City of Virginia Beach - Comprehensive Sea Level Rise and Recurrent Flood Study

Analysis and Incorporation of Rainfall Non-stationarity into Community Flood Resilience

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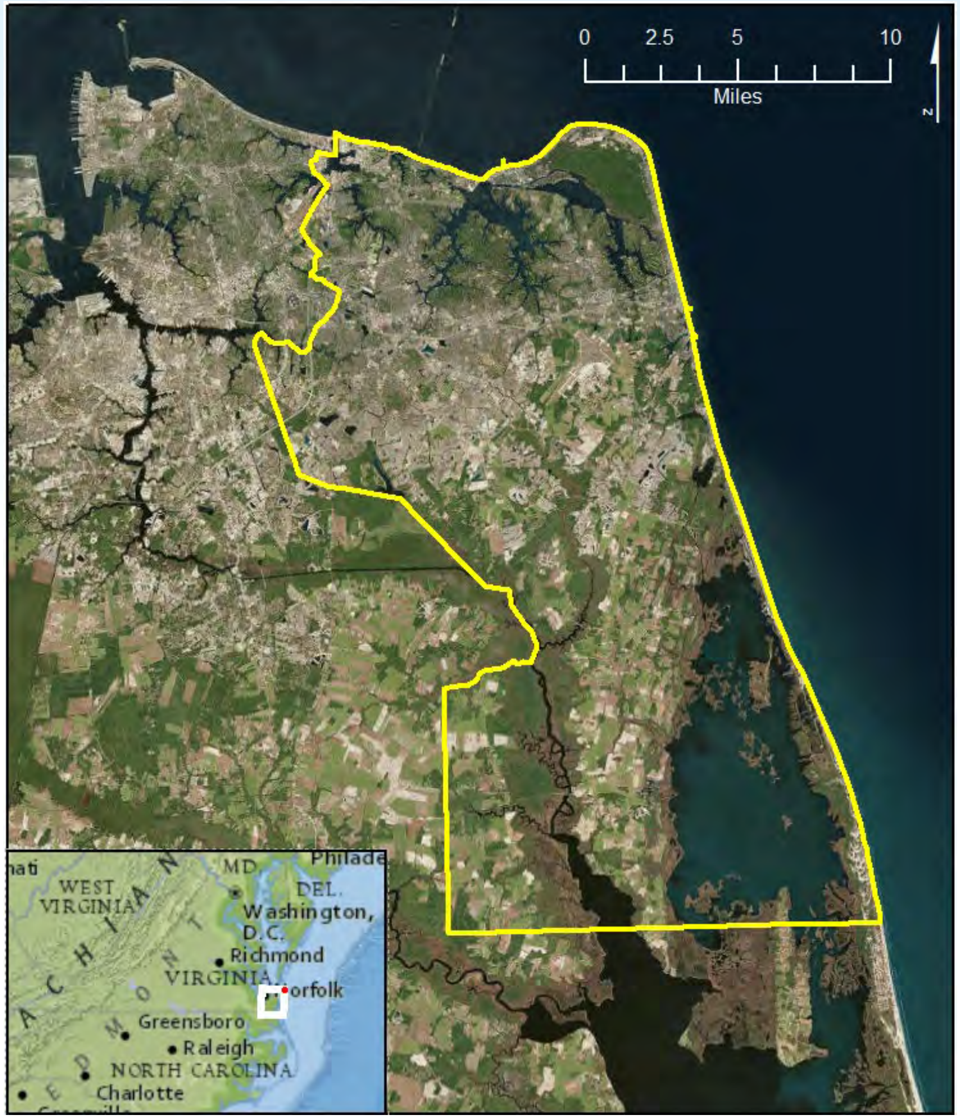
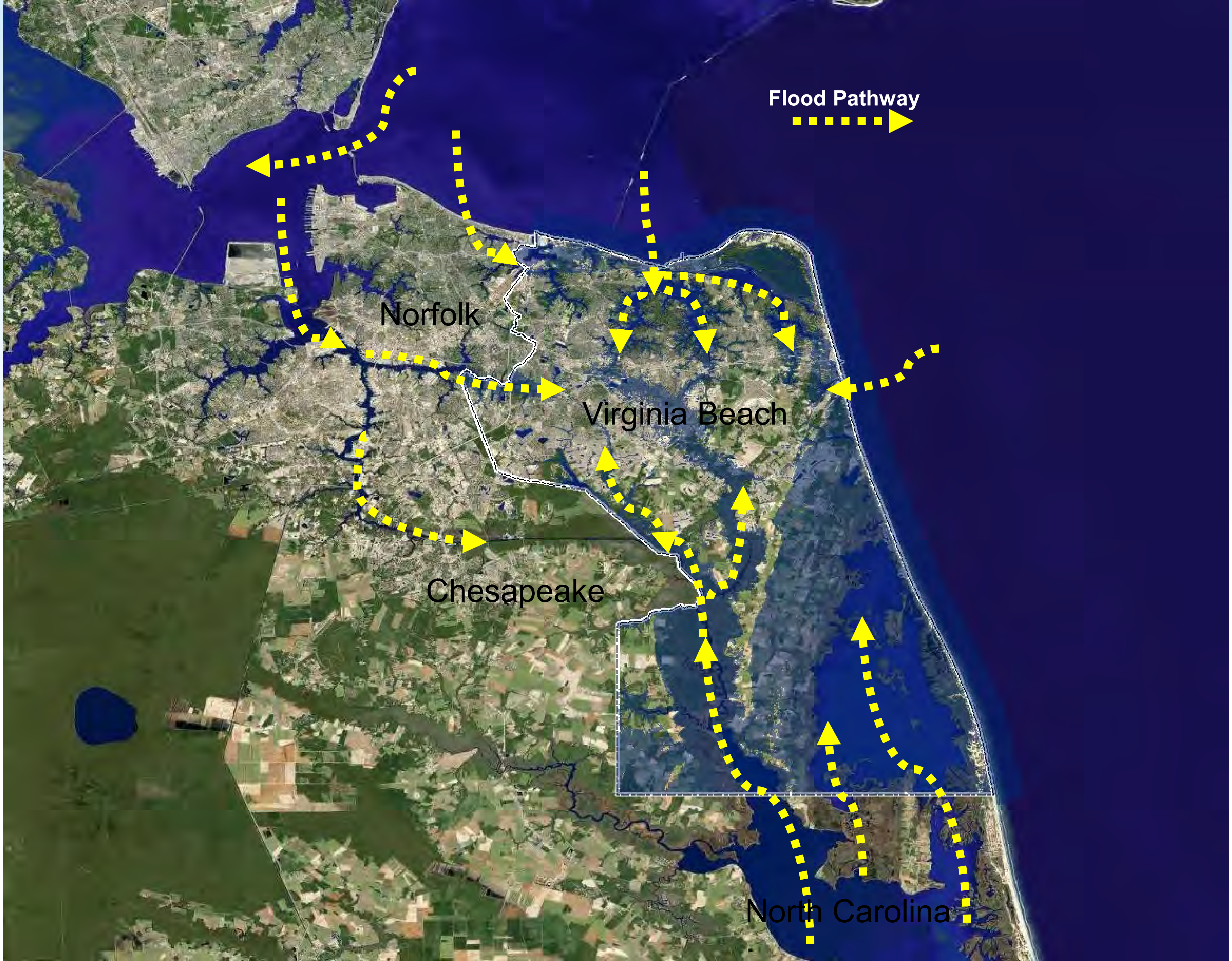
Agenda

- **Overview Virginia Beach's SLR Adaptation Efforts**
- **Holistic Future Conditions**
- **Precipitation Analysis**
  - Historical Analysis
  - Future Projection
- **Incorporation into Adaptation Strategies**

City of Virginia Beach

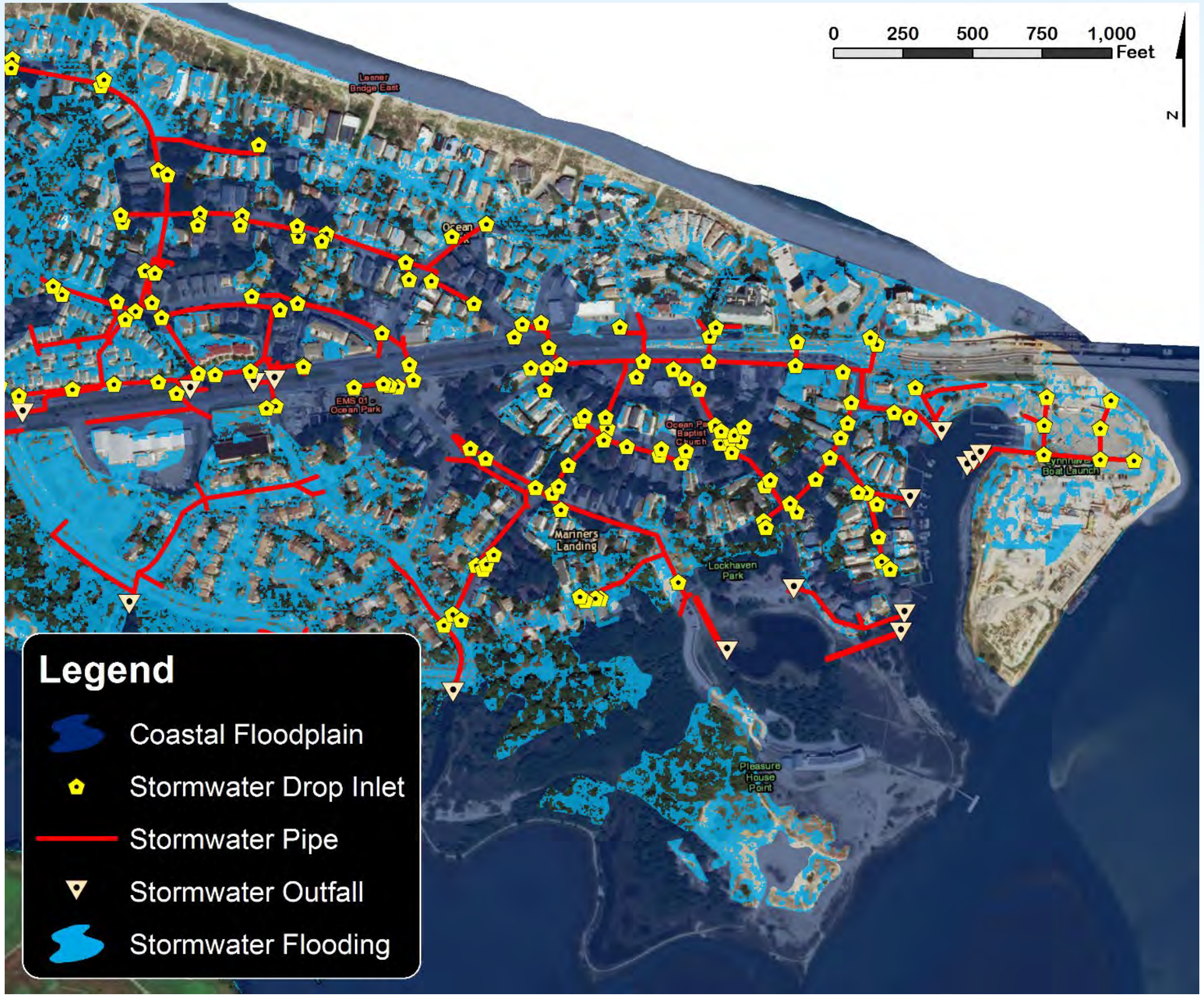


- **Fast Facts**
  - Largest City in Virginia
    - Population: 450k
  - Growth from 1970s-1990s
  - 4 military bases
  - Tourism and Defense Economy
  - Top-ranked US city


Flood Pathway
Norfolk
Virginia Beach
Chesapeake
North Carolina

Combined Impact on Stormwater Analysis

- Higher coastal water levels diminish stormwater system performance



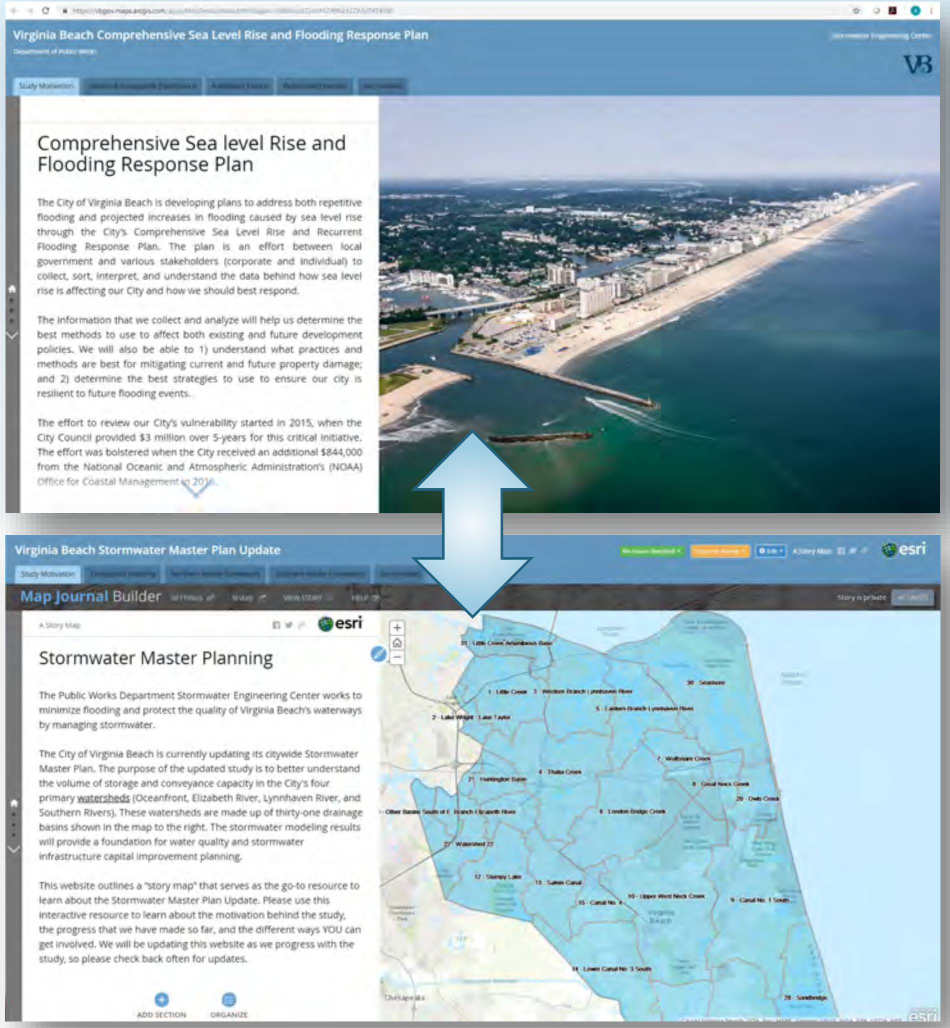
- Coastal Flooding
- Stormwater Conveyance

CDM Smith

- Combined Flooding

Ongoing Studies

Project Website:
http://www.vbgov.com/pwSLR



- **Comprehensive Sea Level Rise and Recurrent Flooding Study**
  - Assessing existing and future flood vulnerabilities and identifying strategies to ensure our city is resilient to future flooding events
- **Master Drainage Study**
  - Detailed inventory and performance assessment of the City's stormwater system
- **Stormwater Master Plan**
  - Identification and prioritization of needed improvements to stormwater system

Study Goal and Outcomes

Goal:

Produce information and strategies that will enable Virginia Beach to establish long-term resilience to sea level rise and associated recurrent flooding

Outcomes:

- A full understanding of flood risk and anticipated changes over planning and infrastructure time horizons
- Risk-informed strategies, including engineered protection and policy to reduce short and long-term impacts
- City-wide and watershed “action plans” for strategy implementation
- A fine-tuned public outreach process to advance resilience initiatives

Timeline of Activities

2015 2016 2017 2018 2019

Planning

- Scenarios
- Conceptual model

Study Progression

- Grant award
- Hazard and risk assessment
- Essential analysis to inform design
- Stormwater coordination
- Policy menu

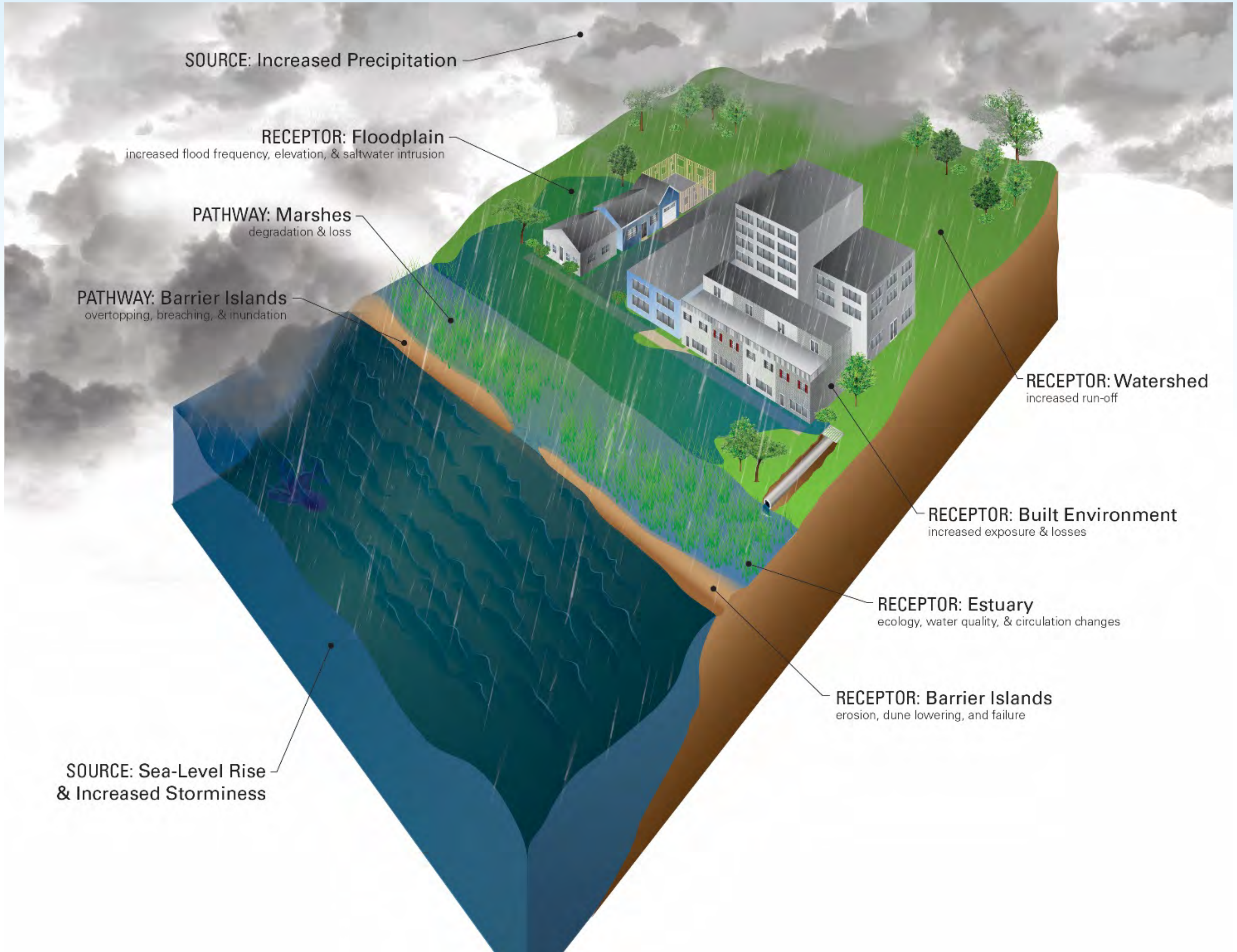
Strategy Focus

- Structural Alternatives
  - City-wide concepts
  - Performance
  - Down-selection
- Policy refinement and rankings

Synthesis

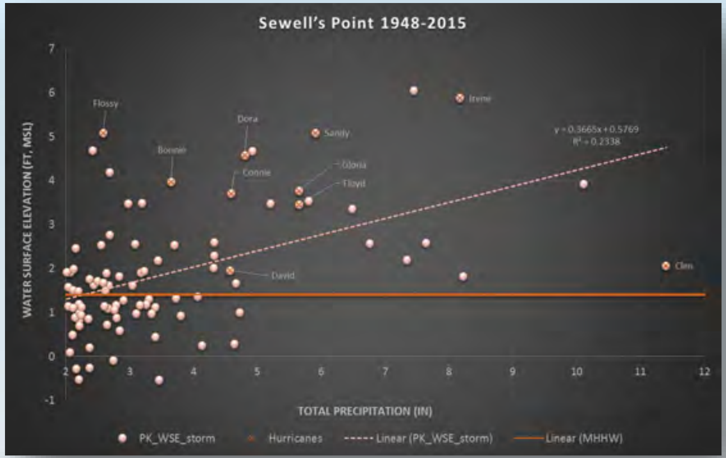
- Neighborhood and site alternatives
- Full Draft Adaptation Plan
- Stakeholder outreach and input

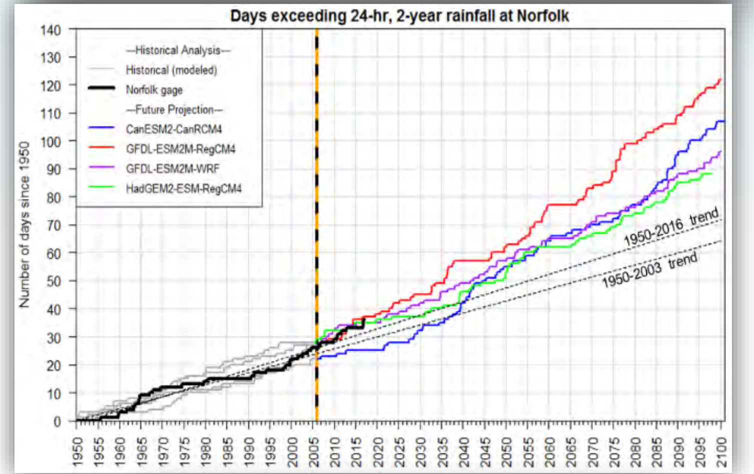
Holistically Planning for Future Conditions

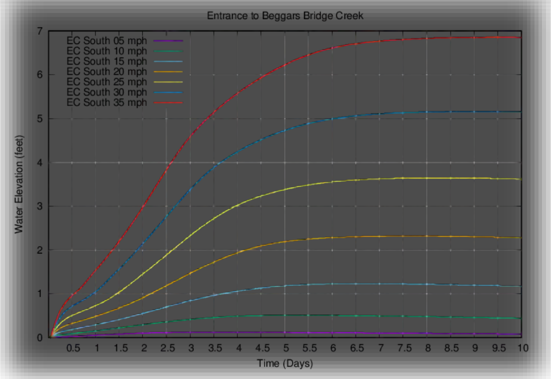


Informing Stormwater Design

- **Rainfall/surge correlation**
  - How often do they co-occur?
- **Joint-probability of rainfall/storm surge**
  - What are the statistical relationships for design?
- **Regional Precipitation Trends**
  - Do we have non-stationarity?
- **Wind Tides**
  - How to address “wind tide” events in the Southern Watershed design tailwater elevations?







Precipitation Analyses

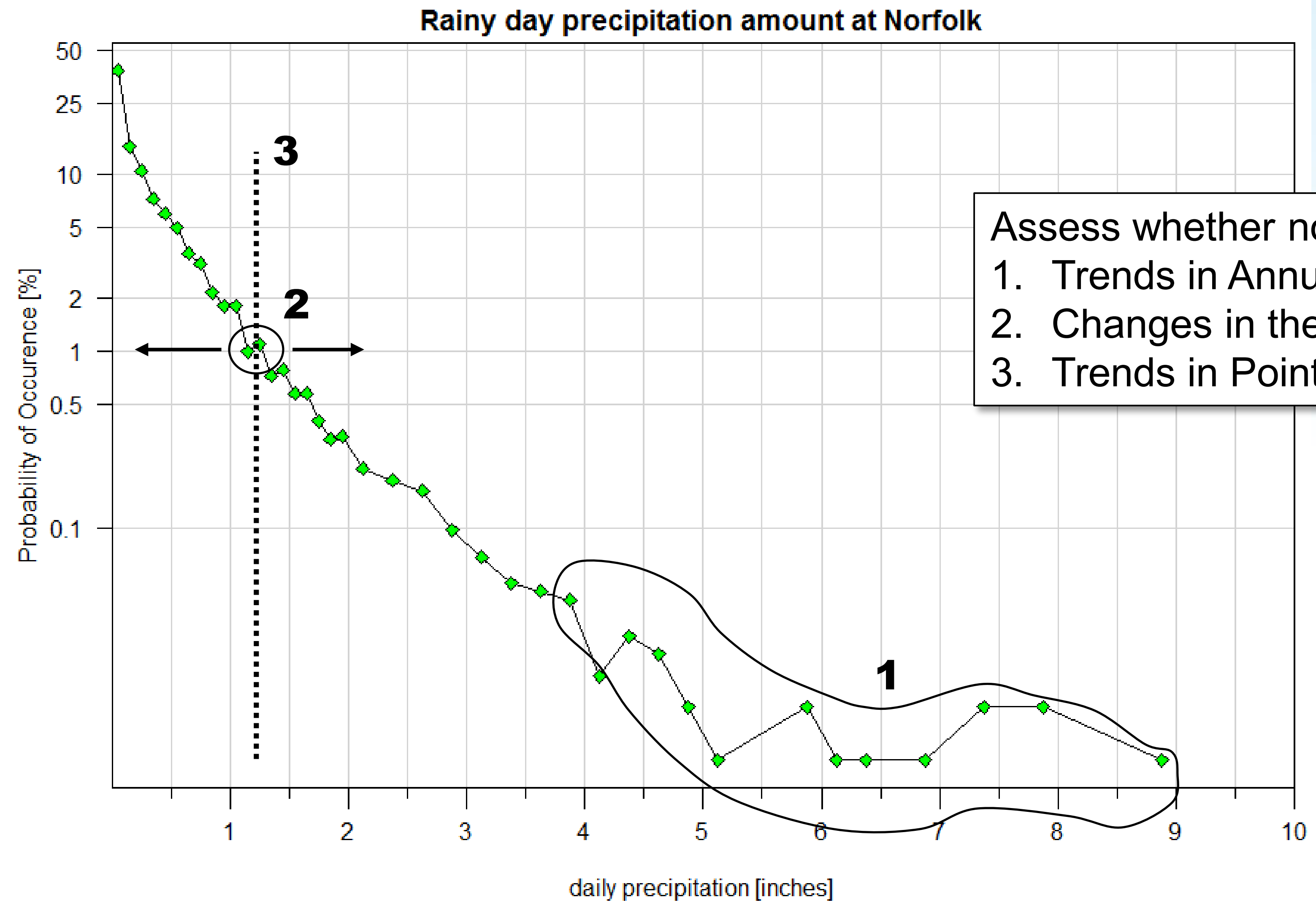
Virginia Beach – 2016 Heavy Rainfall – Opened Eyes

- **July 31 - heavy rainfall**
  - 7.19” of rain in 3 hours
  - 500-1000 year return period
- **September 19 – Julia**
  - 10.20” of rain in 24 hours
  - 100-200 year return period
- **October 8-9 – Matthew**
  - 12.47” of rain in 12 hours
  - >1000 year return period

- ➢ **Is the recent increase in heavy rainfall frequency short-term statistical noise or part of a long-term historical trend?**
- ➢ **What kind of future trend (if any) is being projected by long-range Global Climate Models?**
- ➢ **Does the City need to take steps now by increasing its design rainfall guidance?**

Historical non-stationarity assessment

Testing for non-stationarity

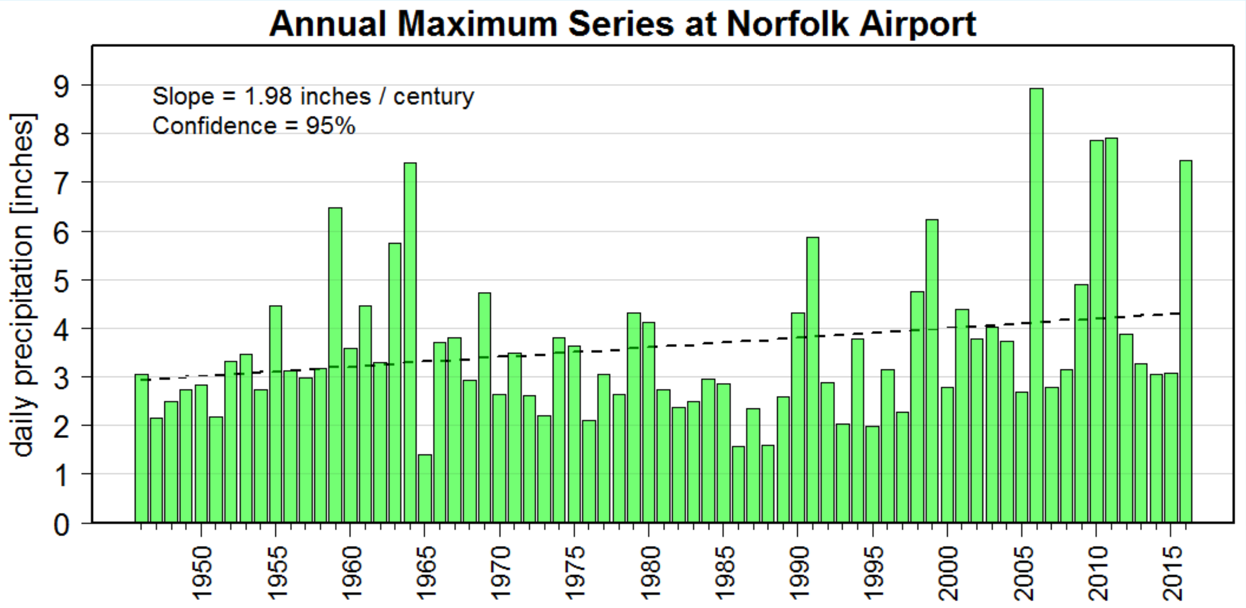


Assess whether non-stationarity exists using:

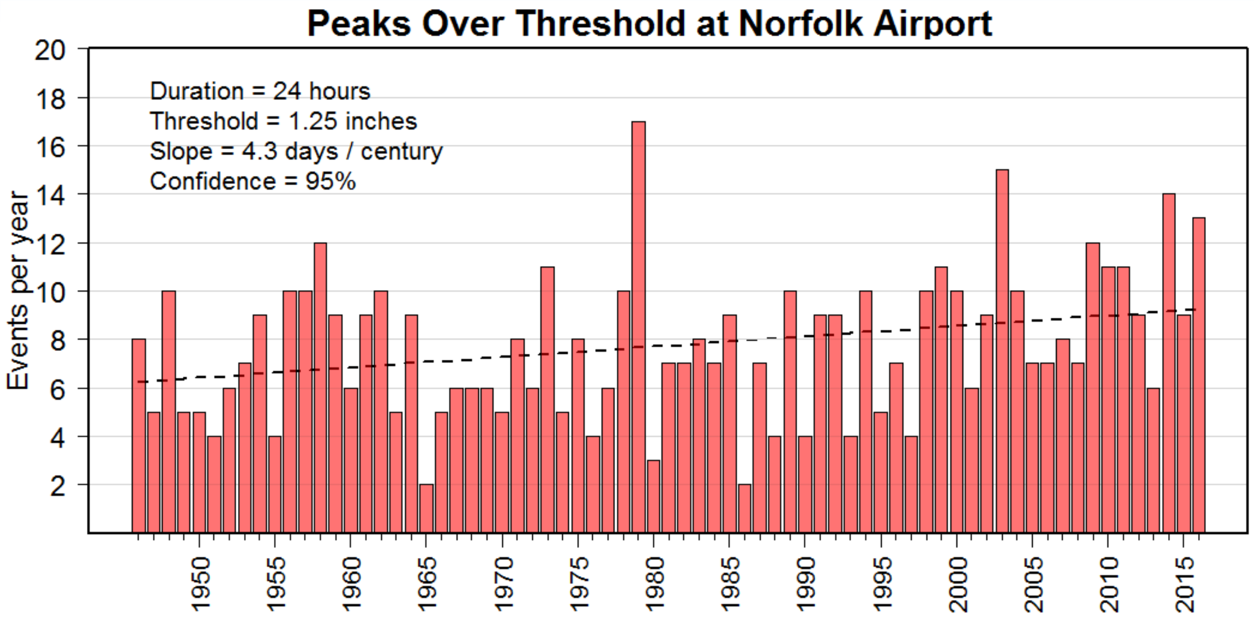
1. Trends in Annual Maximum Series
2. Changes in the 99th percentile value
3. Trends in Points Over Threshold

Gage-level analysis

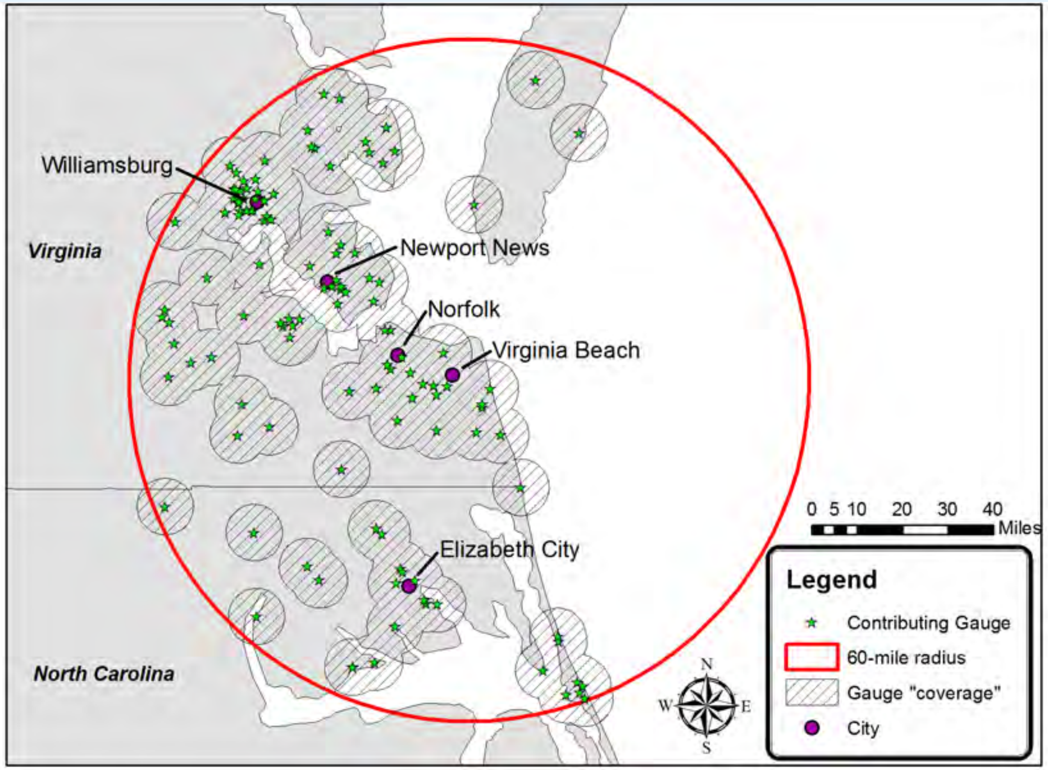
- **Observations**
  - Skew to rare, but high amounts
  - Low-frequency variations, 50-yr period

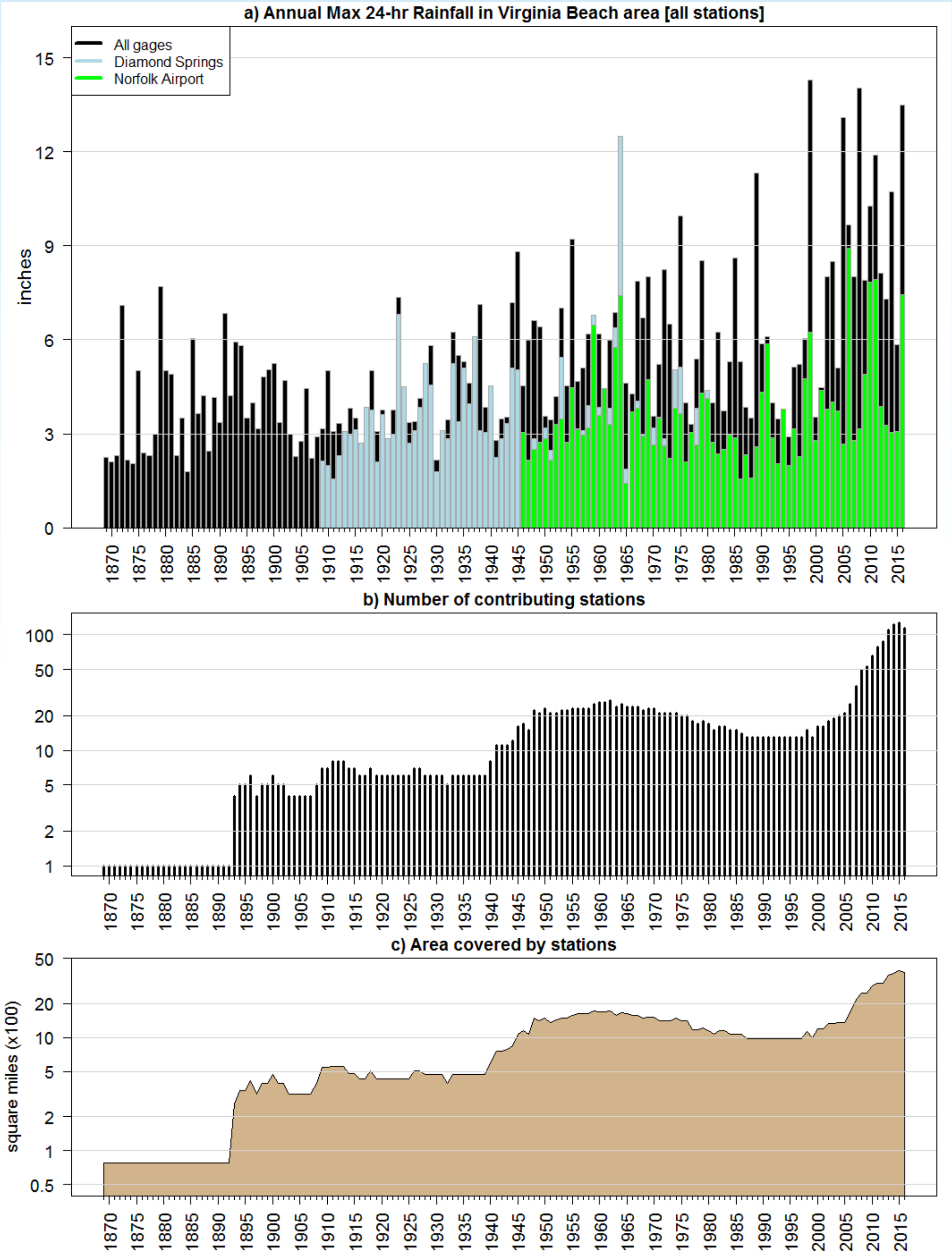


- **Peaks Over Threshold**
  - 1.25” per year threshold

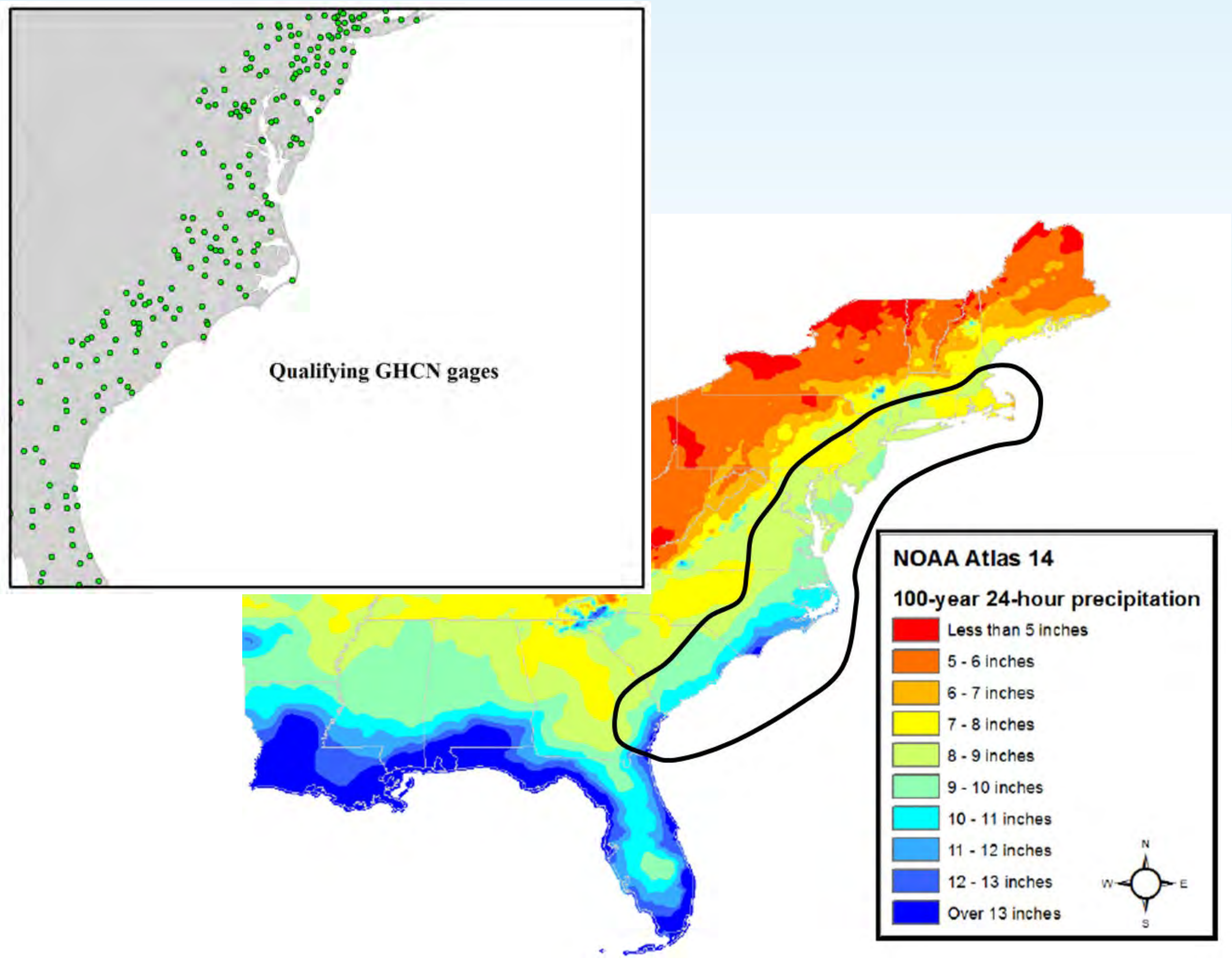


Local-level analysis





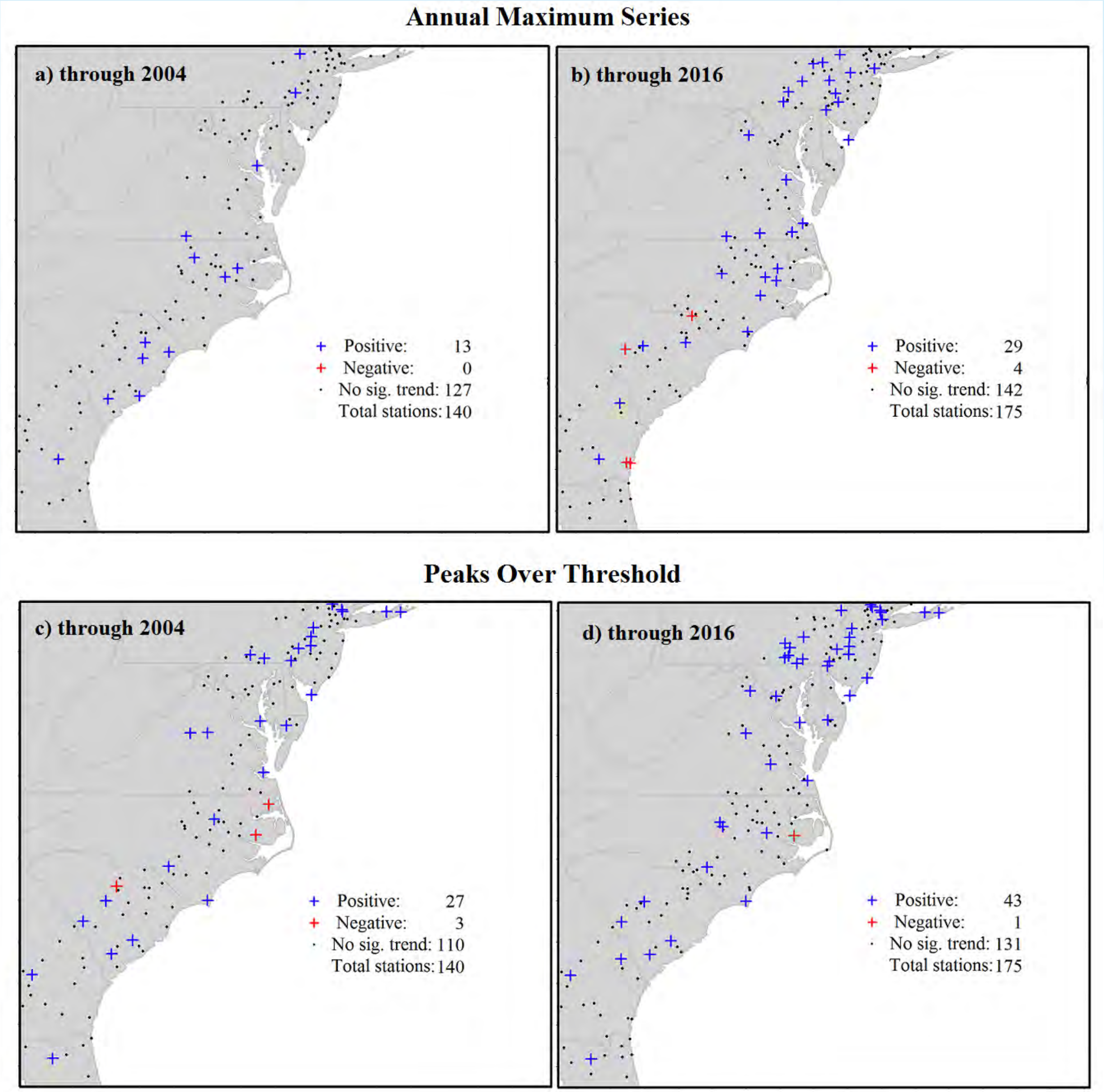
Regional-level analysis – “climate region”



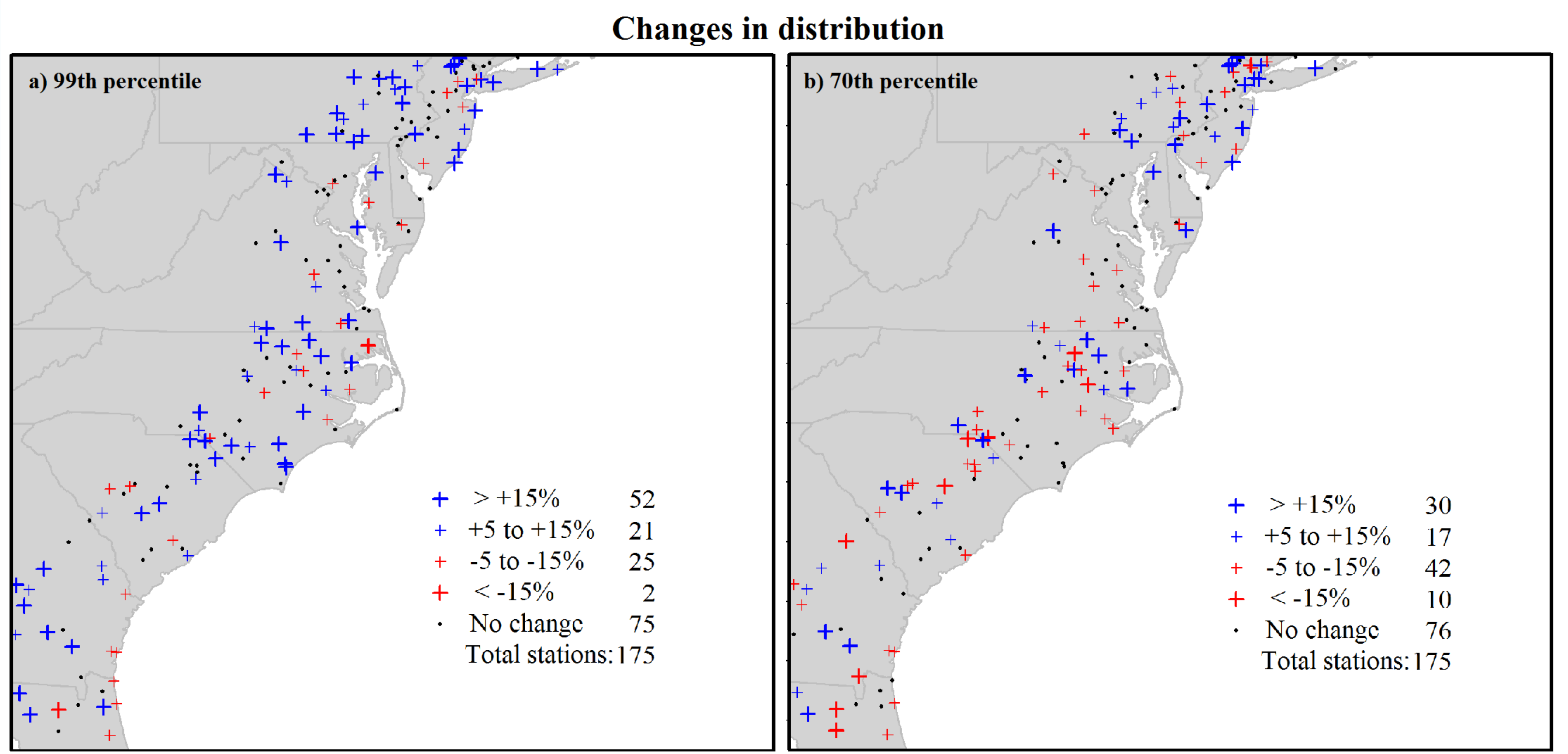
- **Criteria for gages:**
  - In region
  - Years with greater than 9 days missing excluded
  - Last qualifying year 2007 or later
  - At least 60 years of data

Regional Results

- **Testing against 95% confidence interval**
- **Expect ~9 stations show significant positive *and* negative trends**
- **High occurrence of positives**



Changes in distribution are not uniform

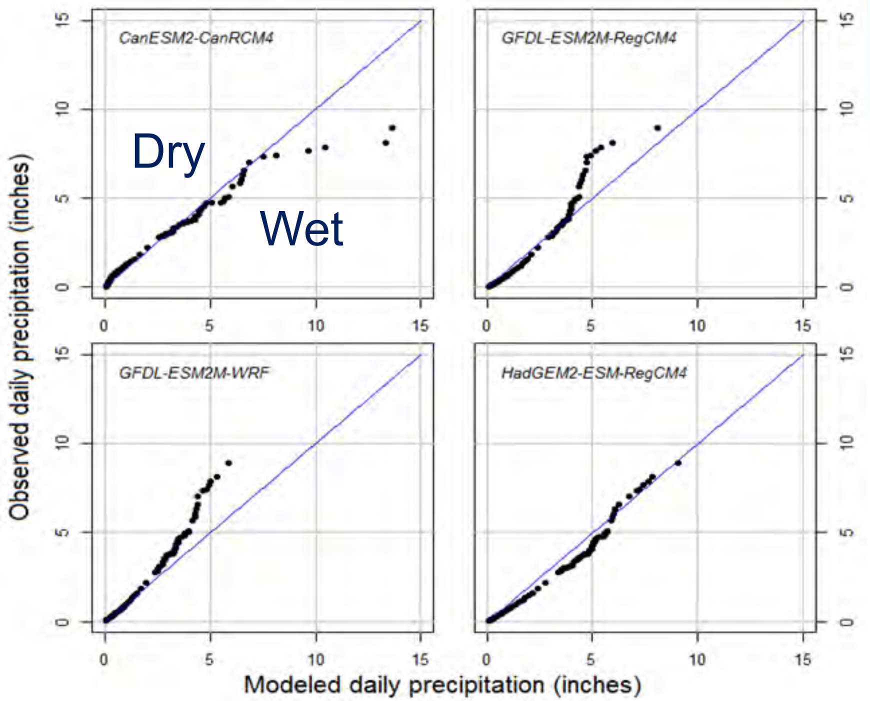


Future Rainfall Projections

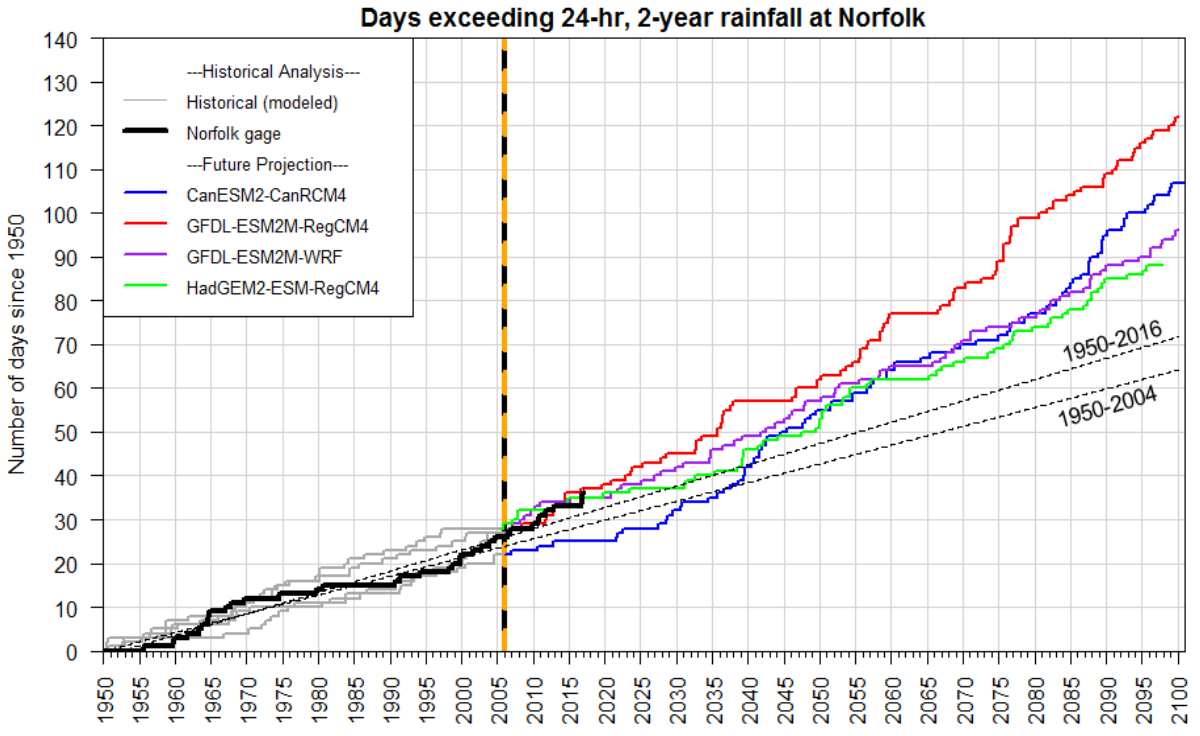
Future Rainfall Projections

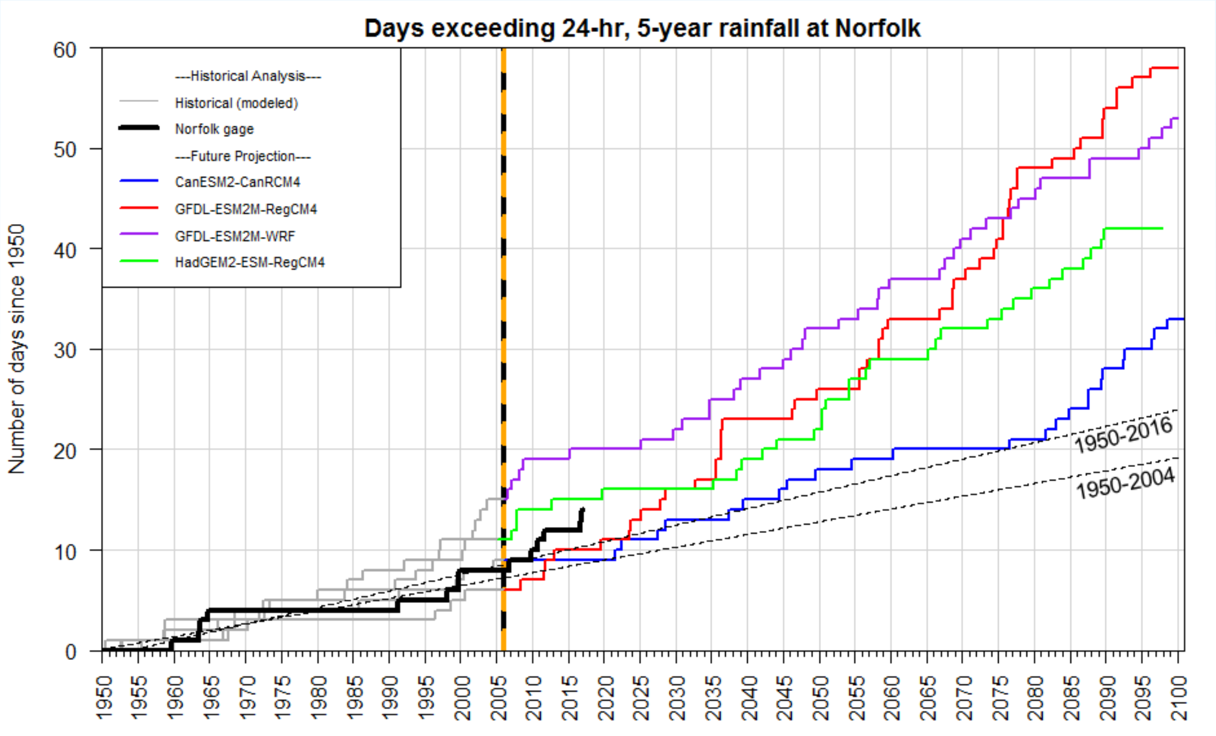
- NACORDEX - Medium and High emission scenarios RCP 4.5 and 8.5
- Analyzed multiple 4 simulations
- Bias correction
- Variable resolution (11 & 44 km)
- Peaks over Threshold
- Probability Frequency Curves

	Global Climate Model (Boundary)	Regional Climate Model
1	CanESM2	CanRCM4
2	GFDL-ESM2M	RegCM4
3	GFDL-ESM2M	WRF
4	HadGEM2-ESM	RegCM4



Future Peaks Over Threshold





- Observed slope = hit rate

Peaks Over Threshold – "decadal hit rates"

- All models point to increased hit rates in future

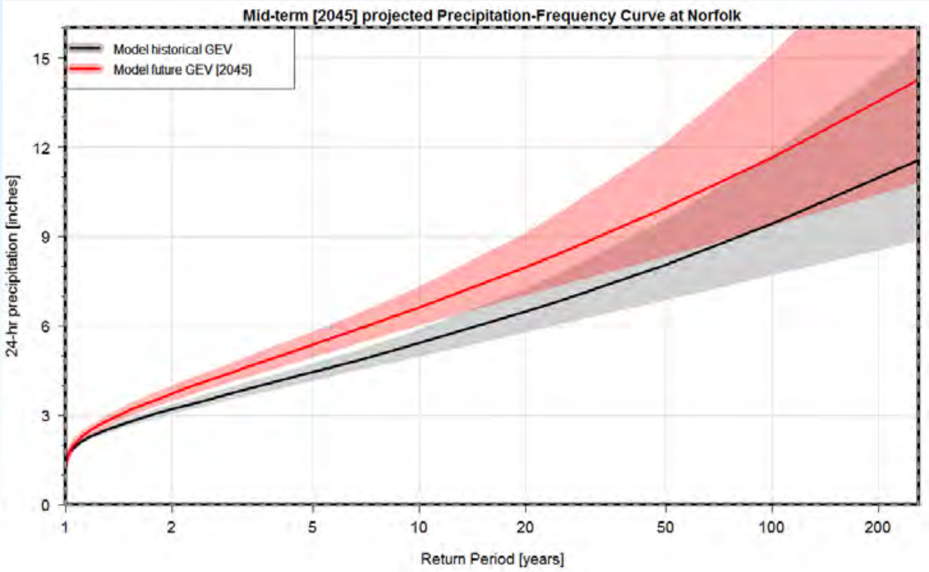
Data type	2-year rainfall hit rate			5-year rainfall hit rate		
	Historical	2045	2075	Historical	2045	2075
Norfolk gage	4.3	---	---	1.2	---	---
Can-ESM2-CanRCM4	3.4	10.8	9.7	1.4	2.8	2.5
GFDL-ESM2M-RegCM4	5.0	9.1	12.1	0.7	5.6	7.7
GFDL-ESM2M-WRF	4.5	7.5	7.5	2.3	4.6	4.6
HadGEM2-ESM-RegCM4	5.7	7.9	6.8	2.2	4.1	3.9
Model Average	4.6	8.8	9.0	1.6	4.3	4.7

Some uncertainty, can be attributed to variability in heavy rainfall statistics

Changes in Probability Frequency Curves

- **RCP 4.5**

Return Period, yr	Modeled Historical Value (in).	Mid-term [2045] Value, in.	Mid-term [2045] % change	Long-term [2075] Value, in.	Long-term [2075] % change
1	1.4	1.6	**+14%**	1.7	**+21%**
2	3.2	3.7	**+16%**	3.7	**+16%**
5	4.4	4.9	+11%	4.9	+11%
10	5.4	5.8	+7%	5.8	+7%
20	6.5	6.7	+3%	6.7	+3%
50	8.0	7.9	-1%	8.0	0%
100	9.4	8.9	-5%	9.2	-2%



- **RCP 8.5**

Return Period, yr	Modeled Historical Value, in.	Mid-term [2045] Value, in. (44 km)	Mid-term [2045] % change (44 km)	Mid-term [2045] Value, in. (11km)	Mid-term [2045] % change (11km)	Long-term [2075] Value, in. (44km)	Long-term [2075] % change (44km)	Long-term [2075] Value, in. (11km)	Long-term [2075] % change (11km)
1	1.4	1.6	**+14%**	1.3	-8%	1.2	-16%	1.7	+21%
2	3.2	3.7	**+16%**	3.7	**+17%**	4.2	**+31%**	3.9	**+22%**
5	4.4	5.2	+18%	5.4	**+21%**	6.0	**+36%**	5.6	**+25%**
10	5.4	6.3	+17%	6.6	**+22%**	7.3	**+35%**	7.0	**+28%**
20	6.5	7.5	+15%	8.0	+23%	8.6	**+32%**	8.5	**+32%**
50	8.0	9.3	+16%	10.0	+24%	10.4	+30%	11.0	+37%
100	9.4	10.8	+15%	11.7	+24%	11.8	+26%	13.3	+41%

Partial Duration Series – RCP 8.5 11-km

			Mid-term [2045]		Long-term [2075]	
Return Period (yr)	NOAA Atlas 14 (in)	Historical Modeled Value (in)	Value (in)	% change	Value (in)	% change
1	3.00	2.7	3.0	**+11%**	**3.2**	**+19%**
2	3.65	3.7	4.4	**+19%**	**4.6**	**+24%**
5	4.72	4.6	5.5	**+20%**	**5.9**	**+28%**
10	5.64	5.4	6.5	**+20%**	**7.1**	**+31%**
20	6.53	6.4	7.8	+22%	8.5	+33%
50	8.26	8.0	9.9	+24%	10.9	+36%
100	9.45	9.7	11.9	+23%	13.2	+36%

What does all this tell us?

- **Historically, precipitation Annual Maximum Series trended upward 3-7% per decade.**
- **Future projections support increases of 5% for the intermediate scenario or 24-27% in the high scenario by 2060.**
- **Current Atlas 14 guidance for the 10-year rainfall event may be 7-10% below the actual localized value based on analysis of two long-record rain gages in the area.**
- **Given these observations, an increase of the City's design guideline for rainfall intensity is justified.**

➢ Using an average of 5% would suggest a 20% increase given a 40-year horizon.

➢ A blend of the two to account for uncertainty in the actual outcome warrants a 15-16% increase.

➢ If such is the case, then even using the intermediate RCP 4.5 projections of 5% would already warrant a 12-15% increase in the Precipitation Frequency curve.

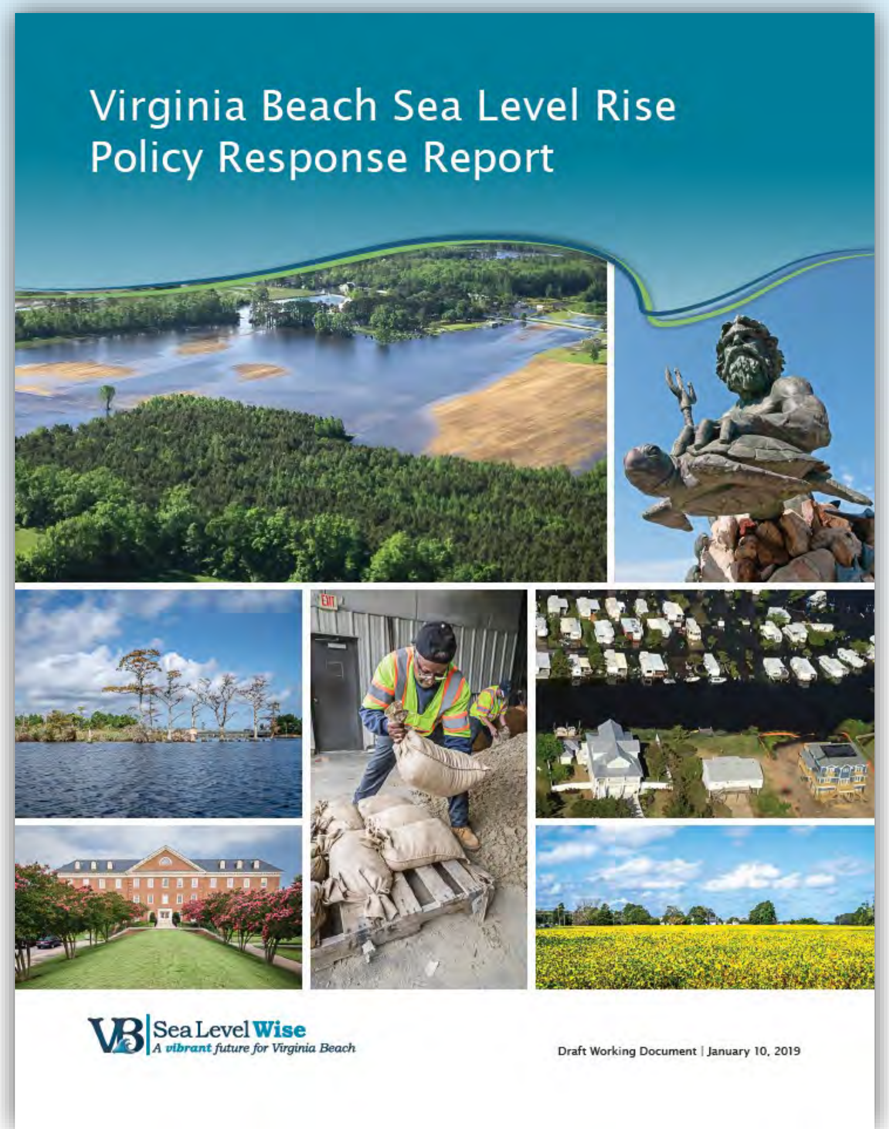
➢ We recommend an increase of 20% over existing guidance for projects that have a typical lifecycle of 40 years.

Incorporation into Adaptation Strategies

Policy Response Overview

What is it?

- Guidelines for instilling best practices to reduce long-term flood risk
- Starting place for evaluation and implementation by City
- Reflection of City wide staff perspective and priorities

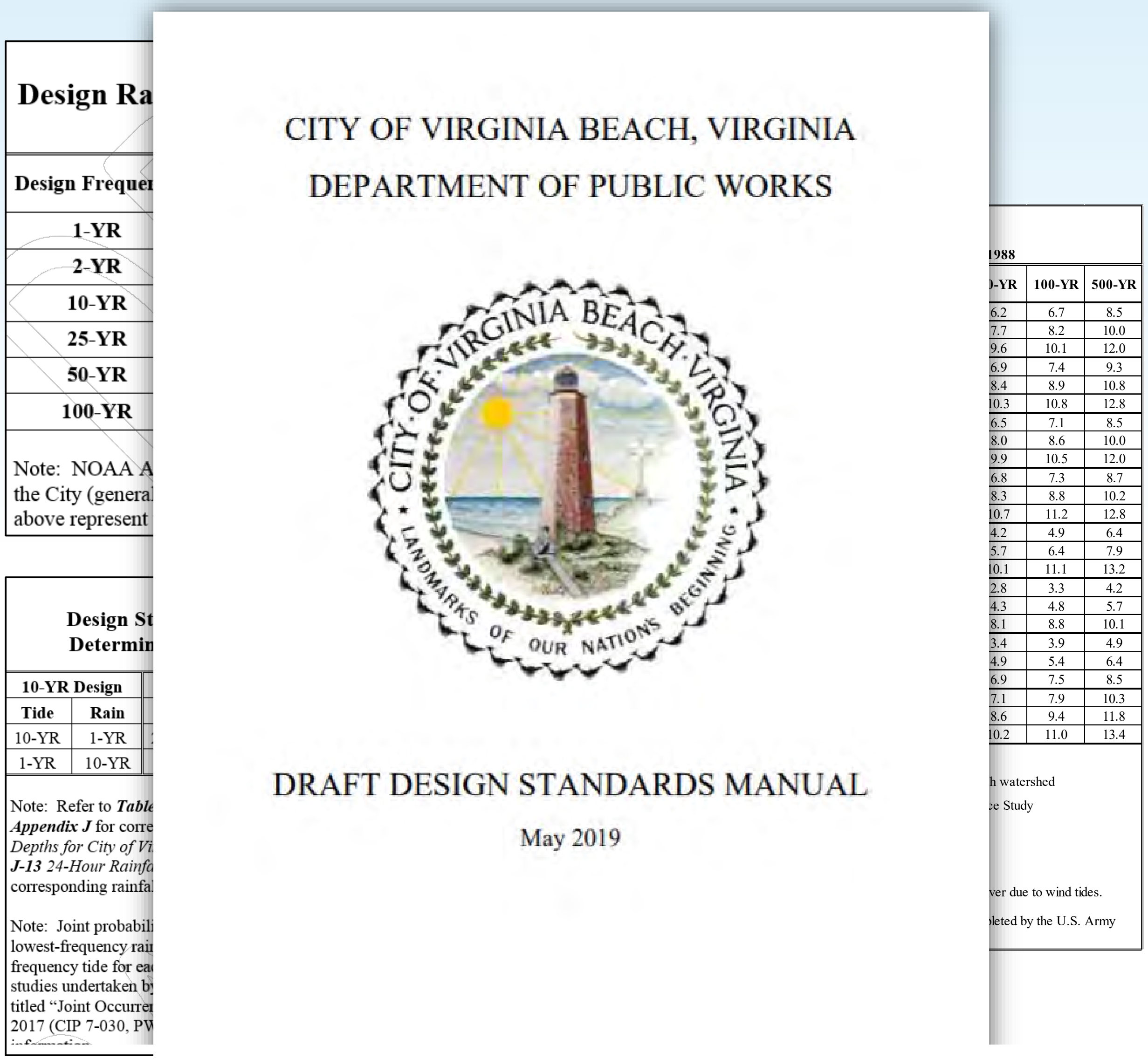


Incorporation into Design Standard

GOAL 2

Enhance the Flood Resilience of Critical Infrastructure and Transportation Systems and Invest in Capital Improvements to Reduce Community Flood Risk

	STORMWATER PLAN AND MANAGEMENT ACTION ITEMS	PRIORITY
1.	Formally adopt the most recent findings regarding sea level rise estimates and increased rainfall provisions into the stormwater design requirements and fully integrate these considerations into stormwater management and design practice.	HIGH



Public Works Design Standards Manual, 2019

- **Major Design Standard Changes to Address Recurrent Flooding and Sea Level Rise:**
  - Requirement to use EPA SWMM software modelling tool for designs with Drainage Area > 20 Ac.
  - Updated Revised Rainfall Depths Based on Future Precipitation Analysis (20% more)
  - Starting Boundary Conditions
  - Specific Requirements Relative to Hydraulic Grade Line
  - Requirement to use City Models Developed of all (31) Drainage Basins
  - Requirement to address Sea Level Rise
  - Requirement to address Groundwater Base Flow in Wet Ponds
- **Draft Manual Complete as of May 1st**
- **Public Comment Period: May 1st through July 31st**
- **Engineering/Development Community Public Meeting to be Held (TBD)**

Draft Document can be found at:
https://www.vbgov.com/government/departments/public-works/standards-specs/Pages/default.aspx

Acknowledgements for Precipitation Analysis

- Technical Team:
  - **City of Virginia Beach:** Greg Johnson, P.E., Shanda Davenport, P.E., CFM, AICP
  - **Dewberry:** Dima Smirnov, P.E., Ph.D.; Jason Giovannettone, Ph.D., P.E., Seth Lawler, Mathini Sreetharan, Ph.D., P.E., Joel Plummer, Brad Workman, Dana McGlone

Questions?

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Project Website:
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Report:
https://www.vbgov.com/government/departments/public-works/comp-sea-level-rise/Documents/anaylsis-hist-and-future-hvy-precip-4-2-18.pdf

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