River Flooding

Identification

1. Indicator Description

This indicator presents the changes in magnitude and frequency of days with large water discharge in rivers and streams from 1965 to 2015. These flooding events are largely influenced by recent local and upstream precipitation. Differences in the size of large events over time (magnitude) or distribution of events over time (frequency) could indicate changes in regional climate.

Components of this indicator include:

- Change in the magnitude of river flooding in the United States from 1965 to 2015 (Figure 1).
- Change in the frequency of river flooding in the United States from 1965 to 2015 (Figure 2).

2. Revision History

August 2016: Indicator published.

Data Sources

3. Data Sources

This indicator is based on instantaneous peak and daily discharge data from stream gauges maintained by the U.S. Geological Survey (USGS). The analysis was first developed by Iman Mallakpour and Gabriele Villarini at the University of Iowa, who published results related to these trends for the north-central United States (Mallakpour and Villarini, 2015). These analyses were then updated and expanded nationwide by Louise Slater and Gabriele Villarini at the University of Iowa. Daily mean and instantaneous peak streamflow data are housed in the USGS National Water Information System (NWIS). The set of stations presented in the indicator derives from the Hydro-Climatic Data Network (HCDN-2009) subset of the Geospatial Attributes of Gages for Evaluating Streamflow (GAGES-II) database, which was developed by USGS and is described in Lins (2012).

4. Data Availability

Trend data for this indicator were obtained directly from Drs. Gabriele Villarini and Louise Slater at the University of Iowa. 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.

Methodology

5. Data Collection

Flooding events featured in this indicator are determined by examining daily water discharge values for each given station. Discharge is defined as the total volume of water that passes through a stream gauge site within a given window of time. Discharge values are determined from data collected at stream gauging stations by devices that record the elevation (or stage) of a river or stream at regular intervals each day. USGS maintains a network of more than 25,000 stream gauging stations throughout the United States (http://waterdata.usgs.gov/nwis/sw). USGS has been collecting stream gauge data since the late 1800s at some locations. Gauges generally are sited to record flows for specific management or legal issues, typically in cooperation with municipal, state, and federal agencies. Stream surface elevation is recorded at regular intervals that 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). The relation between stream stage and discharge is determined and a stage-discharge relation (rating) is developed to calculate streamflow for each recorded stream stage (Rantz et al., 1982). These data are used to calculate the daily mean discharge for each day at each site. This indicator uses these daily mean discharge values as inputs. All measurements are made according to standard USGS procedures (Rantz et al., 1982; Sauer and Turnipseed, 2010; Turnipseed and Sauer, 2010).

This indicator uses data from a subset of USGS stream gauges that have been designated as HCDN-2009 "reference gauges" (Lins, 2012). 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. The subset of reference gauges was further winnowed to meet the following criteria:

- 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. Thus, this indicator excludes stations that start in 1970 or later and stations that end in 2010 or earlier.
- No gaps longer than two consecutive years during the rest of the period.

A total of 526 sites met these criteria for Figure 1, and 481 sites for Figure 2. The year 1965 was selected as a starting point to maximize the number of years and sites available for a national-scale analysis. All of the selected stations and their corresponding basins are relatively independent—that is, the analysis does not include gauges with substantially overlapping watershed areas.

6. Indicator Derivation

Both 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.

Figure 1. Change in the Magnitude of River Flooding in the United States, 1965–2015

Figure 1 shows how the magnitude of floods has changed over the period of study. It is 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.

Figure 2. Change in the Frequency of River Flooding in the United States, 1965–2015

Figure 2 shows how the frequency of river flooding events has changed over the period of study. The analysis uses 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.

7. Quality Assurance and Quality Control

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 are documented in Mallakpour and Villarini (2015).

The GAGES-II database incorporated a QC procedure for delineating watershed boundaries acquired from the National Hydrography Dataset Plus. The dataset was cross-checked against information from USGS's National Water-Quality Assessment Program. Basin boundaries that were inconsistent across sources were visually compared and manually delineated based on geographical information provided in USGS's Elevation Derivatives for National Applications. Other screening and data quality issues are addressed in the GAGES-II metadata available at:
http://water.usgs.gov/GIS/metadata/usgswrd/XML/gagesII_Sept2011.xml.

Analysis

8. Comparability Over Time and Space

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 (Corbett et al., 1943; Rantz et al., 1982; Sauer, 2002). Trends in stream discharge over time can be heavily influenced by human activities upstream, such as the construction and operation of dams, flow diversions and abstractions, and land-use change. To remove these artificial influences to the extent possible, this indicator relies on a set of reference gauges that were chosen because they represent least-disturbed (though not necessarily completely undisturbed) watersheds. The criteria for selecting reference gauges vary from region to region based

on land use characteristics. This inconsistency 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. The reference gauge screening process is described in Lins (2012) and is available in the GAGES-II metadata at:
http://water.usgs.gov/GIS/metadata/usgswrd/XML/gagesII_Sept2011.xml.

Analytical methods for this indicator have also been applied consistently over time and space.

9. Data Limitations

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

1. 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.

2. 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.

3. 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.

4. 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.

10. Sources of Uncertainty

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 (Novak, 1985). 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).

11. Sources of Variability

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.

Some sites may be more affected by direct human influences (such as development and land-use changes) than others. Other sources of variability include localized factors such as topography, geology, elevation, and natural land cover.

12. Statistical/Trend Analysis

A Mann-Kendall test and a Poisson regression were used for data shown in Figures 1 and 2, respectively, to assess trends and their significance. Mallakpour and Villarini (2015) document these methods in more detail. Of the 2,997 sites associated with Figure 1, 569 (19 percent) had significant trends in flood magnitude: 202 with increases and 367 with decreases. Of the 2,337 sites shown in Figure 2, 553 (24 percent) had significant trends in flood frequency: 237 with increases and 316 with decreases. Figures 1 and 2 differentiate between significant trends (larger, solid-color triangles) and insignificant trends (smaller, outlined triangles). In both cases, significance refers to a 95 percent level ($p < 0.05$).

References

Corbett, D.M., et al. 1943. Stream-gaging procedure: A manual describing methods and practices of the Geological Survey. U.S. Geological Survey Water-Supply Paper 888. https://pubs.er.usgs.gov/publication/wsp888.

Lins, H.F. 2012. USGS Hydro-Climatic Data Network 2009 (HCDN-2009). U.S. Geological Survey Fact Sheet 2012-3047. http://pubs.usgs.gov/fs/2012/3047.

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

Novak, C.E. 1985. WRD data reports preparation guide. U.S. Geological Survey Open-File Report 85-480. https://pubs.er.usgs.gov/publication/ofr85480.

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 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.

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.