Chesapeake Bay Program | Indicator Analysis and Methods Document
Stream Water Temperature | Updated July 2018

Indicator Title: Stream Water Temperature

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? Water temperature at each site is measured directly by USGS personnel approximately every eight weeks. 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. Long-term monthly averages were calculated for each site, and individual measurements converted into anomalies (relative to the site-specific mean) to enable comparison across sites.

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

(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) stream temperature data analyzed by John Jastram and Karen Rice of USGS.
- 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 water temperature data from individual stations are publicly available online through the surface water section of NWIS at: http://waterdata.usgs.gov/nwis/sw. Processed results for the entire region (including some sites outside of the Chesapeake watershed and thus not included in this version of the indicator) 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-stream-temperature.

B. Temporal Considerations

(4) Data collection date(s): Data have been collected for many decades. USGS selected 1960 as a starting point for this indicator to balance the number of sites and the length of record. USGS field staff periodically visit each stream gauge station to inspect automated stream height (stage) measuring 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. The sites that met data completeness criteria had an average of eight temperature measurements per year, with the number of measurements in a given year ranging from zero to 27.

(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 USGS, due to some changes in USGS data storage protocols that will need to be addressed

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

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. Data could be aggregated into watersheds at various scales, but some watersheds have multiple sites nested within them, while others do not.

(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 temperature measurements 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 map published as part of EPA's regional indicator at www.epa.gov/climate-indicators/climate-change-indicators-stream-temperature.

D. Communicating the Data

(11) What is the goal, target, threshold or expected outcome for this indicator? How was it established? No explicit target. Stream water temperature is expected to increase over time as a result of global climate change. However, local conditions may vary depending on local climate factors and human activities in the watershed. 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)? From 1960 through 2014, water temperature increased at 78 percent of the stream sites measured in the Chesapeake Bay watershed. Approximately half of these increases were statistically significant (27 out of the 56 sites with increases). Only 6 percent of stations had a significant temperature decrease over the same period.

(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. The water temperature at any given location is a product of many different factors, including sources of water (for example, melted snow, a recent rainstorm, or groundwater), the amount of water in the stream (streamflow), air temperature, plants along the bank (for example, trees that provide shade), and the amount of development within the watershed. Over time, however, an area's climate has the strongest natural influence on a stream's temperature. The original study on which this indicator is based, Rice and Jastram (2015), found significant correlations between air temperature and water temperature at all the sites studied.

Rice, K.C., and J.D. Jastram. 2015. Rising air and stream-water temperatures in Chesapeake Bay region, USA. Climatic Change 128(1):127–138.

(17) What is the key story told by this indicator? Stream temperatures have risen throughout the Chesapeake Bay watershed. The largest increases have occurred in the southern part of the region. Specifically, since 1960, the Chesapeake Bay watershed has experienced an overall increase in stream water temperature.

Temperature has risen by an average of 1.1°F across all sites and 2.1°F at the sites where trends were statistically significant.

E. Adaptive Management

(18) What factors influence progress toward the goal, target, threshold or expected outcome? Factors that can influence stream water temperature include: air temperature; the timing and magnitude of streamflow—which in turn is influenced by precipitation patterns; and human activities such as stormwater management, dams and diversions, and changes in land cover and land use, such as changes in riparian vegetation and shading.

(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, riparian forest buffers, and stormwater management also contribute to the achievement of water quality and habitat 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. 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.

The map for this indicator 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 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 the original peer-reviewed study by Rice and Jastram (2015).

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

Cochrane D., and G.H. Orcutt. 1949. Application of least squares regression to relationships containing auto-correlated error terms. Journal of the American Statistical Association 44:32–61.

Rice, K.C., and J.D. Jastram. 2015. Rising air and stream-water temperatures in Chesapeake Bay region, USA. Climatic Change 128(1):127–138.

(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 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 32 below, the study designers 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.

(24) How well does the indicator represent the environmental condition being assessed? This indicator uses an acknowledged method to analyze trends in water temperature. Although other organizations measure water temperature, USGS's data set arguably provides the most reliable long-term data set with the largest number of available data points.

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

- 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 data set.

- 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 data set 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).

Jastram, J.D., and K.C. Rice. 2015. Air- and stream-water-temperature trends in the Chesapeake Bay region, 1960–2014. U.S. Geological Survey Open-File Report 2015–1207. https://dx.doi.org/10.3133/ofr20151207.

Rice, K.C., and J.D. Jastram. 2015. Rising air and stream-water temperatures in Chesapeake Bay region, USA. Climatic Change 128(1):127–138.

(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 "Stream Temperature" 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 water temperature (Wilde, 2006). Instructions for water temperature measurement during measurement of stream discharge are described in Turnipseed and Sauer (2010).

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

Wilde, F.D. 2006. Temperature (ver. 2). U.S. Geological Survey Techniques of Water-Resources Investigations, Book 9, Chapter A6, Section 6.1. March 2006 edition. http://water.usgs.gov/owq/FieldManual/Chapter6/Ch6_contents.html.

(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 "Stream Temperature" 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. 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 data set 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.

Rice, K.C., and J.D. Jastram. 2015. Rising air and stream-water temperatures in Chesapeake Bay region, USA. Climatic Change 128(1):127–138.

(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 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).

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.

Wilde, F.D. 2006. Temperature (ver. 2). U.S. Geological Survey Techniques of Water-Resources Investigations, Book 9, Chapter A6, Section 6.1. March 2006 edition. http://water.usgs.gov/owq/FieldManual/Chapter6/Ch6_contents.html.

(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. Specifically, USGS focused this analysis on stations that had temperature data in at least 90 percent of the years since 1960. USGS selected 1960 as a starting point to balance the number of sites and the length of record.

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. The map for this indicator shows trends that were determined using ordinary least-squares linear regression of site-specific monthly water temperature anomalies. The Cochrane-Orcutt method was used to remove the effect of serial correlation, thus allowing determination of the statistical significance of water temperature trends at individual stations.