Stream Temperature

Identification

1. Indicator Description

This indicator describes trends in stream water temperature across the Chesapeake Bay region of the United States. Stream water temperature is a useful indicator of climate change for several reasons. Water temperature is a fundamental measure of the condition of all aquatic environments, including the flowing waters in streams and the water bodies that streams flow into. Climatic conditions have a strong influence on water temperature, which, therefore, varies naturally both in time and across the landscape. Several studies have demonstrated a strong correlation between stream temperatures and air temperatures. Stream temperatures can also be influenced by the amount of precipitation, evaporation, and streamflow that occurs within and around the stream. Thus, tracking changes in water temperature is key to better understanding the potential effects of global climate change on freshwater ecosystems. Changes to natural water temperature regimes can result in myriad effects on aquatic organisms, water quality, circulation patterns, recreation, industry, and utility operations.

2. Revision History

August 2016: Indicator published.

Data Sources

3. Data Sources

This indicator is based on an analysis developed by the U.S. Geological Survey (USGS), which was originally published by Rice and Jastram (2015) and subsequently updated with newer data and published in a USGS Open-File Report (Jastram and Rice, 2015). It uses water temperature data from a set of stream gauges operated by USGS.

4. Data Availability

Mike Kolian of EPA developed this indicator in partnership with John Jastram and Karen Rice of USGS. Jastram and Rice (2015) present maps and a table of station-specific trends that form the basis of this indicator. Original observations from individual gauges are stored in the USGS National Water Information System (NWIS). Watershed boundaries and numerous watershed and site characteristics for each stream gauge are available online as part of the GAGES-II database: http://water.usgs.gov/GIS/metadata/usgswrd/XML/gagesII_Sept2011.xml.

Methodology

5. Data Collection

Water temperature data come from a national network of stream gauging stations maintained by USGS. This network includes more than 8,500 stations currently in operation throughout the United States (www.usgs.gov/mission-areas/water-resources/science/usgs-streamgaging-network). Each site contains an automated stream gauge that collects continuous measurements of stream stage (height). USGS field staff periodically visit each station to inspect the equipment and measure other variables such as discharge (flow) and water temperature. These visits typically take place every eight weeks, though the frequency varies from year to year and among sites. USGS staff measured stream temperature by using a calibrated liquid-in-glass thermometer or electronic thermistor near the water surface at each stream gauge site.

This indicator uses data from a subset of USGS stream gauges that were originally selected for analysis by Rice and Jastram (2015). Stream gauges within and near the Chesapeake Bay watershed were chosen on the basis of completeness of water temperature data for 1960–2010, using a criterion of having data in at least 90 percent of the 51 years. USGS selected 1960 as a starting point to balance the number of sites and the length of record. An earlier starting point would have captured many fewer sites, while a later starting point would have shortened the period of record available for analysis. Applying the data availability criteria resulted in a set of 129 sites, of which 104 are independent (i.e., 104 of the watersheds upstream from these gauges do not have another site nested within them). The selected sites had an average of eight temperature measurements per year, with the number of measurements in a given year ranging from zero to 27.

6. Indicator Derivation

Individual measurements of water temperature were converted to anomalies for comparability across the network of stations. Anomalies were computed by subtracting each water temperature measurement from the site-specific monthly mean over the entire period (1960–2014).

Figure 1 shows trends that were determined using ordinary least-squares linear regression of site-specific monthly water temperature anomalies. Regression slopes (degrees per year) have been multiplied by the length of the period (55 years) to derive estimates of total change, which are shown on the map. The Cochrane-Orcutt method (Cochrane and Orcutt, 1949) was used to remove the effect of serial correlation, thus allowing determination of statistical significance.

For more details about analytical methods, see Rice and Jastram (2015).

7. Quality Assurance and Quality Control

Quality assurance and quality control (QA/QC) procedures are documented for measuring stream water temperature (Wilde, 2006). Instructions for water temperature measurement during measurement of stream discharge are described in Turnipseed and Sauer (2010).

Analysis

8. Comparability Over Time and Space

USGS collected and quality-assured all stream water temperature data by following a measurement protocol that has been applied consistently to all sites over time. Analytical methods have also been applied consistently over time and space. Additional statistical analyses performed by USGS demonstrated that although the exact timing and frequency of measurements differed from year to year and site to site, the trend results are statistically robust and unbiased (Rice and Jastram, 2015). USGS used two different verification methods. First, a bootstrapping method confirmed that the irregular data intervals did not impact the direction of any site's significant trends. Second, the USGS principal investigators constructed a synthetic dataset based on a stream gauge that collected water-temperature data every 15 minutes; the data exhibited no water temperature trend. The investigators mimicked the irregular-interval temperature data by selecting random points from the set of 15-minute water-temperature data. They then imposed a trend on these data to see if the linear regression methodology would be able to identify the trend. When a trend was imposed, the methodology was able to identify it a majority of the time. These confirmations add further assurance of the reliability of the findings despite irregularity in the timing of sampling.

9. Data Limitations

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

1. The timing of water temperature measurement is irregular in both time of day and time of year at individual sites, across sites, and over the period of record. This irregularity is a potential source of variability in trend results. As discussed in Section 8, Rice and Jastram (2015) evaluated the potential effects of this irregular sampling scheme. They determined that, while it did not likely induce bias in the trend results, it could cause the trend estimates to be considered conservative—which means that a trend identified as increasing by these methods may actually have a greater magnitude than reported.

2. Gauges used for this indicator are not evenly distributed throughout the study region, nor are they evenly distributed with respect to topography, geology, elevation, or land cover, although a wide range of these physical parameters are represented in the dataset.

3. In addition to climate, changes to a stream's average water temperature over time can be influenced by human activities upstream, such as industrial discharges, the construction and operation of dams, flow diversions and abstractions, and land-use change. The effect of these factors has not been removed from the dataset analyzed. A more detailed analysis of this data set found that water temperature tends to increase more quickly than air temperature in agricultural areas without major dams, but more slowly at forested sites and in areas influenced by dams (Rice and Jastram, 2015). Nonetheless, a comparison of 35 relatively undisturbed reference stations with the remaining 94 stations in this indicator showed no statistically significant difference in trends between the two groups of stations (Jastram and Rice, 2015).

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 water temperature measurements for liquid-in-glass thermometers is 0.5 degrees Celsius (°C) and the precision for electronic thermistors is 0.1–0.2°C (Wilde, 2006).

11. Sources of Variability

Sources of variability include localized factors such as topography, geology, elevation, and natural land cover within individual watersheds. Variability between individual temperature measurements could result from variations in weather—for example, if a recent storm led to an increase in streamflow. Additionally, some sites may be more affected by direct human influences (such as land-cover and land-use change or hydrologic modification) than others. This indicator does not include any sites that are affected by tides.

12. Statistical/Trend Analysis

Figure 1 shows trends that were determined using ordinary least-squares linear regression of site-specific monthly water temperature anomalies, as described by Rice and Jastram (2015). The Cochrane-Orcutt method (Cochrane and Orcutt, 1949) was used to remove the effect of serial correlation, thus allowing determination of the statistical significance of water temperature trends at individual stations. Of the 129 stations analyzed, 60 (47 percent) had trends that were significant to a 95-percent level ($p \leq 0.05$), including 53 stations with temperature increases and seven with decreases.

References

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