Element 10: Needs for Enhancing Monitoring Networks for Watershed Water Temperature Change Impacts

Abstract:

- There is extensive temperature monitoring, carried out by multiple agencies that supports local to baywide tracking of water temperature both spatially and over time.
- There are data gaps for monitoring of temperature thresholds important to living resources. These gaps include high temporal frequency data at the reach-scale in the watershed and for nearshore, shallow tidal waters in the bay. There is interest in coincident air temperature monitoring.
- Results from a poll in the first temperature workshop event indicate our community is most interested in improving our understanding for responses of impacted resources (e.g., hypoxia, fish distributions, bird distributions, wetland migration). Less interest was expressed in more temperature monitoring.

A. Contributors

Peter Tango U.S. Geological Survey (USGS); Breck Sullivan, U.S. Geological Survey; John Clune U.S. Geological Survey, and Scott Phillips, U.S. Geological Survey.

B. Resources

Nontidal data resources have been developed as part of a USGS lead effort to assemble stream water temperature from agencies and institutions across the watershed. The draft of this data synthesis effort is in progress and will be made available as a formal publication known as a "USGS data release".

Primary resources for the tidal monitoring datasets include outputs of the 2017-18 Goal Implementation Team (GIT) funded project on climate indicators for the Chesapeake Bay Program conducted for the Climate Resiliency Workgroup. Two documents located on the CBP Climate Resiliency Workgroup webpage (Climate Resiliency Workgroup | Chesapeake Bay Program) under *Projects and Resources – Climate Change Indicator Frameworks* contain the key reference material:

- See item #10, "Bay Water Temperature" in Climate Change Indicators for the Chesapeake Bay Program: An Implementation Strategy. Submitted to: Chesapeake Bay Program 410 Severn Avenue, Suite 109 Annapolis, MD 21403. Submitted by: Eastern Research Group, Inc. 2300 Wilson Blvd, Suite 350 Arlington, VA 22201. Revised Edition July 13, 2018
- Excel spreadsheet: Monitoring networks 9-21-17

Additional insights are provided from published papers, Chesapeake Bay Program (CBP) webpages, and the Water Quality Standards Attainment and Monitoring Outcome Narrative Analysis completed by the Monitoring Team at the Chesapeake Bay Program during activities linked to work for the CBP Strategic Review System (SRS).

C. Approach

The approach to summarize bay and watershed temperature measurement resources was to reference the following:

a. 2017-18 GIT-funded research synthesis materials prepared during the evaluation of available data sources to support the development of a Bay Temperature Indicator
b. Newest reference to Community Science monitoring where data are reported to the Chesapeake Monitoring Cooperative through their Chesapeake Data Explorer database, and
c. Synthesis effort by USGS collating multi-agency stream temperature data that is being developed into a formal USGS data release. The original scope of the data release was to include only easily accessible public data, but due to Chesapeake Bay Program partner requests, extra efforts are being made to incorporate as many additional datasets (e.g., Aquarius) as possible for this workshop.

D. Synthesis

Overview of Watershed and Tidal Bay Temperature Data

Diverse data resources exist on water temperature measurements in the watershed and bay. Primary resources are characterized as having well represented spatial distribution with consistent data collection methods for extended time series**.** Secondary resources are more limited in spatial distributions, frequencies of measurement or duration of consistent data collection over the time series. Multiple datasets have been used in the analysis and reporting of temperature trends (e.g., Annual Trends by CBP Integrated Trends Analysis Team). Trend results have been presented with different spatial resolution, spatial coverage and time series from long-term single site records to regional multi-site network expressions of temperature change. The importance of any particular dataset for indicator development and analysis will depend on the utility of the indicator to support decision making on management actions and policy decisions, and whether or not any of the existing datasets provide the type of data to inform such an indicator. An example of a management relevant indicator based on local to regional water temperature records may include a Spring Warming Indicator (for fisheries management interests). It is notable that other management relevant indicators developed from local to regional temperature data include Frost Free Days (an agriculturally relevant indicator affecting growing seasons, planting and harvest times, crop options, water use, etc.) and Tropical Nights/Cooling Degree Days (an issue that affects living resource distributions, human health, socioeconomic well-being related to energy needs and energy use, etc.). These

indicators are air temperature related and, while important for many managers, are not derived from our water temperature datasets.

Watershed

Chesapeake Bay Program Nontidal Monitoring Network

The current nontidal monitoring network has 123 water-quality monitoring stations (Figure 1). The network was established in September 2004 with the signing of a Memorandum of Understanding (MOU) where the seven jurisdictions, the Susquehanna River Basin Commission, and USGS all use the same set of standardized CBP protocols that are based on USGS field sampling methods and EPA-approved analytical lab methods. Water temperature data collected at the sites previously supported development of the watershed temperature indicator. These data will be compiled in an upcoming USGS data release described in a later section.

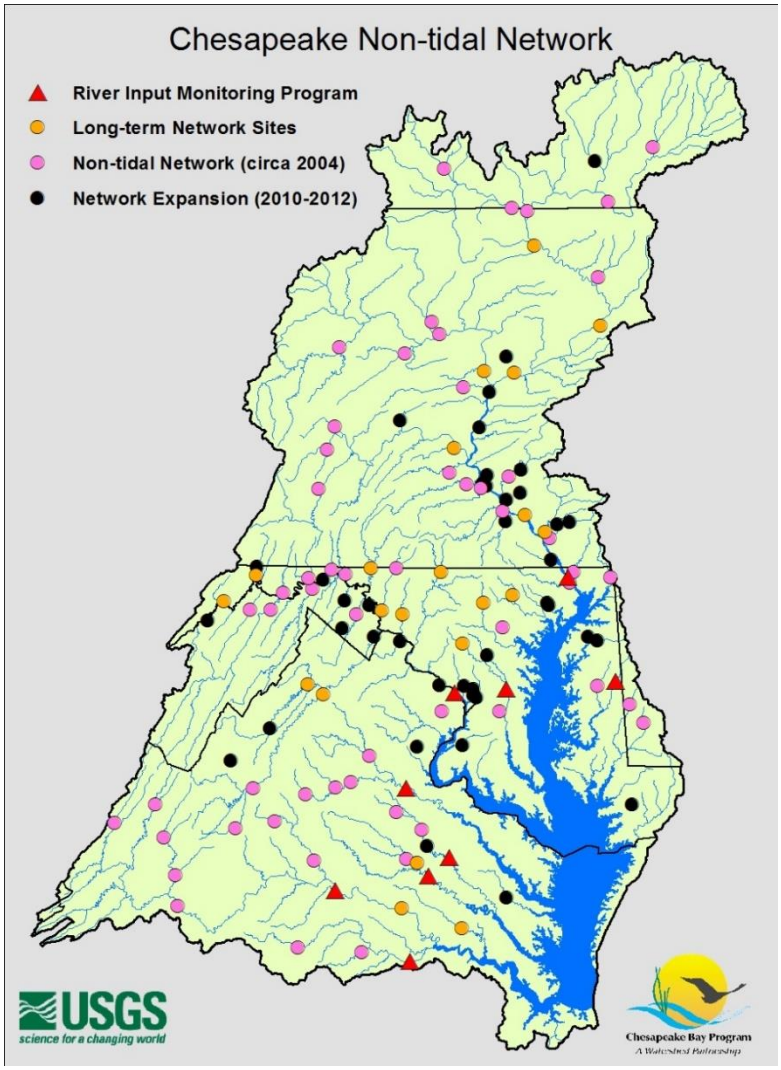

Figure 1. Chesapeake Bay Nontidal Network.

Dataset: Sub-annual stream water temperatures.
Source description: Directly sampled stream water temperatures at designated stream gauge sites.
Organization that collects the data: USGS.
Data source contact: John Jastram, USGS, jdjastra@usgs.gov.
Rationale for selection: Based on the NWIS dataset of stream gauges, which is the best available collection of physical stream parameters: This quality-controlled dataset further enhances the data by limiting potential issues with confounding factors or sites with limited data availability.
Temporal coverage: 1960–present* (*data review for the indicator was current through 2016).
Frequency: Sub-annual, but data are presented as trend over period of record.
Spatial coverage: Chesapeake watershed and immediate surrounding area (129 stations total; 72 in the Chesapeake watershed).
Spatial scale/resolution: Data for individual stations.
Access to data https://waterdata.usgs.gov/nwis.

Watershed Datasets Collated for an Upcoming USGS Data Release

Discrete and continuous monitoring program datasets in the first version of the upcoming USGS data release are included here in the workshop summary of watershed monitoring resources. Stream temperature data are available from multiple agencies across the Chesapeake Bay as raw observations or in aggregate form. *Unit values* (UV) are described as raw (non-aggregated) observations collected as continuous (e.g. every 15 minutes) or discrete (snapshot measurements) and are the most valued format for the wide variety of analysis and modeling needs. *Daily values* (DV) are most often aggregated unit values presented as a mean, minimum or maximum for the day and are useful particularly for long term records where unit values are not available.

- **DV_NWIS** – These data consist of approved daily values (mean, min and max) stored in NWIS from USGS monitoring stations and are available for the entire period of record for a site (Figure 2). There are 297,799 daily values available from 129 sites from 1961 to 2021.
- **UV_NWIS** – These data consist of approved unit values stored in NWIS from USGS monitoring stations as continuous data that are most often recorded every 15 minutes (Figure 3). Depending on the site, approved unit values are available usually after 2017 (sometimes earlier depending on the USGS water science center).
- **UV_AQUARIUS -** These data consist of unit values stored in the USGS Aquarius System (previously ADAPs) from USGS monitoring stations as discrete data recorded whenever technicians perform temperature checks (snapshots) during discharge measurements (Figure 4). There are 116,104 unit values available from 1,769 sites mostly from 1945 to 2021 (some values may be available before 1945). These previously unpublished data have been retrieved internally within USGS and will be available in an upcoming USGS

multi-agency stream temperature data release.

- **UV_WQP -** These data consist of unit values uploaded to the Water Quality Portal (WQP) as discrete and continuous data from multiple agencies (Figure 5). There are approximately 1.2 million unit values available from 28,827 sites mostly from 1963 to 2021 (with a few values available back to 1930).
- **UV_CMC -** These data consist of unit values from the Chesapeake Monitoring Cooperative as discrete data collected by volunteer in the watershed (Figure 6). There are approximately 44,460 unit values available from 1,447 sites mostly from 1992 to 2021 (with a few values available back to 1930). These data can be retrieved online via the Chesapeake Data Explorer

The DV_NWIS and UV_NWIS data can be retrieved via USGS Water Services or dataRetrieval R package (Hirsch and other, 2015) and will also be available in an upcoming USGS multi-agency stream temperature data release. UV_Aquarius currently can only be retrieved internally by USGS but has been approved to be included in the multiagency data release. Quality control measures will be used as part of the data release to address sites with multiple times series due to changes in sampling location or instrumentation (DV_NWIS, UV_NWIS), address outliers and proper unit conversions (UV_Aquarius), or address site duplication, wrong units, coding issues, outliers, detection limits and incomplete metadata (UV_WQP).

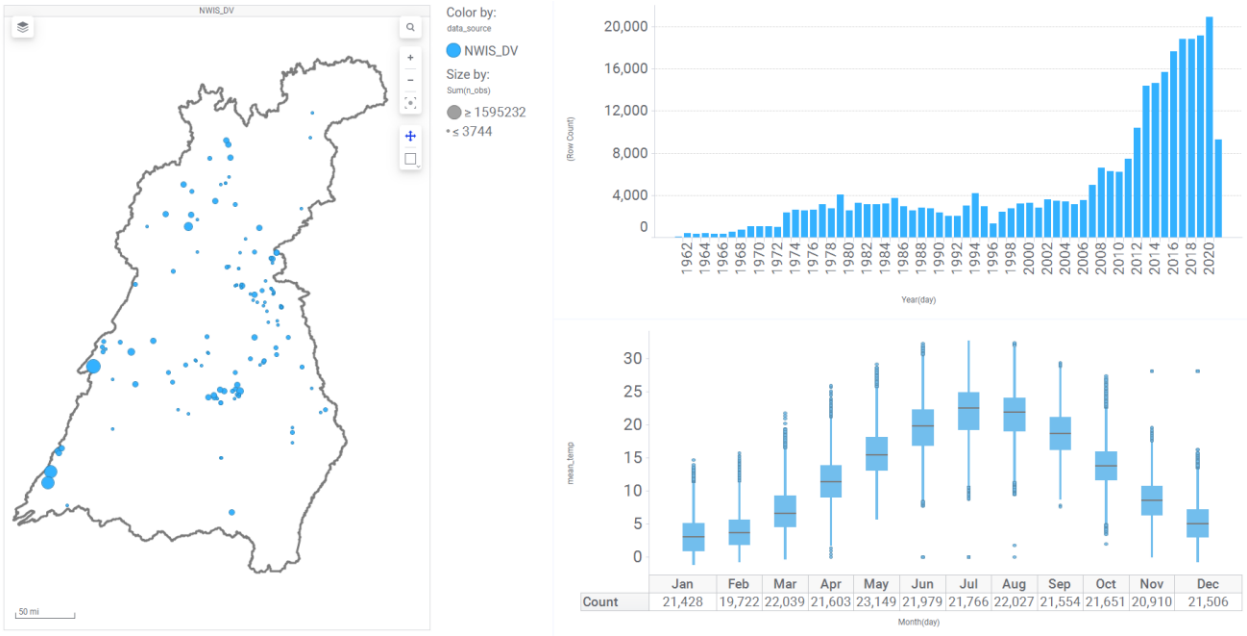

Figure 2. DV_NWIS site locations and data summaries for stream temperature

Figure 3. UV_NWIS site locations and data summaries for stream temperature

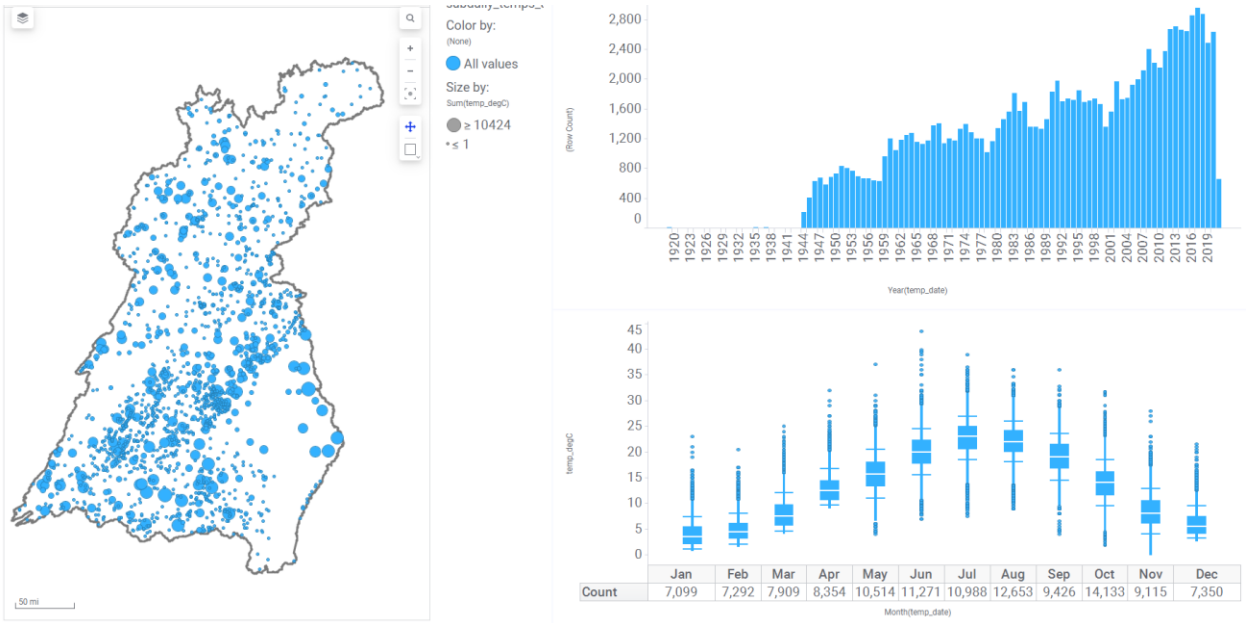

Figure 4. UV_Aquarius site locations data summaries for stream temperature

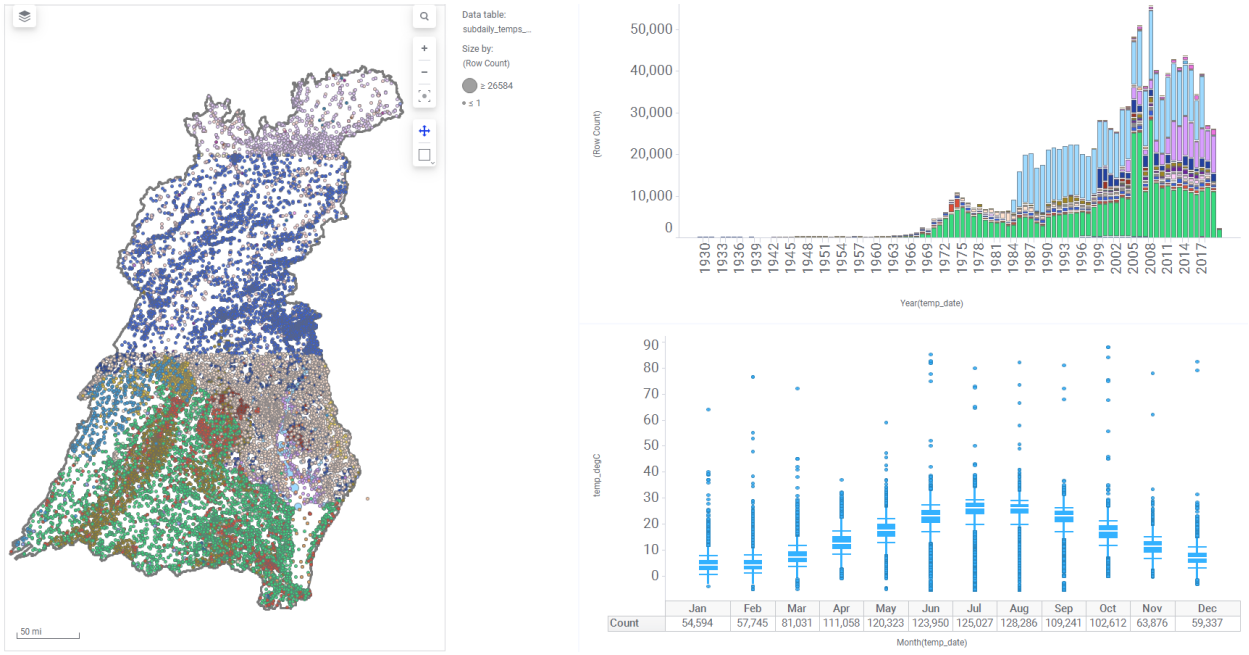

Figure 5. UV_WQP site locations for stream temperature data with data summaries

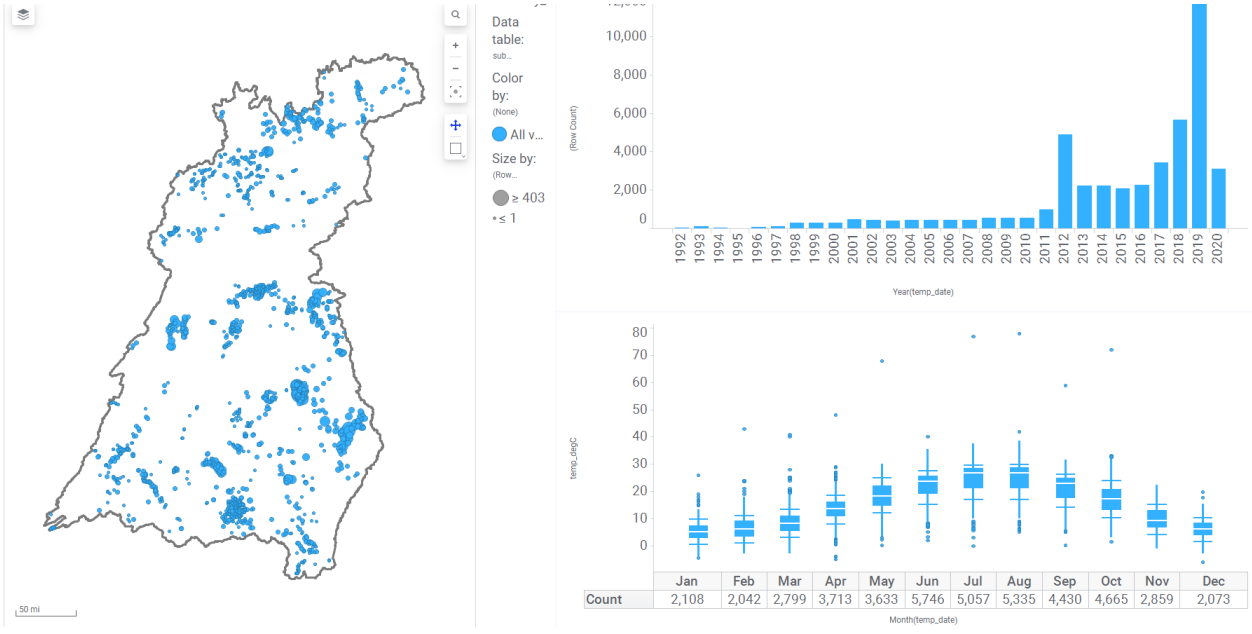

Figure 6. UV_CMC site locations and data summaries for stream temperature

Additional datasets

There are additional datasets (Susquehanna River Basin Commission, Pennsylvania Department of Environmental Protection, Interstate Commission on the Potomac River Basing, etc.) that may not be housed in the WQP and will be processed in later versions of the data release.

Tidal Bay

Primary data sources reflect broad tidal bay coverage, well represented spatial distribution with extended time series**.** The two primary datasets recognized in this review are the Chesapeake Bay Long-term Water Quality Monitoring Program and the National Oceanic and Atmospheric Administration (NOAA) NESDIS Satellite-based data. Secondary data resources reflect high quality data that, by comparison to the primary datasets, are more constrained in some manner (e.g., of limited density, spatial distribution and/or temporal coverage). Nine secondary datasets are recognized, and details are provided below:

Tidal Bay: Primary datasets

Chesapeake Bay Long-term Water Quality Monitoring Program

The current tidal water quality monitoring network was established in 1984, but its first full year of data collection was in 1985. There are 154 active stations sampled for physical, chemical, and biological parameters throughout the water column with baywide consistent collection and analysis protocols (Figure 7). One or more monitoring sites are located in each of the 92 Bay segments. Stations are sampled 1 or 2 times per month depending on location and season for a total of 15 to 16 cruises that collect vertical profiles of water quality conditions. Results are used to assess water quality standards attainment and evaluate the effectiveness of management actions through status and trends assessments for habitat conditions across space and through time. This program is supported under the federal Clean Water Act 117e program which includes 1:1 matching support from grant partners.

Data are available through the Chesapeake Bay Program DataHub. The DataHub is the Chesapeake Bay Program's primary tool for searching and downloading environmental data for the Chesapeake Bay watershed. This interface provides access to several types of data related to the Chesapeake Bay. Chesapeake Bay Program databases can be queried based upon user-defined inputs such as geographic region and date range. Each query results in a downloadable, tab- or comma-delimited text file that can be imported to any program (e.g., SAS, Excel, Access) for further analysis.

To ensure data accuracy, the Chesapeake Bay Program maintains a Quality Assurance Program that monitors and tracks several environmental datasets that look at pollutants, water quality, land use, algae, fish, crabs and submerged aquatic vegetation.

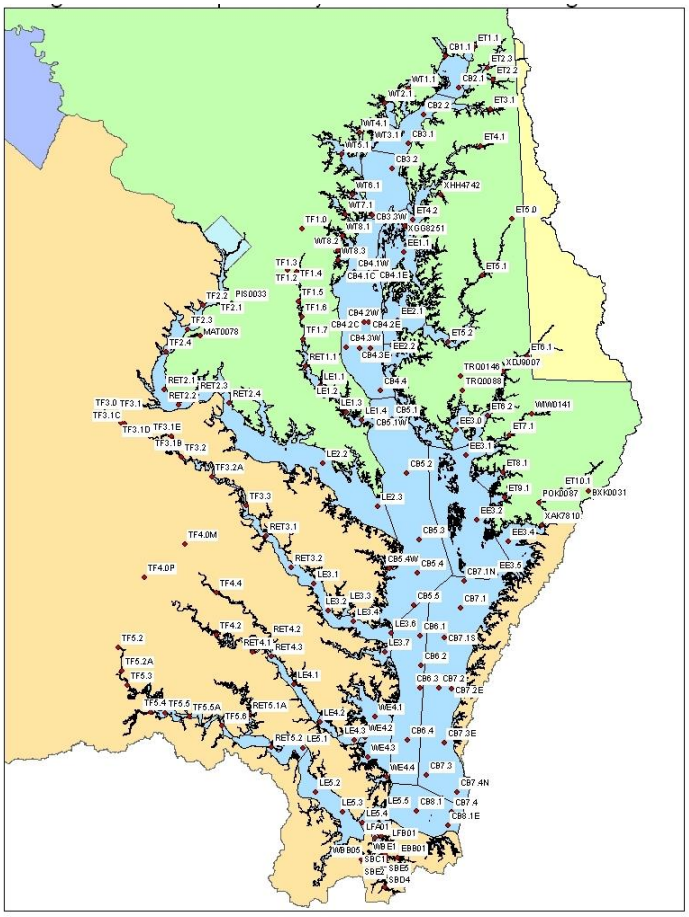

Figure 7. Tidal Chesapeake Bay Long-term Water Quality Monitoring Network

Source description: Annual measurement program, water temperature measurements obtained by hand-held sensor lowered into the water, all mainstem salinity zones and many tidal tributaries up to the head of tide.

Source agency: U.S. EPA Chesapeake Bay Program Office
Source access: CBP Data Hub DataHub (chesapeakebay.net)
Source contact: Mike Mallonee, ICPRB@CBPO, Data Manager mmallone@chesapeakebay.net , Peter Tango, USGS@CBPO Chesapeake Bay Monitoring Coordinator ptango@chesapeakebay.net
Temporal Coverage: mid 1984-present
Frequency: Data collected 2x per month June to September and targeting 1x per month the remainder of the year.
Spatial scale/resolution: point samples throughout the mainstem bay and the 9 major tidal tributaries and many smaller tidal subestuaries
Layers: Surface, Middle, Bottom

Applications: Status, Trends, Model development/calibration/verification, policy making, communication, outreach

NOAA Satellite Data:
This is an ongoing NOAA project to develop a remotely sensed estuarine surface water temperature product consisting of daily water temperature measurements obtained by satellite and averaged by 1-km grid cells. However, the current dataset is relatively recent, only covers a portion of the Bay, and peer-review validation is pending. Continued development of the remote sensing product and expansion to cover the entire Bay would enhance this data source.

Despite the relatively short temporal coverage, this data source possesses high spatial and temporal resolution, as well as robust scientific methods. In addition, NOAA has indicated that retroactive expansion of the dataset back to 2002 might be possible. Satellite data can be compared with *in situ* point data to confirm data quality. While a method has been developed for remote monitoring (a system of averaging grid squares), no method has been selected to aggregate *in situ* data.

Source description: Daily water temperature measurements obtained by satellite and averaged by 1-km grid cells.
Source agency: NOAA National Environmental Satellite, Data, and Information Service (NESDIS).
Source access: https://eastcoast.coastwatch.noaa.gov/time_series_cd.php
Source contact: Ron Vogel, NOAA, ronald.vogel@noaa.gov
Temporal Coverage: 2008-present (potential to stretch back to 2002)
Frequency: Data collected several times per day and rolled up into daily means
Spatial scale/resolution: 1 km^2
Applications: Status, Trends, Model development/calibration/verification

Tidal: Secondary Data Resources

The Chesapeake Bay Interpretive Buoy System (CBIBS)
CBIBS has 10 buoys located throughout the Bay and key tributaries that have been in place since 2010 with continuous data collection. CBIBS provides a rich temporal resolution dataset but does not provide nearly as many sites or as many years of data as the 1984–present Chesapeake Bay Program's long-term Chesapeake Bay water quality monitoring program. Also, some stations do not collect data year-round. CBIBS data could add value in other ways, though—perhaps as a supplementary data source for a future expansion of a water temperature indicator, or for calibration to help with further refinement of satellite data methods.

Reference: Home | Chesapeake Bay Interpretive Buoy System (noaa.gov)

The buoy at the Thomas Point lighthouse
Thomas Point has continuous data collection back to at least 1985, and this long-term record has been extensively studied and gap filled. Measured data are readily available, but the full gap-filled series is not as accessible. While this site has the advantage of high temporal resolution, it does not offer more years of data than the long-term monitoring network, and it only covers one location. However, it could add value as a standard for calibration and assessment of variability. The team that developed the satellite-based dataset has proposed using Thomas Point data to test the robustness of trends derived from both the satellite-based product and the CBP long-term monitoring network.

Reference: NDBC - Station TPLM2 Recent Data (noaa.gov)

Data from long-running individual sites such as the Chesapeake Bay Labatory (CBL) Pier at Solomons Island, the Virginia Institute of Marine Science (VIMS) pier at Gloucester Point, and Osborn Cove
These sites are frequently cited, and they have a notable advantage over the CBP long-term monitoring program in length of record. CBL has collected water temperature data since 1938 and the VIMS pier dataset extends back to the 1950s. Osborn Cove is a citizen monitoring effort led by Kent Mountford which has collected data since 1979 but does not provide extensive spatial coverage compared to the long-term monitoring program or the satellite-based dataset. If a need arises for a metric based on a single site, these locations could be strong candidates.

Chesapeake Bay Program Shallow Water Monitoring Program
Datasets start in 2001 for fixed station continuous monitoring in nearshore waters of the bay and its tidal tributaries, typically in $\leq$2m of water. Data density is typically 15-minute intervals. Data may not be present for a complete year each year but focused on summer seasonal monitoring evaluations. The monitoring program was designed for monitoring to occur in 3-year blocks for each station, consistent with the temporal needs of the Chesapeake Bay water quality criteria evaluations for dissolved oxygen underpinning Clean Water Act-based water quality standards attainment assessment protocols. Therefore, many datasets are short duration, however, some stations transitioned to extended duration monitoring locations and have consistent data for over 10 years.

Reference: Maryland Eyes on the Bay Eyes on the Bay: Continuous Monitoring Data Charts Query (maryland.gov), Virginia VECOS http://web2.vims.edu/vecos/

Community Science: The Chesapeake Monitoring Cooperative's Chesapeake Data Explorer
The Chesapeake Monitoring Cooperative (CMC) connects Community Science initiatives across groups and regions in order to amplify voices and enhance our understanding of the health of the Chesapeake Bay watershed. To accomplish this, the CMC provides technical, programmatic, and outreach support in order to integrate volunteer-based water quality and

macroinvertebrate monitoring data into a centralized data hub, the Chesapeake Data Explorer. These data are publicly available, shared with and used by the Chesapeake Bay Program to assess the health of the Chesapeake Bay and watershed.

As of August 4, 2021, there are over 435,000 water quality data records on file within the database; most are recent data in the last decade, point samples, and a subset are bay water temperature. Data are identified by method and quality assurance level using the CMC Tiered Framework and are owned by the data provider(s) and not the Chesapeake Monitoring Cooperative. Data users are responsible for properly citing the original data provider (Note: Contact information for data providers can be found through links on the CMC's Chesapeake Data Explorer website), and responsible for using provided data in a manner consistent to the quality assurance of the provided data.

Reference: Home Page (vims.edu)

The maturation of the Chesapeake Monitoring Cooperative has demonstrated the utility and the importance of citizen science and alternative monitoring data. Investments in citizen science have helped generate new data streams that can support enhanced analyses of Bay health and reduce the uncertainties of present assessments.

Chesapeake Bay Sentinel Site Cooperative (CBSSC)

There are 11 core sites. Datasets vary by location. Each Chesapeake Bay Sentinel site collects long-term data on marsh elevations, water levels, water quality, emergent vegetation and weather. A sentinel site as defined by NOAA, is "an area within the coastal and marine environment that has the operational capacity for intensive study and sustained observations to detect and understand changes in the ecosystems they represent". The CBSSC extends from the mouth of the bay just north of Virginia Beach to the bay's source, east of Havre de Grace, Maryland, where it meets the Susquehanna River. Some locations have datasets dating back to the 1970s.

Reference: Microsoft Word - CBSSC_Data&InfrastructureSummaryReport_FINAL.docx (chesapeakebayssc.org)

Chesapeake Bay National Estuarine Research Reserve

At least 3 locations in Maryland where continuous monitoring data have been collected for extended periods.

Reference: National Estuarine Research Reserve System (noaa.gov)

NOAA National Data Buoy Center (NDBC)

This program is part of NOAA's National Weather Service. It designs, develops, operates, and maintains a network of data collecting buoys and coastal stations. NDBC provides hourly observations for about 90 buoys and 60 Coastal Marine Automated Network stations. All

stations measure wind speed, direction, and gust; atmospheric pressure; air temperature; sea surface temperature and wave height and period.
Reference: https://www.ndbc.noaa.gov/

E. EVALUATION

Understanding status and trends are often most beneficial with datasets that have long term records (over 20, 10 and 5 years). Trends analysis frequently uses simple linear regression and non-parametric Mann-Kendall trend tests (Kaushal and others, 2010; Ashizawa and Cole, 1994; Webb and Nobilis, 1995; Durance and Ormerod, 2007). These statistical tests can be used to determine any differences in the significance of trends. Tidal trend tests have recently matured into using Generalized Additive Models (GAMs) (Murphy et al, 2019; Testa et al, 2019; Lefcheck et al, 2017). Additional verification of trends and driving factors include Bayesian dynamic linear models (DLMs) (Wagner et al. 2017), Weighted Regressions on Time, Discharge, and Season (WRTDS) (Hirsh and others, 2010) and Process Guided Deep Learning (Zwart et al. 2021) that explore the effects of discharge, land use, air temp, and groundwater on trend patterns (Briggs et al. 2018).

The present state of evaluation of the quality of data resources for 1) assessing status; (2) computing trends, and (3) considerations for STAC workshop (issues, questions, and potential recommendations are summarized (Table 1). Items labelled TBD (To Be Determined) acknowledges the state of the review process such that some datasets already have strong histories of use in status and trends evaluations while other datasets represent new opportunities pending the form of information needs in developing a particular indicator.

Dataset	Primary or secondary	Assessing status	Computing trends	Considerations: Quality, accessibility, considerations of issues, questions, recommendations
Chesapeake Nontidal Network	Secondary	Watershed-wide	Older data yes, (Rice and Jastram 2014).	Data were discrete at the time of sampling, are presently not easily accessed but will be available through the data release. Sampling protocol may not be favorable over the program as temperature data was an ancillary measure.
USGS NWIS Daily Values (DV-NWIS)	TBD	Watershed-wide	TBD	Data are accessible.
USGS NWIS Unit Values (UV_NWIS)	TBD	Watershed-wide	TBD	Data are accessible. There is the potential to combine continuous temperature datasets from other agencies (UV_PADEP, UV_SRBC, etc.)

				for analysis, but comparability among datasets with differing quality assurance measurements (thermistor checks, etc.) may be a challenge.
USGS Aquarius Unit Values (UV_Aquarius)	TBD	Watershed-wide	TBD	Data are accessible internally through USGS, basic quality assurance filters advised before use for analysis. These unit value data were not originally intended by USGS for public release because this was ancillary data used for estimating stream discharge. Collection methods vary as most older temperature readings were made at single point in the stream with a handheld thermistor and newer readings are retrieved from the output of acoustic doppler discharge measurements.
Water Quality Portal (UV_WQP)	TBD	Watershed-wide	TBD	Data are accessible, extensive quality assurance filters are advised before use for analysis. Most of the data is consider discrete and may have been not collected at high enough frequency for status and trends analysis. The data could be parsed into high frequency data (i.e. >10 observations per pay) that may be more useful for status and trends analysis. Data of lower frequency (i.e. <10 observations) could help fill in spatial gaps for stream temperature of streams of all orders.
UV_Chesapeake Monitoring Cooperative	Secondary	Watershed-wide, supplemental	TBD	Data are accessible. Data accessed through CBP Data Hub rather than Chesapeake Data Explorer have been through QA filters. Relatively few data have been collected at sites with sustained sampling design.
Chesapeake Bay long-term water quality monitoring program	Primary	Baywide	Yes – published assessments, established techniques	Annual program, consistent methods, consistent funding support for sustaining a physical water temperature indicator. May not have temporal coverage for connecting ecological impacts depending on interest for a management utility-based indicator.
Satellite-based assessment	Primary	Baywide	Yes – published	Annual program, consistent methods per satellite, when satellites change

			assessments, established techniques	then calibration to historical assessment likely needed. Still working on gaining reliable data in tributaries.
The Chesapeake Bay Interpretive Buoy System (CBIBS)	Secondary	Mainstem bay potential	Exploratory	Supplemental dataset
The buoy at the Thomas Point lighthouse	Secondary	Local	Exploratory	Supplemental
Pier data UMCES-CBL and VIMS; Osborn Cove citizen data	Secondary	Local	Yes	Local, long time series have demonstrated warming consistent with regional, national and global trends. Understand how changes are affecting small local areas, if at all, compared to larger tidal water.
Chesapeake Bay Shallow water monitoring program	Secondary	Local, research support	Local stations with extended (>5 year) time series	Dataset needs to be filtered for longest-term time series with continued operations expected into the future. Breck Sullivan has done some such filtering and continued comparison of water temperature in shallow waters compared to Open Water long-term monitoring stations. Need to understand impacts of near shore characteristics on shallow water.
Community Science	Secondary	TBD	TBD - Exploratory	New program. Supplemental consideration for indicators of status, assessments of trends at this time depending on location and duration of dataset.
Chesapeake Bay Sentinel Site Cooperative	Secondary	TBD	TBD	TBD
Chesapeake Bay National Estuarine Research Reserve	Secondary	TBD	TBD	TBD (Still needs to be evaluated; some monitoring data being used in Fish GIT Spring Warming Indicator)
National Oceanic and Atmospheric Administration's National Data Buoy Center	Secondary	TBD	TBD	TBD (Still needs to be evaluated; some monitoring data being used in Fish GIT Spring Warming Indicator)

Challenges for Enhancing Monitoring Networks

Despite the large amount of watershed and tidal temperature data available, it is thus far challenging and expensive to combine the various data sources into a multiagency dataset for

secondary use (e.g., climate change, etc.). Nationally, the economic loss of ambiguous legacy water quality data (unreliable, not usable) was estimated to be $12 billion (Sprague et al, 2017). Collaborative efforts toward shared and reliable water quality datasets across agencies have the potential to improve the scientific basis for decision making (Clune and Boyer, 2020), but comparability of temperature datasets among so many agencies is challenging due to various methods. Interagency committees on water information can bring together stakeholders and serve an advisory role for sharing recommended sampling, analysis, and metadata protocols, and develop a plan to resolve issues for better secondary use of data (Clune and Boyer, 2020). Reliable (i.e., QA supported) datasets with a shared defined data entry format can help regional, state and local efforts in shared development of status and trends assessments, environmental modeling, water quality criteria, impaired water designations, and conservation planning.

The Scientific Technical Assessment and Reporting Team (STAR) listed the condition of the Chesapeake Bay Program monitoring networks as "fair" during the August 2020 SRS quarterly review to the CBP Management Board. The nontidal network has previously been described as "good" (USEPA 2003). Recommended (i.e., most desirable) levels of support and sustainability were previously outlined for CBP tidal and nontidal monitoring networks (USEPA 2009). However, in the scope of this review, additional datasets that reference other networks have variously become established, sustained, modified and grown, and represent opportunities for use in assessments, indicator development, model development, model calibration and verification, and other analyses.

Network enhancements may occur with more stations, new sensors, new partners, and new approaches. Research often demonstrates the opportunity to apply any such enhancement. However, operationalizing any of these enhancements is more than just acquiring new technology or recognizing a viable means of acquiring new data. Considerations and challenges include 1.) the need to establish a useful sampling design to accommodate such additions, 2.) the infrastructure for collecting and processing data, 3.) the protocols for instrument use agreed upon and approved, 4.) approved QA/QC plans for equipment maintenance and data integrity checks, 5.) data collection decisions on location and frequency, 6.) data storage needs and data storage stewards chosen, 7.) sample handling/sensor data interpretation, 8.) analysis and reporting. Uncertainty in decisions for any one item in the list of needs may limit the adoption of new data collections and their availability.

Funding remains a fundamental management challenge for sustaining existing operations of networks as well as for enhancing the capacity to monitor. Despite this common annual challenge to long-term monitoring programming, many of the programs referenced are balanced by consistent support, providing substantial, valuable, time series from individual sites and have network coverage over the bay or watershed. However, annual cost of living adjustments, infrastructure aging and partner capacities to sustain support represent examples

of vulnerabilities that challenge program sustainability each year. The focus on sustaining existing network operations against the impact of vulnerabilities frequently limits investments to pursue network enhancements.

Reduced capacity of the long-term monitoring program has and will continue to directly result in 1) fewer samples collected and processed in the traditional tidal water quality monitoring program 2) fewer samples collected at some stations in some seasons in the watershed, 3) elimination of stations in the watershed, 4) elimination of programs used to evaluate attainment of water quality criteria for standards attainment assessment in the Bay, 5) elimination of staff support, i.e., total FTE's supported by one state's grant is declining as function of less funding available for monitoring activities, and 6) neglected infrastructure investment – i.e. losing operation of boat which means a state must use some other, more expensive option to collect the data outlined in their SOW.

The implications of reduced monitoring results to inform our analyses include:

- Greater uncertainty toward assessing water temperature trends.
- Greater uncertainty toward assessing the impact of rising water temperatures on ecological resources.
- A longer time to demonstrate progress and achievement of success.
- No dedicated "rainy day fund" to address unexpected costs each year – e.g., extra sampling needed in the event of a major event in the Bay like an oil spill, a hurricane induced high flow event, etc.

Capacity to Monitor

Most programs with a long-term history of data collection have established funding streams to sustain efforts into the future lending themselves to be high value targets for use in applications such as status and trend analyses, indicator development, and model development, calibration, and verification. Regarding enhancements that may fill gaps identified by the CBP Scientific and Strategic Research Framework (SSRF), or provide potential solutions to explore addressing stressors affecting capacity in the monitoring programming include:

- Using new data streams from, and increased coordination with, already funded programs on citizen science, volunteer monitoring, and our enhanced coordination with nontraditional partners.
    - Example is the data already assembled through the work of the Chesapeake Monitoring Cooperative and located in its Chesapeake Data Explorer
    - Opportunities include sensor networks through coordination efforts with groups like Trout Unlimited (contact Than Hitt (USGS) for details)
- Investing in technology that improves monitoring data collection efficiency for scales of space and time where gaps exist, such as:
    - new high-temporal frequency data collection with vertical water quality

monitoring sensor arrays including temperature.

- E.g., See Chesapeake Bay Trust 2019-20 GIT funded project to Caribbean Wind (Wilson D, 2021)
  - Application to water quality patterns across space and time are being supported by the development of a 4D Water Quality Interpolator
    - See CBP Bay Oxygen Research Group (BORG) website for tracking the development of this analysis tool for incorporating and interpreting bay water quality data that will include temperature given its prominence in classifying designated uses for water quality criteria attainment assessments.

- high resolution water temperature data streams from satellite imagery where increased accessibility and availability are being coordinated:
  - E.g., Source agency: NOAA National Environmental Satellite, Data, and Information Service (NESDIS). Source access: https://eastcoast.coastwatch.noaa.gov/time_series_cd.php Source contact: Ron Vogel, NOAA, ronald.vogel@noaa.gov
- intelligent algorithms (AI/ML) developments capable of interpreting and translating 'big data' sources for use in spatial and temporal analyses, reducing uncertainty and improving efficiencies in data collections.

As part of the CBP work to incorporate additional data streams, especially real-time and other new high temporal data streams, there is a need to continue refining analyses to improve understanding of major drivers of temperature change and to better distinguish the response of impacted resources around the watershed, within and across tidal tributaries, and along the mainstem Bay. Participants in the first STAC Rising Water Temperature Cross-Workgroup meeting highlighted the need for better tools for analysis and reporting using the diversity of existing data collections in addition to the need for more data resources. They also prioritized the need for investment in relevant monitoring information around resource impacts in response to temperature change and management actions such as the response to seagrass and fish distributions. Continued collaboration and engagement with science providers will produce successful research and analysis with reliable monitoring data that will move progress forward on addressing questions for management actions.

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