Chesapeake Bay Program | Indicator Analysis and Methods Document
Upstream Flooding | Updated July 2018

Indicator Title: Upstream Flooding

Relevant Outcome(s): Climate Monitoring and Assessment

Relevant Goal(s): Climate Resiliency

Location within Framework (i.e., Influencing Factor, Output or Performance): Influencing Factor for other Outcomes. These indicators are "Outputs" themselves, called for in the Climate Monitoring and Assessment Outcome of the 2014 Watershed Agreement.

A. Data Set and Source

(1) Describe the data set. What parameters are measured? What parameters are obtained by calculation? For what purpose(s) are the data used? The magnitude and frequency of river flooding presented in this indicator are based on discharge measurements from stream gauges, measured in cubic feet or cubic meters per day. Stream gauges measure stream elevation continuously, and USGS personnel measure actual discharge (volume of flow) at each site every four to eight weeks. This combination of variables allows USGS to calculate an elevation/discharge relationship that then makes it possible to calculate the daily mean discharge for each day at each site. Flood magnitude and frequency are based on analysis of daily discharge over time.

This indicator has been adapted from a national indicator maintained by the U.S. EPA. For more detailed information about EPA's indicator, see www.epa.gov/climate-indicators/climate-change-indicators-river-flooding.

(2) List the source(s) of the data set, the custodian of the source data, and the relevant contact at the Chesapeake Bay Program.
- Source: U.S. Geological Survey (USGS) streamflow data analyzed by Drs. Gabriele Villarini and Louise Slater at the University of Iowa
- Custodian: Michael Kolian, Office of Atmospheric Programs, U.S. EPA
- Chesapeake Bay Program Contact (name, email address, phone number): Laura Drescher, Indicators Coordinator; drescher.laura@epa.gov, 410-267-5713

(3) Please provide a link to the location of the data set. Are metadata, data-dictionaries and embedded definitions included? Underlying streamflow data from individual stations are publicly available online through the surface water section of NWIS at: http://waterdata.usgs.gov/nwis/sw. Sites were narrowed down based on site characteristics, which are available for each stream gauge in the GAGES-II database at: http://water.usgs.gov/GIS/metadata/usgswrd/XML/gagesII_Sept2011.xml. A list

of the HCDN-2009 subset of stations is available online at: http://water.usgs.gov/osw/hcdn-2009. These sources provide metadata and data descriptions. Processed results for the nation are available in spreadsheet and map files on EPA's "Climate Change Indicators in the United States" website at www.epa.gov/climate-indicators/climate-change-indicators-river-flooding.

B. Temporal Considerations

(4) Data collection date(s): USGS has been collecting stream gauge data since the late 1800s at some locations, but this indicator starts in 1965 to maximize the number of years and sites available for a national-scale analysis.

(5) Planned update frequency (e.g., annual, biannual, etc.):
- Source Data: USGS streamflow data updated annually
- Indicator: To be determined through further discussion with EPA and the University of Iowa

(6) Date (month and year) next data set is expected to be available for reporting: To be determined through further discussion with EPA and the University of Iowa

C. Spatial Considerations

(7) What is the ideal level of spatial aggregation (e.g., watershed-wide, river basin, state, county, hydrologic unit code)? This indicator works best as a disaggregated map that shows trends at each individual monitoring site. The data are not designed for aggregation into larger spatial units.

(8) Is there geographic (GIS) data associated with this data set? If so, indicate its format (e.g., point, line polygon). Yes, point data.

(9) Are there geographic areas that are missing data? If so, list the areas. No, but station density varies depending on where USGS stream gauges with high-quality long-term data happen to be located.

(10) Please submit any appropriate examples of how this information has been mapped or otherwise portrayed geographically in the past. See the maps published as part of EPA's national indicator at www.epa.gov/climate-indicators/climate-change-indicators-river-flooding.

D. Communicating the Data

(11) What is the goal, target, threshold or expected outcome for this indicator? How was it established? No explicit target. River flooding is expected to increase in magnitude and frequency in many areas as a result of more extreme precipitation

events associated with climate change. However, human actions ranging from stormwater management to larger flood control activities may help to mitigate this effect. The purpose of this indicator is to monitor the extent to which this climate-related attribute is changing—which, in turn, can inform management decisions designed to increase climate resiliency.

(12) What is the current status in relation to the goal, target, threshold or expected outcome? Not applicable.

(13) Has a new goal, target, threshold or expected outcome been established since the last reporting period? Why? Not applicable.

(14) Has the methodology of data collection or analysis changed since the last reporting period? How? Why? No.

(15) What is the long-term data trend (since the start of data collection)? Floods have become larger and more frequent since 1965 at a majority of sites in the Chesapeake watershed, but most of these observed trends are not statistically significant.

(16) What change(s) does the most recent data show compared to the last reporting period? To what do you attribute the change? Is this actual cause or educated speculation? This indicator views data in a long-term context suitable for climatological analysis. Long-term increases and decreases in the magnitude and frequency of river flood events generally coincide with increases and decreases in the frequency of heavy rainfall events. Correlation and causation analyses are described in the works cited at www.epa.gov/climate-indicators/climate-change-indicators-river-flooding. Authoritative scientific literature (e.g., assessments by the Intergovernmental Panel on Climate Change and the U.S. Global Change Research Program) has established that climate change is contributing to changes in the frequency of heavy rainfall events.

(17) What is the key story told by this indicator? Floods have generally become larger in rivers and streams of the Chesapeake watershed since 1965. Of the 47 sites with adequate data, 34 experienced increases in the size of flooding events. However, only one site had a statistically significant increase (at a 95 percent confidence level). Since 1965, large floods have become more frequent at 30 out of 42 sites in the Chesapeake watershed with sufficient data. However, only two sites had statistically significant increases (at a 95 percent confidence level). Increases and decreases in frequency and magnitude of river flood events generally coincide with increases and decreases in the frequency of heavy rainfall events.

E. Adaptive Management

(18) What factors influence progress toward the goal, target, threshold or expected outcome? Factors that can influence the magnitude and frequency of upstream flooding include: the timing, magnitude, and frequency of heavy precipitation events; climate change (to the extent that it influences heavy precipitation events); stormwater inputs (affected by land cover and land use in the watershed, as well as stormwater management infrastructure); flood control activities on certain rivers (e.g., management of dams and diversions); and the extent of wetlands and their ability to buffer larger-than-normal flows. To reduce the influence of some of the non-climatic factors on this indicator, this indicator uses data from a subset of USGS stream gauges that have been designated as HCDN-2009 "reference gauges." These reference gauges have been carefully selected to reflect minimal interference from human activities such as dam construction, reservoir management, wastewater treatment discharge, water withdrawal, and changes in land cover and land use that might influence runoff.

(19) What are the current gaps in existing management efforts? Mitigation of climate change requires coordinated global action that is beyond the purview of the Chesapeake Bay Program, but local and regional actions to reduce greenhouse gas emissions can still contribute to these broader solutions.

(20) What are the current overlaps in existing management efforts? Land cover/land use and stormwater management also contribute to the achievement of water quality goals that are central to the *Chesapeake Bay Watershed Agreement*.

(21) According to the management strategy written for the outcome associated with this indicator, how will we (a) assess our performance in making progress toward the goal, target, threshold or expected outcome, and (b) ensure the adaptive management of our work? Not applicable to this outcome.

F. Analysis and Interpretation

Please provide appropriate references and location(s) of documentation if hard to find.

(22) What method is used to transform raw data into the information presented in this indicator? Please cite methods and/or modeling programs.

Stream gauges measure stream surface elevation continuously and record readings at regular intervals every day of the year. Intervals vary from station to station—typically every 15 minutes to one hour. Streamflow (or discharge) is measured at regular intervals by USGS personnel (typically every four to eight weeks).

Trends in the magnitude of floods are based on an analysis of the annual maximum instantaneous peak discharge values at each site. Calculation of the magnitude trend uses a block approach, whereby the largest instantaneous discharge value for each calendar year is identified. A Mann-Kendall test was used to calculate whether the sizes of these annual maximum flood events have a discernable trend over the period of record. The Mann-Kendall approach is a widely used non-parametric test of whether a variable is statistically trending upward or downward.

Trends in the frequency of floods are based on a "peaks-over-threshold" approach, which sets a baseline daily discharge value for which events are considered to be "flooding." This threshold value is defined as the value that produces an average of two flood events per year. During a 50-year study period, this approach essentially involves identifying the 100 largest days of discharge at each station. By analyzing when these 100 largest discharge events fall during the period of study, this indicator is able to identify whether such large events have become more or less frequent over time. Trends and their significance were determined through Poisson regression, which is a widely used method to assess trends in count data—in this case, the number of large flooding events per year. For the calculation of frequency trends, flood events were only considered discrete events when separated by at least 15 days.

These methods were originally published in a peer-reviewed analysis of flooding in the north-central United States and subsequently expanded nationwide. The original peer-reviewed analysis can be found in: Mallakpour, I., and G. Villarini. 2015. The changing nature of flooding across the central United States. Nature Climate Change 5:250–254.

This indicator has been adapted from a national indicator maintained by the U.S. EPA. For more detailed information about methods, see EPA's technical documentation for the "River Flooding" indicator at www.epa.gov/climate-indicators/downloads-indicators-technical-documentation.

(23) Is the method used to transform raw data into the information presented in this indicator accepted as scientifically sound? If not, what are its limitations? Yes. The method has been peer reviewed for publication in the scientific literature, as described above. It has also been peer reviewed for inclusion in EPA's climate change indicator suite, which requires each indicator to meet a set of 10 criteria for data quality (see the technical documentation overview at www.epa.gov/climate-indicators/downloads-indicators-technical-documentation).

One acknowledged methodological limitation is that in calculating changes in frequency over time, truly discrete flood events may have fallen within a window smaller than 15 days, thereby masking suitably distinct events as if they were part of a single event.

(24) How well does the indicator represent the environmental condition being assessed? This indicator uses an acknowledged method to analyze trends in flooding, although it is not the only method of doing so. Another option would be to

analyze trends in relation to flood stages at stream gauges where flood stages have been defined. Each method has advantages and disadvantages.

Factors that may impact the confidence, application, or conclusions drawn from this indicator are as follows:

- This analysis is restricted to locations where streamflow is not highly disturbed by human influences, including reservoir regulation, diversions, and land cover change. However, changes in agricultural practices, land cover, and land use over time could still influence trends in the magnitude and frequency of flooding events at some sites. The criteria for selecting reference gauges vary from region to region based on land use characteristics, which means that a modestly impacted gauge in one part of the country (e.g., an area with agricultural land use) might not have met the data quality standards for another less impacted region.

- Large daily discharges do not necessarily correlate to the risk posed to river communities and surrounding areas. Protective infrastructure, such as levees and seawalls, can provide a measure of safety to vulnerable areas.

- Reference gauges used for this indicator are not evenly distributed throughout the United States, nor are they evenly distributed with respect to topography, geology, elevation, or land cover.

(25) Are there established reference points, thresholds, ranges or values for this indicator that unambiguously reflect the desired state of the environment? No.

(26) How far can the data be extrapolated? Have appropriate statistical methods been used to generalize or portray data beyond the time or spatial locations where measurements were made (e.g., statistical survey inference, no generalization is possible)? No attempt has been made to extrapolate data beyond the sampled sites and the timeframe of analysis. No attempt has been made to interpolate results between sampled sites. It is most appropriate to focus this indicator on the specific sites where data have been collected.

G. Quality

Please provide appropriate references and location(s) of documentation if hard to find.

(27) Were the data collected and processed according to a U.S. Environmental Protection Agency-approved Quality Assurance Project Plan? If so, please provide a link to the QAPP and indicate when the plan was last reviewed and approved. **If not, please complete questions 29-31.** No.

(28) *If applicable:* Are the sampling, analytical and data processing procedures accepted as scientifically and technically valid? Yes. All measurements are made according to standard USGS procedures. Analytical and data processing procedures have been peer reviewed and accepted as valid.

(29) *If applicable:* What documentation describes the sampling and analytical procedures used? See the technical documentation for EPA's "River Flooding" indicator at www.epa.gov/climate-indicators/downloads-indicators-technical-documentation, as well as the USGS and scientific literature references cited therein.

(30) *If applicable:* To what extent are procedures for quality assurance and quality control of the data documented and accessible? Quality assurance and quality control (QA/QC) procedures are documented for measuring stream stage (Sauer and Turnipseed, 2010), measuring stream discharge (Turnipseed and Sauer, 2010), and computing stream discharge (Sauer, 2002; Rantz et al., 1982). Stream discharge is typically measured and equipment is inspected at each gauging station every four to eight weeks. The relation between stream stage and stream discharge is evaluated following each discharge measurement at each site, and shifts to the relation are made if necessary. Additional QA/QC procedures for the analysis are documented in Mallakpour and Villarini (2015).

Mallakpour, I., and G. Villarini. 2015. The changing nature of flooding across the central United States. Nature Climate Change 5:250–254.

Rantz, S.E., et al. 1982. Measurement and computation of streamflow. Volume 1: Measurement of stage and discharge. Volume 2: Computation of discharge. U.S. Geological Survey Water Supply Paper 2175. http://pubs.usgs.gov/wsp/wsp2175.

Sauer, V.B. 2002. Standards for the analysis and processing of surface-water data and information using electronic methods. U.S. Geological Survey Water-Resources Investigations Report 01-4044. https://pubs.er.usgs.gov/publication/wri20014044.

Sauer, V.B., and D.P. Turnipseed. 2010. Stage measurement at gaging stations. U.S. Geological Survey Techniques and Methods book 3. Chap. A7. U.S. Geological Survey. http://pubs.usgs.gov/tm/tm3-a7.

Turnipseed, D.P., and V.P. Sauer. 2010. Discharge measurements at gaging stations. U.S. Geological Survey Techniques and Methods book 3. Chap. A8. U.S. Geological Survey. http://pubs.usgs.gov/tm/tm3-a8.

(31) Are descriptions of the study design clear, complete and sufficient to enable the study to be reproduced? Yes. The technical documentation for EPA's "River Flooding" indicator at www.epa.gov/climate-indicators/downloads-indicators-

technical-documentation, as well as the USGS and scientific literature references cited therein, provide thorough documentation to allow methods to be reproduced.

(32) Were the sampling, analytical and data processing procedures performed consistently throughout the data record? Yes. All USGS streamflow and discharge data have been collected and extensively quality-assured by USGS since the start of data collection. Consistent and well-documented procedures have been used for the entire periods of recorded discharge at all gauges. Analytical procedures were applied consistently for the entire period of interest.

(33) If data sets from two or more sources have been merged, are the sampling designs, methods and results comparable? If not, what are the limitations? Not applicable, as all data derive from one source.

(34) Are levels of uncertainty available for the indicator and/or the underlying data set? If so, do the uncertainty and variability impact the conclusions drawn from the data or the utility of the indicator? Uncertainty estimates are not available for this indicator as a whole. As for the underlying data, the precision of individual stream gauges varies from site to site. Accuracy depends primarily on the stability of the stage-discharge relationship, the frequency and reliability of stage and discharge measurements, and the presence of special conditions such as ice. Accuracy classifications for all USGS gauges for each year of record are available in USGS annual state water data reports. USGS has published a general online reference devoted to the calculation of error in individual stream discharge measurements (Sauer and Meyer, 1992).

Streamflow and discharge naturally vary from day to day. This indicator intentionally captures some of this variability by focusing on the magnitude and timing of daily peaks. Peak streamflow and discharge also vary from year to year as a result of variation in precipitation, air temperature, and other factors. This indicator focuses on long-term trends over a 50-year period to reduce the "noise" associated with interannual or decadal-scale climate variability.

Sauer, V.B., and R.W. Meyer. 1992. Determination of error in individual discharge measurements. U.S. Geological Survey Open-File Report 92-144. http://pubs.usgs.gov/of/1992/ofr92-144.

(35) For chemical data reporting: How are data below the MDL reported (i.e., reported as 0, censored, or as < MDL)? If parameter substitutions are made (e.g., using orthophosphate instead of total phosphorus), how are data normalized? How does this impact the indicator? Not applicable, as no chemical data have been collected.

(36) Are there noteworthy limitations or gaps in the data record? No. This indicator has been restricted to sites that do not have significant gaps during the period of

interest (1965–2015). Specifically, all sites have at least 30 years of data during the period of interest (1965–2015), no more than four consecutive years of missing data at the beginning or end of the period of interest, and no gaps longer than two consecutive years during the rest of the period.

H. Additional Information (*Optional)*

(37) Please provide any further information you believe is necessary to aid in communication and prevent any potential misrepresentation of this indicator. A Mann-Kendall test and a Poisson regression were used for magnitude and frequency, respectively, to assess trends and their significance. Mallakpour and Villarini (2015) document these methods in more detail. In both cases, significance refers to a 95 percent level ($p < 0.05$).

Mallakpour, I., and G. Villarini. 2015. The changing nature of flooding across the central United States. Nature Climate Change 5:250–254.