Streamflow

Identification

1. Indicator Description

This indicator describes trends in the magnitude and timing of streamflow in streams across the United States.

Components of this indicator include trends in three annual flow statistics:

- Magnitude of annual seven-day low streamflow from 1940 through 2009 (Figure 1)
- Magnitude of annual three-day high streamflow from 1940 through 2009 (Figure 2)
- Timing of winter-spring center of volume date from 1940 through 2009 (Figure 3)

2. Revision History

December 2011: Indicator developed
April 2012: Indicator updated with a new analysis

Data Sources

3. Data Sources

This indicator was developed by Drs. Mike McHale, Robert Dudley, and Glenn Hodgkins at the U.S. Geological Survey (USGS). It is based on streamflow data from a set of reference stream gauges specified in the Geospatial Attributes of Gages for Evaluating Streamflow (GAGES) database, which was developed by USGS and is described by Falcone et al. (2010). Daily mean streamflow data are stored in USGS's National Water Information System (NWIS).

4. Data Availability

EPA obtained the data for this indicator from Drs. Mike McHale, Robert Dudley, and Glenn Hodgkins at USGS. Similar streamflow analyses had been previously published in the peer-reviewed literature (Hodgkins and Dudley, 2006; Falcone et al., 2010). The USGS team provided a reprocessed dataset to include streamflow trends through 2009.

Streamflow data from individual stations are publicly available online through the surface water section of NWIS at: http://waterdata.usgs.gov/nwis/sw. Reference status and watershed, site characteristics, and other metadata for each stream gauge in the GAGES database are available online at: http://esapubs.org/archive/ecol/E091/045/.

Methodology

5. Data Collection

Streamflow is determined from data collected by devices called stream gauges, which record the elevation (or stage) of a river or stream at regular intervals each day. USGS maintains a national network of stream gauging stations, including more than 7,000 stations currently in operation throughout the contiguous 48 states (http://water.usgs.gov/wid/html/SG.html). USGS has been collecting stream gauge data since the late 1800s at some locations. However, gauges have not been not placed randomly; instead, they have been generally sited to capture information from relatively large perennial streams and rivers to record flows for specific management or legal issues. Stream surface elevation is recorded at regular intervals at each gauging station—typically every 15 minutes to 1 hour.

Streamflow (or discharge) is measured at regular intervals by USGS personnel (typically every four to eight weeks). The relation between stream surface elevation and discharge is determined and used to calculate streamflow for each stream stage measurement (Rantz et al., 1982). These data are used to calculate the daily mean discharge for each day at each site. All measurements are taken 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 "reference gauges" (Falcone et al., 2010). Reference gauges have been carefully selected to reflect minimal interference from human activities such as dam construction, reservoir management, wastewater treatment discharge, water withdrawals, and changes in land cover and land use that might influence runoff. The subset of reference gauges was further winnowed on the basis of length of period of record (70 years) and completeness of record (greater than or equal to 80 percent for every decade). Figures 1 and 2 are based on 211 sites. Figure 3 relies on 55 sites because it is limited to watersheds that receive 30 percent or more of their total annual precipitation in the form of snow. This additional criterion was applied because the metric in Figure 3 is used primarily to examine the timing of snowmelt-related runoff. All of the selected stations and their corresponding basins are independent—that is, the analysis does not include gauges that are upstream or downstream from one another.

All watershed characteristics, including basin area, station latitude and longitude, and percent of precipitation as snow were taken from the GAGES database. Basin area was determined through EPA's National Hydrography Dataset Plus and supplemented by the USGS National Water-Quality Assessment Program and the USGS Elevation Derivatives for National Applications.

6. Indicator Derivation

Figures 1 and 2. Volumes of Seven-Day Low (Figure 1) and Three-Day High (Figure 2) Streamflows in the United States, 1940–2009

Figure 1 shows trends in dry conditions using seven-day low streamflow, which is the lowest average of seven consecutive days of streamflow in a calendar year. Hydrologists commonly use this measure because it reflects sustained dry conditions that result in the lowest flows of the year. Seven-day low flow can equal zero if a stream has dried up completely.

Figure 2 shows trends in wet conditions using three-day high streamflow, which is the highest average of three consecutive days of streamflow in a calendar year. Hydrologists use this measure because a three-day averaging period has been shown to effectively characterize runoff associated with storms and peak snowmelt over a range of watershed areas.

Rates of change from 1940 to 2009 at each station were computed using the Sen slope, which is the median of all possible pair-wise slopes in a temporal dataset (Helsel and Hirsch, 1992). The Sen slope was then multiplied by the number of years of the trend period (i.e., 70) to estimate total change over time. Trends are reported as percentage increases or decreases, relative to the beginning Sen-slope value.

Figure 3. Timing of Winter-Spring Runoff in the United States, 1940–2009

Figure 3 shows trends in the timing of streamflow in the winter and spring, which is influenced by the timing of snowmelt runoff in areas with substantial annual snowpack. It does so using the winter-spring center of volume (WSCV) date, which is the date when half of the total volume of water between January 1 and May 31 has passed by the gauging station. Trends in this date are computed in the same manner as seven-day low flows and three-day high flows, and the results are reported in terms of the number of days earlier or later that WSCV is occurring. For more information about WSCV methods, see Hodgkins and Dudley (2006) and Burns et al. (2007).

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 surface elevation and stream discharge is evaluated following each discharge measurement at each site and the relationship is adjusted if necessary.

The GAGES database incorporated a QC procedure for delineating the 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 metadata available at:
http://esapubs.org/archive/ecol/E091/045/metadata.htm.

Analysis

8. Comparability Over Time and Space

All USGS streamflow 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 streamflows at all gauges (Corbett et al., 1943; Rantz et al., 1982; Sauer, 2002).

Trends in streamflow over time can be heavily influenced by human activities upstream, such as the construction and operation of dams, discharge of treated wastewater, 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 due to the land use characteristics. This inconsistency means that a modestly impacted gauge in one part of the country (for example, an area with significant agricultural land use) might not have met the data quality standards for another less impacted region. The reference gauge screening process is described in Falcone et al. (2010) and is available in the GAGES metadata at: http://esapubs.org/archive/ecol/E091/045/metadata.htm.

Analytical methods have been applied consistently over time and space.

9. 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).

10. Sources of Variability

Streamflow can be highly variable over time, depending on the size of the watershed and the factors that influence flow at a gauge. USGS addresses this variability by recording stage several times a day (typically 15-minute to 1-hour intervals) and then computing a daily average streamflow. Streamflow also varies from year to year as a result of variation in precipitation and air temperature. Trend magnitudes computed from Sen slopes provide a robust estimate of linear changes over a period of record, and thus this indicator does not measure decadal cycles or interannual variability in the metric over the time period examined.

While gauges are chosen to represent drainage basins relatively unimpacted by human disturbance, some sites may be more affected by direct human influences (such as land cover and land use change) than others. Other sources of variability include localized factors such as topography, geology, elevation, and natural land cover. Changes in land cover and land use over time can contribute to streamflow trends, though careful selection of reference gauges strives to minimize these impacts.

Although WSCV is largely driven by the timing of the bulk of snow melt in areas with substantial annual snowpack, other factors also will influence WSCV. For instance, a heavy rain event in the winter could result in large volumes of water that shift the timing of the center of volume earlier. Changes over time in the distribution of rainfall during the January–May period could also affect the WSCV date.

11. Statistical/Trend Analysis

The maps in Figures 1, 2, and 3 all show trends over time that have been computed for each gauging station using a Sen slope analysis. Because of uncertainties and complexities in the interpretation of

statistical significance, particularly related to the issue of long-term persistence (Cohn and Lins, 2005; Koutsoyiannis and Montanari, 2007), significance of trends is not reported.

12. 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 land cover and land use over time could still influence trends in the magnitude and timing of streamflow at some sites.
2. 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.

References

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