapes, and other open spaces to conserve ecosystem values and functions and provide associated benefits to human populations" (Allen, 2013). People do not typically think of forests, wetlands, and other natural ecosystems as a form of infrastructure. However, they have the ability to prevent sediment and other pollutants from ending up in streams or larger waterways. Plants within these ecosystems can also act as a filtration system to improve water quality. Green infrastructure Best Management Practices (BMPs) collect stormwater and/or encourage it to infiltrate in place, and include examples such as rain gardens, rain barrels, or permeable pavement.

Green infrastructure has been found to complement gray infrastructure while also making it more cost-efficient. Using a combination of green and gray infrastructure simultaneously reduces the volume of stormwater collected in the gray infrastructure and thereby helps in avoiding overflow events during extreme precipitation events.

As with any type of infrastructure, there are strengths and weaknesses; these are summarized in Table 3, below:

Table 3: Strengths and weaknesses of infrastructure

Infrastructure	Strengths	Weaknesses
Gray	▪ Expertise in construction and design already exists ▪ Decades of experience ▪ Strong understanding of how these approaches function and the level of protection they provide ▪ Ready to withstand precipitation and storm events as soon as they are implemented	▪ Doesn't adapt with changing climate and precipitation patterns ▪ Weakens over its lifetime ▪ Can cause habitat loss and negative impacts on ecosystems ▪ Can lull communities into believing they are protected no matter what the storm capacity is ▪ No co-benefits occur with good weather

Green	▪ Provides many co-benefits in addition to protection (ex. fishery habitat, water quality, carbon sequestration) ▪ System grows stronger with time as it becomes established ▪ Can adapt to changing climate conditions ▪ Affordable to construct and maintain and has the ability to self-repair	▪ It can take a long time for ecosystems to become established to provide the necessary level of protection ▪ Permitting for natural projects can be more difficult to process compared to hard infrastructure ▪ Requires a considerable amount of space to implement ▪ Growing but still limited expertise in this infrastructure
Hybrid	▪ Capitalizes on the best characteristics of both types of infrastructure ▪ Allows for innovation ▪ Can provide a greater level of confidence in protection ▪ Can be used in areas where there is limited space ▪ Financially feasible in comparison to strictly gray infrastructure projects	▪ This form of infrastructure is new and therefore there is little data on how well these systems perform overtime ▪ Need more research on what the BMPs of hybrid systems provide ▪ Can still have some negative impacts on species diversity and habitat health ▪ Permitting for hybrid projects may be more intensive than permitting for a gray infrastructure project

Sutton-Grier, et. Al. (2015).

Bioswales and rain gardens are two types of easily implemented landscaping features that have the ability to slow, collect, and filter stormwater. They are some of the best examples of systems that can be utilized alongside gray infrastructure to reduce stormwater runoff while also improving the quality of the stormwater (Rain, 2019). Rain gardens are most commonly used in residential areas and have a slight downward slope that allows the rainwater to be collected. . Rain gardens consist of native soils and plants and often have a pipe, rain spout, or underdrain connecting it to the impervious surface to be treated. Bioswales are designed to concentrate or remove debris and pollution from stormwater and consist of a vegetated drainage course with a gentle slope. They achieve the same goal as rain gardens but are constructed to handle a specific amount of runoff from larger, impervious areas such as roadways or parking lots (Rain, 2019). Since they are built to collect and treat a higher amount of water, they are often deeper than rain gardens and greater in length.

In Virginia, the Resilient Hampton project was started in order to reduce flood risk from increased precipitation using methods to slow, store, and redirect the rainfall. The goals of the project are to reduce flood risk and combined sewer overflow while capturing stormwater for water supply, improving water quality, and providing other environmental benefits. The town looked at the approaches utilized in the Netherlands to start their design plans. The 'Dutch Approach' takes into consideration the natural flow of water and understands that combinations of both larger, gray measures with smaller, green ones, lead to the most successful hybrid systems. From here, Hampton created their own plan to implement hybrid infrastructure with the following goals (City of Hampton, 2019):

- Develop a levee in the coastal zone with flood gates
- Embrace the creek system; give room to the creeks to expand and fall with change in climate
- Connect all of the gray infrastructure elements with a green system
- Improve public participation in water management

The implementation of rain gardens and bioswales in addition to gray infrastructure has the ability to lessen the damage caused by stormwater runoff. Connecting the infrastructure improves water quality and slows down movement, which also decreases erosion rates. Public participation in water management requires citizens, firms, and institutes to help. Residents can participate by adding greenery to impervious surfaces, implementing permeable parking lots, putting in gardens, and storing rain water in rain barrels. Slowing, storing, and redirecting rainfall through hybrid- infrastructure projects will allow the town of Hampton to increase their resilience for increased extreme precipitation events (City of Hampton, 2019).

The effectiveness of implementing hybrid infrastructures can be measured using either, or both, of the following tools:

1. Genuine Progress Indicator (GPI)
2. Green vs. Gray Analysis (GGA)

The Genuine Progress Indicator (GPI) is utilized by the City of Baltimore in order to quantify the economic benefits of their Stormwater Management Plan (SMP). The GPI policy analysis includes a menu of GPI boosting BMPs for varying communities throughout the city to utilize. Among the changes required to upgrade impervious acres are: parks, open space, street trees, and rain gardens. While these options were picked for urban infrastructure specifically, the GPI measure can be utilized in multiple communities in order to analyze the effectiveness of green or hybrid infrastructure in localities with high amounts of impervious infrastructure. The GPI measures economic wellbeing by considering the benefits of economic activity through the observation of three major factors: (Talberth, 2015):

- Economic benefits received from consumption of goods and services
- Economic benefits received from social and community assets; public parks, infrastructure, etc.
- Economic costs including environmental degradation, social costs such as unemployment, poverty, and spending on items that are not actually consumed such as insurance

The Green vs. Gray Analysis (GGA) was developed by the U.S. Center for Sustainable Economy. GGA extends conventional public infrastructure models to aid in the evaluation of the cost effectiveness of the technological and adaptive solutions being considered. GGA considers the unique roles of wetlands, forests, riparian zones, and other natural elements that play a role in enhancing water quality, flow, and other environmental objectives. The analysis is utilized in order to determine whether investments into green or hybrid options are a more cost-effective approach in comparison to gray counterparts (Green-Gray Analysis, 2018).

Policy Option 3: Implement Stormwater Utility

In order for stormwater infrastructure to be successful, it must be properly constructed, managed, and maintained. A major issue faced with stormwater management is the limited amount of funding available to properly maintain infrastructure that has already been put into place. Many pipe structures become full of sediment and pollutants while transporting stormwater. This sediment often settles for decades in these pipe systems and reduces the systems carrying capacity. As the Eastern Shore begins to experience more extreme precipitation events, these systems will continue to fill with sediment while losing carrying capacity. Removal of the sediment and other pollutants alone has the potential to return over half of the carrying capacity to the systems (J. George, personal communication, June 2019).

Stormwater management can be costly and funding stormwater management programs through a utility can help offset costs to local government while providing benefits to the community. The main concept behind stormwater management practices is that property owners receive some form of benefit from the system being maintained. For any service, users are required to provide some sort of fee or compensation. Therefore, most stormwater utility fee rates should be based on the size or footprint of the structural part of the property. The structural part of the property is referred to as the impervious surface. This is typically a hard surface that water is unable to permeate such as a roof, patio, paved area, or sidewalk. The fee should be based off of these impervious surfaces because it hinders the process of water infiltrating the ground, increasing the volume and flow of stormwater that a community must manage.

A stormwater utility fee allows for the community to:

- Create equitable and fair allocation of stormwater management costs
- Support the reduction of flooding and water quality issues stemming from stormwater runoff
- Address and reduce water quality stressors
- Create a stronger accountability for stormwater management spending and generate revenue

While considering the implementation of a stormwater utility, it is important to understand the unique circumstances of each municipality. Due to land use and development, stormwater system issues, regulatory mandates, and economic and socio-political considerations, stormwater credits and incentives should not be viewed through a “one size fits all” lens. When implementing a utility system, it is important to have flexibility in order to successfully develop and implement programs that best fit the needs of each individual community. There is a balancing act that needs to be considered when determining how stormwater utility systems will be implemented.

Fee structures may include flat or tiered rates. Most commonly, fee structures are separated between residential and nonresidential property owners. Those owning residential property pay a flat rate stormwater fee which greatly lowers administrative costs. However, this is not feasible with nonresidential properties as they may vary greatly in size and area of impervious surface coverage (Kirk, 2019). These nonresidential properties often utilize a tiered rate system based on their estimated impervious surface. This tiered rate system charges based on amount of impervious surface area on a property. Those with less impervious surface area pay a lower fee than those with higher amounts of impervious surface area.

Based on the annual report conducted by Black & Veatch Management Consulting, LLC. The average monthly residential charge ranges from $0.75 in Hamilton County, Tennessee to $40.07 in Seattle, Washington, with the true average falling closer to $5.50 (Kumar & White, 2018). Local governments implementing stormwater utilities have the ability to set their own prices based on the amount of funding they require for their stormwater system management. Localities may wish to ease into the addition of the utility and slowly increase the fee over the years in order to meet management and maintenance needs. A study completed by the Environmental Finance Center at the University of North Carolina found that of those municipalities who have implemented a utility, 18.2% have not raised fees and only one utility has raised fees every year since 2010 (EFC, 2018).

On the Eastern Shore in 2013, the Town of Oxford created the Oxford Stormwater Task Force. This campaign was kick-started thanks to the national Fish and Wildlife Foundation Technical Assistance Grant and the University of Maryland’s Environmental Finance Center as a first step in addressing stormwater flooding. Oxford experiences nuisance flooding due to the combination of stormwater and high tides regularly. Most commonly, local topography traps stormwater and creates pooling. Often times, stormwater pools because high tides cause flood gates to close, leaving rainfall with nowhere to go. When extreme precipitation events occur, these issues intensify and flooding becomes a major issue on roadways and in lower-lying areas. Stormwater becomes a serious contributor to flooding and high water during high tide and storm surge events. The town is dependent on a properly designed and maintained stormwater system in order to remediate high water impacts, regardless of their cause.

The Stormwater Task Force created recommendations for the Town of Oxford, which suggested the implementation of a stormwater utility. The task force focused on obtaining local input on stormwater impacts and determining viable solutions. The task force worked to ensure the Oxford's stormwater management program addressed local infrastructure and regulatory needs sustainably. In order to finance and ensure long-term funding for these sustainable stormwater practices, funding outside of the local budget is necessary. It was suggested that the stormwater utility be implemented in order to create funds devoted to stormwater management.

In response to these suggestions, Oxford created their own tiered version of a stormwater utility that was determined based on recommendations provided by the task force, property value, and other tax structures. This number was then added onto the tax base and helped to create a $100,000 annual fund used for capital expenditures. These expenditures include, but are not limited to, equipment, planning studies, tide gates, and matching funds for major infrastructure projects. However, the difference between this stormwater utility and others being utilized across the U.S. is that it also considers shoreline protection. Oxford recognizes that communities on the Eastern Shore experience flooding form both rain events and rising tides. In order to gain support from its citizens for additional taxes, it needed to be personal, it needed to clearly address the needs of the community. Oxford's Stormwater Management Shoreline Protection (SMSP) Fund clearly identifies the purpose of the utility in its name. Resilience from increased flood events is dependent on managing stormwater, protecting the shoreline, and protection of infrastructure, which are all points considered when managing Oxford's stormwater fund.

There are upfront costs necessary in order to implement a stormwater utility. However, when done properly, the utility has the ability to generate revenue while proactively addressing the stormwater needs of the community. The dedicated revenue stream also makes communities eligible for grants and loan programs that would otherwise be out of reach (McIntosh & Vicari, 2018).

Policy Option 4: Adopt Executive Order Criteria Into Development Standards

Federal Executive Order 11988 focuses on floodplain management. The E.O. requires federal agencies to avoid, whenever possible, the adverse impacts associated with the occupancy and alteration of floodplains. It also requires avoidance of direct and indirect support of floodplain development wherever there is a practicable alternative. The purpose of this objective is to reduce risk of flood loss, minimize impacts of floods on human safety, health, and welfare, while also restoring and preserving the natural and beneficial values served by flood plains. Floodplains, when undeveloped, have the ability to (Flooding, n.d.):

- Store water and control erosion during flood events – offer a broader area for rivers to spread out and acts as temporary storage, reducing flood peaks
- Provide water quality maintenance by reducing sediment loads, filtering impurities, and moderating water temperature
- Recharge groundwater, increasing freshwater aquifer quantities
- Create habitat for various fish and wildlife
- Produce recreational opportunities and economic benefit

The guidelines of the E.O. address a step-by-step process that should be considered during the decision-making process of a development project with the potential to impact a floodplain.

Maryland issued its own Executive Order 01.01.2012.29, Climate Change and "Coast Smart" Construction, which was enacted into law in 2014 and subsequently amended in 2018 and 2019. This law established the Maryland Coast Smart Council, which was tasked with developing and administering Coast Smart siting and design criteria to address sea level rise and coastal flood impacts on capital projects. The E.O. and subsequent law direct state agencies to consider these threats in the siting and design of state structures in order to avoid or minimize their impacts. The legislation requires that all new and substantially reconstructed infrastructure that is located in Special Flood Hazard Areas be planned with at least two feet of freeboard above the 100-year base flood elevation. Freeboard refers to the amount of distance above a base flood elevation and results in lower flood risk and insurance rates (FEMA, n.d.). Similar to the Federal Order, the Maryland E.O. and law initially applied only to state facilities and structures, including transportation facilities. Amendments to the law in 2018 and 2019 redefined the purview of the guidelines to state and local capital projects exceeding $500,000 in cost, of which at least half of the funding is from State funds. This change is effective as of July 1, 2020.

These two E.O.'s are examples of the federal and state government taking the initiative to increase long term resilience to storm-related flooding. By adopting similar criterion for all floodplain regions on the Eastern Shore, local governments would be best preparing their communities for future climate change impacts. Investing time and finances into changing development standards now will save the additional costs of repairs from damage in the future.

Policy Option 5: Create Recovery Plans Which Prioritize Flood Mitigation and Future Flood Risk

Flooding is the most common natural disaster in the world and 75% of all presidential disaster declarations are associated with flooding (Nationwide, 2019). Being prepared for flooding events and having fleshed out disaster recovery plans in place are crucial for successfully handling natural disasters. It is important for communities on the Eastern Shore to develop their own local recovery plans that evolve alongside the changing environment. The Upper Eastern Shore Regional Recovery Plan is a step in the right direction for communities. However, every community is different; there is not a one size fits all disaster recovery plan that can be used. Communities may choose to base their plans off of the regional plan and make additions as they see necessary for their residents.

Disasters have the ability to occur at any time with little to no warning. Community needs often exceed what is readily available and require organization and planning to be executed swiftly in order for them to recover. These efforts can occur concurrently and at different rates depending on the magnitude and nature of damage. The purpose of these disaster preparedness plans is to aid in the coordination of efforts following a devastating event. There are many people, departments, and organizations involved in disaster recovery efforts. These plans help to describe roles and responsibilities of each group, while also allowing for information and resource sharing. The creation of short, intermediate, and long-term recovery structures allows for all needs of the community to be met throughout the disaster recovery process.

The short-term recovery phase of the plan may last anywhere from a few days to several weeks depending on the nature of the disaster. This phase includes:

- Mass care efforts such as sheltering
- Testing and provision of clean food and water
- Debris removal, particularly from transportation routes

- Healthcare, whether it be emergency, temporary, or basic medical services
- Assessing community risks and vulnerabilities

Intermediate recovery transitions following short-term and usually marked by the opening of a Disaster Recovery Center. This center is used to help provide information and resources to residents. The intermediate recovery phase is characterized by the transition back to a community- driven effort with less government involvement (UES Recovery Plan, 2016). Activities include:

- Providing temporary housing solutions
- Debris removal and restoration of infrastructure
- Continued health care and medical support
- Supporting the reestablishment of local businesses

Lastly, the transition to the long-term recovery phase occurs when the community has taken over the effort and is being provided support by the local government. By this phase,

- Long term housing solutions have been developed and are in the process of being implemented
- Infrastructure is being rebuilt
- Health care facilities are being reestablished
- Economic revitalization strategies are being implemented

Along with these recovery phases, a few categories should be covered in these plans, and if resources allow, working committees to specialize in each group should be established (Long-term, n.d.):

- Needs Assessment and Case Management – Development of a system that helps to determine where funding should go, setting up logistics trainings
- Housing and Construction – Identifies residents who have immediate housing needs and their housing options post-disaster; Aid in reconstruction assessments and project plans
- Community Resiliency and Engagement – Create a vision for how strong communities can be rebuilt following disaster
- Volunteer Coordination – both local and national; set up volunteer training programs for assistance following the event
- Finance, Allocations, and Development – continuing to find funding and donations to meet the financial needs of residents
- Communications and Public Relations – keeping the public informed of any decisions or decision- making processes, providing status updates, and maintain internal communication to keep all committees up to date
- Emotional and Mental Wellness – support those who experienced loss during the disaster rebuild and recover

The Maryland Emergency Management Agency has provided a planning toolkit and other resources on their website to help aid local governments in developing their own disaster preparedness and recovery plans.

Policy Option 6: Restore Unutilized Agricultural Lands to Natural Ecosystem

As rainfall events become more frequent and produce more precipitation, areas that already experience flooding during extreme precipitation events will become flooded more often. Much of this flooding occurs on agricultural land where wetlands once existed and are now being utilized for crop or livestock. As these areas experience more frequent flooding, the agricultural land will become unsuitable for planting or growing. Crop yields will decrease and farmers will experience losses in income from once fertile land. By restoring these areas to natural wetlands, farmers will be able to control flooding while also creating different types of income streams.

The goal of this policy option is to determine the most vulnerable areas to flooding. Local governments may utilize input from local farmers, community GIS specialists, or public comment periods to determine which agricultural lands may become unsuitable for farming practices as increases in stormwater runoff are experienced. Prioritizing at risk areas for restoration projects will benefit both farmers and community members. Restoring these natural habitats improves nutrient management practices, reintroduces natural filters, and eliminates substantial amounts of phosphorus, nitrogen, and sediment from surrounding ecosystems.

Restoration of wetlands and other natural habitats has the ability to protect agricultural, residential, and commercial properties from impeding floodwaters. Wetlands are areas where water covers soil all or part of the time (U.S. EPA). These ecosystems are important because they protect and improve water quality, provide fish and wildlife habitats, store floodwaters, and maintain surface water flow during dry periods. Wetlands prevent flooding by temporarily storing and slowly releasing stormwater. The vegetation in wetlands holds soils in place, while also reducing water flow, allowing pollutants and sediments to settle before moving along towards waterways.

Eastern Shore communities thrive on resource-based industries such as fisheries, agriculture, forest products, tourism, and outdoor recreation. By restoring these natural habitats through restoration projects, Eastern Shore communities will be able to thrive economically. A study completed in 2012 on the economics of natural areas found that overall, Delmarva contributes $15 billion in ecological services annually. 7,000 farms yield $2.8 billion in farm products per year on 1.3 million acres and outdoor enthusiasts spend up to $3.9 billion per year supporting 27,900 jobs (cite). In 2016 alone, visitor spending contributed $270 million to Virginia's Delmarva (Clower & Bellas, 2017).

The Maryland Department of Natural Resources (DNR) supports restoration projects through funding opportunities and other resources. Similarly, on the federal level, the U.S. Fish and Wildlife Service (USFWS) has funding options available through the North American Wetland Conservation and the National Coastal Wetland grant programs. The Department of Agriculture also offers funding through their Natural Resources Conservation Service agency. This funding is available to agricultural land that becomes unusable for cultivation and therefore can be converted back to its natural wetland ecosystem. There are also other partners within USFWS who are dedicated to restoring habitats and locating the proper funding and resources to do so.

Additionally, this policy option is closely related to the Community Rating System (CRS) which stems from FEMA's National Flood Insurance Program and the points-earning capacity of activities related to open space preservation. CRS recognizes communities whose activities generate and contribute data that assist in creating more accurate flood insurance ratings. CRS encourages communities to implement mapping and information programs and to create comprehensive floodplain management programs. The following local efforts are considered when rating comprehensive floodplain management:

- Protect lives
- Further public health, safety, and welfare
- Minimize damage and disruption to infrastructure and critical facilities

- Preserve and restore the natural functions and resources of floodplains and coastal areas
- Ensure the new development does not cause adverse impacts elsewhere

Communities receive their CRS classification based upon the total credit for their completed activities. There are ten CRS classes, with Class 1 requiring the most credit points and providing the greatest discount in terms of flood insurance. These class ratings are based upon a credit point system. These credit points are awarded for approved CRS activities, each having a varying amount of possible points earned. This policy option could potentially fall into three categories within the CRS: Open Space Preservation (420), Stormwater Management (450), Flood Plain Management (510). Together this could provide a community with a savings of 25% on all federally-backed flood insurance policies.

Policy Option 7: Prepare Plans for Future Funding and Grant Opportunities

As state, federal, and private funding becomes available to local governments who are attempting to implement or upgrade their stormwater management systems, it is crucial that the governments are ready prepared to act. Having the capacity to handle money and begin the implementation of a project within a feasible time window is crucial. Without funding, the above policy options may be difficult to implement, manage, and maintain over an extended period of time. Being prepared for financial opportunities whenever they may arise will set Eastern Shore communities up for success.

There are a few ways that local governments can prepare for these funding opportunities. The organizations that are the most successful in receiving grants are those who do not chase grants, but rather have well-designed programs that require supplemental funding (Karsh & Fox, 2014). These programs or projects produce a mission that drives the organization and creates commitment to gaining funding. It is easier to find grants that support a program and mission than it is to locate funding and create projects that fit within the narrow scope.

Local governments may request funding in order for an inventory to be completed based on all current stormwater infrastructure. It will also allow for the creation of a master plan concerning stormwater and shoreline infrastructure for when future grant prospects arise. Smaller projects located within this master plan may be taken on by local governments depending on costs and stormwater fund availability. Local governments could either directly or in partnership with an external grant writer, create pre-packaged grant projects. Based on the stormwater master plan, stakeholders will know which projects need to be completed. From here, the community can invest the time up front to determine what these objectives will cost and how quickly they need to be addressed. They can essentially create these pre-packaged grant applications so they are ready to be submitted as soon as funding becomes available.

The foundation of these pre-packaged grant projects are the organizational documents. Typically, grants require tax documents, vision statements, operating budgets, and other supporting documents. In order to be best prepared, the following information should be collected, organized, and updated regularly:

- Overview of the locality
    - Number of residents, method of governance, description of local elected officials, crime and health statics, immigrant information, unemployment rates, number of town workers, unions, and accomplishments
- Information about the various neighborhoods and sections of the locality
- Overview of the particular agency or department applying for the grant
    - This should include agency structure and mission, overall budget, staffing, leadership,

responsibilities, existing related grants, and any relevant awards

- Organizational chart
  - Can easily be utilized to show to whom the grant-funded staff will report and how the program will be an integral part of the department

Having these documents readily accessible is the first step in preparing for the grant application process. The next is having a wish list of project ideas that stem from the masterplan. Some of these may be major projects, however funding to support the project as a whole may not be available all at one time. Breaking down larger projects into smaller, more manageable projects may also be beneficial when looking for funding opportunities.

For those local governments who may find themselves to be stretched for time and resources to complete the grant writing process, there are federal agencies and private individuals that are willing to ghost write grants. For example, the U.S. Fish and Wildlife Service will write grants for local governments that are unable to be utilized on the federal level. There are also many individuals who specialize in grant research and writing that work freelance and may be hired as needed by local agencies.

VI - Evaluative Criteria

Local governments can evaluate policy options and their respective outcomes by utilizing the following four criteria. These criteria may be considered equally or weighted to address the concerns of the community, but all should be included in the evaluation process.

Environmental Impact

This criterion assesses the projected effects of the policy option on the Eastern Shore's environment, including the health of local ecosystems. As a rich, natural area, the Eastern Shore serves as a valuable habitat for many species. Environmental impact can be evaluated as low, medium, or high, where high represents significant negative environmental consequences, such as habitat loss or pollution.

Cost Effectiveness

This criterion assesses the monetary cost of lives and land protected due to the policy option. The "do nothing approach" may serve as the baseline for the analysis, and costs may differ among alternatives, from raw materials to administrative fees. When possible, the cost of each option should be quantified and transformed into a qualitative rating of low, medium, or high, where high represents effective, low-cost options.

Political Feasibility

This criterion assesses whether an option is practical given the current political climate, and is concerned with the likelihood of policy implementation by legislators and other governing officials. The political feasibility of a policy option is deeply related to its cost effectiveness. This criterion also accounts for the public's perception of the option. Political feasibility may be assessed with input from key stakeholders and should be related on the same qualitative scale of low, medium, or high.

Social Welfare

This criterion assesses the degree to which an option increases the welfare of residents in the community by decreasing the area's social vulnerability, which refers to the ability of a community to anticipate, cope with, and adapt to natural hazards. The physical health and safety, cultural, and equity implications of each policy option should be considered. Furthermore, estimates of potential property damage should be used to gauge whether the social welfare impacts of an alternative are low, medium, or high, where high corresponds with the highest level of social welfare/lowest level of vulnerability.

VII - Conclusion

The downscaled precipitation research conducted by Dr. Brubaker and her team clearly indicate that extreme precipitation events are becoming more intense and bringing more rain, a trend which will continue and escalate in the coming decades. These patterns of intensification are most predominate in the southern part of ESLC’s territory but should not be discounted anywhere on the Eastern Shore. Governments and communities need to start taking concrete steps to prepare for these events. In order to be successful in dealing with these increases in rainfall, local governments must start preparing their communities for the future today.

Each community on the Eastern Shore is different and therefore policy options should be evaluated by each government to determine their own best-fit. In order to choose the most viable option(s) for the community to implement, the criteria above should be utilized to evaluate prior to incorporation. Taking action to prepare residents and businesses for the present and future effects of climate change will allow for the creation of successful, resilient communities.

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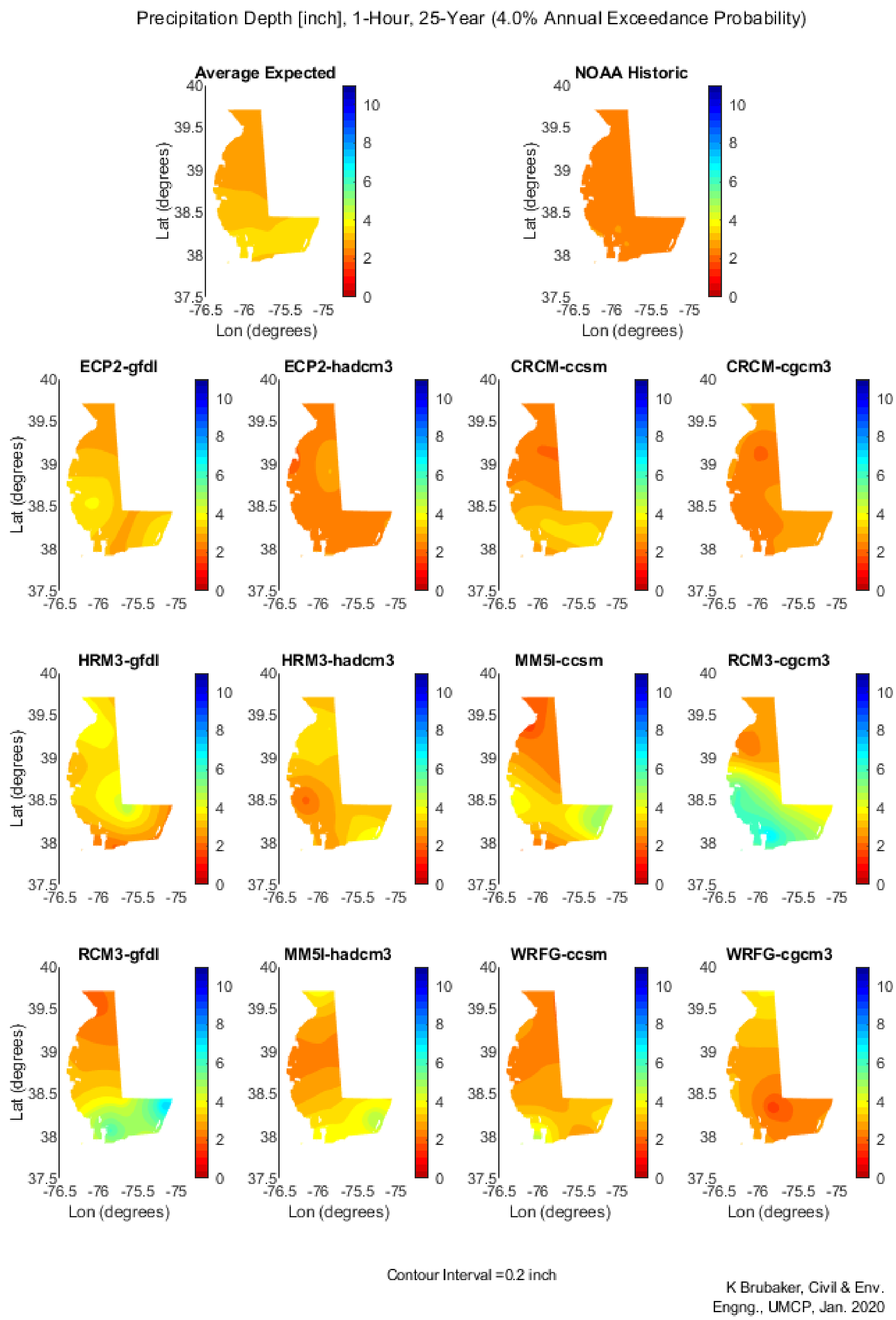
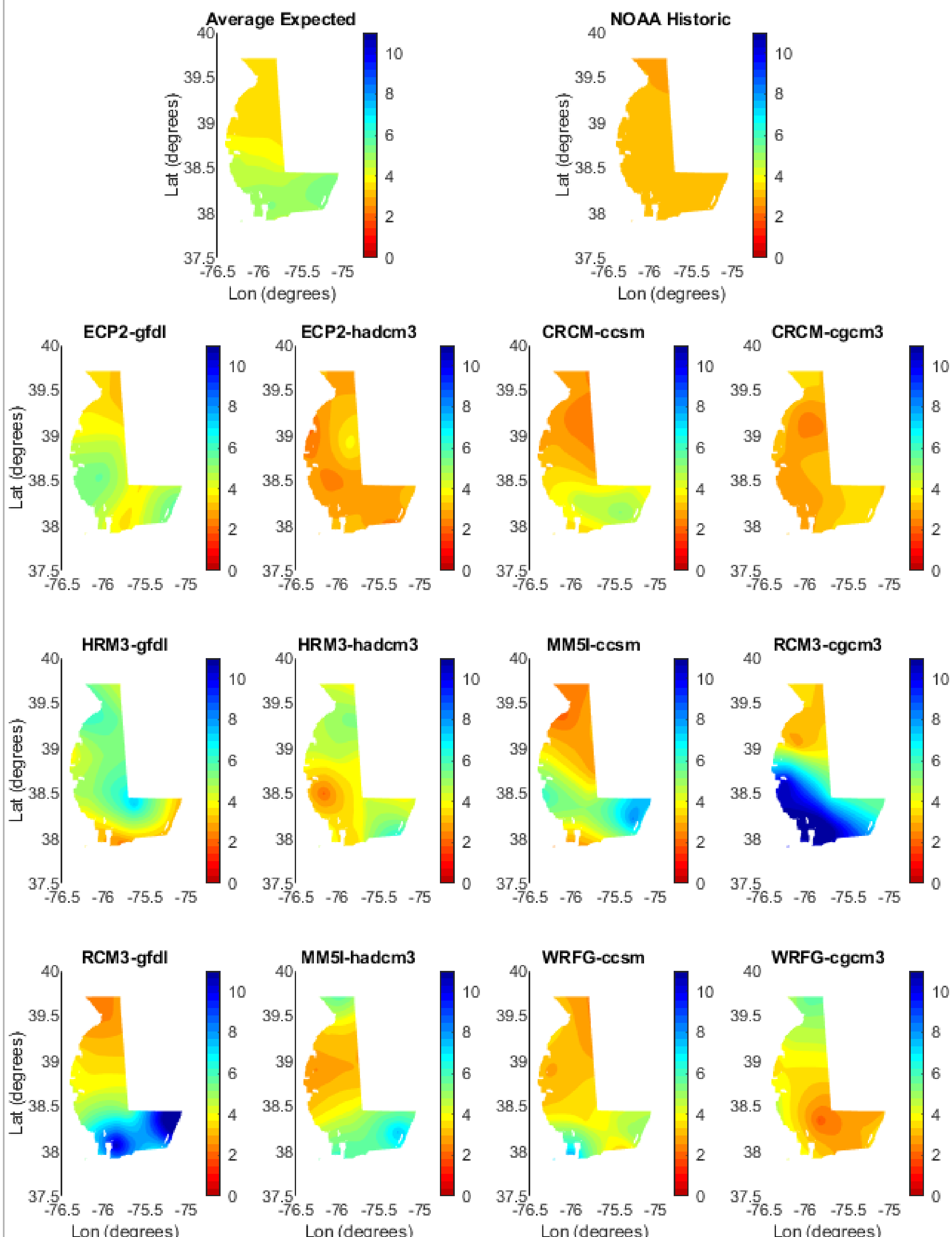
Appendix I: Precipitation Depth Models

The following maps show projected mid-century precipitation compared to the current (historic) NOAA average of 12 global-regional model pairs (upper left) and individual global-regional model results.



Precipitation Depth [inch], 1-Hour, 100-Year (1.0% Annual Exceedance Probability)



Contour Interval =0.2 inch

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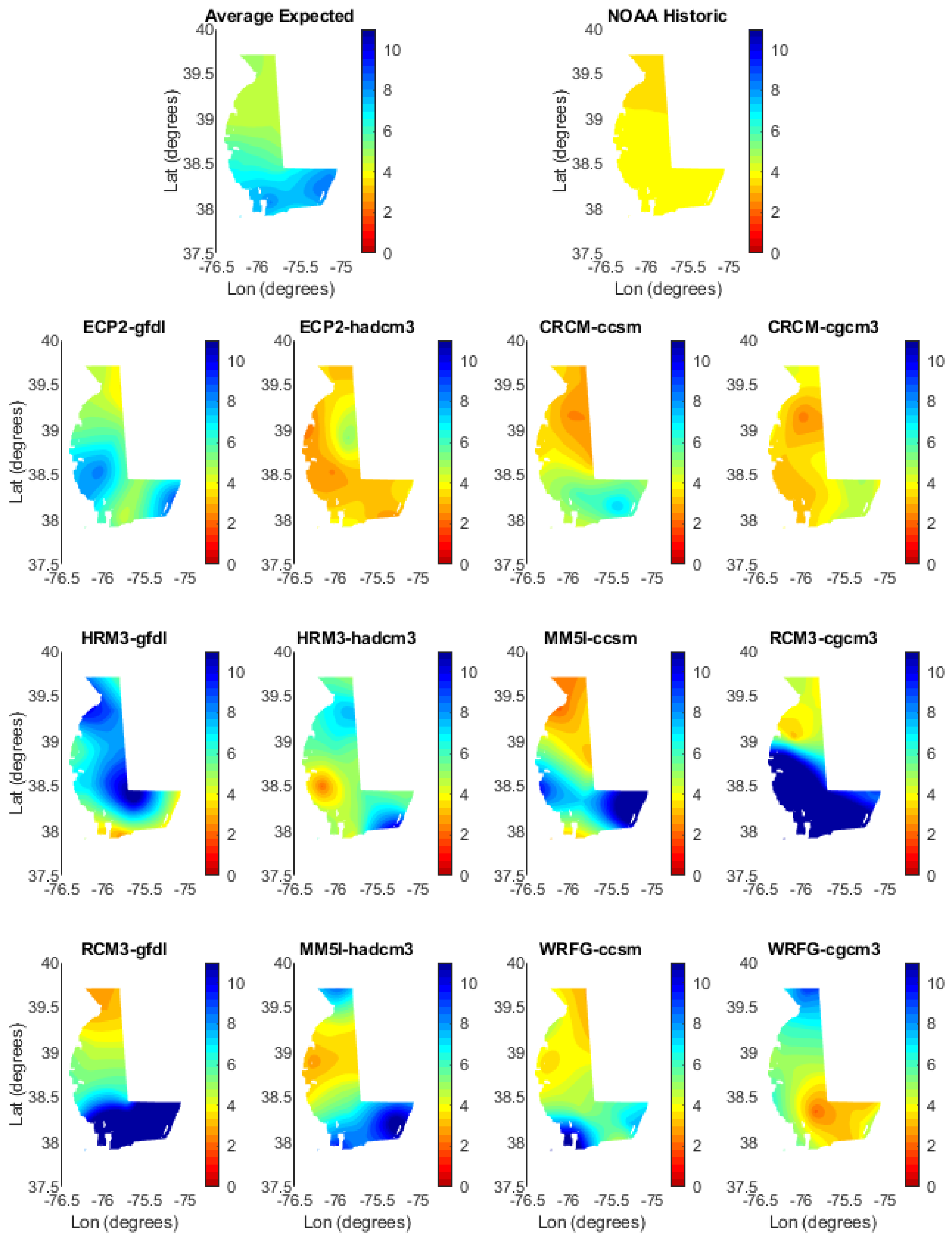
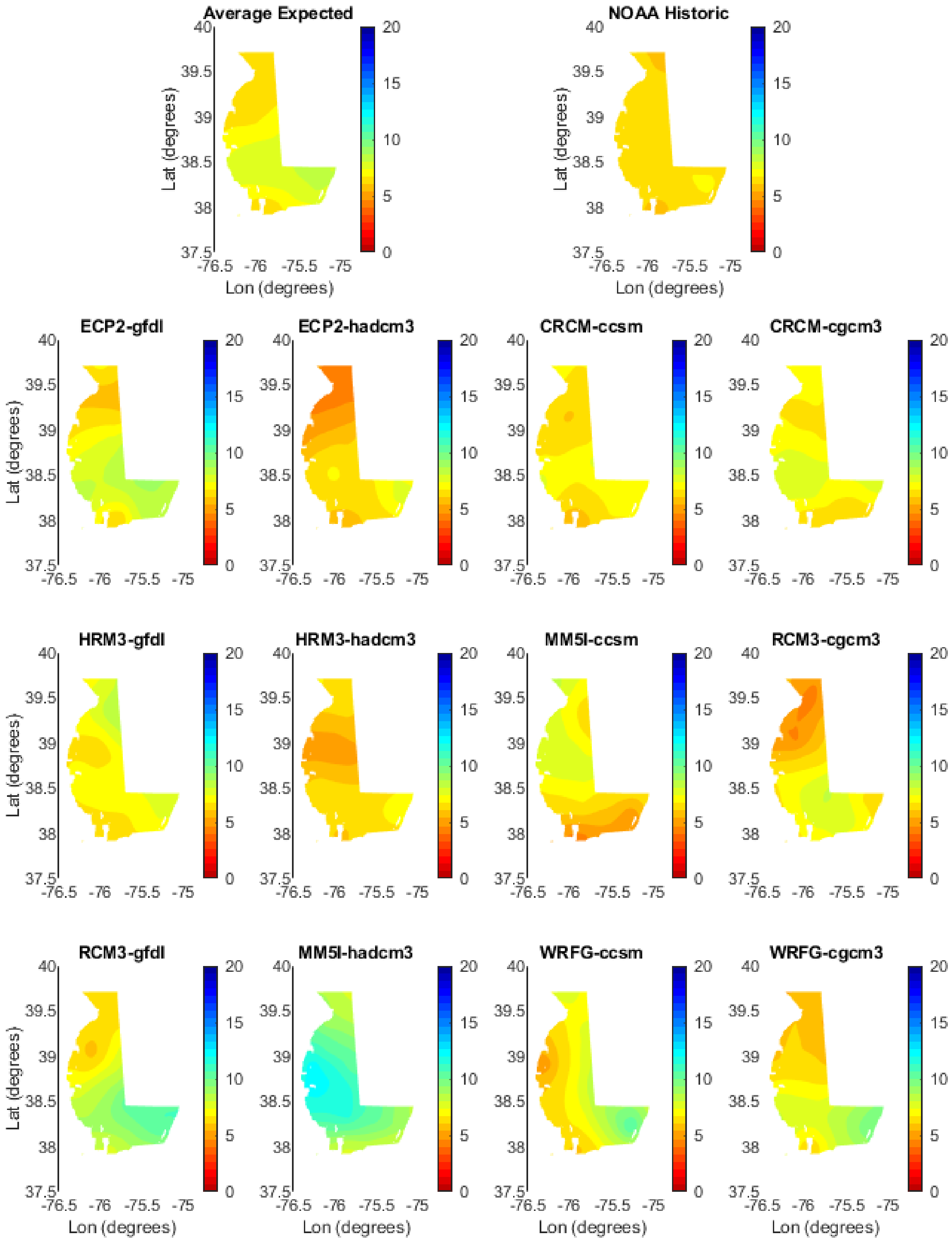
Precipitation Depth [inch], 1-Hour, 500-Year (0.2% Annual Exceedance Probability)



Contour Interval =0.2 inch

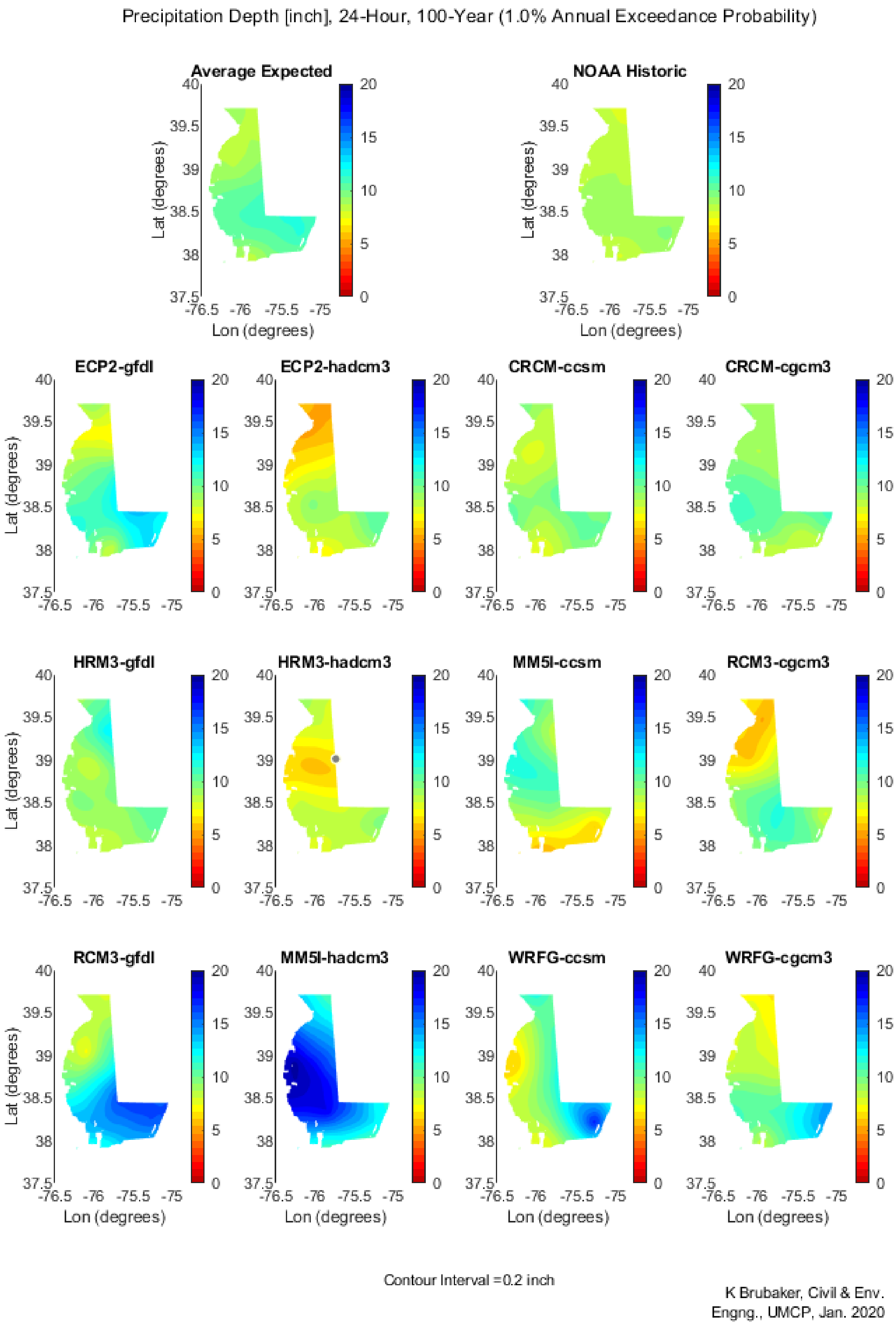
K Brubaker, Civil & Env. Engng., UMCP, Jan. 2020

Precipitation Depth [inch], 24-Hour, 25-Year (4.0% Annual Exceedance Probability)

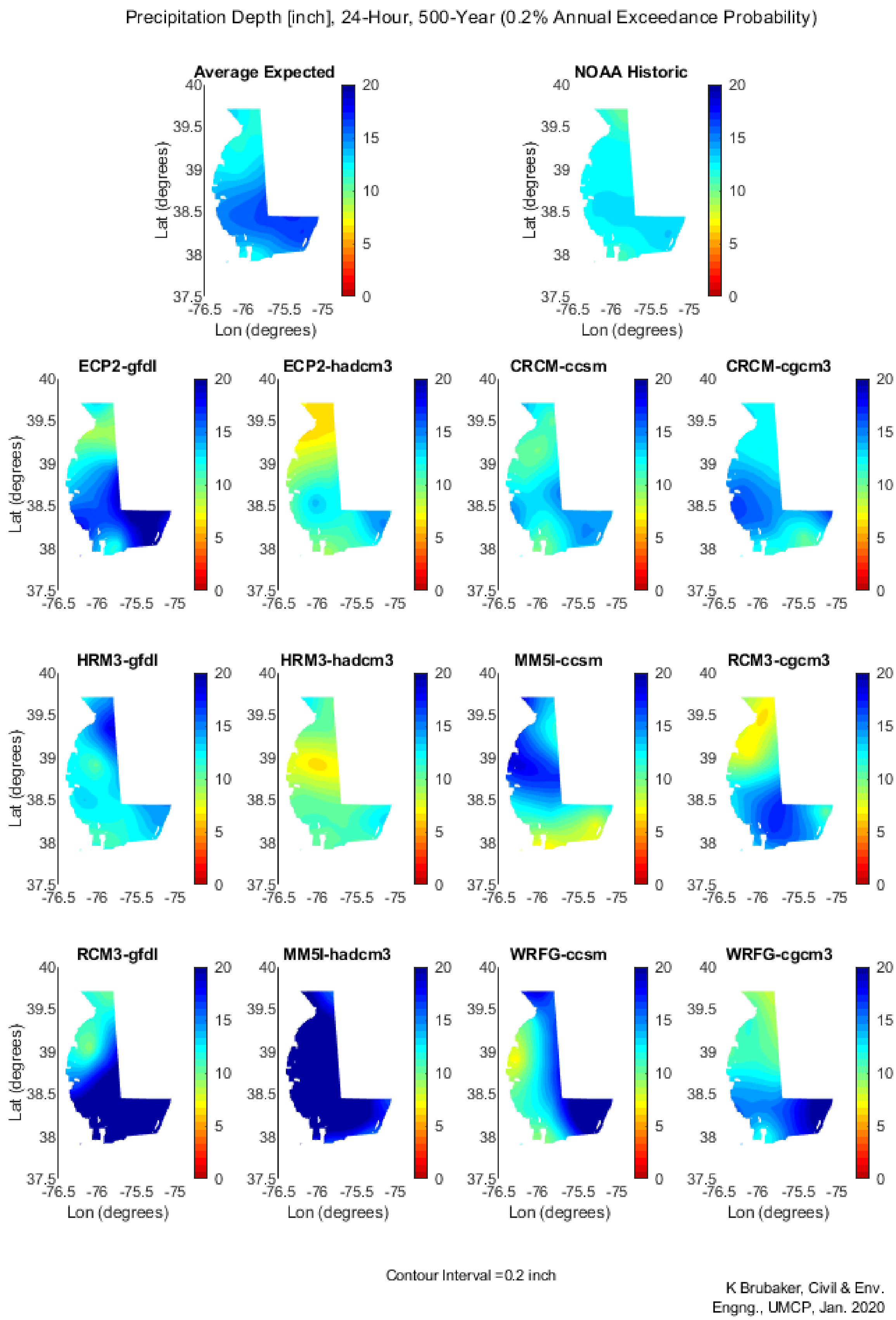


Contour Interval =0.2 inch

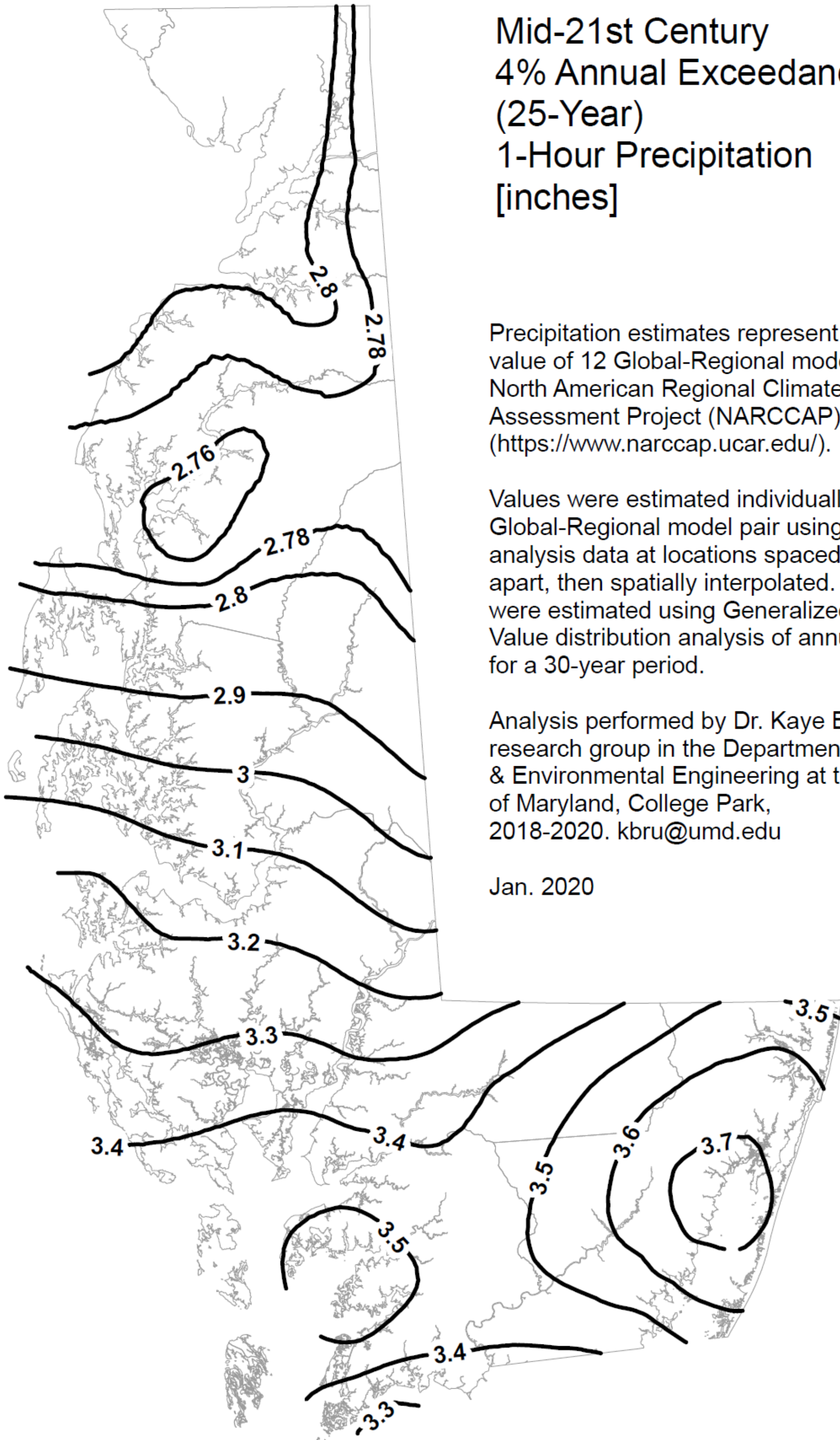
K Brubaker, Civil & Env. Engng., UMCP, Jan. 2020



Precipitation Depth [inch], 24-Hour, 100-Year (1.0% Annual Exceedance Probability)
Average Expected
NOAA Historic
ECP2-gfdl
ECP2-hadcm3
CRCM-ccsm
CRCM-cgcm3
HRM3-gfdl
HRM3-hadcm3
MM5I-ccsm
RCM3-cgcm3
RCM3-gfdl
MM5I-hadcm3
WRFG-ccsm
WRFG-cgcm3
Lat (degrees)
Lon (degrees)
Contour Interval =0.2 inch
K Brubaker, Civil & Env. Engng., UMCP, Jan. 2020


Precipitation Depth [inch], 24-Hour, 500-Year (0.2% Annual Exceedance Probability)
Average Expected
NOAA Historic
ECP2-gfdl
ECP2-hadcm3
CRCM-ccsm
CRCM-cgcm3
HRM3-gfdl
HRM3-hadcm3
MM5I-ccsm
RCM3-cgcm3
RCM3-gfdl
MM5I-hadcm3
WRFG-ccsm
WRFG-cgcm3
Lat (degrees)
Lon (degrees)
40
39.5
39
38.5
38
37.5
-76.5
-76
-75.5
-75
20
15
10
5
0
Contour Interval =0.2 inch
K Brubaker, Civil & Env. Engng., UMCP, Jan. 2020

Appendix II: Precipitation Contour Maps



Mid-21st Century
4% Annual Exceedance Probability
(25-Year)
1-Hour Precipitation
[inches]

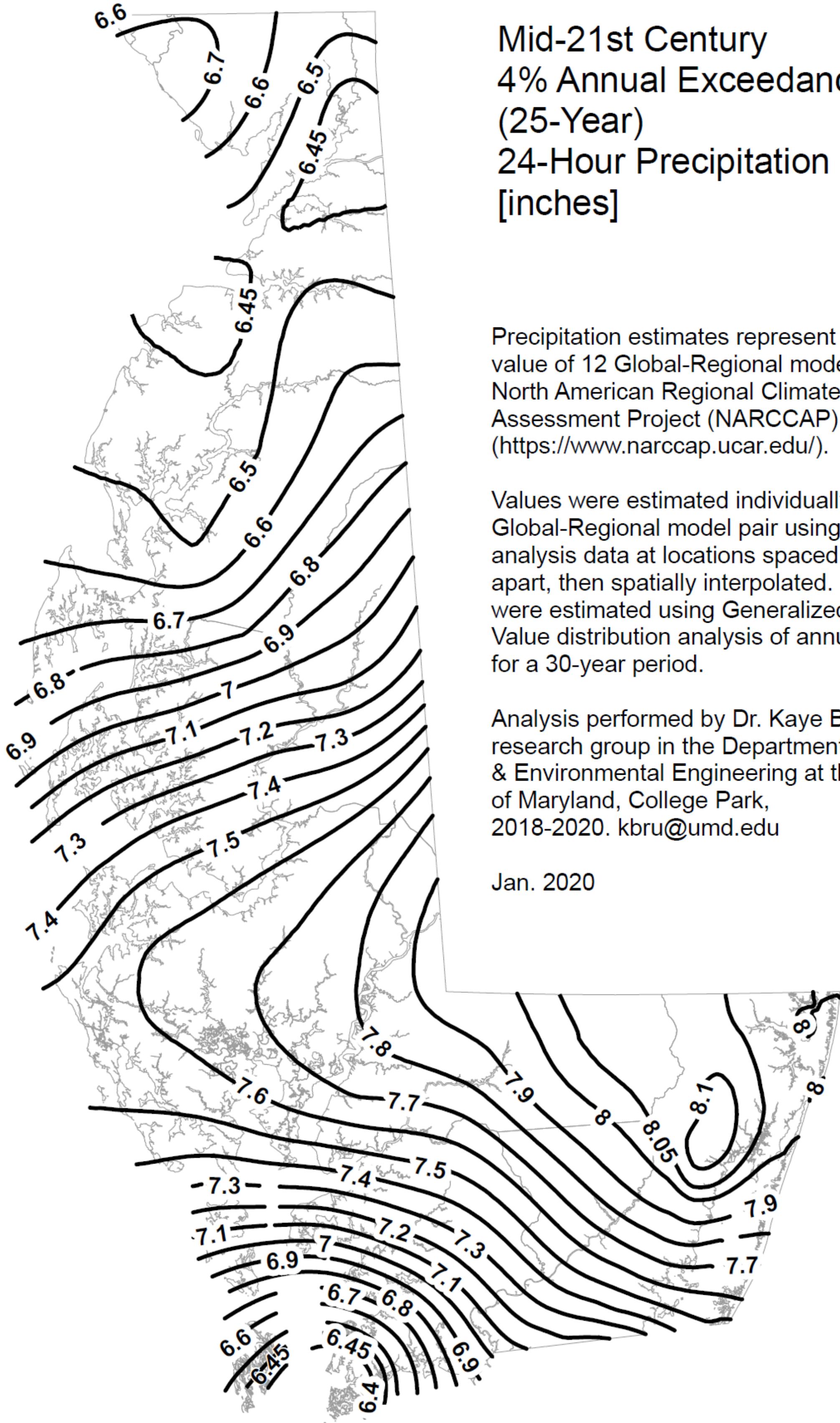
Precipitation estimates represent the average value of 12 Global-Regional model pairs in the North American Regional Climate Change Assessment Project (NARCCAP) (https://www.narccap.ucar.edu/).

Values were estimated individually for each Global-Regional model pair using 3-hour model analysis data at locations spaced 50 km apart, then spatially interpolated. Quantiles were estimated using Generalized Extreme Value distribution analysis of annual maxima for a 30-year period.

Analysis performed by Dr. Kaye Brubaker's research group in the Department of Civil & Environmental Engineering at the University of Maryland, College Park, 2018-2020. kbru@umd.edu

Jan. 2020

Mid-21st Century
4% Annual Exceedance Probability (25-Year)
24-Hour Precipitation Depth [inches]



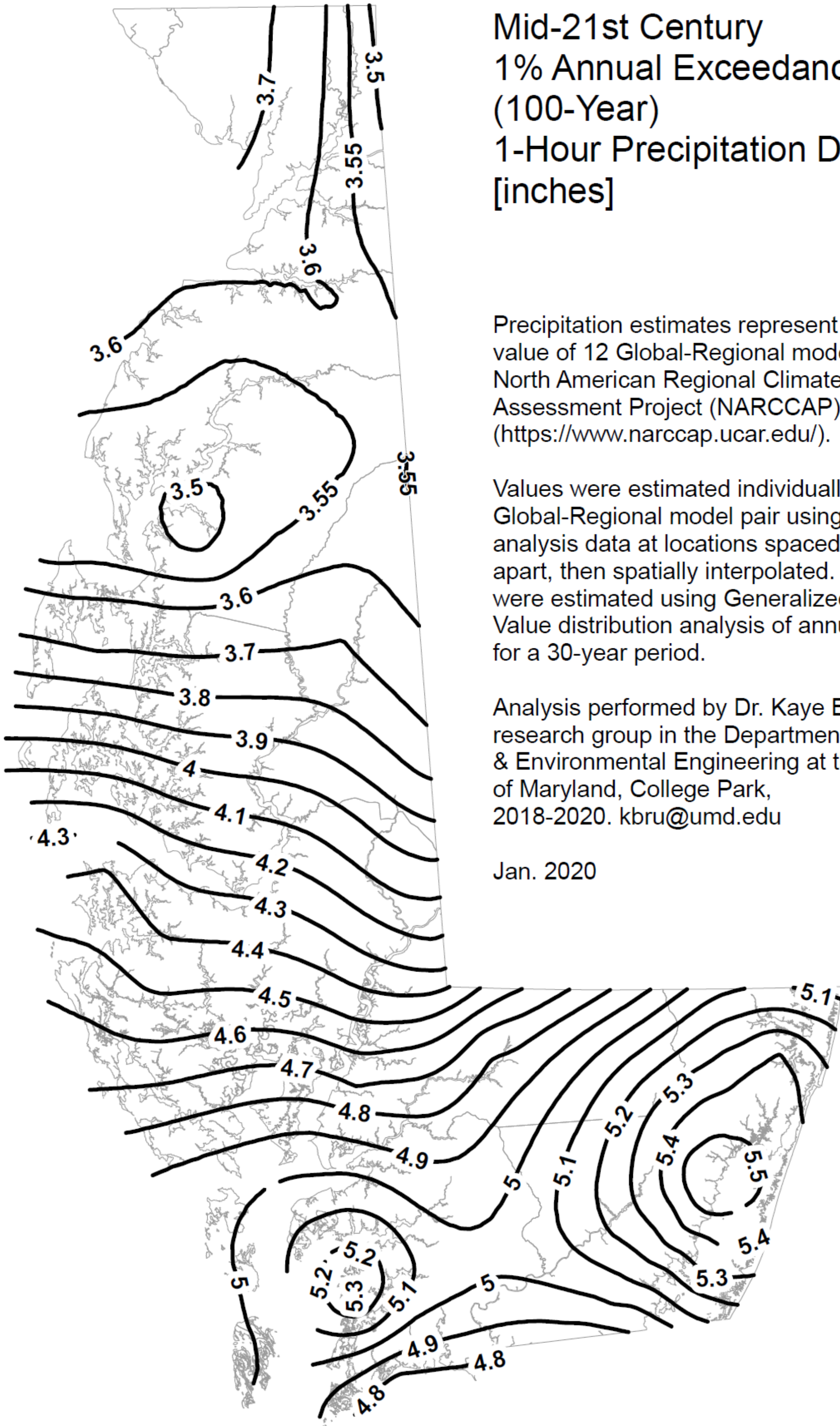
Precipitation estimates represent the average value of 12 Global-Regional model pairs in the North American Regional Climate Change Assessment Project (NARCCAP) (https://www.narccap.ucar.edu/).

Values were estimated individually for each Global-Regional model pair using 3-hour model analysis data at locations spaced 50 km apart, then spatially interpolated. Quantiles were estimated using Generalized Extreme Value distribution analysis of annual maxima for a 30-year period.

Analysis performed by Dr. Kaye Brubaker's research group in the Department of Civil & Environmental Engineering at the University of Maryland, College Park, 2018-2020. kbru@umd.edu

Jan. 2020

Mid-21st Century
1% Annual Exceedance Probability (100-Year) 1-Hour Precipitation Depth [inches]



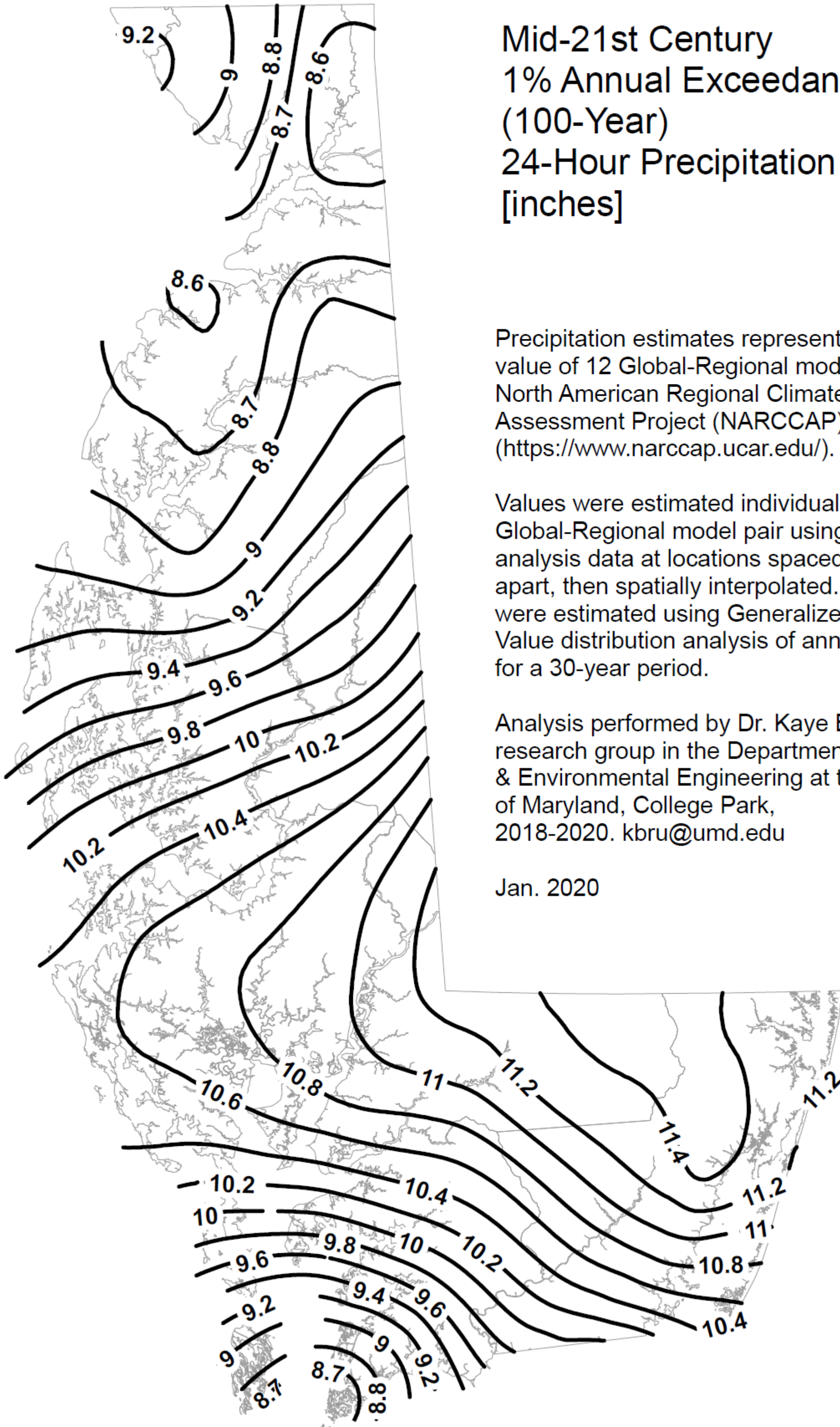
Precipitation estimates represent the average value of 12 Global-Regional model pairs in the North American Regional Climate Change Assessment Project (NARCCAP) (https://www.narccap.ucar.edu/).

Values were estimated individually for each Global-Regional model pair using 3-hour model analysis data at locations spaced 50 km apart, then spatially interpolated. Quantiles were estimated using Generalized Extreme Value distribution analysis of annual maxima for a 30-year period.

Analysis performed by Dr. Kaye Brubaker's research group in the Department of Civil & Environmental Engineering at the University of Maryland, College Park, 2018-2020. kbru@umd.edu

Jan. 2020

Mid-21st Century
1% Annual Exceedance Probability (100-Year) 24-Hour Precipitation Depth [inches]



Precipitation estimates represent the average value of 12 Global-Regional model pairs in the North American Regional Climate Change Assessment Project (NARCCAP) (https://www.narccap.ucar.edu/).

Values were estimated individually for each Global-Regional model pair using 3-hour model analysis data at locations spaced 50 km apart, then spatially interpolated. Quantiles were estimated using Generalized Extreme Value distribution analysis of annual maxima for a 30-year period.

Analysis performed by Dr. Kaye Brubaker's research group in the Department of Civil & Environmental Engineering at the University of Maryland, College Park, 2018-2020. kbru@umd.edu

Jan. 2020

Appendix III: Brief Summary of Future Precipitation Procedures and Results

Changing Precipitation Patterns on Maryland's Eastern Shore
Brief Summary of Future Precipitation Procedures and Results
K. Brubaker, Jan 2020

Procedures

This study uses model analysis data produced by the North American Regional Climate Change Assessment Program (NARCCAP, http://www.narccap.ucar.edu/). According to the NARCCAP web site,

> The NARCCAP modelers [ran] a set of regional climate models (RCMs) driven by a set of atmosphere-ocean general circulation models (AOGCMs) over a domain covering the conterminous United States and most of Canada. The AOGCMs [were] forced with the SRES A2 emissions scenario for the 21st century. Simulations with these models were also produced for the current (historical) period. The RCMs are nested within the AOGCMs for the current period 1971-2000 and for the future period 2041-2070.

The A2 scenario is described as being "on the higher end" of the future-climate scenarios used in the IPCC 2001 and 2007 reports; the NARCCAP selected a single future-climate CO_2 concentration pathway due to resource constraints; they explain that any planned adaptation to a more aggressive assumed future climate will also provide for response to more moderate climate change that may occur. The RCMs generate results on a 50-km grid.

Analysis steps:

1. Extract 30 years of 3-hour precipitation from each of 12 NARCCAP Regional/Global model (RGM) combinations at locations in and around the study area.
2. At each model location, generate a time series of annual maximum 3-, 6-, 9-, 12-, 15-, 18-, 21-, 24- and 48-hour precipitation for the time period 1971-2000. Most RGMs had 30 years of analysis, although several had 28 or 29 complete years.
3. At each model location, fit a Generalized Extreme Value distribution separately for each of the 9 durations. This distribution gives the probability of exceeding a certain precipitation depth in any year.
4. At each model location, smooth the collection of duration-specific GEV curves to generate a full intensity-duration-frequency curve (IDF) for each analysis location by fitting a 4-parameter nonlinear function of duration (D) from 3 to 48 hours and average return period (T) from 2 to 1000 years.
5. At each model location, extrapolate the IDF curve to 1-hour duration using the fitted function.
6. At each model location, repeat steps 1-5 for the model-generated future precipitation (2041-2070).
7. For each model location, calculate a set of change factors. The change factor is a dimensionless value defined as $[i(D,T)_{\text{future}} - i(D,T)_{\text{current}}]/i(D,T)_{\text{current}}$ where i is precipitation intensity, D is duration, and T is average return period.
8. For each RGM, for the selected durations (D) and average return periods (T), spatially interpolate the change factors from the 50-m grid of the RGM to the 750-m grid of the NOAA precipitation data.

9. For each RGM, for the selected durations (*D*) and average return periods (*T*), generate a map of future precipitation values by applying the change factors to the NOAA precipitation quantiles.

10. For each of the selected durations (*D*) and average return periods (*T*), calculate an ensemble expected future precipitation map by averaging the 12 maps.

The ensemble average values calculated in Step 10 are considered the final product of this analysis. They are presented in the form of contour maps of precipitation depth for selected durations (*D*) and average return periods (*T*), and as Depth-Duration-Frequency (DDF) and Intensity-Duration-Frequency (IDF) curves for selected locations on Maryland's Eastern Shore.

The variation among the individual future predictions generated in Step 9 are shown in a set of small maps for several example durations (*D*) and average return periods (*T*).

Comments on Results

The results show increases in precipitation depth (and intensity) over the entire study region for all durations and average return periods. Relative increases are greater for short, more intense precipitation events (e.g., 1-hour). The implications for the Eastern Shore are increased volume of rain-induced, inland (pluvial) flooding and faster rise of flood waters. Anticipated sea-level rise and coastal or storm-surge flooding will exacerbate the effect of pluvial flooding by suppressing the gradients that would allow flood waters to run off.

The results show increases in the 1-hour duration precipitation for all average return periods over the Eastern Shore. There is some geographic variation: The increases are greater moving South in the study region, particularly for the very infrequent events (for example, the 100- and 500-year 1-hour precipitation).

The results also show increases in the 24-hour duration precipitation. Relative increases in the 24-hour duration are less extreme than for the 1-hour duration. Geographically, the largest increases appear in a swath across the Eastern Shore at about 38.5°N latitude.

Communities who choose to incorporate these results into planning and design guidance should be aware that they are based on a global climate model scenario that assumes a high-end CO_2 concentration pathway. The model analyses used in this study are from four different global-scale atmosphere-ocean general circulation models, downscaled to the North American continent using six different regional climate models. The different global- and regional-scale models incorporate different approaches to the atmospheric and land-atmosphere interaction processes that are known to be critical to precipitation formation. These differences result in variations in the predicted future precipitation patterns generated by each global-regional model combination. The averaging process smooths out the most extreme model predictions (both large and small).