Developing Future Projected Intensity Duration Frequency (IDF) Curves for the Chesapeake Bay Watershed

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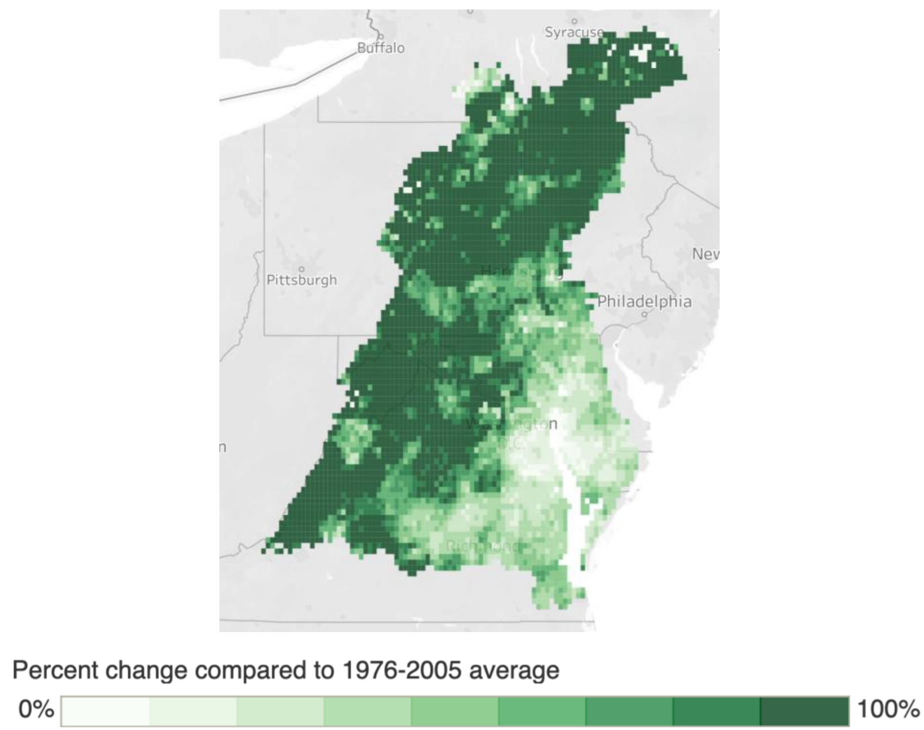
a NOAA Mid-Atlantic RISA team

The Chesapeake Bay has experienced increases in extreme precipitation over the past decade; increases are projected to grow by 2100.

Project Motivation:

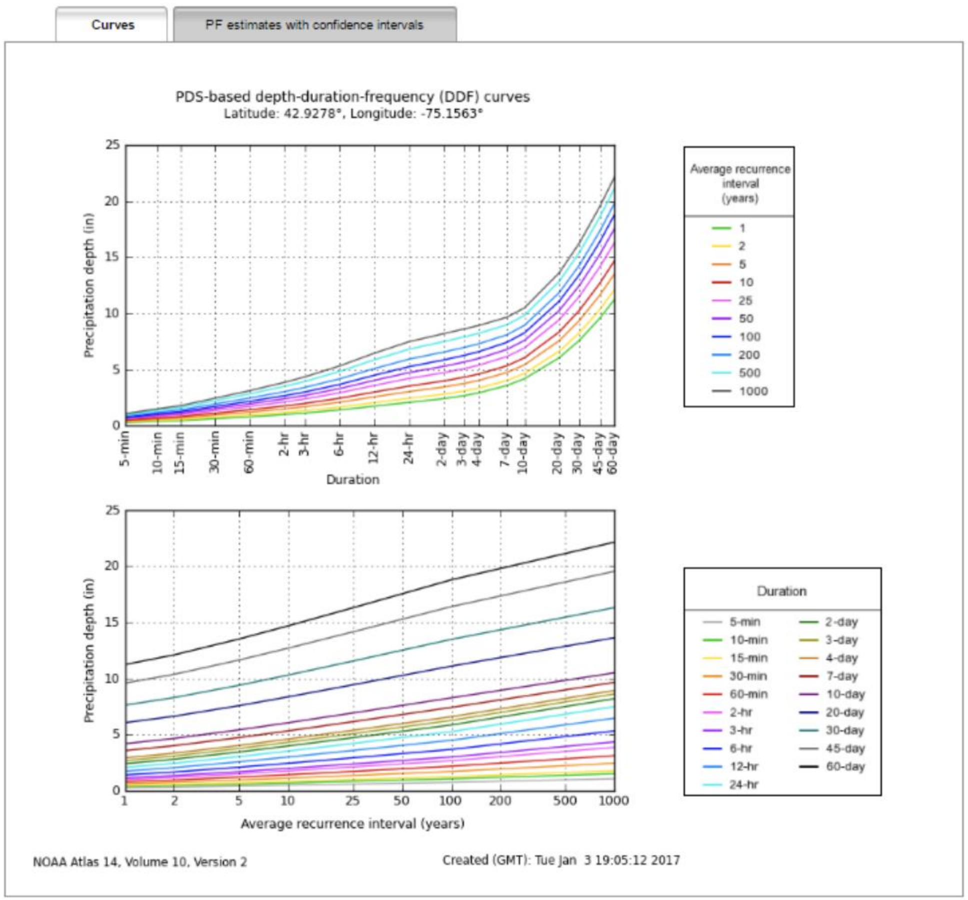
To design and build infrastructure assets to withstand anticipated future precipitation conditions, design standards should reflect future precipitation projections and not solely be based on historical precipitation records.

Projected Change in Average Annual Number of Days with Precipitation above 3” (2036-2065, High Emissions Future)



Source: https://www.midatlanticrisa.org/data-tools/climate-data-tools/extreme-precipitation-projected.html

Intensity-Duration-Frequency (IDF) curves are based on statistical analysis of historical rainfall

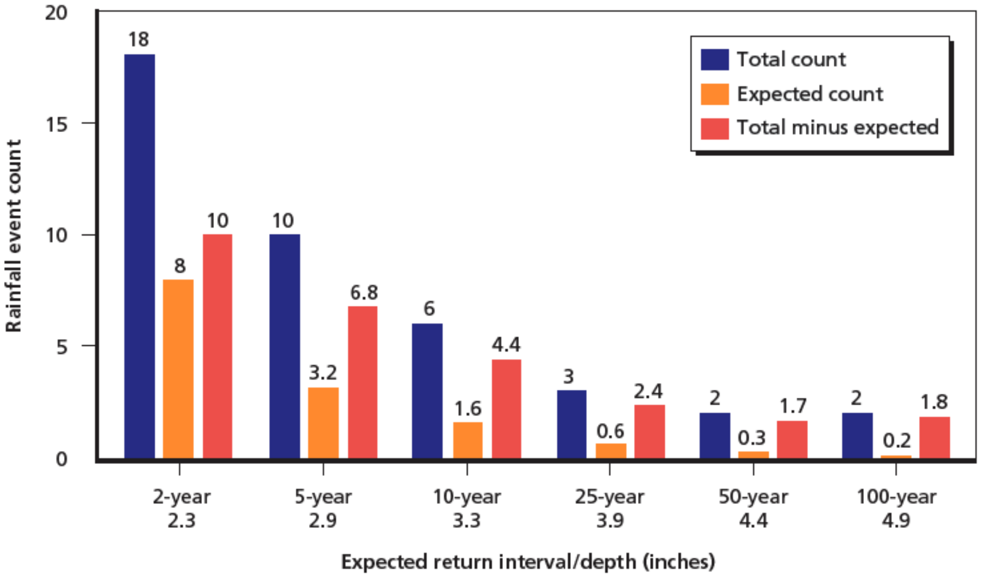


Source: https://www.weather.gov/media/owp/hdsc_documents/NA14_Sec5_PFDS.pdf

- For many locations, NOAA's Atlas 14 is the primary source of IDF curve values used for planning and design.
- For the majority of the Chesapeake Bay Watershed, Atlas 14 does not incorporate data after 2000.
- Atlas 14 also relies on assumptions of stationarity.

Even under recent climate, research shows that IDF curve values may be underestimates for some locations

This figure compares the observed 24-hour rainfall events in a part of Pittsburgh, PA from 2003-2018 to Atlas 14 estimates.



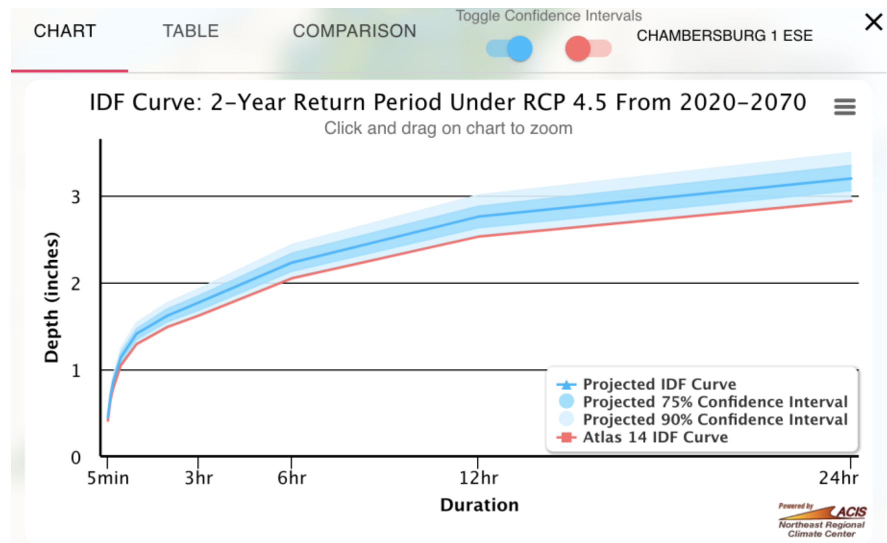
Credit: Fischbach et al. (2020): https://www.rand.org/pubs/research_reports/RRA564-1.html

Though not conclusive (one location, limited 16-year time series), this figure shows a larger number of extreme rainfall events compared to the Atlas 14 expected count.

This study developed future projected IDF curves for the entire Chesapeake Bay Watershed and Virginia

This project produced:

1. Station-based projected IDF curves (complete);
2. An interactive online tool (beta version);
3. A technical report (draft under review);
4. A recorded webinar (in development).



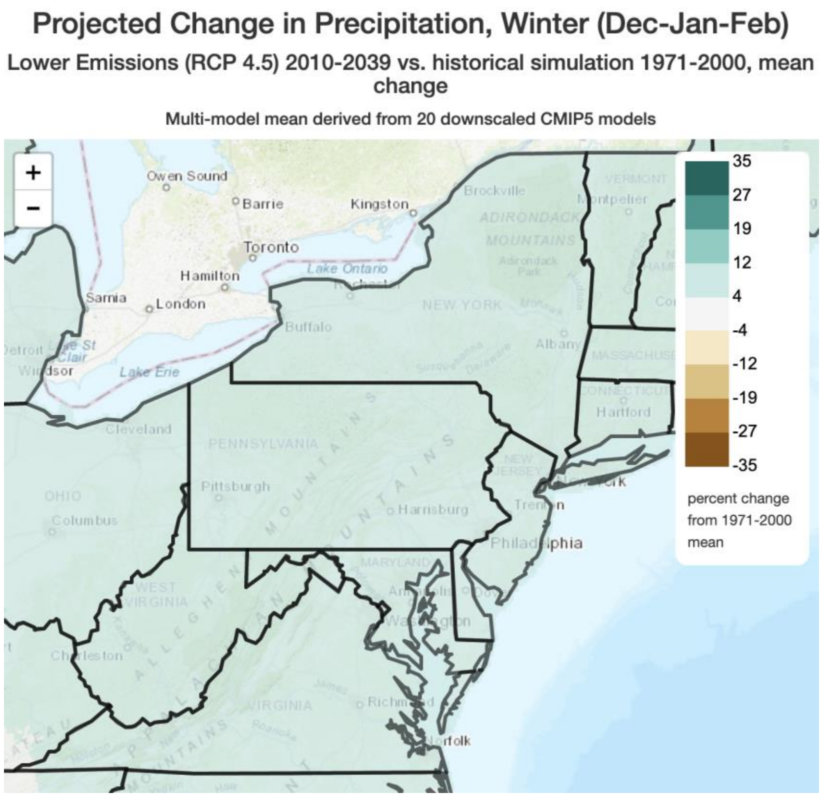
The Bay Program funded the Chesapeake Bay Watershed. The Virginia Transportation Research Council (VTRC) and the Commonwealth Center for Recurrent Flooding Resiliency (CCRFR) funded the extension to all counties in Virginia

The technical report details the project's data and approach

- Chapter 1 – overview and motivations
- Chapter 2 – regional context
- **Chapter 3 – data choice**
- **Chapter 4 – methods**
- **Chapter 5 – overview of the results; how to use and access the interactive tool**
- Chapter 6 – reflections on methods, results and next steps

Reviews back on 5/7/2021

Data overview



Source: MACA https://climate.northwestknowledge.net/MACA/tool_summarymaps2.php

- Station-based Historic Precipitation Data
  - National Weather Service (NWS) Cooperative Observer Program Network (COOP)
    - Used in Atlas 14
- Modeled Precipitation Data
  - North American Coordinated Regional Downscaling Experiment (NA-CORDEX),
  - Multivariate Adaptive Constructed Analogs (MACA),
  - Localized Constructed Analogs (LOCA),
  - Bias-Correction and Constructed Analogs version 2 (BCCAv2)

Daily and hourly station-based precipitation data

- Daily precipitation records for 480 base sites based on the following criteria:
  - Included in NOAA Atlas 14 Volume 2 or Volume 10;
  - Contain a data record that extends from at least 1950 through 2019;
  - Have less than 5% of daily precipitation data missing.
- Hourly precipitation records for 85 sites:
  - NOAA National Centers for Environmental Information (NCEI) COOP-Hourly Precipitation Data (HPD) Version 2 for stations with available records after 2014;
  - NCEI's Hourly Precipitation Dataset (HPD), known historically as DSI-3240 for stations with records ending prior to 2014;
  - NCEI Surface Data Hourly Global (DS3505) for NWS Automated Surface Observing System stations

Downscaled climate model datasets

- Global climate models (GCMs) provide modeled historic and project future estimates of precipitation at coarse spatial scales
  - These estimates are available from 1950-2100 for 35 global climate models under a range of scenarios of future atmospheric greenhouse gas concentrations.
- Downscaled climate data offers higher spatial and, in some cases, temporal resolution, but a range of methods exist.

Dataset	CMIP5 GCMs	RCPs	Approximate gridded spatial resolution	Temporal resolution	Downscaling approach
BCCAv2	21	2.6, 4.5, 6.0, 8.5	12 km (7.5 miles)	Daily	Statistical
MACA	20	4.5, 8.5	4 km (2.5 miles)	Daily	Statistical
LOCA	32	4.5, 8.5	6 km (3.7 miles)	Daily	Statistical
NA-CORDEX	4	8.5	25 km (15.5 miles)	Sub-daily	Dynamical
NA-CORDEX	1	4.5	50 km (31 miles)	Sub-daily	Dynamical
NA-CORDEX	5	8.5	50 km (31 miles)	Sub-daily	Dynamical

These datasets are based upon rigorous data requirements and use peer-reviewed methodologies.

Methods overview

1. Calculate Atlas 14 IDF curves from station-data for the fifty-year base period 1950-1999;
2. Calculate modeled historic and future projected IDF curves from gridded downscaled climate model data for 1950-1999 (modeled historic) and 2020-2069 and 2050-2099 (future projected), for each grid cell, downscaling method, GCM, and RCP;
3. Compute change factors for each future time period, which relate future IDF curves to historic modeled IDF curves, for each grid cell, downscaling method, GCM, and RCP;
4. Quantify uncertainty in change factor calculations for each grid cell, due to statistical model fit, downscaling method, GCM, and RCP; and
5. Aggregate change factors and uncertainty ranges to county scale.

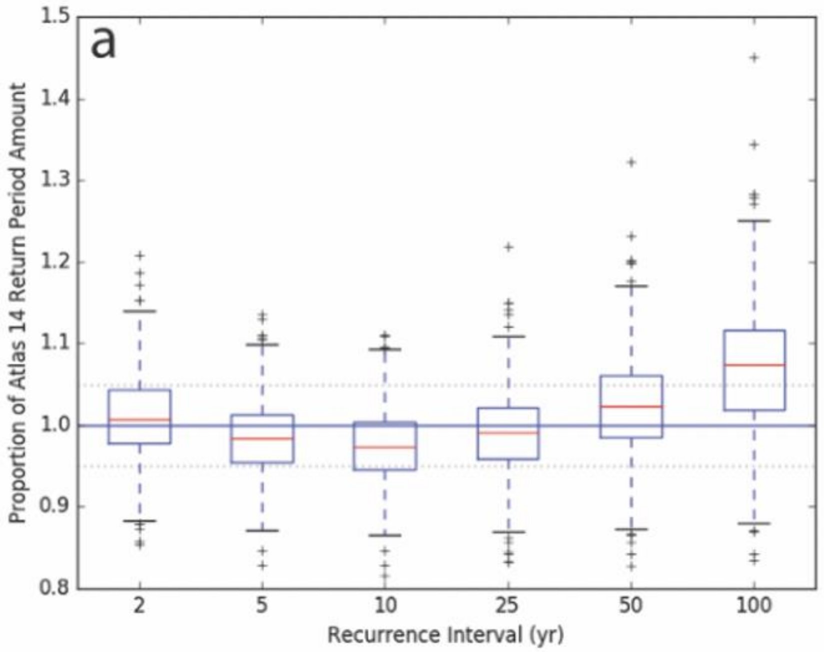
Step 1. Station-based Atlas 14 IDF curves

- Goals:
  - Replicate the approaches taken to derive Atlas 14 values available from NOAA's PDFS;
  - Make sure methods used in Step 2 are comparable to Atlas 14;
- Methods:
  - Generate partial duration series (PDS);
  - Use L-moments to fit a generalized extreme value (GEV) to each station's PDS;
  - Calculate rainfall amounts corresponding to recurrence probabilities of 50%, 20%, 10%, 4%, 2% and 1% (i.e. 2-, 5-, 10- 25-, 50- and 100-year storms) for one to 24 hour durations;
  - Follow regional L-moments procedure on station data, incorporating neighboring stations.

Step 1. Station-based Atlas 14 IDF curves

- Differences between our approach and Atlas 14 values were generally small and values within the published Atlas 14 confidence intervals.
- Note that the values that are ultimately shown in the online tool are taken directly from Atlas 14.

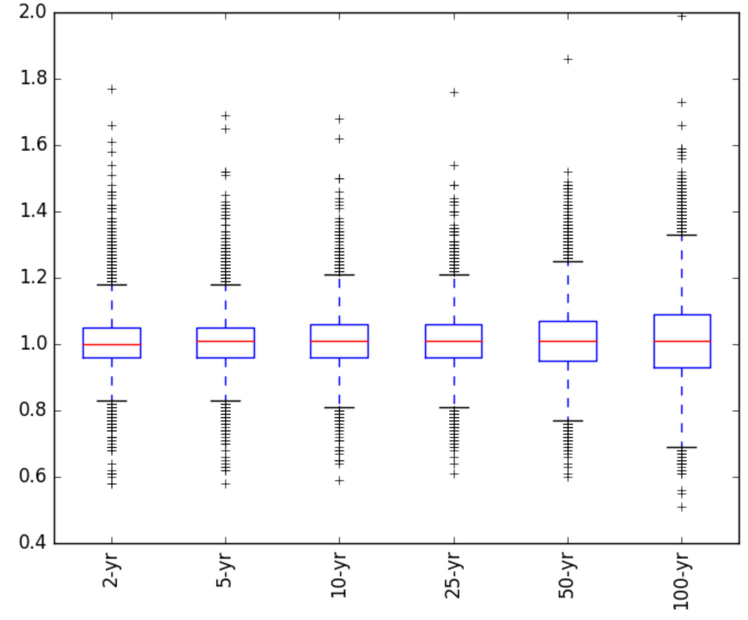
Differences between 1-day (converted to 24-hour) Atlas 14 and project computed recurrence interval rainfall amounts



Step 2. Downscaled climate model data IDF curves

- For each downscaled climate model dataset, grid cell, GCM and RCP:
  - Generate PDS;
  - Parameterize GEV with the L-moments method;
  - Estimate the 24-hour precipitation amounts for 2-, 5-, 10-, 25-, 50- and 100-year storms
- Additional analyses found:
  - L-moments performed well compared to other commonly used methods*;
  - Single grid L-moments approach were found to be on average the same as the regional L-moments.

Ratio of change factors calculated with regional L-moments to single grid L-moments for NA-CORDEX (RCP 8.5, 2050-2099) (y-axis) for each recurrence interval (x-axis)



NOTE: The y-axis shows the ratio of the change factor calculate with the regional L-moments approach compared to the single-grid L-moment.

**Maximum Likelihood Estimator (MLE) and the Generalized Maximum Likelihood Estimator (GMLE) methods*

Step 3. Climate change-informed IDF curve change factors

- Change factors are based on the quantile delta method (QDM) in which changes between historic and future values are estimated separately by quantiles.
- Change factors calculated for each:
  - Recurrence interval, Grid cell, Future time period (both 2020-2069 and 2050-2099), Downscaled climate model dataset, GCM and RCP

$$2yr\ Change\ Factor_{2020-2069} = \frac{2yr,\ 24hr\ rainfall\ depth_{2020-2069}}{2yr,\ 24hr\ rainfall\ depth_{1950-1999}}$$

Step 3. Climate change-informed IDF curve change factors

- Change factors were selected because they:
  - Are widely used and conceptually simple to understand
  - Can translate the estimated changes in IDF curves calculated from downscaled climate model output to Atlas 14 values
  - Avoid some of the complexities of other approaches
  - Eliminate biases that a GCM or downscaling method may introduce

Step 3. Climate change-informed IDF curve change factors

- The change factor calculation in this study assumes changes in 24 hour precipitation events are scalable across durations.
  - More research is needed to better understand and detect changes in hourly extremes compared to daily extremes in GCMs;
  - Previous analysis show that for selected cities in the broader region one-hour and 24-hour duration change factors are virtually equal;
  - Our own analysis revealed that this assumption was still appropriate.

Step 3. Climate change-informed IDF curve change factors

- Finally, a comparison of change factors across all four downscaled climate model datasets found that BCCAv2 and MACA produced results inconsistent with known regional patterns.
- Change factors for LOCA and NA-CORDEX are included in final data in the online tool.

Step 4. Uncertainty bounds for IDF curve change factors

- Uncertainty in the IDF curve change factors resulted from:
  - L-moments statistical fitting technique,
  - downscaling methods,
  - GCMs,
  - future greenhouse gas concentration scenario (RCP).
- Parametric bootstrapping used to calculate uncertainty from L-moments method
- Change factors were calculated across each downscaled dataset (LOCA and NA-CORDEX) and GCM for each grid cell
- For each grid cell, RCP and return period, summary statistics (median, 25^{th}, 75^{th}, etc.) on full range of results

Step 5. County-level change factors with uncertainty bounds

County-level change factors calculated with:

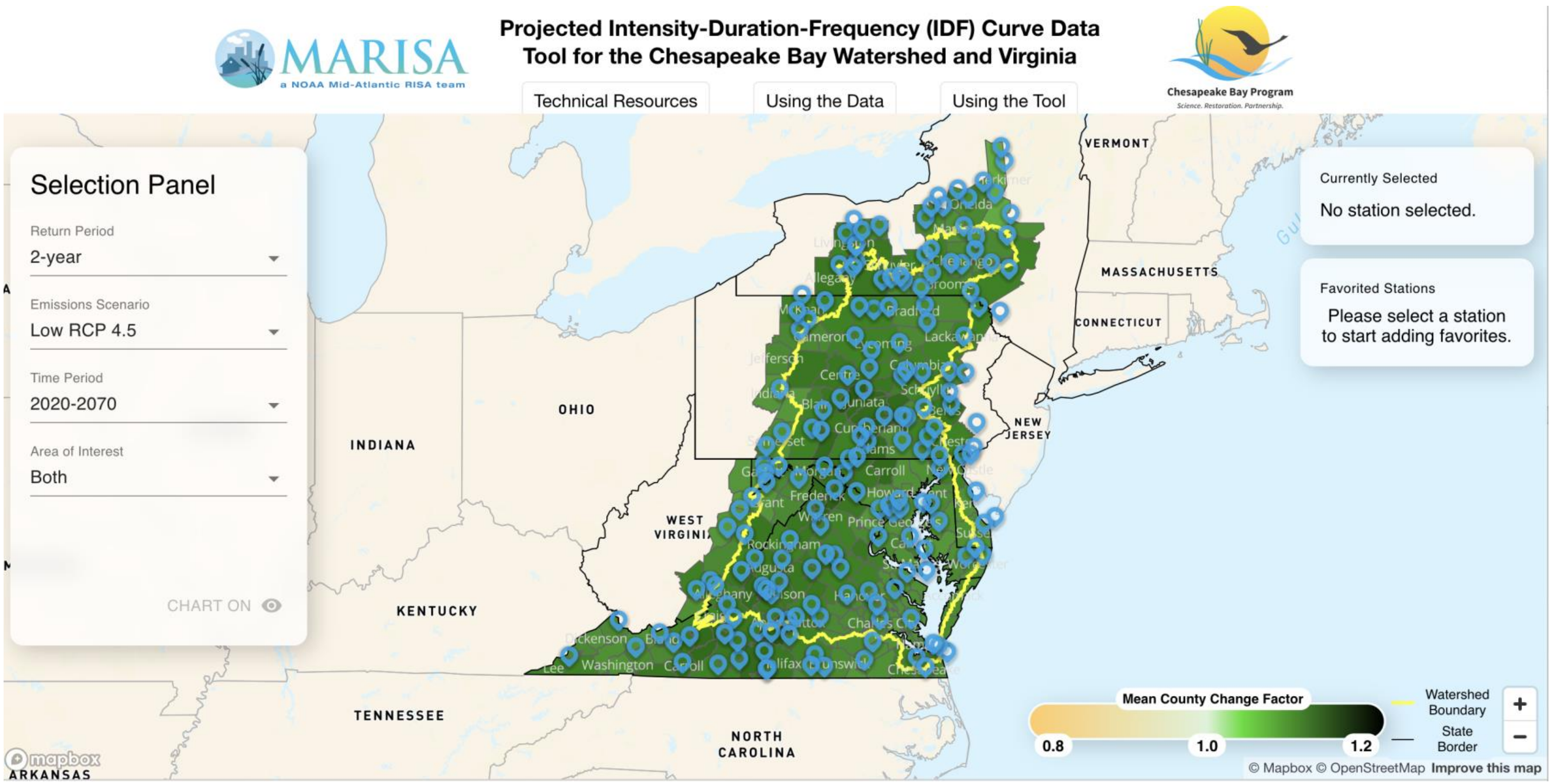
- Area-weighted average of the change factors for the grid cells or portions of grid cells within county boundaries.
  - Calculated for the median, 25th, 75th, 10th and 90th percentile change factors for each county, RCP and recurrence interval.
- An additional analysis found low variance across grid cells within a county.

Change factors and projected IDF curves are available in an online tool

Study results are:

- IDF curve change factors calculated at the county-level for each time period, RCP and recurrence interval
- Change factors are applied to Atlas 14 values from stations with adequate records to generate projected IDF curves at:
  - 2-, 5-, 10-, 25-, 50-, and 100-year recurrence intervals
  - 1-, 2-, 3-, 6-, 12-, 18-, and 24-hour durations

Change factors and projected IDF curves are available in an online tool



BETA VERSION OF TOOL

Thank you to our funders and collaborators!

CCRFR

CBTRUST
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A Watershed Partnership

VTRC
Virginia Transportation Research Council

RAND CORPORATION

Carnegie Mellon University

Cornell University

a NOAA Mid-Atlantic RISA team

NOAA

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Art DeGaetano and team – Cornell

Costa Samaras, Tania Lopez-Cantu, Marissa Webber – Carnegie Mellon

Questions

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This study leveraged the best available science to develop climate change-informed IDF curves

The project team based data and method choice on the following:

- Projected IDF curves should be relevant the engineering community in a manner consistent with their current use, namely applicable to Atlas 14.
- Uncertainty ranges resulting from method and data choice should be clear and well characterized.
  - No single dataset or methodology can fully represent a complex hydrological system, whether historic or projected.
- Methods should be transparent and reproducible.