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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Brian K. Batten, Ph.D., CFM | Dewberry
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
Combined Impact on Stormwater Analysis

- Higher coastal water levels diminish stormwater system performance

- Coastal Flooding

- Stormwater Conveyance

- Combined Flooding
Ongoing Studies

• 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

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

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

(a) 99th percentile
- > +15%: 52
- +5 to +15%: 21
- -5 to -15%: 25
- < -15%: 2
- No change: 75
Total stations: 175

(b) 70th percentile
- > +15%: 30
- +5 to +15%: 17
- -5 to -15%: 42
- < -15%: 10
- No change: 76
Total stations: 175
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

<table>
<thead>
<tr>
<th>Global Climate Model (Boundary)</th>
<th>Regional Climate Model</th>
</tr>
</thead>
<tbody>
<tr>
<td>1 CanESM2</td>
<td>CanRCM4</td>
</tr>
<tr>
<td>2 GFDL-ESM2M</td>
<td>RegCM4</td>
</tr>
<tr>
<td>3 GFDL-ESM2M</td>
<td>WRF</td>
</tr>
<tr>
<td>4 HadGEM2-ESM</td>
<td>RegCM4</td>
</tr>
</tbody>
</table>
Future Peaks Over Threshold

- Observed slope = hit rate
Peaks Over Threshold – “decadal hit rates”

• All models point to increased hit rates in future

<table>
<thead>
<tr>
<th>Data type</th>
<th>2-year rainfall hit rate</th>
<th>5-year rainfall hit rate</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Historical</td>
<td>2045</td>
</tr>
<tr>
<td>Norfolk gage</td>
<td></td>
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<tr>
<td>Can-ESM2-CanRCM4</td>
<td>3.4</td>
<td>10.8</td>
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<tr>
<td>GFDL-ESM2M-RegCM4</td>
<td>5.0</td>
<td>9.1</td>
</tr>
<tr>
<td>GFDL-ESM2M-WRF</td>
<td>4.5</td>
<td>7.5</td>
</tr>
<tr>
<td>HadGEM2-ESM-RegCM4</td>
<td>5.7</td>
<td>7.9</td>
</tr>
<tr>
<td>Model Average</td>
<td>4.6</td>
<td>8.8</td>
</tr>
</tbody>
</table>

Some uncertainty, can be attributed to variability in heavy rainfall statistics.
## Changes in Probability Frequency Curves

### RCP 4.5

<table>
<thead>
<tr>
<th>Return Period, yr</th>
<th>Modeled Historical Value, in.</th>
<th>Mid-term [2045]</th>
<th>Long-term [2075]</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Value, in.</td>
<td>% change</td>
<td>Value, in.</td>
</tr>
<tr>
<td>1</td>
<td>1.6</td>
<td>+14%</td>
<td>1.7</td>
</tr>
<tr>
<td>2</td>
<td>3.7</td>
<td>+16%</td>
<td>3.7</td>
</tr>
<tr>
<td>5</td>
<td>4.9</td>
<td>+11%</td>
<td>4.9</td>
</tr>
<tr>
<td>10</td>
<td>5.8</td>
<td>+7%</td>
<td>5.8</td>
</tr>
<tr>
<td>20</td>
<td>6.7</td>
<td>+3%</td>
<td>6.7</td>
</tr>
<tr>
<td>50</td>
<td>7.9</td>
<td>-1%</td>
<td>8.0</td>
</tr>
<tr>
<td>100</td>
<td>8.9</td>
<td>-5%</td>
<td>9.2</td>
</tr>
</tbody>
</table>

### RCP 8.5

<table>
<thead>
<tr>
<th>Return Period, yr</th>
<th>Modeled Historical Value, in.</th>
<th>Mid-term [2045]</th>
<th>Long-term [2075]</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Value, in.</td>
<td>% change</td>
<td>Value, in.</td>
</tr>
<tr>
<td>1</td>
<td>1.6</td>
<td>+14%</td>
<td>1.3</td>
</tr>
<tr>
<td>2</td>
<td>3.7</td>
<td>+16%</td>
<td>3.7</td>
</tr>
<tr>
<td>5</td>
<td>5.2</td>
<td>+18%</td>
<td>5.4</td>
</tr>
<tr>
<td>10</td>
<td>6.3</td>
<td>+17%</td>
<td>6.6</td>
</tr>
<tr>
<td>20</td>
<td>7.5</td>
<td>+15%</td>
<td>8.0</td>
</tr>
<tr>
<td>50</td>
<td>9.3</td>
<td>+16%</td>
<td>10.0</td>
</tr>
<tr>
<td>100</td>
<td>10.8</td>
<td>+15%</td>
<td>11.7</td>
</tr>
</tbody>
</table>

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*Note: The table above shows the projected changes in precipitation frequency for different return periods under RCP 4.5 and RCP 8.5 scenarios.*
### Partial Duration Series – RCP 8.5 11-km

<table>
<thead>
<tr>
<th></th>
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</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Value (in)</td>
<td>% change</td>
<td>Value (in)</td>
<td>% change</td>
</tr>
<tr>
<td>1</td>
<td>3.00</td>
<td>+11%</td>
<td>3.2</td>
<td>+19%</td>
</tr>
<tr>
<td>2</td>
<td>3.65</td>
<td>+19%</td>
<td>4.6</td>
<td>+24%</td>
</tr>
<tr>
<td>5</td>
<td>4.72</td>
<td>+20%</td>
<td>5.9</td>
<td>+28%</td>
</tr>
<tr>
<td>10</td>
<td>5.64</td>
<td>+20%</td>
<td>7.1</td>
<td>+31%</td>
</tr>
<tr>
<td>20</td>
<td>6.53</td>
<td>+22%</td>
<td>8.5</td>
<td>+33%</td>
</tr>
<tr>
<td>50</td>
<td>8.26</td>
<td>+24%</td>
<td>10.9</td>
<td>+36%</td>
</tr>
<tr>
<td>100</td>
<td>9.45</td>
<td>+23%</td>
<td>13.2</td>
<td>+36%</td>
</tr>
</tbody>
</table>
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

<table>
<thead>
<tr>
<th>STORMWATER PLAN AND MANAGEMENT ACTION ITEMS</th>
<th>PRIORITY</th>
</tr>
</thead>
<tbody>
<tr>
<td>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.</td>
<td>HIGH</td>
</tr>
</tbody>
</table>

TABLE J-12
Design Tidal Elevations for Virginia Beach
All Elevations in feet relative to the North American Vertical Datum (NAVD) of 1988

<table>
<thead>
<tr>
<th>Location</th>
<th>Design Level</th>
<th>1-YR</th>
<th>2-YR</th>
<th>3-YR</th>
<th>5-YR</th>
<th>10-YR</th>
<th>25-YR</th>
<th>50-YR</th>
<th>100-YR</th>
<th>500-YR</th>
</tr>
</thead>
<tbody>
<tr>
<td>Lynnhaven Bay &amp; Eastern Branch</td>
<td></td>
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<td></td>
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<tr>
<td>Lynnhaven Bay &amp; Incl. all areas other than Eastern Branch</td>
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<td></td>
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<td></td>
<td></td>
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<tr>
<td>Chesapeake Bay</td>
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<tr>
<td>Atlantic Ocean &amp; Rudee Inlet</td>
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<td></td>
</tr>
<tr>
<td>Back Bay, North of Beggars Bridge Creek</td>
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<td></td>
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<tr>
<td>Back Bay, South of Beggars Bridge Creek</td>
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<td></td>
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<tr>
<td>North Landing River</td>
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<tr>
<td>Elizabeth River</td>
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<td></td>
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</tbody>
</table>

Notes:
2. Lynnhaven, Elizabeth River, and Atlantic Ocean elevations were sourced from the 2015 FEMA Flood Insurance Study
3. Back Bay and North Landing River elevations were sourced from CIP 7-030, PWCN-15-0014, WO2A
4. The values do not represent potential wind-driven water levels in the Back Bay and North Landing River
5. The 5-year return period should be used as a minimum elevation for design in Back Bay and North Landing River due to wind tides.
6. Conditions related to a 3-ft rise in sea level include non-linear increases derived from numerical modeling completed by the U.S. Army Corps of Engineers and the North Carolina Floodplain Mapping Program

Energy and Power Systems

DRAFT DESIGN STANDARDS MANUAL
May 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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Report:

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